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Ambient Assisted Living

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Preface

Active and Assisted Living (AAL) has been recognized for its crucial role in determining the quality of life in the future of our society. This principle has been confirmed by such institutions as the European Commission, an organization that clearly sees AAL as the "fundamental block" in addressing the challenges of demographic changes, sustaining people in productive and healthy work, keeping people at home healthy, independent, and integrated, and improving the delivery of care where and when needed. These are very demanding challenges for which AAL can guarantee products and services that improve the quality of life for people in all phases of life, combining new technologies and social environments. Recent advances in a number of research areas have helped the vision of AAL to become a reality and have allowed integration of new AAL technologies into human lives in a way that will benefit all.

All these aspects were explored during the Ninth Italian Forum on Active and Assisted Living (ForItAAL), in July 2018, Lecce, Italy. It is one of the most important annual events for researchers, professionals, developers, policy-makers, producers, service providers, carriers, and end-user organizations working in the different fields of AAL, who present and disseminate results, skills, prototypes, products, and services. The book presents the refereed proceedings of the Forum and reviews the status of researches, technologies, and recent achievements on AAL. Different points of view, from research to practice, cover interdisciplinary topics, combine different knowledge, expertise, needs, and expectations, and thus offer a unique opportunity to all those directly or indirectly interested and involved in the field of AAL. The book discusses the promises and possibilities of growth in AAL. It lays out paths to meet future challenges and will provide crucial guidance in the development of practical and efficient AAL systems for our current and future society.

Lecce, Italy

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A Personalised Virtual Coach to Counteract Ageing Decline: The H2020 NESTORE Project

Maria Renata Guarneri, Alfonso Mastropietro, Maurizio Caon, Laura Fernandez Maldonado, Francesco Furfari, Giuseppe Andreoni and Giovanna Rizzo

Abstract Ageing population is growing faster in EU. ICT can provide solutions for Active Ageing; however, the success of novel ICT solutions depends on the user perception of their efficacy to support toward health promotion and global wellness. In this context, the H2020 project NESTORE (Non-intrusive Empowering Solutions and Technologies for Older people to Retain Everyday life activity) will develop an innovative, multidimensional, personalised e-coaching system to support healthy ageing by: (1) Generating and sustaining motivation to take care of health; (2) Suggesting healthy nutrition and personalised physical and mental coaching, as well as

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On behalf of the NESTORE Consortium.

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social interaction, to prevent decline and preserve wellbeing. NESTORE started in September 2017 and will last three years. It involves 16 partners from 7 European countries.

Keywords Ageing · Virtual coach · ICT

1 Introduction

Due to longer life expectancy and the declining fertility rates, the proportion of people aged over 65 years is growing faster in most of the developed countries. Some forecasts suggest that the population of elderly people will almost double from 87.5 million in 2010 to 152.6 million in 2060 [1].

The emerging social aspect related to ageing population introduces some crucial challenges to society and healthcare systems. Without adequate adjustments, i.e. social, economic and demographic policies as well as changes in people's behaviours, the process can trigger certain negative consequences in the long term. In order to maximise the wellbeing of older people and to reduce the economic burden of their care, the health systems should promote "healthy ageing" as much as possible. Healthy ageing is a common word that represents a complex intervention because it tackles all the human domains: physical, metabolic, cognitive, social, etc. Thus, a multidomain, multifactorial system to promote proper healthy strategies has to be designed and NESTORE project aims at this integrated vision as we will explain below.

Furthermore, promoting healthy ageing could represent a strategic opportunity for the economic growth thanks to the higher spending capacity of older people (over € 3.000 billion for the population <65). The EU has focused its attention on the concept of "Silver Economy" which is driven by the rise of new consumer markets and by the need to improve the sustainability of public expenditure linked to ageing.

In this direction, the rapid development of the ICT, and in particular mobile technologies, offers an important opportunity for addressing the development of integrated solutions to support active and healthy ageing. The availability of new integrated ICT technologies and its widespread diffusion could contribute dramatically to the implementation of a sustainable silver economy. Moreover, ICT solutions allow, in an innovative manner, introducing the possibility of a new technological framework to re-design the healthcare system model.

In this context, the **project NESTORE** (Novel Empowering Solutions and Technologies for Older people to Retain Everyday life activities), funded by EU H2020 programme, was designed and developed [2].

The project aims at the development of an integrated solution, based on non-obtrusive interaction with the person, which will support healthy older people to sustain their healthy life by promoting personalised pathways to wellbeing. The personalised support will be provided by an intelligent e-coaching system, which leveraging monitoring technologies, social connectivity and gamification mechanics are able to support older people to maintain independence by encouraging them to become co-producers of their wellness (patient empowerment) by:

- **generating self-awareness** (understanding risks associated with ageing),
- **enhancing and sustaining motivation to take care of their health** (solutions that support healthy lifestyles and are able to evolve as the person ages).
- **support the healthy ageing process** based on healthy nutrition and adequate physical and mental activity/exercise.

2 The Wellbeing Dimensions of NESTORE

Ageing is a multi-domain process. It involves the social, economic, physical, psychological and mental spheres and all these domains are strongly interconnected. Some crucial factors that affect the wellbeing and the quality of life of the subjects are the nutritional habits, physical activity, mental health and social capital.

Good nutrition plays a significant role in the wellbeing of healthy older people and in delaying and reducing the risk of contracting diseases. General dietary recommendations on what should be eaten are relevant and important for older people. They should, for example, not choose food that has a high salt or sugar content; they should choose soft fats instead of hard fats, choose food with good carbohydrates and large amounts of fibre, and prepare their food with as little cooking fat as possible. Other important dietary components include vitamin D and calcium, especially considering the high prevalence of osteoporosis and hip fractures.

Ageing can be related to **psychological and cognitive decline** [3]. Mental Health was defined by the WHO as "a state of wellbeing in which the individual realises his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community". In order to ensure a mentally healthy status, some interventions should be provided considering many aspects, such as participation in meaningful activities, strong personal relationships, physical health.

Ageing is characterised, among other things, by **motor function impairment** such as coordination difficulty, increased variability of movement, slowing of movement, and difficulties with balance and gait in comparison to young adults [4]. These deficits have a negative impact on the ability of older adults to perform activities of daily living and may result in social exclusion as well as in an increased risk of traumatic events (i.e. falls). Even if dysfunctions of the central and peripheral nervous systems are not involved, progressive and generalised loss of skeletal muscle mass and strength (sarcopenia) may play an important role [4]. Physical activity is believed to be the most effective of all interventions proposed to counteract skeletal muscle impairment in older adults, improving quality of life and functionality [5, 6].

Another important aspect is the preservation of the social capital provided by older people. The socio-economic status, social integration and high personal competencies are related to higher subjective wellbeing. The quality of the **social contacts** is, as well, an important factor to consider for a better wellbeing [7]. Moreover, the voluntary work, as well as the educational and social activity group interventions, can improve the mental health and prevent social isolation and loneliness among the older people.

3 Scope of NESTORE and Key Innovations

NESTORE proposes the development of a multi-dimensional system that covers all main domains affected by the ageing process, able to provide services, applications and a rewarding system to support active and healthy ageing with a user-centred approach.

While leveraging the state-of-the-art technologies, the innovation brought about by NESTORE relies, first, on its integration capacity. We can see NESTORE according to different perspectives:

1. As a platform, providing a set of basic services that can be leveraged by different apps, potentially offered by different stakeholders;
2. As a companion, offering personal and personalised support according to the user needs and interests;
3. As a social support, easing communication with family and friends as well as with carers, but also able to propose external service offerings based on "group" interests.

The main outcome of NESTORE is an e-coaching system [8], which may be implemented through a dedicated mobile App and also embodied in a smart object offering tangible interfaces in relation to the user's preferences. This e-coach will suggest and guide the user toward different "wellbeing pathways" providing tailored interventions exploiting personalised preferences and capabilities. The target population will include "fit older people" (i.e. good physical performance and low risk of near-future disabilities).

Key innovation element is the development of a multi-domain "cloud-based intelligence" able to interpret different signals coming from an extensive sensing system, to provide feedback that is meaningful, timely and relevant to the user. The effectiveness of the feedback will be assured by the adoption of well-assessed psychological developmental regulation and health behaviour change models, such as the SOC model [9] and the Health HAPA approach [10]. Emotion analysis and recognition, emotional computing, tangible and affective interfaces, will be used to ensure user engagement with the e-coaching system. According to such models, we have developed the concept of "pathways of interest" able to provide hints, suggestions and services according to the user's elective preferences while ensuring that all the five dimensions of wellbeing are satisfied to maximise the overall health status.

The coaching on the different pathways will be supported by different techniques, leveraging multimodal communication in order to provide an engaging and playful user experience: (1) natural dialogue with the user; (2) tangible interfaces for self-reflection and behaviour change; (3) social and environmental support through the social platform; (4) serious games and gamification; (5) apps for self-monitoring.

From the user point of view, NESTORE can be seen according to two different perspectives: friend and coach.

As a friend, NESTORE fully understands the emotional status and the wishes of the user; it is able to establish a personal and long-lasting relationship with the user interacting in a natural way.

As a coach, NESTORE understands the "weaknesses" of the user and proposes actions and activities that compensate shortcomings, re-establishing a status of well-being and maintaining such status in time. NESTORE is a ubiquitous conversational agent acting as a caring coach that will interact with the user assuming many forms, will use different modalities (voice, text, apps, tangible interfaces), and will be adapted to the user's preferences and to the contextual information.

In order to ensure user acceptance of the e-coaching system, co-design and participatory approaches will be adopted and used throughout the project duration. Such tools and methods will seek to engage and elicit information related to perception, acceptance and usability of technology to support healthcare and wellbeing.

4 The NESTORE Methodological Approach and Validation

The NESTORE scientific and technical approach is modelled around two guiding principles: (i) combining agility and structure and (ii), adopting Co-Design and UCD (User-Centred Design) as methodological approaches for the overall definition of the NESTORE solution [11].

i. *Agility and structure*. NESTORE is driven by a combination of Agile Development methods and techniques with the structure necessary to a large and distributed collaboration effort.
ii. *Adoption of Co-Design and UCD*. NESTORE methodology incorporates the overarching principle of having users as active, participating actors in the project in the typical approach of UCD.

This general approach has been translated into the following strategic planning choices:

1. The iterative process structured along major milestones is enriched by intermediate working releases (with varying, incremental set of features);
2. The system architecture development is linked to the integration work in which all the different modules and elements are made available for technical and users' short or long-time evaluations. The NESTORE Integration strategy is entrusted also with the mission of maintaining a unifying technology view;

3. The user point of view is championed and maintained through a co-design approach that will be adopted for the definition of the system requirements and for the user testing that will be performed by means of small-scale pilots;
4. Agility steers the work by avoiding a once-in-a-time, "big design upfront" effort, and making instead service design a continuous task in the project lifetime, to guarantee that technological innovations and user feedback are effectively translated in the NESTORE features;
5. Scenarios and requirements will be used as flexible design tools. From the business and end-users point of view, NESTORE will work with mock-ups and working prototypes.

The strategic planning choices listed above strongly shape the scientific and technical approach followed by the project. The structure of the project has been designed to satisfy the above principles with technical work-packages working in close cooperation, guided by a set of user-based requirements that are implemented in an incremental manner and verified with the users in a continuous cycle. The NESTORE structure has been organised according to the workflow described and depicted below:

Requirements Definition, for defining the functional requirements taking into accounts the ageing process.

Iterative Design of NESTORE Solution, for providing the user point of view and refine requirements according to a co-design methodology.

This will guide the:

Development of NESTORE platform and components: this work is organised according to three lines of research: (i) the "passive" sensing system based on wearable sensor technologies and environmental sensors, (ii) the interpretation and reasoning algorithms, and (iii) the user interface at large, the interaction with the virtual coach and the engagement of the users via a social platform as well as series of serious games.

The above components will be brought together through the:

– **Integration of the NESTORE System** that will provide the overall technical solution for the provision of the user services (see Fig. 1),
– **Evaluation and User Feedback**: this phase will generate insights about the service value from the user point of view and will feedback in a new updated loop.

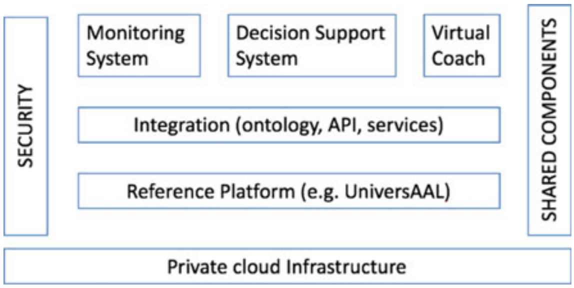

Fig. 1 Integration architecture

The integrated system will be tested in three pilot sites (Italy, Spain and The Netherland).

The piloting test will evaluate the *usability, sensors and devices functionality, and overall user acceptance*. In particular, experience of the participants with the system will be evaluated, considering different aspects such as: **quality of technology** (efficiency, effectiveness, usefulness, completeness and accuracy), **reliability of the system** (reliability, security, interoperability and ease of repair and maintenance), **usability and acceptance** (ease of use, graphic design acceptance, user satisfaction, navigation, user control, time, user experience, mental effort, support, learning and acceptance), **use of monitoring** (frequency, modus operandi, user profile, context in the platform's use), **problem solving** (useful alerts, false alarms, emergency calls, quality life improvement, isolation problems solution, cognitive stimulation and physical activity motivation).

In the pilots, the *efficacy of the system will also be evaluated in each one of the wellbeing domains* (physical-physiological, nutritional, cognitive, mental, social) included in NESTORE: validated clinical measurements, like additional questionnaires, medical imaging and signals, clinical geriatric evaluation in supervised sessions, will be considered to provide quantitative metrics of validations on:

- Physiological status and physical activity behaviour (Sedentariness, muscle strength and cardiorespiratory fitness, sleep quality, and active physical behaviour);
- Nutritional behaviour (quality of diet and quantity of food)
- Cognitive function (memory, processing speed, reaction time, verbal fluency)
- Mental status and social behaviour (depressive symptoms, life satisfaction, social relation and integration).

Some complementary measurements will help to provide information on possible positive effects on the body produced by using the NESTORE platform.

Moreover, *techno-economics will be evaluated*, as well as the feasibility of different organisational and business models aimed at achieving the sustainability of the NESTORE solution.

5 Cost-Effectiveness and Sustainability of NESTORE

Past literature pointed out that the interventions addressed to increase the awareness about physical-physiological, nutritional, cognitive, mental and social conditions of 60+ citizens are cost-effective from the national healthcare system perspective: indeed, they allow, for instance, to reduce the number of avoidable hospitalisations and drug consumption as well as to improve the management of chronic diseases and citizens' quality of life.

According to this perspective, the Pilots will gather evidence on the fact that the NESTORE technological solutions enable citizens/users to improve their conditions (physical, cognitive, mental and social) as well as their behaviours (e.g. eating habits, etc.). With regard to the effectiveness, the focus will be also on the wellbeing as well as on users' empowerment, health literacy and capability of self-care. Indeed, regardless of the IT literacy, NESTORE is expected to improve all these aspects.

The necessary condition for generating cost-effective impacts on the system will be the effective usage of NESTORE solutions by the citizens/users.

Past studies highlighted that most of the technological solutions aimed at maintaining lifestyle and supporting self-care and care management are not used regularly by users/citizens and thus their results fall far behind their promises or what measured in 'Lab' contexts. The main reasons, as known, are two: (i) they are not considered relevant/useful, (ii) they are not easy to use.

Considering this, the project will allow to test and assess with final users the perceived usefulness and the ease of use of the different NESTORE solutions in order to gather evidence on their actual usage; moreover, through qualitative and co-design approaches will be analysed the willingness of citizens to adopt these solutions in the long-term.

All data collected by the Pilots and during the co-design process will permit to assess the potential cost-effectiveness of NESTORE and its technological solutions compared to the current practices by means of a control group.

6 Conclusions

Within NESTORE, we attempt to support healthy ageing with an integrated, user-centred and non-obtrusive approach, tested in real-life environments, in order to achieve wide acceptance by the target users as well as to accelerate the digital innovation process. Therefore, we believe that this project has the potential of delivering sustainable innovation in the area of active and healthy ageing. Currently, the User's analysis was run and the matching among requirements from users, technology, and expert is running to provide the first version of the platform design.

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References

1. Population ageing in Europe: facts, implications and policies (2014). https://ec.europa.eu/research/social-sciences/pdf/policy_reviews/kina26426enc.pdf
2. NESTORE official web-site https://nestore.ro/home
3. Klimova B, Valis M, Kuca K (2017) Cognitive decline in normal aging and its prevention: are view on non-pharmacological lifestyle strategies. Clin Interv Aging 12:903–910
4. Di Tano G, Fulle S, Pietrangelo T, Bellomo R, Fanò G (2005) Sarcopenia: characteristics, genesis, remedies. Sport Sci Health 1(2):69–74
5. Nelson ME, Rejeski WJ, Blair SN et al (2007) Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. Med Sci Sports Exerc 39(8):1435–1445
6. Freiberger E, Sieber C, Pfeifer K (2011) Physical activity, exercise, and sarcopenia—future challenges. Wien Med Wochenschr 161(17–18):416–425
7. Charles S, Carstensen LL (2010) Social and emotional aging. Annu Rev Psychol 61:383–409
8. Kamphorst BA (2017) E-coaching systems. Personal Ubiquitous Comput 21(4):625–632
9. Freund AM, Baltes PB (1998) Selection, optimization, and compensation as strategies of life management: correlations with subjective indicators of successful aging. Psychol Aging 13(4):531
10. Schwarzer R, Lippke S, Luszczynska A (2011) Mechanisms of health behavior change in persons with chronic illness or disability: the Health Action Process Approach (HAPA). Rehabil Psychol 56(3):161
11. Beyer H, Holtzblatt K, Baker L (2004) An agile customer centred method: rapid contextual design. In: Lecture notes in computer sciences. Springer

Multi-domain Model of Healthy Ageing: The Experience of the H2020 NESTORE Project

Alfonso Mastropietro, Christina Roecke, Simone Porcelli, Josep del Bas, Noemi Boquè, Laura Fernandez Maldonado and Giovanna Rizzo

Abstract Ageing is a complex multidimensional and multifactorial process associated with the decline in multiple physiological systems which can lead to frailties and disabilities over the lifespan. With the aim of supporting healthy older adults in order to sustain their wellbeing and capacity to live independently, the NESTORE project was recently funded by the EU Commission. In order to take into account the complex interactions among different aspects involved in the ageing processes, a model of healthy ageing was developed in NESTORE. This model included three core dimensions related to older people wellbeing (Physical/Physiological, Nutritional, Cognitive/Mental/Social). The NESTORE model was intended to provide a structured arrangement of the knowledge coming from such different domains in order to provide a simplified pool of information for: (i) the characterization of the

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older adults, (ii) the personalization of the coaching plans and (iii) the implementation of an effective ICT system.

Keywords Healthy ageing model · Multi-domain · NESTORE

1 Introduction

The European population aged 65 years and older is expected to increase from 17.4% to nearly 30% by 2060 [1] while the population of those aged 80 years and older is predicted to triple during the same period [2]. Ageing is associated with the decline in multiple physiological systems which can lead to frailties and disabilities over the lifespan [3]. Importantly to note, despite many age-related changes and preconceptions of marked declines, many older adults in the early later adult decades are cognitively healthy [4]. In order to plan policies with the main goal of mitigating the effects of the increasing ageing population on the socio-economical system, the European Commission has identified **active and healthy ageing** as a major societal challenge common to all European countries.

In this context, the **NESTORE project** (Novel Empowering Solutions and Technologies for Older people to Retain Everyday life activities), which was recently funded by EU commission within the H2020 programme, was designed and proposed [5].

NESTORE aims at supporting healthy older adults in order to sustain their well-being and capacity to live independently by promoting personalized pathways to wellbeing. NESTORE's ambitious objective is to develop an innovative, **multi-dimensional**, cross-disciplinary and personalized **coaching system** that, leveraging ICT social connectivity, will support older adults by encouraging them to become co-producers of their wellness. NESTORE is a project that contemplates from early stages the end-user involvement to guarantee the reflection of real users' needs and preferences.

Since ageing is a complex multidimensional and multifactorial process, within the NESTORE project, a model of healthy ageing was developed. This model included three core dimensions related to well-being (Physical/Physiological, Nutritional, Cognitive/Mental/Social).

The NESTORE model of healthy ageing is described in detail in the next paragraphs.

2 NESTORE Model of Healthy Ageing

The NESTORE Model of Healthy Ageing was aimed at providing a structured knowledge, built on the expertise of the NESTORE experts (exercise physiologists, nutritionists, lifespan psychologists, geriatricians), able to characterize the person in terms of both status and behaviour. In particular, the formalisation proposed in this paper is intended to provide organized information about healthy ageing-related domains that can be useful to support reasoning, to manage the information flow and to facilitate the interoperability between devices and platforms used to monitor older adults' status and behaviour. A similar descriptive model has been adopted in a previous European project aimed at counteracting obesity in young people [6], in order to provide structured information and ontological representation of physical/psychosocial/behavioural characteristics of the target user [7].

In NESTORE, the final user is an older adult (65–75) living an autonomous life and interested in maintaining or promoting her/his wellbeing and quality of life, without any clinically relevant impairment and/or pathology.

Based on this user definition, the model adopts a multi-domain classification, which includes: **Physiological Status and Physical Activity Behaviour, Nutrition, Cognitive and Mental Status and Social Behaviour**. For each domain, the model includes:

(a) The definition of the domain variables that are useful for the characterization and monitoring of the person.
(b) The relationships among the domain variables taking into account: (1) the direct causal relationships; (2) the indirect causal relationships; (3) the correlations between 2 variables; (4) the mathematical expressions for derived variables.

The development of a structured model was specifically thought to support the development of the NESTORE ontology and also for profiling activities and, consequently, for the personalization of coaching activities.

The characterization of a subject using such a holistic approach is aimed at improving the engagement of the users since it is helpful for a more effective implementation of the Selective Optimization with Compensation (SOC) [8] and Health Action Process Approach (HAPA) [9] models that will guide the NESTORE coaching system.

3 Physiological Status and Physical Activity Behaviour

With advancing age, structural and functional decline occurs in most physiological systems, even in the absence of evident disease. These age-related physiological changes involve a broad range of tissues, organ systems, and functions, which, cumulatively, can affect activities of daily living and the preservation of physical independence in older adults [10].

In NESTORE, the characterization of the physiological status of the subjects was structured in four subdomains: (1) **Anthropometric Characteristics** containing the main anthropometric variables describing body dimensions; (2) **Cardiovascular System**, which contains the main physiological variables that influence transport of nutrients, oxygen, carbon dioxide, hormones, and blood cells from the lungs to peripheral tissue and vice versa; (3) **Respiratory System**, containing the main physiological variables related to structure and function of the organs designated

Table 1 List of variables included in physical activity behaviour subdomain which is part of the physiological status and physical activity behaviour domain

Subdomain	Physical activity behaviour
Variables	Distance, exercise duration, exercise intensity, exercise type (cardiorespiratory, muscle strengthening, balance, flexibility), exercise frequency, fatigue accumulation, grade, activity energy expenditure, rate of perceived exertion, sedentariness, speed, steps (number of steps, stride), upper limb movements

to exchange blood gases between ambient air and blood cells; (4) **Musculoskeletal System**, which contains the key physiological variables related to the ability of skeletal muscle to generate force and power.

Moreover, a description of the variables describing the ability of a subject to perform exercise limited from the cardiorespiratory system (**Cardiorespiratory Exercise Capacity**) or musculoskeletal system (**Strength-Balance-Flexibility Exercise Capacity**) as well as the usual behaviour of a subject during every-day life (**Physical activity Behaviour**) was also included in the model. Finally, a description of the main factors related to sleep (**Sleep Quality**) was also included in this specific domain.

An example of a list of variables, included in the Physical Activity Behaviour subdomain, is reported in Table 1, whereas the block-diagram representing the relationships among variables, within the same subdomain, is shown in Fig. 1.

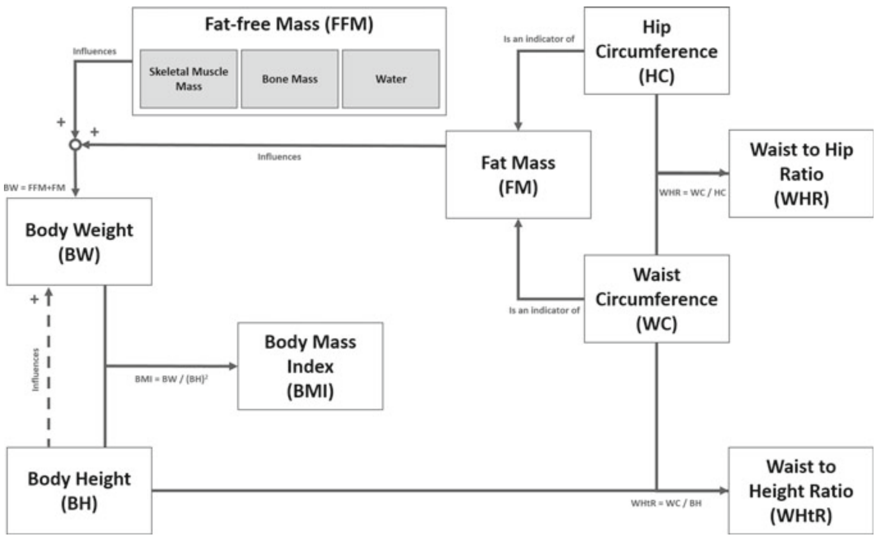

Fig. 1 Relationships among variables in the physical behaviour subdomain

Table 2 List of variables included in the anthropometric characteristics subdomain which is part of the nutrition domain

Subdomain	Anthropometric characteristics
Variables	Body height, body weight, body mass index, fat mass, fat-free mass, hip circumference, waist circumference, waist to hip ratio, waist to height ratio

4 Nutrition

Nutrition is an important element of health among older adults since it affects the whole process of ageing. The prevalence of malnutrition increases in older adults and it is associated with a decline in functional status, impaired muscle function, decreased bone mass, immune dysfunction, anaemia, reduced cognitive function and mortality [11]. Moreover, there are notable alterations related to ageing, such as body composition remodelling and metabolic dysregulation, which could be nutritionally managed.

In NESTORE, the nutrition domain was organized into four subdomains: (1) **Anthropometric Characteristics**, which is in common with the Physiological domain; (2) **Blood Parameters** which contain 3 crucial metabolic risk factors (glucose, cholesterol and triglycerides) for highly prevalent pathologies in aged adults like diabetes and cardiovascular disease; (3) **Energy Balance** which describes the components implicated in human energetic balance, a key factor for the regulation of body weight, mainly energy expenditure and energy intake; (4) **Nutrition Habits** which describes variables directly related to the study of a subject's dietary habits, including nutrient intakes.

An example of a list of variables, included in the Anthropometric Characteristics subdomain, is reported in Table 2, whereas the block-diagram representing the relationships among variables, within the same subdomain, is shown in Fig. 2.

5 Cognitive and Mental Status and Social Behaviour

Ageing is often associated with a decline in mental capabilities including biologically-driven cognitive domains such as memory, executive functions, processing speed and reasoning. These skills compose the so called fluid intelligence and are important for carrying out everyday activities and for retaining an independent life [12, 13].

At the same time, social and emotional experiences partly change and partly remain relatively intact with increasing age. In particular, social networks become smaller overall while remaining relatively stable in terms of the number of emotionally close others, the emotions experienced by the persons in day-to-day life tend to be more stable, and overall subjective well-being is well-maintained. In addition, social roles change quantitatively and qualitatively [14].

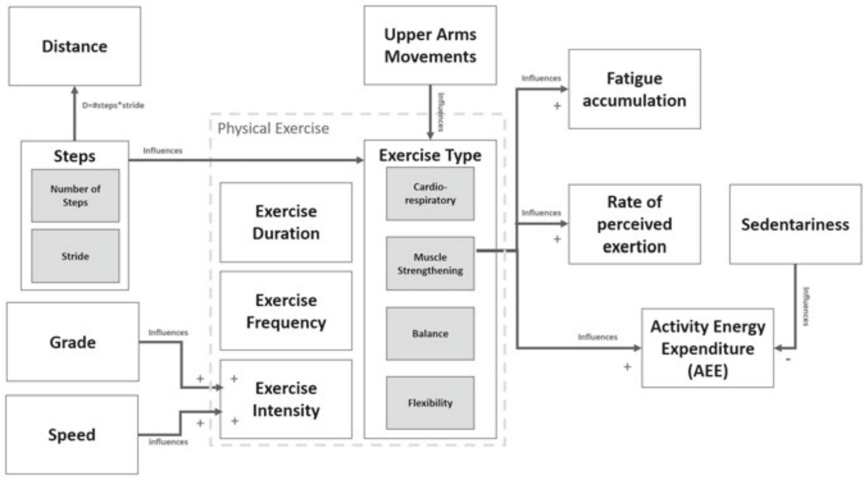

Fig. 2 Relationships among variables in the anthropometric characteristics subdomain

In NESTORE, this complex domain was composed of four subdomains: (1) **Cognitive Status** which describes a range of intelligence domains that describe biologically- and experience-/knowledge-driven facets of cognition and intelligence, (2) **Mental Status**, including traits of psychological functioning in the area of subjective well-being, self and personality and social integration/feelings of loneliness. The two domains of status or trait variables will allow describing a dispositional profile of a person's general resources in the cognitive and mental domain. These will be complemented by (3) **Mental Behaviour and States**, which capture the within-person processes mainly in emotional functioning that are observable in daily life on the basis of self-reported experiences and as information extracted from text bodies and speech, and (4) **Social Behaviour** which analyses the social context of the users involved in the studies and in using the NESTORE system. The social behaviour analysis aims at measuring both qualitatively and quantitatively some core variables describing the social behaviour of users in terms of (a) existence of social interactions through self-reported diaries and with sensing devices, (b) the number and duration of such interactions, and (c) possibly, the location of the interactions.

An example of a list of variables, included in the Cognitive and Mental Status and Social Behaviour subdomain, is reported in Table 3, whereas the block-diagram representing the relationships among variables, within the same subdomain, is shown in Fig. 3.

Table 3 List of variables included in the mental status subdomain which is part of the cognitive and mental status and social behaviour domain

Subdomain	Mental status (psychological functioning)
Variables	Personality (extraversion, agreeableness, openness to experience, conscientiousness, neuroticism, control beliefs, self-efficacy), social network/integration (quantity, quality, loneliness, support), subjective well-being (life satisfaction, positive affective states, negative affective states)

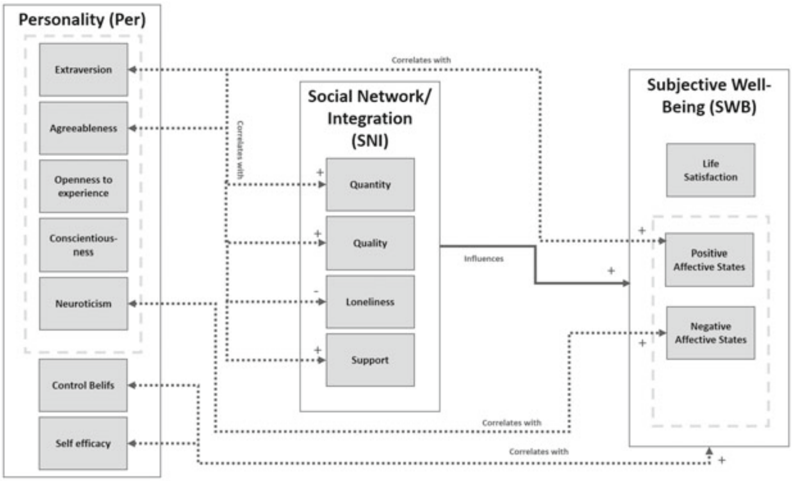

Fig. 3 Relationships among variables in the mental status (psychological functioning) subdomain

6 NESTORE Healthy Ageing Model Outcomes

The knowledge integration model presented in this paper is mainly intended as a necessary **preliminary step** to provide a wide-ranging semantic representation of the ageing subject profiles. In this context, this model will be useful **to support specific inference within a comprehensive ontology model** of the healthy ageing-related knowledge that will be implemented in NESTORE.

The NESTORE model of healthy ageing provides the list of variables, their relationships (intra- and inter-domain), the range of normality of each variable and the measurement scenarios that represent the basic foundation of the NESTORE technological implementation and of the system intelligence.

In particular, the proposed approach has a direct effect on:

- **System Requirements**. Wearable and environmental sensors and devices, composing the monitoring system, will be selected according to the variables included in the model.
- **System Intelligence**. The decision support system will be developed according to the variables relationships and ranges reported within the model.

- **Coaching Plans Definition**. The coaching activities in physical, nutrition, cognitive and social domains are designed and tailored to the subjects profiles taking into account the information provided by the integrated knowledge.
- **Pilot Studies**. The efficacy of the system will also be evaluated in each one of the well-being domains included in NESTORE: validated clinical measurements in each health domain will be definitely defined according to the model.

7 Conclusions

The NESTORE model of Healthy Ageing is the outcome of a prolific multidisciplinary cooperation and convergence among experts belonging to different scientific fields. The NESTORE model was intended to provide a structured arrangement of the knowledge coming from such different domains in order to provide a simplified pool of information for: (i) the characterization of the older adults, (ii) the personalization of the coaching plans and (iii) the implementation of an effective ICT system.

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References

1. European Commission: Active ageing and solidarity between generations—a statistical portrait of the European Union (Eurostat report 2012)
2. European Commission: Eurosat: population structure and ageing. http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Population_structure_and_ageing#Future_trends_in_population_ageing
3. Clegg A, Young J, Iliffe S, Rikkert MO, Rockwood K (2013) Frailty in elderly people. The Lancet 381(9868):752–762
4. Wagster MV, King JW, Resnick SM, Rapp PR (2012) The 87% guest editorial. J Gerontol A Biol Sci Med Sci. 67(7):739–740
5. NESTORE official web-site https://nestore.ro/home
6. Carrino S, Caon M, Angelini L, Mugellini E, Khaled OA, Orte S, Vargiu E, Coulson N, Serrano JC, Tabozzi S, Lafortuna C, Rizzo G (2014) PEGASO: a personalized and motivational ICT system to empower adolescents towards healthy lifestyles. Innov Med Healthc
7. Sojic A, Terkaj W, Contini G, Sacco M (2016) Modularising ontology and designing inference patterns to personalise health condition assessment: the case of obesity. J Biomed Semant 7(1):12
8. Freund AM, Baltes PB (1998) Selection, optimization, and compensation as strategies of life management: correlations with subjective indicators of successful aging. Psychol Aging 13(4):531

9. Schwarzer R, Lippke S, Luszczynska A (2011) Mechanisms of health behavior change in persons with chronic illness or disability: the Health Action Process Approach (HAPA). Rehabil Psychol 56(3):161
10. Boss GR, Seegmiller JE (1981) Age-related physiological changes and their clinical significance. West J Med 135(6):434
11. Amarya S, Singh K, Sabharwal M (2015) Changes during aging and their association with malnutrition. J Clin Gerontol Geriatr 6(3):78–84
12. Geary DC (2005). The origin of mind: evolution of brain, cognition, and general intelligence. American Psychological Association
13. Rowe JW, Kahn RL (1997) Successful aging. The Gerontol 37(4):433–440
14. Charles ST, Carstensen LL (2010) Social and emotional aging. Annu Rev Psychol 61:383–409

New Models in Managing Out-of-Hospital Care of Chronic Patients and Aging Population

Ilir Qose, Raffaele Conte, Francesco Sansone and Alessandro Tonacci

Abstract Success story: When Care and Informatics know-how embrace patients' needs and make possible new Out-of-Hospital Integrated Care Models. Healthcare is reforming to focus on the patients, to put them in the center of care and have medical professionals around them, working together in a collaborative and efficient way. Important not for profit Care providers, like Cooperatives, are playing a central role, upgrading to Integrated Solutions Coordinators. Patient engagement is crucially important in raising the level of care, and the involvement of non-medical professionals can further improve the treatment outcome. The usage of a collaborative healthcare platform can therefore provide significant benefits to the patients, and such positive results can be achieved in a user-friendly online environment.

Keywords Aging · Care models · Healthcare management · Out-of-hospital care

1 Introduction

Integrated care is considered a potential solution to the care of several chronic patients, however still displaying several key issues, as normally happens with all the care models in their infancy [4, 12]. The implementation of such model of care is possible, provided that careful planning, strong leadership and managerial support take place [12]. In this framework, the role of several health professionals, including

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practice nurses, practice managers and administrative staff becomes pivotal, thus shifting the classical paradigm of care provision to a single patient-centric model.

Within this framework, AICare aims to fill this important gap by providing a smart, technology-based affordable solution to respond to the needs for care of a wide range of patients.

In this regard, the article describes a successful implementation of this regional out-of-hospital integrated care platform provided in collaboration between COOSS Marche, a social, healthcare, welfare and education service provider, Aicare Srl, an Innovative Social StartUp, and other players, including the National Research Council (CNR), the widest public research entity in Italy.

2 Integrated Out-of-Hospital Care Solutions

The best description for today's aging population is the so-called Silver Tsunami [2], and the sector primarily affected is that of Health and Social Care. Specifically focusing on national data, in Italy the public National Health Fund is between 113 Billion €/year with an additional 37.3 Billion € paid by privates for out-of-pocket services. A study recently performed by the Italian Ministry of Health found that over the next 10 years an additional € 40–50 Billion € will be needed, and since public funds will be not be able to bear this burden, most of the funding will come directly from families [6, 7].

As the Clients' population matures, the care provision paradigm is required to shift taking into account a different instance of the "patient", which should be, at the same time:

- Customer (a person who pays and, therefore, is owed Quality Service);
- Citizen (a person who pays taxes and contributes to the society);
- Patient (a person for whom access to Healthcare is a right).

Furthermore, this aging population is moving most of the costs towards Chronic Care Pathologies' Management, which are nowadays agreed to be exclusively performed out of Hospital within a Continuity of Care Strategy.

Technological advancements and an increasing data-sharing culture are changing the framework at a faster rate than ever before. For instance, data shows that 35% of patients check their symptoms online before reaching out to a Doctor [10]. On the other side, while technology is making a host of services and smart devices possible, there are very significant challenges that arise from the need for more integrated solutions to put together Administrative Leaders, Care Leaders and IT Leaders.

Within this ecosystem, important not-for-profit Care Providers like COOSS Marche in Italy [3], are hyper-aware of their Social Responsibility, and are moving to provide their contribution by promoting and piloting solutions that could either be integrated and retrofitted into existing public solutions, or pave the way for future models adopted by the public sector.

Fig. 1 The AiCare model

2.1 *The Birth of the AICare Idea and the First Applications*

In 2017, COOSS Marche promoted the incorporation and control of an Italian Social Innovative StartUp, named Aicare Srl [1], aimed at making Out-of-Hospital Solutions more accessible. The company became operative in Q2/2017 and launched its market ready Minimal Viable Product (MVP) in Q3/2017. Early 2018, another two Italian not-for-profit Care Providers (Codess Cooperativa Sociale and Consorzio Sisifo) joined Aicare as shareholders. This fact puts Aicare as an ideal integration point, where Administration, Care and IT come together (Fig. 1).

During Q3/2017, the first Integrated solutions were launched in the market, under the name “AiCuore”, focusing on Aging Population affected by Chronic Heart Failure (CHF). Specifically, CHF patients were divided into 2 groups: (i) Post Acute, and (ii) Patients affected by CHF under therapy at home, which have not been hospitalized before during high temperature periods at Summer. In the previous procedure, those patients required support from a group of persons, medical and non-medical professionals. More specifically, nurses needed to make frequent house calls to take measurements and provide the patients with appropriate care and patients had to be carried to clinics for checkup and ECG. In the present pilot, an integrated package was developed, consisting of Integrated Assistance for CHF Users performed by the Cardiologist and the Cooperative, and a related integrated team was created. In more detail, the protocol foresaw an Initial Visit (for hospitalized patient at discharge), the delivery of a home-monitoring kit (scale, sphygmomanometer and pulse oxymeter), one weekly visit of the nurse at home, practicing ECG at home, as well as a Coaching Course, named Family Learning, administered to groups of 25 persons each, where the patients, their family, caregivers, the Case Manager and MD Specialists (one at once) are involved in 8 weekly one-hour sessions. The protocol is expected to use smart equipment, in order to perform physiological measurements through devices capable of sending data automatically to the AiCare platform. With this approach, the system can relieve the physicians of performing time-consuming tasks, as physicians and caregivers get correct physiological values almost in real time without leaving their clinic or hospital.

2.2 Pilot Study Population

The first pilot study of the AICare platform involved 50 patients (NYHA II and III), of which 22 were post-acute CHF and 28 non-hospitalized CHF. Interestingly, 13 out of 22 post-acute patients had therapy change during the 6 months pilot and there have been 4 re-hospitalizations avoided. The non-hospitalized patients had 3 therapy corrections. 6 patients of the post-acute group agreed to continue the service privately after the pilot ended. The pilot above described for the CHF patients is the base of the service model available in the market by Aicare Srl for Chronic Users. The same integrated model (Initial Visit, Home Monitoring Kit Devices, Integrated Platform, Case Manager, Home Care Assistant, MD Specialist, Marketplace) will be applied to protocols for COPD, Diabetes and Dementia. The field for a similar model is huge in the market, considered that 70% of people aged 65+ will need for long-term care.

3 Aicare Marketplace: Improved Accessibility Putting the Patient at the Center of Care

Countless studies have shown how engaging the patient improves disease management results. So far, the patient was often seen as one of the actors in the process of care or even excluded from decision-making. Putting the patient in the center of care empowers the patient and provides them with a further motivation to follow the proposed program. However, this process is often difficult, since the medical staff does not have the appropriate tools to accomplish this task. Therefore, it is pivotal for people with chronic illnesses, elderly patients and their family caregivers to not be just one of the participants in the process of treatment and care but rather to be considered the focus of all involved actors that, in turn, should stimulate the patient to actively participate to this process. According to the IFIC (International Foundation for Integrated Care), this is the third wave of integration in care and concerns cooperation between patients and professionals [5]. This takes form in self-management support by professionals, in a jointly managed health record and in shared decision-making. In this framework, the terms “consumer” and “patient” are becoming less popular and are being replaced with words such as “partner” and “co-producer”, whereas care

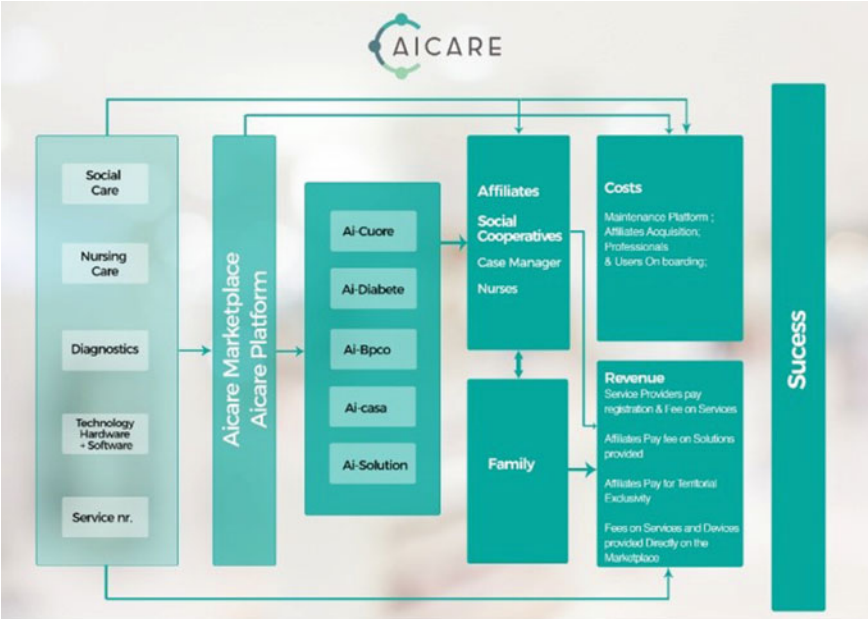

Fig. 2 The AiCare layout

services are always more "person centered". From the point of view of Information Technology (IT), the biggest challenge identified concerns with the establishment of a joint, digital health record for doctors and patients, and the ease of communication between professionals and patients through e-mail and screen-to-screen contact.

3.1 The AICare Model

The key to success of the AICare system is briefly summarized in Fig. 2.

As indicated, AICare binds together new concepts of social care, nursing care, diagnostics and technology in a new framework aimed at reducing the costs normally required to implement and provide such services, by not sacrificing quality of care and generating, at the same time, revenues.

The social care is performed providing personal care and services for social support to people who are in need due to old age, illness or disability. This is mainly performed at home by nurses involved within the AICare structure, integrating at the same time the concept of nursing care. The provision of the AICare services features diagnostics as one of its cornerstones, allowing the patient to be followed at home also under this point of view.

All these characteristics are implemented thanks to a massive technology effort. Indeed, technological advancements enter within AICare in a two-level mode: (i) they allow the provision of services directly at home taking advantage of portability and miniaturization of the diagnostic devices; (ii) they enable AICare to offer the opportunity to sell services directly online, with an online booking system and secured, verified transactions.

Actually, the services offered by the AICare framework include: AI-Cuore, tailored to patients at risk for cardiovascular events, AI-Diabete, addressed to diabetic subjects, AI-BPCO, which includes services dedicated to patients with pulmonary dysfunction, AI-Casa, featuring service packets dedicated to home monitoring and assistance, and AI-Solution, customizing the services to the end-user needs.

In this framework, affiliates to the AICare facilities will represent the key actors for the service provision, mainly including Social Cooperatives, with their key figures represented by case managers and nurses. Their role include both the provision of healthcare-related services and the continuous interfacing with patients and relatives (see Fig. 3).

The model is conceived to be economically viable and sustainable, with an accurate cost-to-benefit assessment performed prior to the inclusion on the market and before entering new services.

The main costs foreseen include the maintenance of the AICare platform and the sustenance of the professionals adhering to the platform. On the other hand, revenues arise from the payments of the affiliates to take part in the platform, as well as from fees paid by the end-users of the AICare solutions directly on the marketplace implemented (Fig. 4).

3.2 The AICare Platform in Brief

The tool that can bind the different roles together is represented by a collaborative portal platform displaying the ability to integrate different information systems and to provide the users with appropriate rights to view medical documentation, measurements, and the patient's health record remotely, to communicate with the case manager and to book, pay and evaluate services. Summarizing, the aim of the platform is to integrate all actors and all process steps in the same place. On the other side, in order to have a qualitative service, the case manager (nurse or social worker) should coordinate the process, and the IT should be adopted in existing services making them less working intensive. The health institution or doctors themselves can share health-related information and general health advices and articles about diseases. In this framework, huge service providers, like Social Cooperatives, own all the necessary resources and the capacity to be the center of this model.

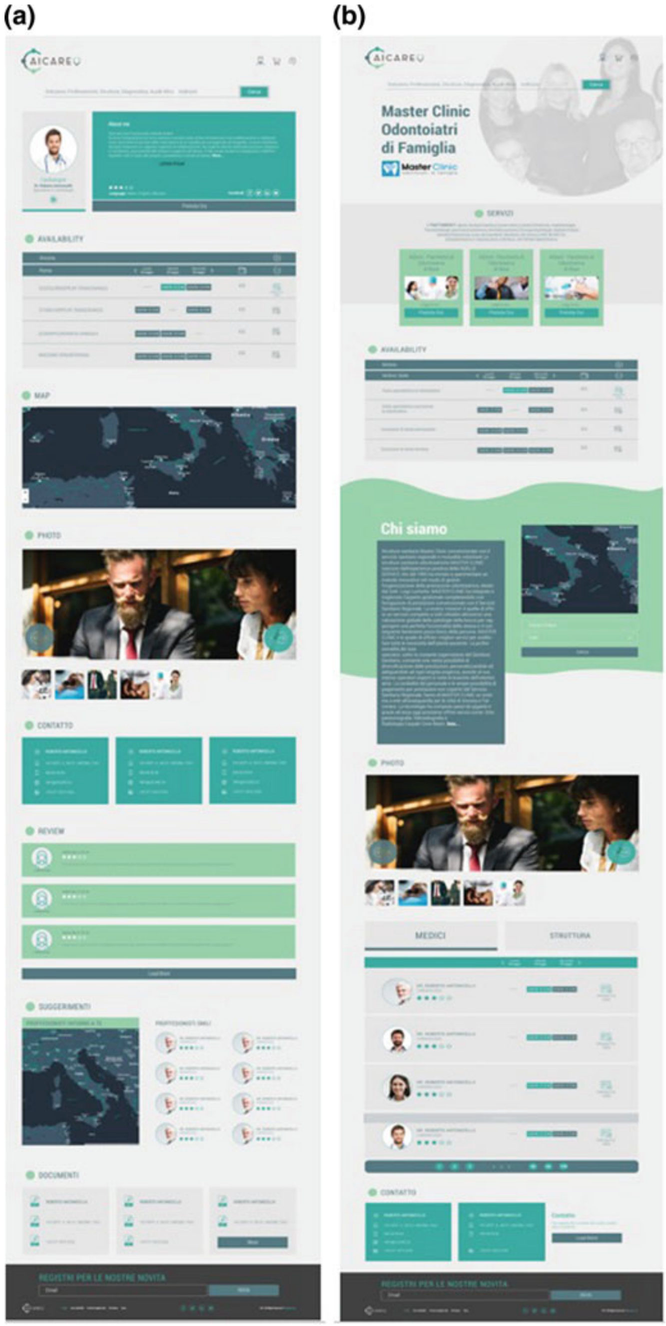

Fig. 3 Example of the AiCare web-pages dedicated to doctors (**a**) and service providers (**b**)

Fig. 4 Example of the marketplace web-page

4 Involvement of Non-medical Professionals in the Care Program

In the framework of the integrated care model described above, the end-users of the services proposed and implemented do not require just a traditional professional medical care, but they also need for a strong community and social support, involving both social workers and family members. Indeed, people often respond better to "familiar" individuals, subjects who they already know: hence, providing family members and friends with all the tools necessary to help in the well-being of their loved ones is thought to contribute to the overall positive outcome [8].

5 Different Approaches: "Top-Down" in National Systems Versus "Bottom-Up" in Private Care Options

In the framework of integrated care, most public/national health systems feature a "Top-Down" approach, meaning that they cover the widest array of patients. This kind of patient care is generalized but, for the public sector, cost-efficient. However, "Bottom-Up" solutions are nowadays extensively tested, especially in the private sector, where the specific patient represents the center of the care system, with their care customized to fit the patient at best [9]. However, this model can fully work only when the service model is included in the national and regional policies and is recognized by the National Health Systems. Somewhat similarly, the Integrated Assistance Package for CHF patients is already recognized by some Italian Regional Health Systems. Through the use of smart health IT solutions, achieving such a specific care plan is made significantly more simple. The patient's input is taken into account and the best solution is customized to the person's needs, thus providing the patient with an appropriate professional care and, in addition, non-medical (social, emotional, etc.) support. With such a model, an important shift of the paradigm is present, since the Social Cooperative becomes the coordinator and the actor that takes charge of the full Care Process for the Chronic Aging Patient, and the Cooperative's Nurse becomes the Care Manager. Therefore, the Nurse acquires a more important role within the care process, with responsibilities spanning from the coordination of the Cooperative to the increase of their responsibility with respect to third parties, including physicians. Starting from that, the user can book an integrated solution directly to the Cooperative, and later the cooperative will engage its own staff, including nurses and social operators, involve external staff, including medicine specialists, acquire and integrate technological (both software and hardware) tools.

6 Collaboration Between Partner Companies/Hospitals

Using a collaborative portal platform, different institutions can seamlessly work together, under a coordinator, to ensure the best care for the patient, as well as to make the solution patient-centric. More specifically, hospitals, private care providers, non-governmental organizations, as well as other end-users, including patients' friends and family, can work together using the unified system in order to ensure the best quality of care. The whole process described above is going to be digitalized, including the service request by the user, the service definition (user + care manager), the service implementation (care operator), the service evaluation (user and family) and the administrative aspects (user or public administration).

7 Working on All Aspects of Health—Not Only the Disease

The AiCare portal platform can overtake the borders of classical care provision approaches, taking advantage of important aspects rarely taken into account until nowadays, among which Family Learning, a specific learning oriented to users affected by chronic diseases and their families or informal caregivers [11]. This measure is nowadays fundamental, since family is more and more involved in the management of the chronicity connected to the disease of the beloved person. As the shift in medicine is gradually moving towards disease prevention, wellness and monitoring a person's (not yet a patient) health and keeping him healthy, the portal can also act as a platform usable by dietitians, personal trainers and other individuals invested in the person's health. This information is also made available to medical experts, such as the person's General Practitioner in order to achieve optimal results.

8 Conclusions

The collaborative health portal platform here described aimed to combine all the key aspects described above in order to provide the patients and the end-users at large with an optimized healthcare model with respect to traditional approaches. In this way, paperwork is reduced, efficiency increased and care results are improved when smart technology and integrated care model are implemented. The main advantages of this approach rely on the following points: (i) the centrality of the patient, which becomes the real "first actor" of the care provision process, (ii) the development of an integrated solution, (iii) the opportunity of scaling the integrated solution directly at home, (iv) the possibility of providing a continuity of care, not only limited to the hospital/clinics but widely expanded also at home, and (v) the setup of a sustainable economic model, since the cooperative manages the whole care process, with significantly lower costs when compared to the framework in which such task is carried out by public authorities.

References

1. AICare s.r.l. (2016). https://www.aicare.eu
2. Bartels SJ, Naslund JA (2013) The underside of the silver tsunami–older adults and mental health care. N Engl J Med 368(6):493–496
3. COOSS Marche (2015). http://www.cooss.it/
4. Goodwin N (2016) Understanding and evaluating the implementation of integrated care: a ‘three pipe’ problem. Int J Integr Care 16(4):1–2
5. IFIC: patient is partner, not a consumer (2016). http://integratedcarefoundation.org/blog/patient-ispartner-not-consumer
6. Italian Government: 2016 Budget Law (2016). http://www.gazzettaufficiale.it/eli/id/2016/12/21/16G00242/sg
7. Italian Ministry of Economy and Finances: 2017 monitoring report of healthcare expenditure (2017). https://welforum.it/wp-content/uploads/2017/09/Rapporto-spesa-sanitaria.pdf
8. McKinsey&Company: the evidence for integrated care (2015). https://www.mckinsey.com/~/media/McKinsey/Industries/Healthcare%20Systems%20and%20Services/Our%20Insights/The%20evidence%20for%20integrated%20care/The%20evidence%20for%20integrated%20care.ashx
9. Mukamel DB, Haeder SF, Weimer DL (2014) Top-down and bottom-up approaches to health care quality: the impacts of regulation and report cards. Annu Rev Public Health 35:477–497
10. USA Today (2013). https://www.usatoday.com/story/news/nation/2013/01/14/googling-medical-advice/1833947/
11. Whitters HG (2018) Family learning to inclusion in the early years: theory, practice, and partnerships. Routledge, London
12. Yu S, van Gool K, Edwards K et al (2018) The business of integrated care: implementing new models of care in a fee-for-service setting. J Integr Care 26(1):16–28

From Ambient Assisted Living to Society Ambient Living

Laura Burzagli, Pier Luigi Emiliani and Simone Naldini

Abstract The developments of TLC networks and computer-based equipment allow the test of the Ambient Intelligent (AmI) concepts. In this paper these ideas are discussed from the perspective of activities carried out as an effort to help people (mainly old people) to live independently and comfortably. Three levels of implementations are discussed: the present situation, where intelligence is mainly meant as the use of computer-based equipment, able to adapt their behaviour to different users, the developments in progress, where equipment are connected under an intelligent control in the environment, for the implementation of functionalities and the communication with other supporting people, and future extension to the entire communication network, where intelligent user agents are able to look for potentially interesting contacts and negotiate to check promising opportunities, before involving users themselves.

Keywords Intelligence · Environment · Services

1 Introduction

Ambient intelligence (AmI), in particular its application for the support of people with activity limitations (mainly old people) in the house environment, has been normally identified as Ambient Assisted Living (AAL) up to 2014 when in EU documents the meaning of AAL was updated to Active and Assisted Living [1]. It is a concept leading to a new generation of products integrated in the living environment and controlled by services, which will offer functionalities able to support people in living independently and more comfortably.

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They could really have an important impact on independent living, e.g. of old people, but also on the well-being of the entire population. This is particularly true if they are designed using a appropriate generalisation of the Design for All Approach (DFA—The design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design) and addressing real needs of people.

The model behind the AAL approach is that people at home are surrounded by intelligent objects, through which functionalities are made available. They may be useful:

1. To control their physical status from a health care perspective;
2. To control their activities in order to monitor possible accident (e.g. falling) or to avoid dangerous situations (e.g. water spilling in the kitchen);
3. To use home equipment (e.g. the oven or the dish washing machine);
4. To help them in performing activities (e.g. using home appliances for preparing a meal);
5. To support them from a psychological perspective;
6. To connect them with the outside world.

In the paper a short description of the present situation and possible improvements are presented with main emphasis on the increasing importance of ambient intelligence and on the support that can be obtained with the integration in the communication networks. In Sect. 2, the problems will be mainly discussed from the conceptual perspective. Section 3 will be devoted to the presentation of some general solutions at the functional block level. In Sect. 4 examples of implementation of the experimental solutions, addressing complex problems related to well-being, will be offered, with particular reference to solitude.

2 From Tradition to Innovation

The implementation of environments able to satisfy all the requirements listed in the introduction requests time and effort, particularly points 5 and 6 that need the use of artificial intelligence, i.e. the evolution of ambient assistive environments to ambient intelligent environments.

The quantity and quality of intelligence necessary can be understood considering the ISTAG document [2], where the main high-level design requirements of an ambient intelligence environment are listed. It must be:

1. Unobtrusive (i.e. many distributed devices are embedded in the environment, and do not intrude into our consciousness unless we need them);
2. Personalized (i.e. it can recognize the user, and its behaviour can be tailored to the user's needs);
3. Adaptive (i.e. its behaviour can change in response to a person's actions and environment);

4. Anticipatory (i.e. it anticipates a person's desires as much as possible without the need for mediation).

First, it is evident that these necessary features require a generalisation of the Design for All definition to be read "The design of products and environments to *be useful to* all people, to the greatest extent possible, without the need for adaptation or specialized design". This shifts the emphasis from usability, mainly related to the assistive technology environment, to usefulness, fundamental for the entire population. Then, it implies the integration of human and artificial intelligence, shifting the emphasis from checking whether an equipment and its interfaces are accessible to people to anticipating the activities they need to perform for living independently and comfortably and trying to make them possible in ways, which are suitable for individuals in continually changing physical and psychological situations.

Fortunately, the problem of the activities necessary to people for living have been carefully studied and classified, in the WHO ICF classification (International Classification on Functioning and Disabilities) [3]. An example particularly relevant for understanding the importance of telecom networks, activities part of social interactions in ICT can be found in both the Activities and the Environmental Factors sections. Chapter 7 (Interpersonal Interactions and Relationships) describes in detail all tasks and actions required for simple and complex interactions among people.

Even a preliminary analysis of the ICF classification clearly shows the difficulties of the problems connected with social interactions. First, the list of interpersonal communications (d730–d779) is of interest from the perspective of exemplifying the complexity of the social network of each person. It makes possible the formal identification of how many types of relationships need to be considered and the possible problems of all of them. In a preliminary examination, the d750 (d7500–d7504) and d760 (d7601–d7603) classes may be considered. For example, for the Family Relationships class (d760), the Parent-child and Child-parent relationships (d7600, d7601), the Sibling relationships (d7602), and the Extended family relationships (d7603) can be examined. These imply interactions between people of different ages, which is one of the points of discussion when network-mediated interactions are considered. Another element in this analysis is the group of Informal Social relationships (d7500–d7504). Five different groups of people are considered: friends, neighbours, acquaintances, co-inhabitants, and peers. The groups in the social life of people outside the family are completed with groups that are part of the Formal relationships (d740). In this group of particular relevance is the group of service providers. Even if social interactions of people are probably reduced when they grow old, some of them are important for social integration. One example is the group of service providers, public as the ones dealing with certifications or hospital reservations or private, as shops where e.g. food can be ordered or bought. If people may be kept connected to their social environment, particularly when they leave their home to be recovered in an institution, this can significantly contribute to their well-being [4].

Finally, it is interesting to point out that:

1. The ICF is presented as an open classification, that is the level of details to describe the activities necessary for obtaining a goal can be refined as much as necessary for the specific application;
2. It point out the abilities necessary for carrying out the different activities, with a direct identification of possible problems if some abilities are reduced allowing a direct identification of possible substitution with available abilities;
3. It also exists as an ontology allowing, in principle, an easy integration in reasoning schemes.

2.1 Generalization of the Assistive Technology Approach

In the first phase, AAL activities, even aiming to the use of the Design for All approach, were influenced by the widely diffused assistive technology ideas, which are explicitly present in the term "usable" in the definition of DFA. Therefore, environments available today have mainly the following features:

1. An emphasis on monitoring health with sensors able to control the right functioning of the main organs (e.g. the heart);
2. An emphasis on security with sensors able to monitor the position and possible problems of people (e.g. falling) and the possible misuse of equipment (e.g. gas switched on);
3. Control of single equipment (e.g. the oven);
4. Interfaces based on the adaptation of standard interfaces of equipment;
5. Use of network connection mainly for connection with service centres (e.g. hospitals for medical control).

The environments are made up of a set of computer based equipment, normally not interconnected, taking care of single functionalities of the house and of possible problems of people living in them. Telecommunication networks are mainly used for connection with professional service centres and people officially taking care of the individuals at home. Their main purpose is to keep people at home as much as possible to reduce costs for public administration. Very low effort is devoted to their well-being, for example their psychological problems as sense of solitude and depression.

2.2 Increasing Use of Intelligence

The above considered model is mainly based on the development of basic technology and aims to use its emerging deployment to solve specific problems of people (mainly old people) living alone. More recently, the interest is growing for the integration of computer-based technology in complex environments, aiming to favour activities that people need to perform in them according to the ICF classification. Moreover, the designers start to realise that the environments should be implemented to favour the performance of activities not only significant for the physical, but also for the psychological welfare and to evolve according to the varying user needs and the availability of new technology. Obviously, individuals might have different preferences about how these activities should be organised and carried out and a lot of research activity on user preferences is necessary to set up and feed the user models necessary to reason about their requirements.

The main difference between a caregiver and the environment in supporting people is that the caregiver has a brain, i.e. s/he is able to reason about user needs. On the contrary, the environment is not able to reason at all in most of the present intelligent environment. How and to what extent this is possible or will be possible is under discussion. However, a reasoning system as the one schematised in Fig. 1 is supposed to be the core of any environment if this must be able to collect, produce and organise the knowledge necessary for identifying the functionalities and the interaction compatible with individual preferences in their continuously varying living situation.

Its main components are briefly described in the following. After the definition of activities and sub activities, the identification of functionalities (services), necessary to support these activities (e.g. feeding), is necessary. They may include technological functionalities in the kitchen and remote human support. Examples are: control of the single appliances, access to recipes documentation in electronic format, access to social networks, etc. This must be done taking into account the abilities of the different people who are supposed to use the kitchen. Only at the end, interaction aspect needs to be taken into account, even if only at the functional level: for example, the use of complex descriptions of recipes can be difficult for older people with decreased cognitive capabilities.

The produced knowledge must be formalised, e.g. in ontologies, to be available to the reasoning components. For example, an available ontology about feeding can be adopted and gradually enriched, or a new ontology can be created [5]. Moreover, information coming from social networks and any other application such as a forum, if conveniently processed, can contribute to the ontology construction.

Several technologies can be available for the implementation of the selected functionalities. The features of the technologies must be described in a formalised way together with the communication protocols.

After a careful selection, all the collected knowledge need to be integrated. This must be carried out under the control of a reasoning system (intelligence in the environment) able to use the knowledge in the ontologies or in other structured or partially structured forms:

1. To adapt the application to the single user;
2. To learn from the usage, to refine the formalised knowledge memorised in the ontologies and/or other organised forms and to introduce necessary updates;
3. To evolve the functionalities together with the evolution of technology;
4. To propose the suitable interaction.

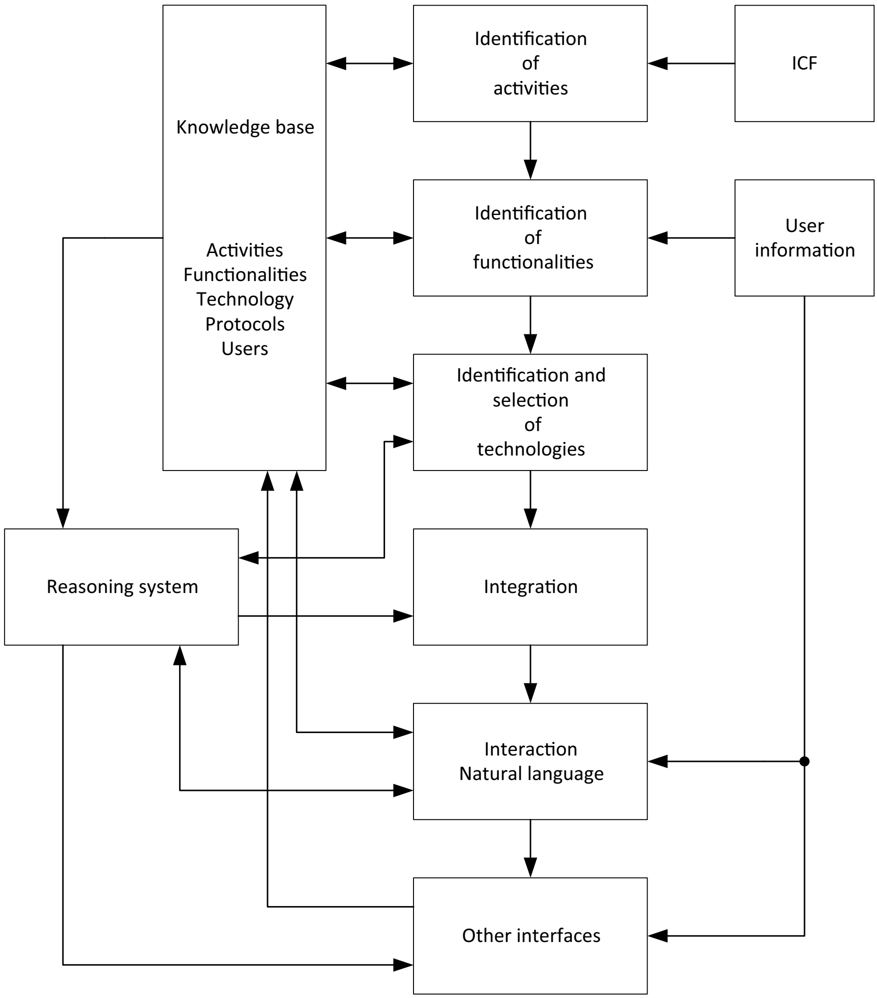

Fig. 1 The structured approach

From the interaction perspective, it is important to observe that in complex situations as the ones emerging in the ambient intelligence environments, interaction cannot only be analysed from the perspective of being able to access the available interface. A real exchange of information between people and the system, which must be able to assist the users, learn from their behaviour, test the validity of its assumptions and react to explicit requests, must be established.

People are normally used to exchange information through face-to-face conversation in natural language. Natural language is the "natural" interface between them. Therefore, the interaction between the environment and people living in them should probably be mainly based on a dialogue in natural language. Trends of developments in information technology and artificial intelligence (see, for example, the SIRI applications by Apple [6] and the Watson project by IBM [7]) show real possibilities of a successful evolution in this direction.

Obviously, also a communication in natural language may create interaction problems to some groups of people with activity limitations. These problems must be identified and formalised, and the reasoning system is supposed to introduce the necessary adaptations as a function of the user and the carried out activity.

3 Technology Developments

Three levels of possible implementations are discussed.

3.1 Environments with Intelligent Objects

According to the previous discussion, the present implementation of intelligent environments can be schematised as depicted Fig. 2. The computer-based (and therefore potentially intelligent) equipment are augmented with adapted interfaces, when necessary, and made available to the user. In agreement with their intellectual abilities, the users may only receive simple inputs and, in addition to the performance of the requested activity (e.g. switch on the oven) react with simple acknowledgments or can carry out complex dialogues. Moreover, the environment and the user can be connected to different alarm services or to a person (for example a son), who is in charge of her security.

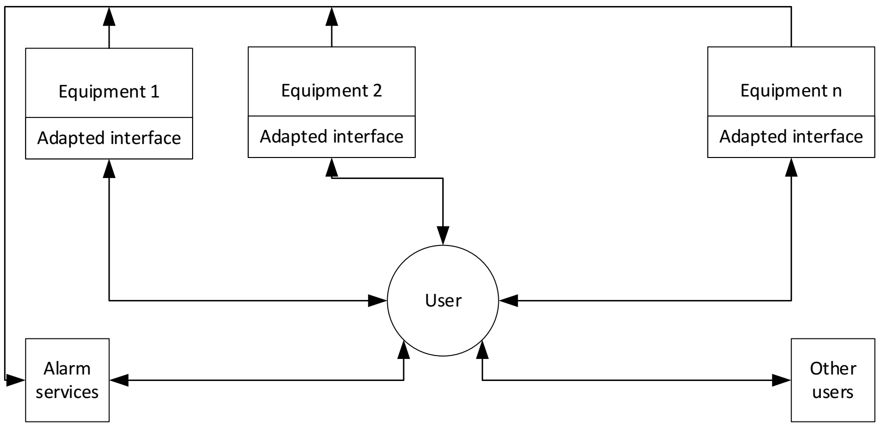

Fig. 2 Intelligent components in the environment

3.2 Intelligent Environments and Dedicated Networks

Figure 3 is a schematic description of a real intelligent environment as it is presently emerging.

Intelligent equipment are connected among themselves and to the user through a reasoning system that is the main intelligent block of the system. It uses the inputs from the equipment and the users and the knowledge in the knowledge base to decide about actions of the entire system and to filter relevant information that can be used to enrich the knowledge base itself. At this stage, what functionality has to be made available to the user is decided and, according to her abilities, the right dialogue is structured and is implemented with commands sent to the multimedia interface through the user agent.

The set of functionalities made available may be simple as switching on a lamp or complex. The user can tell the system: I am hungry. This start a composite set of operation. Examples are: control of the diet of the person; examination of what she ate during the day; control of what is available in the fridge or in the pantry; discussion with her about different options; suggestion of different recipes; programming of all the equipment necessary for cooking.

The user agent is a very important part of the system. For example, it can contact the medical centre if some physical parameter is slightly out of range and discuss with the doctor whether the intervention of the user is necessary, thus probably creating anxiety or the doctor can personally take care of the problem. On a higher level of

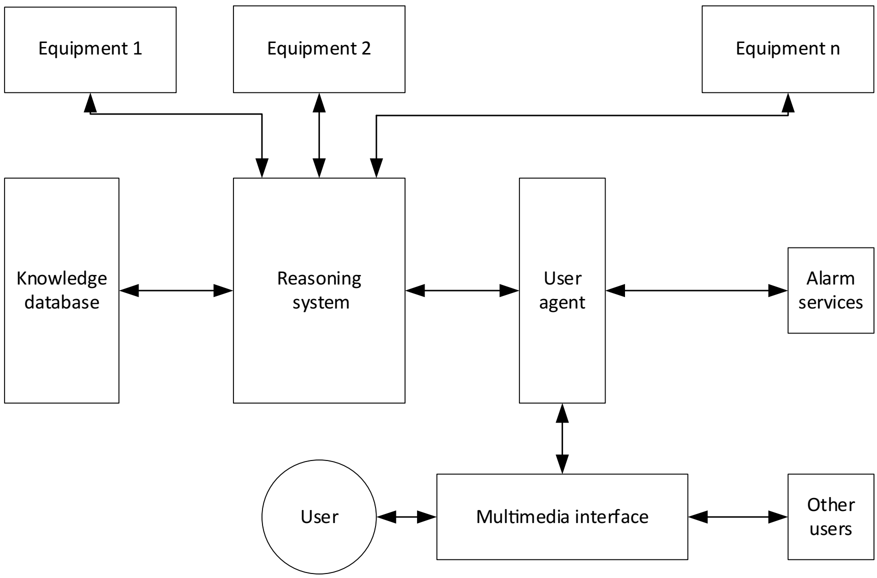

Fig. 3 An intelligent environment

necessary intelligence, if the user appears slightly depressed and the system knows that in this case the user likes to speak with friend X, the agent can check if the friend is available physically or psychologically to help, before creating expectation in the user.

Examples will be presented in the following section.

3.3 Extension to the Entire Society

The following development will be the interconnection of the individual intelligent environment with the entire network, populated of other intelligent environments, according to the scheme of Fig. 4.

Every intelligent environment is a system as the one shown in Fig. 3 with user agents also used as a general interface with the network. They are particularly important. The idea is that when a special problem or an information need arises that cannot be satisfied in an intelligent environment as the one depicted in Fig. 3, the user agent can start exploring the network. Discussing with other user agents it can explore the possibility that the need can be satisfied by the user of the intelligent environment whose agent has been contacted. The contact between the users is established only when the user agents "think" that it can be useful.

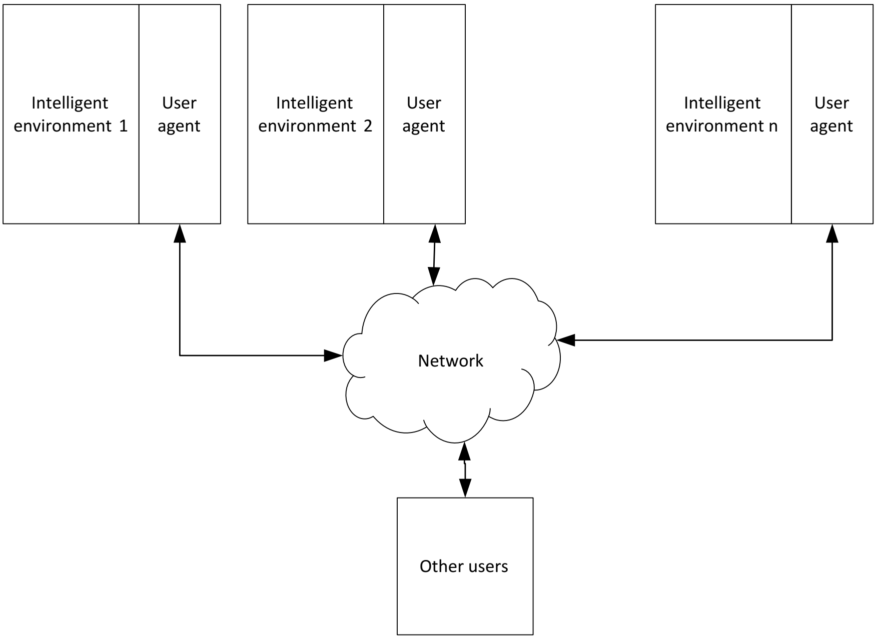

Fig. 4 Intelligent network

4 Examples of Experimental Implementation

A specific example of the concepts presented in this contribution is an application already implemented in an experimental version in our laboratory, related to a particular condition of people: loneliness. Even if this condition is not a pathology, it can favour a wide set of diseases, varying from depression to stroke and many others. According to a large number of scientific publications [8], one of the most useful remedies to face this problem is an improvement of interpersonal relationships. At the technological level, the environment can be equipped with a set of not obtrusive sensors, able to recognize the state of a person and to communicate her condition to the control system. The control system can provide the person with suggestions to improve her condition.

In order to create a first implementation of this service, the social contexts that are physically closer to the person have been considered, for example neighbours at home or colleagues in the office, if the person is not yet retired. This leads to the identification of groups of people, who are supposed to be available to cooperate in the service.

A profile for each person of this specific group is created, such as for each individual inhabitant in a building. Reasoning about such profiles in term of abilities, interests and on-going activities, the application can provide each person feeling solitude with appropriate suggestions for specific activities to be carried out or connections to be established with one or more members of the group. Experts, such as doctors or caregivers, can fill a preliminary list of suggestions, according, as a starting point, with an initial list of activities obtained from the aforementioned ICF document [3]:

D166	Reading
D450	Walking
D470	Moving using transportation
D550	Eating
D570	Looking after one's health
D620	Shopping
D630	Preparing meals
D750–760	Informal social relationship
D910	Community life (organization)
D920	Recreation and leisure (sport, exhibition, hobbies…)

The suggestions can be accepted and put in practise, or rejected by the user. For the nature of data and the objective of such application, it is clear that the use of static data during the phase of suggestions selection is not sufficient. Suggestions really specific can be given to each user only if a strategy of decision-making is adopted, a strategy able to consider the continuous development of needs, present situation and preferences of users.

In order to implement a system, which is dynamic and tailored for the user, it is necessary to integrate in the process of suggestions selection, elements of Artificial

Intelligence. In this example, a Machine Learning system has been introduced that according to a set of inputs is able to give the "best" suggestion based on previous decisions of the user. Machine Learning allows detecting all changes of the behaviour of each user and adapting in real time the choice of suggestions.

5 Conclusion

The opportunities offered by the AmI concepts are of particular interest, particularly from the perspective of the support to people who may have problems in living independently (not only people with specific activity limitations, but also "normally" aging people).

However, according to the authors, this will be only possible if the typical approach of assistive technology is abandoned and, starting from the AmI approach, the knowledge about the adaptations needed for the performance of useful activities is developed and integrated as a component of the knowledge describing the possible implementations for the population at large.

References

1. Strategy 2014–2020 for the active and assisted living programme, http://www.aaleurope.eu/wp-content/uploads/2015/11/20151001-AAL-Strategy_Final.pdf
2. Ducatel K, Bogdanowicz M, Scapolo F, Leijten J, Burgelman JC (2001) Scenarios for ambient intelligence in 2010. Technical report, Information Society Technologies Programme of the European Union Commission (IST)
3. World Health Organization (2001) International classification of functioning, disability and health: ICF
4. Bothorel C, Lohr C, Thepaut A, Bonnaud F, Cabasse G (2011) From individual communication to social networks: evolution of a technical platform for the elderly. Toward useful services for elderly and people with disabilities. LNCS 4128:145–152
5. LanguaLTM—The international framework for food description, http://www.langual.org/Default.asp. Cited 01 Jun 2018
6. SIRI applications by Apple, http://www.apple.com/ios/siri/. Cited 01 Jun 2018
7. IBM Watson, http://www-03.ibm.com/innovation/us/watson/. Cited 01 Jun 2018
8. Niedzwiedz CL, Richardson EA, Tunstall H, Shortt NK, Mitchell RJ, Pearce JR (2016) The relationship between wealth and loneliness among older people across Europe: Is social participation protective? Prev Med 91:24–31

Designing Multidimensional Assessment of ICTs for Elderly People: The UNCAP Clinical Study Protocol

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Abstract The elder with mild or moderate cognitive impairment (MMCI) suffers from progressive cognitive decline with increasing difficulties in performing activities of daily living. Information and Communication Technology (ICT) for Healthcare can provide solutions to relief the caregivers' burden and to support the elder in maintaining dignity and independence. The UNCAP European project aimed at developing and testing a bundle of hardware and software technologies able to fit the individual needs of the elder with MMCI and his/her formal and informal caregivers. A multicenter clinical investigation was designed for assessing improvements in the quality of life of all users (elderly with MMCI and their caregivers) and the impact on the use of resources for care. Six pilot sites in Italy were involved in this clinical investigation. A complex set of assessment tools allowed exploring a wide range of dimensions and to extract common indicators and outcomes in accordance to the assessment dimensions required by the Health Technology Assessment approach.

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Keywords Clinical investigation · Healthy aging · ICT · Health technology assessment

1 Background and Rationale

1.1 Aging of EU Population and Needs for Innovative Technologies

The world's population is ageing rapidly with an estimation of one out of five people over 65 years old by 2030 compared to one out of 10 today. Due to chronic age-related illnesses, many seniors progressively lose their autonomy and become more dependent on others, finally reaching the stage when they need round-the-clock care from their family members or caregivers.

One of the most important chronic diseases that affect the ageing population is dementia. It accounts for 4.1% of total disease burden among people aged over 60 and 40% of people older than 85. The number of people affected by this disease is increasing exponentially. Worldwide, 47.5 million people have dementia and there are 7.7 million new cases every year (WHO Fact sheets N° 362, March 2015). Numbers are nearly doubling every 20 years [18].

The Global Deterioration Scale (GDS) [19] categorizes cognitive and functional abilities are into seven stages, ranging from "no cognitive decline" in the first stage to "very severe cognitive decline" in the seventh stage. Stage five denotes the point where it becomes difficult for the patient to live independently and assistance is needed from his/her family and/or caregivers. During stages three to five (mild and moderate cognitive impairments, MMCI), the elder suffers from progressive cognitive decline and experiences increasing difficulties in performing Activities of Daily Living (ADLs). In some instances, MMCI elders may understand what they are supposed to be doing but they may not understand the instructions, or forget them midway through a task. They may also fail to recognize objects for what they are (agnosia) or know how to execute learned tasks (apraxia). This means that the caregivers have to be present to support patients during their activities, and slowly, over time, increase the support they provide as the disease evolves [1].

Older adults, including people with MMCI, desire to remain in their homes as they age [9]. Declining physical and mental capabilities create significant challenges to manage increasing care needed to remain living at home (home care scenario) or at long-term care facilities (residential care scenario).

People with MMCI have more than triple the number of hospitalizations compared with older adults with other conditions [7] and consequent burden of care is relevant. Family caregivers experience high levels of stress, burden and custody charge that lead to negative physical, psychological and social, outcomes [8, 18, 20, 25]. Caregivers of people with MMCI must cope with their loved one's progressive memory loss, self-care impairment and communication breakdown. Caregiving stress, strain and burden contribute to negative physical and mental health outcomes that include depression, insomnia and psychotropic medication use, with notable increases in caregiver morbidity and mortality [16]. Caregivers separated by distance face unique challenges as they manage caregiving from afar. They may worry about their family member's safety and security, medication schedules, wandering, and need for information and socialization. The distant caregiver may be unaware of the needs of their family member, placing further burden on the onsite caregiver(s) [7].

Since the 1980s, technology has been investigated as a possible support for aging in place [20]. As technology advances, so will new opportunities to reduce the burden of caregiving elderly with MMCI.

1.2 Evaluating Safety and Effect of Innovative Technologies

UNCAP technology has been developed under the framework of the UNCAP European Projects (Ubiquitous iNteroperable Care for Ageing People, EU Grant Agreement number: 643555) and was specifically aimed at addressing the needs of ageing people with cognitive impairment (CI) and dementia.

Enhancing the well-being of people with these conditions is a complex and evolving task. UNCAP fostered a modern non-pharmacological approach as an appropriate initial strategy in the support and care of individuals with CI. UNCAP was designed to assist the individual in maintaining dignity and independence and generally improving users' quality of life. It exploited the latest available technologies to create a sensitive bundle of tools to aid individuals, families and carers in managing their specific needs.

UNCAP was aimed at alleviating a disease (i.e. mild and moderate cognitive impairment), thus being a medical device. Before entering into the market, a premarket clinical investigation was required to assess safety and effects of the innovative medical device.

The design of a clinical investigation for such a technology represented a complex task because the technology allows personalization according to the specific needs of the target user. To this aim, a clinical pilot study has been proposed and realized. The study presented here was designed and performed in different settings (home care and long-term care facilities) representative for the potential setting of use of the system. Moreover, subjects were enrolled according to common inclusion and exclusion criteria, but eliciting specific personal needs that required testing personalized configuration of the system.

The clinical investigation has been evaluated by both the local ethical committees and the National Competent Authorities before starting subjects' recruitment.

2 The UNCAP Bundle

2.1 System Architecture

Individuals with CI or dementia may have problems with their environment leading to stress, agitation and anxiety, and UNCAP can facilitate a reduction of these and other stressors. These interventions can be simple, such as redirecting and refocusing the individual, increasing social interaction, establishing regular habits eliminating sources of conflict and frustration, or more complex. UNCAP provides a range of sophisticated technologies assisting the individual to move safely around their home or general environment by using "transparent" monitoring tools and sensing aids. UNCAP also has the capability to monitor physical movements, cognitive levels and clinical parameters, promoting exercise and training at emotional, physical and cognitive levels.

In practice, UNCAP is a product suite comprising of a low-cost Android-based unit, called the "UNCAP BOX" and a set of hardware and software compatible technology that can be tailored on user needs. The box is connected to a standard digital television set with a USB port. This allows for the collection of data from different indoor and outdoor localization technologies including sensor flooring and camera-based detection systems and from sensors measuring vital parameters such as glucometer, oximeter or blood pressure meter. The system makes the data available, via secure communication channels, to the "UNCAP CLOUD" for the access of authorized caregivers. The UNCAP BOX provides also an interface for individuals, caregivers and family members who can communicate (also via video conference), exchange health data (via HL7 standard http://www.hl7.org), access assessment of the individual's health conditions (through InterRAI™ assessment tools and methodology, http://www.interrai.org and Atl@nte suite, http://www.sistematlante.it) as well as place emergency calls (Fig. 1).

The UNCAP BOX supports interoperable communication, via KNX open protocol (http://www.knx.org), with building automation systems and delivers tailored services including individual lighting controls and "activity reminders", for example flashing lights. The UNCAP BOX is completed by an App for smartphones or tablets. This provides a convenient portable access to UNCAP services and allow accessing selected UNCAP services in online and offline mode or from locations that are not compatible with the UNCAP infrastructure.

UNCAP is made available as a bundle composed of multiple detachable modules and services. The set of compatible devices and software packages is:

- UNCAP box
- Web app
- UNCAP app
- System bus
- Clinical record (Atl@ante)
- Communication system

Fig. 1 The UNCAP system (http://www.uncap.eu/)

- Glucometer (e.g. iHealth BG5 gluco-monitoring system)
- Safety support (MentorAge®)
- Sensor mats (SensFloor®)
- Oximeter (e.g. jumper medical JPD-500F oximeter system)
- Blood pressure monitor (e.g. BM-85, Beurer)
- Scale (e.g. iHealth Lite system)
- Smartwatch (e.g. Pabble Watch Classic)
- EEG monitor (e.g. EPOC, Emotiv)
- Serious Game (from Media and MIRo Lab, University of Trento)
- Serious Game (webFitForAll, from Aristotle University of Thessaloniki, Laboratory of Medical Physics)
- Location System (energy efficient Real Time Localization System from ZIGPOS).

2.2 Indication for Use

UNCAP is a medical device intended for the use by the human being with the aim of alleviating a disease.

Specifically, UNCAP is a bundle made of software and hardware components that:

- supports the autonomy and the improvement of the quality of life and dignity of the elderly with mild or moderate cognitive impairment;

- allows the remote clinical evaluation and the monitoring of the health status through the shared management of the elderly with mild or moderate cognitive impairment in home-care and residential healthcare settings by formal and informal caregivers;
- provides services and tools for the physical (exer-games) and cognitive (serious games) rehabilitation and tools for fall prevention with the aim of postponing the cognitive deterioration of the elderly with mild or moderate cognitive impairment.

A comprehensive view of all UNCAP services and functionalities is provided in Table 1.

3 Available Evidences on ICTs for the Elderly with CI

Since no previous clinical study for testing safety and performance of UNCAP was available at the time of the study planning, a clinical evaluation on equivalent or similar technologies was performed according to the EU guidelines on medical devices (MEDDEV. 2.7.1 rev.3 "Clinical Evaluation: a guide for manufacturers and notified bodies"). The literature search resulted in few studies conducted on integrated solutions with claims similar to UNCAP.

There was very little in the systematic reviews specifically concerning patient safety and it was not clear whether adverse events did not occur or whether there was a lack of reporting. Available information showed that cognitive stimulation did not induce differences in the MMCI user mood, and no behavioral function or problem behavior was noted [2, 23]. There was no indication of increased strain on family caregivers adopting technologies for elders with MCCI [23] that in general appeared to be safely used.

Literature search reported, in general, a good acceptability and satisfaction by demented persons and caregivers, a good usability and performances, ranging from moderate to good, for technologies with available clinical data [6].

Results of rigorous clinical studies on integrated technologies are still missing. Studies including people with MMCI exposed to single IT systems or smaller bundle of technology showed that monitoring systems could significantly decrease the burden for formal or informal caregivers [12].

Ambient Assisted Living technologies that required minimal interaction from the service user and appliances that were specifically designed to address particular problems led to more successful outcomes for the person with dementia [10]. In a clinical trial of 10 subjects with moderate to severe dementia, the COACH system increased by 25% the number of handwashing steps that were correctly completed without caregiver assistance [15].

Systems for monitoring of vital signs and basic metabolic parameters have high potential [14, 21], but no clinical studies with dementia subjects were retrieved from literature [5]. Tracking and wayfinding systems, based on GPS intervention, increased the ability of people with dementia to go outside independently, resulting

Table 1 UNCAP functionalities

Service	Short description
Monitoring	To continuously assess health state of users from a range of different sensors as well as their physical activity levels. The information collected and securely stored in digitalized clinical folder allows remote assessment by doctors when the direct contact is not necessary
Digitalized clinical folder	To allow store and exchange of clinical data based on existing open standards. This ensures continuity of care at different levels of intensity. This service includes the management of: • Care protocol, necessary treatment and medications, including appointments with caregivers, reminders about which medicine should be taken at the right time, support for checklists, etc • Historical information of the patient's clinical records, including the caregivers involved • Support of a diary containing general observations on the patient, often used in the case of access to "daily care" structures, not involving medical cares
Reminder	To help users recalling activities and help finding the needed items to perform them
Communication	To help the user easily communicating with family members, friends, and caregivers via simple interfaces available through their TV or smartphone/tablet. Communication between formal and informal caregivers is facilitated to consider all the dimensions of the elder profile and needs: from the objective information concerning the MMCI user health, habits, and practical needs, to more subjective considerations, for example concerning the users' mood, desires or relationships with the care givers
Emergency call	To trigger alert messages to caregivers when abnormal clinical health is detected or when "sentinel events" are identified
Fall detection	To trigger alert in case one of the different technologies detects the user falling (e.g. the sensor floor, the cameras, the smartphone algorithm, etc.)
Clinical assessment	To assert the MMCI user's conditions (physical and cognitive) and evolution in time through the use of the internationally validated multi-dimensional test scales
Cognitive or physical exercises	To create incentive mechanisms to help keeping users healthy from a physical and cognitive point of view through games (or other strategies) based on use of data from localization technologies (e.g. to challenge users to walk more)
Guiding	To help users reaching a given location (inside or outside the building) or locating devices/objects of daily use, e.g. the remote control of the TV
Spatio-temporal geofencing	To trigger alerts to caregivers when the user leaves designated areas or behaves abnormally at unusual times (e.g. leaving the room during the night)
Data repository and exchange	To provide a secure cloud storage space used to archive confidential data through open cryptographic libraries or on encrypted partitions

in more freedom of the elder away from caregivers, and decreased the levels of stress of both the primary user and the caregivers [17].

Tracking systems integrated with fall prevention device were highly effective in reducing the relative risk of falls in person with dementia [22].

Cognitive aids can reduce the number of nighttime calls [4]. Cognitive stimulation has been shown to have positive effects in elderly with MMCI over and above any medication effects with a consistent benefit on cognitive function, self-reported quality of life and well-being at follow-up [23]. Although the cognitive effect of Serious Games played by older adults has not yet been studied thoroughly, combined physical and cognitive training have the potential of improving global cognition in patients with MCCI [3]. Results of a multicentre study including 322 older adults indicated that combined physical and cognitive training improves global cognition in a dose-responsive manner but these benefits may be less pronounced in older adults with more severe neurocognitive disorders [3].

In a summary, indications for use of UNCAP technology were supported by knowledge and data available in literature from several partially-equivalent technologies that have been experimented on MMCI elders and their caregivers. However, considering the scarcity of specific clinical data supporting the use of ICTs in alleviating cognitive impairment and improving quality of life of older adults affected by CI, new clinical investigations were needed.

4 Study Design

UNCAP modularity is conceived to allow the customization of the bundle features according to the actual care setting and the needs of both primary (seniors with MMCI) and secondary (informal and formal caregivers) users' needs. According to this, UNCAP was tested for caring elderly people with MMCI in two different settings:

- long term care facilities as an additional care device;
- primary user home for providing home care services.

Each of the pilots implemented a specific set of UNCAP features chosen according to the specific application scenario, environment and users' needs.

The modularity and adaptability of UNCAP in different scenarios reflects the complexity of the clinical investigation to assess UNCAP usability and safety, users' acceptance, satisfaction and quality of life. However, all pilot sites shared the same research questions, with a common set of primary and secondary endpoints and evaluation tools.

The investigation was conducted as a pre-market randomized controlled prospective parallel multicentre study.

4.1 Objectives and Research Questions

The study aimed at assessing improvements in the quality of life of users and the impact on the use of resources for care due to the adoption of UNCAP technology. The objective of the investigation was also to assess safety and usability of UNCAP in responding to the needs of elderly people with mild and moderate cognitive impairment as well as evaluating primary and secondary users' acceptance and satisfaction.

The above reported objectives were summarized in the following research questions:

- Does the introduction of a personalized UNCAP bundle improve the users' quality of life?
- Does UNCAP have an impact on the caring for elderly with MMCI?
- What is the safety and usability of UNCAP in caring elderly patients with MMCI?
- What is users' satisfaction and acceptability of UNCAP?

4.2 Study Dimensions and Outcome Variables

Considering the multiple dimensions to assess in the study, a comprehensive set of outcome variables was defined as reported in Table 2.

4.3 Primary and Secondary Hypotheses and Study Endpoints

To properly address the research questions reported above, primary and secondary endpoints of the study were formulated and challenged by well defined working hypothesis making use of the outcome variables reported in Table 2. Study endpoints and working hypotheses of the study are summarized in Table 3.

4.4 Criteria for Recruiting Participants

The study was designed to examine UNCAP technology as an intervention within the subject home or at long-term facilities. Therefore, participant samples included only people who live at their home or at long-term facility and who were diagnosed from mild cognitive impairments to moderate cognitive decline (MMCI).

Detailed below are conditions regarding all user groups, inclusion and exclusion criteria and procedures for recruitment.

Table 2 Outcome variables of the study (EP: elderly person, primary end-user; ICG: informal caregiver; FCG: formal caregiver; QoL-AD: Quality of Live Alzheimer Disease [13]; FES-I: Falls Efficacy Scale-International [24], SQLC: Scale of Quality of Life of Care-Givers [11])

Study dimensions	Outcome variables
Quality of life	QoL-AD score (EP)
	SQLC score (ICGs) FES-I score
Perceived usability	Number of primary users (%) in the test group considering UNCAP features as "usable"
User acceptance	Number of primary users (%) in the test group considering UNCAP features as "acceptable" Number of primary users (%) in the test group willing to complete the study by using UNCAP technology for 6 a months period
User satisfaction	General satisfaction EP score General satisfaction ICG score General satisfaction FCG score Number of primary users (%) in the test group expressing as "satisfied" about UNCAP in respect to the specific need Number of ICGs (%) in the test group expressing as "satisfied" about UNCAP in respect to the specific UNCAP component Number of FCG (%) expressing as "satisfied" about UNCAP in respect to the specific UNCAP component
Safety	Number of Adverse Events (AE) Number of Adverse Device Effect (ADE) Number of Serious Adverse Events (SAE) Number of Serious Adverse Device Effect (SADE)
Impact	Number of medical examinations by general practitioner Number of medical examinations by other physicians Number of referrals to the emergency department Number of hours per month spent by nurses caring for participant Number of hours per month spent by FCG caring for EPs Number of hours per month spent by ICG caring for the EP Number of days off work for family members for caring EP Number of technical interventions for device malfunction
Primary user needs, health profile and autonomy	Personal Health Profile (PHP) key from ATL@NTE

4.4.1 Users Definition and Needs

Primary end-user: the old person (subject) with Mild and Moderate Cognitive Impairments who was using UNCAP or to which UNCAP technology was provided for. These people have difficulty in their everyday life, which comes due to cognitive problems and mild or moderate dementia. This group could directly benefit from the UNCAP technology and was expected to increase the quality of life of its members.

Table 3 Study endpoints and working hypotheses. (EP: elderly person, primary end-user; ICG: informal caregiver; FCG: formal caregiver; QoL-AD: Quality of Live Alzheimer Disease [13]; FES-I: Falls Efficacy Scale-International [24], SQLC: Scale of Quality of Life of Care-Givers [11])

Priority level	Study endpoints	Working hypothesis
Primary	UNCAP increased the "Quality of Life" for the elderly with MMCI	UNCAP will increase the QoL-AD score of primary users by 9% in the test group in respect to control group
Secondary	UNCAP had positive effects in the "Quality of Life" of the primary users and their caregivers	UNCAP will increase SQLC score of ICGs in the test group after six months of use UNCAP will reduce FES-I score of EPs in the test group after six months of use
	UNCAP had no negative effects in the safety of the primary users	UNCAP will not determine any severe adverse events related to the device in the test group after six months of use
	UNCAP was positively accepted and used	75% of participants in the test group will be able to use UNCAP features 75% of ICGs in the test group will report acceptance of UNCAP as support in their care for EP 75% of test group participants will report satisfaction of UNCAP
	UNCAP had a positive impact on the burden of care for elderly wit MMCI	UNCAP will reduce the overall burden of care by 10%

Secondary end-users: persons directly being in contact with the primary end-user, such as formal and informal care persons, family members, friends. This group was expected to benefit from UNCAP technology directly when using the services and indirectly when the care needs of primary end users are reduced. Secondary end users were grouped into two sub-categories according to the following:

- Informal care-givers (ICG): very often the closest family members are the direct care-givers and supporters in the daily care for the MMCI subjects
- Formal care-givers (FCG): Professional care providers (physicians, nurses, professional caregivers at home).

4.4.2 Inclusion Criteria

Based on the main user groups considered in the study, the safety, acceptability and satisfaction of UNCAP were evaluated on the following three test groups:

- EP group—of primary end users: Elderly People with cognitive problems or mild dementia.

- ICG group—of secondary end users: Informal Care Givers. This includes close family members or family friends who take care of the senior.
- FCG group—of secondary end users: Formal Care Givers. This test group includes home care personnel and specialized care-giver personnel at long term care facilities.

The target primary end-user group (EP group) were elderly persons with Mild and Moderate Cognitive Impairments (MMCI) (2–3 stage and partially 4 stage, since some of 3 stage subjects, in 6-month duration of the test project periods, might progress to stage 4). The trial participants were classified according to CPS score at enrolment.

Specific inclusion criteria for primary users included:

- Age above 60 years
- Lives at home, or in a long term facility
- Diagnosed with Mild or Moderate Cognitive Impairment (MMCI) with a CPS score of 2–3 at enrolment
- The MMCI diagnoses and stage is defined by a specialist (neurologist, geriatric specialist, etc.)
- Can self understand and give consent to participate in the project trial
- Having a close relative or family-friend which is willing to help for the participation to the project trials as an informal caregiver is considered as preferential but not mandatory.

ICGs was considered as secondary users if they were:

- 18 years old or older
- actively involved caregiver for the care recipient (provide at least on average of 5 h of supervision or direct assistance per week)
- planning to remain in the area for the duration of the intervention and follow-up
- has performed the informal caregiver role for more than 6 months
- Not having dementia at any stage.

FCGs was considered accordingly to their willingness to cooperate. Once the potential FCG were identified, they were contacted by one of the researchers (e.g. pilot responsible) who further explained the project and answered any questions they might have. Formal caregivers were asked to identify the care giving situation from their (professional) point of view regarding ICG status, EP status and care giving situation. FCG completed a screening tool to determine their occupational status and role in the care team. Formal caregivers were encouraged to participate in the home visit of EP to assess the situation, setting and possible solutions. They were asked for general satisfaction and specific satisfaction about UNCAP system features. Moreover, they were asked to provide data for addressing efficiency of the care system in respect to the primary user at both the enrolment and discharge time.

4.4.3 Exclusion Criteria

The following exclusion criteria were identified for the primary end-user. Those subjects meeting the following conditions were excluded from the study.

- Mild neurocognitive disorder due to:
  - Drug abuse due to the presence of co-morbidities with Personality Disorder not compatible with this study
  - HIV infection, since medical complications are not manageable
  - Nutrition deficiencies
- Participants whose dementia is reversible (nutrition deficiencies)
- Presence of psychiatric co-morbidity
- Presence of behavioral disorders (difficult research management)
- Individuals with severe functional or sensory impairment (e.g. visual impairment or certain physical disabilities), that could jeopardize the use of technological devices tested in the study
- Individuals enrolled in a pilot study whose condition shows a rapid decline towards more severe forms of cognitive diseases or other conditions that result in an inability to use the technological devices tested in the study.
- Life expectancy <1 year

Due to matters related to budget limitations and costs per pilot, secondary exclusion criteria for the subjects of the test group were:

- Participants living at home who do not have Internet access or for whom there is no possibly to provide such infrastructure.
- Participants living in big homes (due to the limitation to buy and install many sensors in their homes).

4.5 Recruitment Process

Several strategies were defined and implemented for realizing an effective and unbiased recruitment process.

Potential participants were recruited with the help of general practitioners and nurses, aging and cognition specialists, memory and dementia clinics operating at the local care structures.

Another activity which helped recruiting test subjects living at home was the availability of a living lab, where a ready, full optional UNCAP bundle, was installed with the purpose of:

- demonstration of the systems to potential test participants and their relatives (they were able to see, and experience the system before deciding to join the controlled study and be convinced that UNCAP technology was user friendly and also aesthetically acceptable);

- try in reality the system and provide indication for customization of UNCAP bundle according to specific patients' needs;
- provide training to enrolled end-users;
- gain hands-on experience of the full options UNCAP system to informal and formal caregivers.

Another used approach was to contact the informal caregivers of potential primary users. This approach was pursued for recruiting MMCI elders living at their home. The advantage of this approach is that when the close relative or partner is positive about the possibility of assessing UNCAP technology, he/she could easily convince the primary end-user to take part in the trials. During this contact, primary caregivers assessed eligibility criteria or primary and secondary end user before asking for availability to participate in the study.

Primary users then needed a clinical evaluation by a specialist (neurologist, geriatric specialist, etc.) and a rating of cognitive decline.

Eligible participants received a visit by one or more research members at their long- term facility or at their home according to the local setting.

This visit served to present both oral and written information regarding the research and the clinical investigation as well as:

- Obtain informed consent of participants.
- Measure the level of cognitive impairment with Atl@nte.
- Measure quality of life at enrolment (with QOL-AD questionnaire).
- Conduct an assessment of the participant needs.
- Document user's behaviors that could present safety concerns.
- Identify potential sites for UNCAP equipment deployment at the user's premises.
- Ascertain caregivers' familiarity with technologies.

4.6 Sample Size

A total of 120 elderly persons with mild or moderate cognitive impairment were recruited at the six Italian pilot sites. In addition to the primary users (elderly persons, EPs), the study plan aimed also to enroll 102 secondary users, including 72 informal caregivers and 30 formal caregivers (Table 4).

Among the recruited users, a randomization procedure allocated the primary users (EP) and their ICGs (when available) to test and control groups for a total of:

- 96 users (60 EPs + 36 ICGs) in the control group (enrolled in the study and managed according to the local standard of care)
- 96 users (60 EPs + 36 ICGs) in the test group (enrolled in the study and managed with UNCAP in addition to the local care).

The primary hypothesis is that UNCAP technology can improve the quality of life among elderly with mild or moderate dementia.

Table 4 Target end-user involvement per group and per pilot center

Pilot site	Geographical location	EP—elderly with MMCI	ICG—informal caregivers	FCG—formal caregivers
Rehabilitation center “Villa Rosa”	Pergine (TN)	20 10 tests, 10 controls	12 6 tests, 6 controls	5
Long term care facility “Creusa Brizi Bittoni”	Città della Pieve (PG)	20 10 tests, 10 controls	12 6 tests, 6 controls	5
Long term care facility “Villa Bianca”	Tarzo (TV)	20 10 tests, 10 controls	12 6 tests, 6 controls	5
Long term care facility “Villa Serena” ULSS n°5 Ovest Vicentino	Lonigo (VI)	20 10 tests, 10 controls	12 6 tests, 6 controls	5
Long term care facility “La pieve” ULSS n°5 Ovest Vicentino	Montechio Maggiore (VI)	20 10 tests, 10 controls	12 6 tests, 6 controls	5
Long term care facility “Villa Serena” ULSS n°5 Ovest Vicentino	Valdagno (VI)	20 10 tests, 10 controls	12 6 tests, 6 controls	5
Total participants		120 60 tests, 60 controls	72 36 tests, 36 controls	30

No previous research was retrieved from literature to document quantitatively such hypothesis with a controlled study. Only references have been found that indicate that there is a relation between quality of life and cognitive impairment. Logsdon et al. [13] reported an average QoL-AD score of 39.8 (spreading 5.8) and 39.2 (spreading 4.7), respectively for elderly with a MMSE within the range 17–21 (mild cognitive impairment) and with MMSE > 22 (moderate to severe cognitive impairment).

Considering that a MMSE within the range 17–29 characterized the primary users recruited in this study, a QoL-AD at approx. 39.5 points (spreading 5,3) were expected among the EP test group.

The study was aiming to measure a relative increased QoL with 9% (QoL-AD = 43, spreading 5, 3), p-value of 5%, power 90%.

It was calculated that $N = 49$ subjects need to be used in the control and test group (total 98 subjects), in order to prove the hypothesis with significance.

Considering a potential 10% drop out and an additional 10% of EPs unwilling to accept the UNCAP technology after the training phase and leaving the study before the planned discharge time, the number of test EP was set to $N = 60$, meaning 10 persons in the test group and 10 persons in the control group for each pilot site.

In order to have statically valid test results, the test and control groups of the elderly were randomly selected by using block randomization procedure.

4.7 Control Groups for Primary End-Users (EP) and ICGs

The control EP group was expected to be as characteristically similar to EP test group as possible. EP were recruited with the very same procedures and in the same structures where the test group was obtained.

The control group consisted of an equal number of subjects from primary end-user group to allow for a good comparison. They were going to be involved as the test participants from the beginning months of the test period and relevant tests were applied to them too. As for the test group, control group was also administered by all tests, except for specific test addressing user acceptance and user satisfaction of the UNCAP technologies because they were not expose to any technological intervention.

Control group of Informal care givers was constituted by the ICGs of the EP control group.

FCG had no control group since this clinical investigation provided only an inventory non-comparative study in respect to the FCG satisfaction about UNCAP technology.

4.8 Randomization Procedures

Randomization was performed on primary users at enrolment using block randomization of five subjects through specific software on a centre-by-centre basis.

Since there was also an interest in studying QoL of informal caregivers, a total of 72 ICGs were recruited and associated to the same test or control group of the elderly person they take care. Therefore, ICGs grouping was based on EP randomization.

Sealed envelopes containing the randomization assignment were provided to each pilot centre. On the external side of the envelope, a number was reported. At the enrolment of the EP, after obtaining his/her informed consent to participate to the clinical investigation, the randomization envelope identified by the same number reported in the EP's ID was opened. The result of the randomization assignment was recorded on the “Matching sheet”.

4.9 Criteria for Discontinuing Individuals

The participant could voluntarily elect to discontinue participation in the study at any time.

Moreover, if at any time the investigator determined it was not in the best interest of the participant to continue in the trial, the person was excluded from the study.

At the end of the training phase the EP was asked about the acceptability of the UNCAP system. If the participant did not wish to use UNCAP, the subject was discontinued from the study and the collected data was used only for acceptance evaluation. Whenever the EP asked to exit the study, the corresponding ICG (if present) was discontinued as well.

If the participant failed to follow the procedures of the study, the investigator might discontinue participation in the study, providing supporting documentation in the study file.

The reason for removal of a participant from the study after the enrolment had to be always documented.

5 Study Procedure

A total of about 7 months was expected from the involvement of each participant (from enrolment to discharge).

The study timeline was structured according to the following time-points:

- T0: Enrolment time.
- T1: Test group training with UNCAP (within 1 month from enrollment).
- T2: evaluation of UNCAP acceptance and starting of UNCAP evaluation (immediately after training)
- T3: intermediate UNCAP evaluation (after three months from T2)
- T4: End of the evaluation period and patient discharge from the study (after six months from T2).

The total expected length of the study was 12 months. This allowed a gradual enrolment of the primary users and caregivers, thus guaranteeing an adequate training and proper time for UNCAP hardware installation at users home or long term care facilities.

5.1 T0 (Enrolment Time)

Individuals with MMCI and their informal caregivers were recruited in each pilot site according to the procedures reported in "Selection process". FCGs was recruited after an informative meeting describing UNCAP technologies and study design. The investigator responsible of the pilot site organized the informative meeting in collaboration with the principal investigator.

The investigator checked inclusion and exclusion criteria as detailed in "Inclusion criteria" and "Exclusion criteria" sections. Participants fulfilling inclusion criteria were informed on the possibility to participate to the clinical investigation. Information were provided to the primary user and to his/her caregiver by the local investigator or a delegate representative. Brochures and informative documents describing UNCAP technologies were also provided.

Written informed consent was obtained from EPs and ICGs (when available) by using dedicated forms (Primary End user information sheet and informed consent form; ICG information sheet and Informed consent form). A participant ID was generated at the time of enrolment, just after having obtained the participant informed consent. Participant ID was immediately reported on the matching sheet together with name and surname of the participant, birth date and group allocation (test or control). Participant matching sheet had to be stored under the responsibility of the local investigator and was not accessible to any other person.

A baseline clinical evaluation with recognition of patients' needs was performed at enrolment by using Atl@nte online form. Atl@nte ID was the same ID code defined at enrolment. A set of data collection forms and questionnaires were filled/administered by each user type at enrolment. The following data collection forms and questionnaires were obtained for both test and control group users.

Primary user:

- EP enrolment data collection form (DCF)
- Narrative collection of needs
- Administration of validated questionnaire "QoL-AD"
- Administration of structured questionnaire "General EP satisfaction"
- Administration of validated questionnaire "FES-I".

Informal caregivers:

- ICG enrolment DCF
- Narrative collection of needs
- Administration of validated questionnaire "QoL-AD"
- Administration of validated questionnaire "SQLC"
- Administration of structured questionnaire "General ICG satisfaction"
- Administration of structured questionnaire "Impact".

Formal caregivers:

- FCG enrolment DCF
- Administration of structured questionnaire "General FCG satisfaction"
- Administration of structured questionnaire "Impact".

Based on the data collected with Atl@nte (e.g., activities of daily living, personal health profile) and from enrolment questionnaires, including the narrative description, the local investigator defined the list of user's needs and filled the "DCF for participant needs and UNCAP personalization".

5.2 T1 (UNCAP First Time Exposure for Test Groups. Training)

Hardware and software configuration of the UNCAP bundle to be delivered to the users (test group only) was defined according to the user needs defined at T0 and were indicated in the "DCF for participant needs and UNCAP personalization". UNCAP configuration was defined with the support of engineering and technical personnel from the UNCAP project.

A period of system testing and users' training was planned to guarantee the correct usage of UNCAP hardware and software components.

5.3 T2 (Evaluation of UNCAP Acceptance and Starting of UNCAP Evaluation)

At the end of the testing and training period, primary end user (test group only) were asked to fill the questionnaire on "UNCAP perceived usability and user acceptance". They were also asked if they wanted to accept continuing the study or prefer exiting.

Before deploying the personalized UNCAP bundle at the primary user home or at the long-term facility where the primary user was hosted, a final optimization of the system was possible according to the environmental and structural context or other specific users' requirements.

Primary users and their ICG in the test group showing (at least partial) acceptance of the technology and willing to prosecute with the study used UNCAP bundle for a total of six months. Conversely, primary users and their ICG in the control group willing to prosecute with the study received the local standard of care for a total of six months.

5.4 T3 (Intermediate UNCAP Evaluation)

At T3 (three months after the start of the UNCAP evaluation period) both test and control groups of primary users were assessed with Atl@nte for obtaining their updated personal health profile.

The concern for falls of primary user in both test and control groups was re-assessed by administering the FES-I questionnaire.

Primary users and their ICGs in the test group used UNCAP bundle for the remaining three months before study completion while primary users in the control group received the local standard of care for the remaining three months before study completion.

5.5 T4 (End of the Evaluation Period)

At T4 (six months after the start of the UNCAP evaluation period) a set of data collection forms, questionnaires and open questions were filled/administered by each user type at the end of the evaluation period. The following data collection forms and questionnaires were obtained for both test and control group users (except from differently indicated).

Primary user:

- Administration of questionnaire and narrative self-report form "Usability and Satisfaction EU" (only for EU test group)
- Administration of validated questionnaire "QoL-AD"
- Administration of structured questionnaire "General EP satisfaction"
- Administration of validated questionnaire "FES-I".

Informal caregivers:

- Administration of structured questionnaire "Usability and Satisfaction ICG" (only for EU test group)
- Administration of validated questionnaire "QoL-AD"
- Administration of validated questionnaire "SQLC"
- Administration of structured questionnaire "General ICG satisfaction"
- Administration of structured questionnaire "Impact".

Formal caregivers:

- Administration of questionnaire "Usability and Satisfaction FCG"
- Administration of structured questionnaire "General FCG satisfaction"
- Administration of structured questionnaire "Impact".

At both test and control groups of primary users were assessed with Atl@nte for obtaining their final personal health profile.

Once all questionnaires were filled and information were collected, participants were discharged from the study.

6 UNCAP Multidimensional Assessment

The evaluation of a complex bundle of assistive technologies is a not straightforward issue as it should provide evidence of safety and effect for a variety of needs elicited from several different users (primary end users, formal caregivers, informal caregivers).

Moreover, the impact of the adoption of such a technology in different settings (home care, residential care), requires the feedback from different stakeholders. Eventually, the developed technology has to be compliant with the legal and ethical framework, its use should be compatible with recommendations and existing guidelines and its introduction in the care system supported by a body of scientific evidences.

The evaluation process should be multifaceted and requires a well-defined framework to be pursued effectively and exhaustively.

Healthcare Technology Assessment (HTA) is the scientific methodology able to evaluate in a comprehensive way these technologies according to several different dimensions including safety, effectiveness, costs, impacts and more.

The assessment tools used in the study and above illustrated meet the requirements of a multidimensional assessment in accordance with the HTA methodology.

The "HTA Core Model" is the reference framework for the HTA methodology that has been delivered by the EUnetHTA European Project (http://www.eunethta.eu/hta-core- model) aiming at the universalization of the elements of an HTA evaluation. However, ICT applications for health present specific characteristics, in terms of reliability, accuracy, etc. compared with other medical devices, making the traditional "HTA Core Model" not easily applicable.

More recently, a new goal was reached in Telemedicine, defining the "Model for Assessment of Telemedicine" (MAST) (http://www.mast-model.info/) delivered by the MethoTelemed European Project. MAST re-adjusted the "HTA Core Model", identifying the following seven dimensions for the analysis of Telemedicine technologies:

- Health's problem and use of technology;
- Safety;
- Clinical effectiveness;
- Patient perspective;
- Economic aspects;
- Organizational aspects;
- Socio-cultural, ethical and legal aspects.

Noteworthy, the tools used for the UNCAP multidimensional assessment allowed to evaluate many of the dimensions required by MAST methodology (Table 5).

Table 5 Assessment tools used for UNCAP technology in accordance to MAST multidimensional assessment methodology (QoL-AD: quality of live Alzheimer disease [13]; FES-I: falls efficacy scale-international [24], SQLC: scale of quality of life of care-givers [11])

UNCAP assessment tool	MAST dimension
Systematic review Market analysis	Health problem and characteristics of the application
Clinical evaluation (according to MEDDEV. 2.7.1 rev.3) Adverse event reporting form (according to MEDDEV 2.7/3)	Safety
Systematic review of clinical literature Clinical evaluation INTERRAI assessment tools Validated questionnaires (QoL, FES-I)	Clinical effectiveness

(continued)

Table 5 (continued)

UNCAP assessment tool	MAST dimension
Users reporting forms and structured questionnaires (acceptability, usability, satisfaction)	Patient perspective
Structured questionnaire on impact	Economic aspects
Structured questionnaires for healthcare providers	Organizational aspects
Structured questionnaires and User reporting forms Validated questionnaires (SQLC)	Socio-cultural, ethical and legal aspects

7 Conclusions

In order to comply the forthcoming Regulation on Medical Device (2017/745 EU), CE marking of any innovative medical device based on ICTs should be supported by data on safety and effect. If required data could not be extrapolated from the existing literature, new clinical investigations should be realized. Moreover, a more comprehensive evaluation, covering also the economic and social impact for the introduction of a radically new technology is advised to support the adoption of new technology in the healthcare system.

This paper reported a possible framework for facing the complex issue of innovative technology assessment when indications for use include multiple users and settings as it is the case of ICTs developed for assisting the elderly with CI.

The UNCAP study was approved by all local ethic committees and results are available on the project web site (www.uncap.eu).

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References

1. Aloulou H, Mokhtari M, Tiberghien T et al (2013) Deployment of assistive living technology in a nursing home environment: methods and lessons learned. BMC Med Inform Decis Mak 13:42. https://doi.org/10.1186/1472-6947-13-42
2. Armstrong N, Nugent C, Moore G et at (2010) Using smartphones to address the needs of persons with Alzheimer's disease. Ann Telecommun 65:485–495
3. Bamidis PD, Fissler P, Papageorgiou SG et al (2015) Gains in cognition through combined cognitive and physical training: the role of training dosage and severity of neurocognitive disorder. Front Aging Neurosci 7:152. https://doi.org/10.3389/fnagi.2015.00152
4. Baruch J, Downs M, Baldwin C et al (2004) A case study in the use of technology to reassure and support a person with dementia. In Moriarty J (ed) Dementia. Innovative practice vol 3(3). SAGE Publications, USA, pp 371–392

5. Bharucha AJ, Anand V, Forlizzi J et al (2009) Intelligent assistive technology applications to dementia care: current capabilities, limitations, and future challenges. Am J Geriatr Psychiatr: Off J Am Assoc Geriatr Psychiatry 17:88–104. https://doi.org/10.1097/jgp.0b013e318187dde5
6. Boman IL, Persson AC, Bartfai A (2016) First steps in designing an all-in-one ICT-based device for persons with cognitive impairment: evaluation of the first mock-up. BMC Geriatr 16:61. https://doi.org/10.1186/s12877-016-0238-x
7. Bossen AL, Kim H, Williams KN et al (2015) Emerging roles for telemedicine and smart technologies in dementia care. Smart Homecare Technol Telehealth 3:49–57. https://doi.org/10.2147/shtt.s59500
8. Brodaty H, Green A (2002) Who cares for the carer? The often forgotten patient. Aust Fam Phys 31:833
9. Centers for Disease Control and Prevention (2013) The state of aging and health in America. http://www.cdc.gov/aging/help/dph-aging/state-aging-health.html
10. Cook DJ, Augusto JC, Jakkula VR (2009) Ambient intelligence: technologies, applications, and opportunities. Pervasive Mob Comput 5:277–298
11. Glozman JM, Bicheva KG, Fedorova NV (1998) Scale of Quality of Life of Care-Givers (SQLC). J Neurol 245:S39–S41
12. Lexis M, Everink I, van der Heide L, Spreeuwenberg M et al (2013) Activity monitoring technology to support homecare delivery to frail and psychogeriatric elderly persons living at home alone. Technol Disabil 25:189–197
13. Logsdon RG, Gibbons LE, McCurry SM et al (2002) Assessing quality of life in older adults with cognitive impairment. Psychosom Med 64:510–509
14. Medical mood ring (2004) Technology review. http://www.techreview.com/Biotech/13546/. 2007
15. Mihailidis A, Barbenel JC, Fernie GR (2004) The efficacy of an intelligent orthosis to facilitate handwashing by persons with moderate-to-severe dementia. Neuropsychol Rehabil 14:135–171
16. Monin J, Schulz R (2009) Interpersonal effects of suffering in older adult caregiver relationships. Psychol Aging 24:681–695
17. Pot AM, Willemse BM, Horjus S (2012) A pilot study on the use of tracking technology: feasibility, acceptability, and benefits for people in early stages of dementia and their informal caregivers. Aging Ment Health 16:127–134
18. Prince M, Jackson J (2009) International AD: world alzheimer report 2009. In: Alzheimer's disease international. http://www.alz.co.uk/research/files/WorldAlzheimerReport.pdf
19. Reisberg B, Ferris S, De Leon M, Crook T et al (1988) Global deterioration scale (GDS). Psychopharmacol Bull 24:661
20. Schulz RS, Sherwood PR (2008) Physical and mental health effects of family caregiving. Am J Nurs 108:23–27
21. Tadiran Life Care Aerotel Medical Systems (2007) http://www.tadlifecare.com/index.php?id=197
22. Tchalla AE, Lachal F, Cardinaud N et al (2013) Preventing and managing indoor falls with home-based technologies in mild and moderate Alzheimer's disease patients: pilot study in a community dwelling. Dement Geriatr Cogn Disord 36:251–261
23. Woods B, Aguirre E, Spector AE et al (2012) Cognitive stimulation to improve cognitive functioning in people with dementia. Cochrane Database Syst Rev 15:2 CD005562
24. Yardley L, Beyer N, Hauer K et al (2005) Development and initial validation of the Falls Efficacy Scale-International (FES-I). Age Ageing 34:614–619
25. Zarit S (2006) Assessment of family caregivers: a research perspective. Family Caregiver Alliance, San Francisco, CA

A Technological Approach to Support the Care Process of Older in Residential Facilities

Ennio Gambi, Manola Ricciuti, Gianluca Ciattaglia, Lorena Rossi, Paolo Olivetti, Vera Stara and Rossana Galassi

Abstract Faced with an increasing number of elderly housed in residential facilities, there is a request for greater transparency regarding the state of health of the guests and the level of assistance that these guests are offered. The OPENCARE project described in this article aims to respond to this need to promote communication between residential structures and guest families, by introducing a technological platform able to meet this requirement without the need to increase the workload of the operators. Therefore, this article describes the solution adopted, which are based both on data acquired from sensors and on those entered by the operators through a suitably designed interface.

Keywords Elderly care process · Sensor network · AAL technology

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1 Introduction

The costs of continuing care for elderly people are destined to increase significantly in the coming years as a consequence of the increase in the number of elderly population. The objective of keeping the elderly in their home clashes with the progressive phenomenon of polypathology, that, with the increasing of aging, may lead to disability; afterward, with the evolution of the family structure, the choice of a residential structure represents the only possible solution.

However, the system of residential care is today a definition that includes within it a series of clearly inhomogeneous realities. In recent years the development of regional autonomy has led to a multiplication of residential care models, with the relative multiplicity of definitions. Not all regions have invested in the sector with serious consequences on the quality of care and life of the guests. International studies also suggest that the lowering of quality standards in residential care, in the face of an apparent momentary reduction in costs at the level of the individual structure, could potentially cause higher costs for the health service as a whole [1]. For example, as a consequence of unsuitable personal standards, the quality of clinical care processes is more likely to be lowered, as a consequence the conditions of the most fragile patients might worsen (think of the management of pressure sores or bladder catheters), resulting in a larger use of drugs and treatment devices (antibiotics for urinary infections and devices for the dressing and management of bedsores) or resort to hospital treatment. For an example, at least 25 adverse reactions occur each year as a result of errors in the administration of drugs in medium-sized facilities (11% of which have serious consequences for the host) [2] (Source: BMJ). Not surprisingly, the number of disputes between structures and families over the years has multiplied with the occurrence of situations of serious abuse and negligence that have also reached the burden of the news. Moreover, only in 2014 the Carabinieri of the NAS (Nucleo Anti Sofisticazioni of Italian Interior Ministry) have imposed 1,310 penal sanctions following 3,992 controls in structures for elderly people (Source: Italian Health Ministry).

Transparency and traceability are a key factor for the quality of care in residence. The solutions currently available do not address the problem in an integrated way but they try to offer solutions to specific problems (falls, access control, linen management). The objective of the recently funded project named OPENCARE is to propose a unique technological solution that leads to the adoption of a new patient-centered management model. This solution will include the possibility of integration with the regional Electronic Health Record for what is relevant and will be open to the general practitioner (who is the main health reference for the patient in the structure) and to the family members. The use of sophisticated management interfaces that allow the recording of actions without increasing the workload for the operators will make the traceability of the activities extremely simpler, facilitating the possibility of professional audits and the triggering of virtuous formal recognition paths (quality certification) of the quality of care.

In particular, there are increasing demands on e-health care services and smart technologies needed for frail elders with chronic diseases [3, 4].

The aim of the present paper is to show the technological platform that is the base of the activities of OPENCARE. The paper is organized as follow: Sect. 2 describes the architecture of the technological platform, while Sect. 3 discusses the collected data. Finally, Sect. 4 draws the main conclusion of the work.

2 The OPENCARE Architecture

The technological platform of OPENCARE is depicted in Fig. 1. At the basis there are the data collected by the sensors inside the user's room, and the information provided by the caregivers through suitably designed tablet interfaces. This information is provided, as previously introduced, without increasing the workload for the caregivers, and are related to the health status of the user, to the sanitary cares received by the user and to daily activities organized for the considered user. The purpose of leaving the workload of the caregivers unaltered is obtained with the cost of a good design of the interactive interface, that must be intuitive and must require as little as possible to use the keyboard. This last kind of data requires the authentication of the caregiver, in order to associate each action with the caregiver that performs that action, and of the user, with the aim to know the user that receive that particular action.

All the collected data are stored to be processed in order to generate alarm messages to the caregivers inside the residential structure, and to provide information to the user's family about the user health status and the cares he receive. The collected data are completed with the information provided by a telemedicine system, that transfer to the storage system user's data relative to Blood Pressure, ECG, SPO2, temperature, Glucose level of the Blood and so on. Personal data and pharmacological therapy of each user are also stored, together with diet requirements. It is of interest to stress that the OPENCARE solution is an enabling platform for different acquisition technologies, implementing in this way an interoperability solution between heterogeneous data acquisition systems using different data transmission formats [5].

An important aspect related to the acquisition of a large amount of data generated by different sensors is their synchronization, which can be dealt following different approaches [6]. In this case, it was preferred to centralize the synchronization on the server storage, which applies a time stamp to all the records received, thus applying its own time reference at the moment of data acquisition.

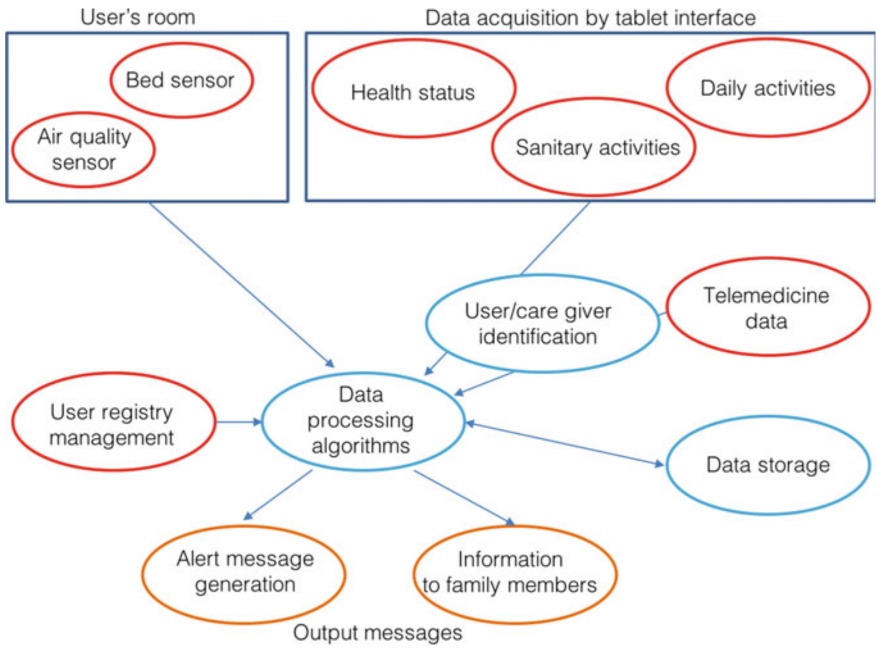

Fig. 1 Technological platform architecture

2.1 Air Quality Sensor

The aim of the sensor is the detection of parameters relating to the air quality such as Volatile Organic Compounds and Ammonia, in addition to temperature and humidity. While Temperature and Humidity are related to normal housing atmosphere conditions, Ammonia and Volatile Organic Compounds might be leads for the detection of physiological releases as well as for some pathologies [7]. From a functional point of view, the sensor acquires the data measured by two sensitive elements [8] and encapsulates them in an MQTT [9] message to be transferred to the storage server. For the assembly of the components a box was used, where the air is forced to enter. In fact, while the temperature and humidity sensitive element is located outside the box, the ammonia sensitive element is inside. To facilitate the flow of air, a 4 cm fan running at 5 V was applied to the inner surface of the box, suitably perforated.

The choice of the sensitive elements was a key point in the development of the air quality sensor. An analysis of the scientific literature [10] showed that the MQ137 [11] device was the most sensitive to both Ammonia and Volatile Organic Compound among all the commercially available sensitive elements. This sensitivity is of interest for the aim of our project, since the detection of ammonia and volatile organic components in the air is related to the presence of urine, feces or otherwise poor hygiene. The sensor is powered at 5 V and has an analog output but in order to work correctly it needs to be heated, then absorbing a current of 200 mA; for this reason, once it is switched on, it is necessary to wait about 48 h for its stabilization.

As the sensitive element for temperature and humidity the DTH22 [12] was chosen, both for the availability on the market in a single easily usable packaging, and for the presence of dedicated libraries. It interfaces I2C to the acquisition card.

The Adafruit Feather M0 WiFi was selected to collect the data from sensitive elements and their transmission. It is powered at 5 V via microUSB and can be battery powered, which is recharged by an internal circuit, but the high absorption of the sensitive elements makes this possibility useless, since cannot be guaranteed a significant autonomy. The data provided by the sensitive elements are read and incapsulated inside a MQTT message sent to the storage server every 10 min.

2.2 Bed Sensor

The purpose of the bed sensor is the detection of the vital parameters of a user present in bed. The Murata SCA11H sensor has been selected, which must be positioned between mattress and net, following a precise orientation. This sensor is equipped with accelerometers; the detect data are processed inside the sensor to extract some parameters, including strength of the signals, heart and respiration rate, which are sent in http format to a server at fixed intervals. Particularly delicate is the configuration of this sensor, that requires both a calibration phase of the accelerometers and the definition of the WiFi network to be connected together with the address and port of the server to which the data are to be transferred.

2.3 Data Introduced by Tablet Interface

According to current legislation, operators of residential structures must daily record information about users, both concerning health status and activities carried out, both sanitary, hygienic and general. Since there is no legislation concerning the modalities of recording this information, each residential structure operates in a different way, ranging from its own electronic format of data entry to the compilation of paper forms. The first goal of this function of OPENCARE is to standardize the information that is collected, together with a common way of inserting it.

However, this activity was preceded by an intense project work aimed at defining the information to be acquired, such as to gather the requests of all the residential structures participating in the project. Having also acquired the awareness that a real acceptance of this modality of data entry by the operators of the residential structures can be achieved only by introducing a simplification of their work, a particular attention has been given to the design of the interface. In fact, the interface was built in such a way as to be highly intuitive, thus requiring a very low learning curve and exclusively in graphical form. The possibility of inserting information in textual form is left, but only for very special cases.

3 Data Acquisition and Elaboration

As previously introduced, the data acquired from the air quality and bed sensors are stored on a data base. Figure 2 shows the record of the Air quality sensor, each of one with the time stamp introduced by the storage server. The db record stores an incremental number, the ID number of the sensor, ammonia, humidity and temperature values, and finally date and time. As an example the temporal evolution of the Ammonia during 3 days is depicted in Fig. 3, related to the data acquired by a sensor placed in a 4 people room. The figure shows an almost constant evolution of ammonia/VOC values, testifying to a substantial good level of hygiene inside the room. Then there are highlights some curve peaks, whose short duration is indicative of the fact that the operators of the residential structure act quickly when necessary.

For the same 3 days, the trend of temperature and humidity values is shown in Fig. 4. As it is possible to see, the temperature is within a limited range of variability, and even the humidity does not vary excessively in the days examined.

Figures 5 and 6 show some results derived from the data acquired by the bed sensor. In fact, the information related to the signal level measured by the accelerometers is used to understand if the bed is occupied, or if the user got up. From Fig. 5 are evident the time ranges in which the bed is occupied (marked with "YES" in the figure) while outside these intervals the accelerometers detect anomalous signals,

History of Sensor ID#4 Return to Sensor List

Download History of Sensor #4

Delete History of Sensor #4

History ID	Sensor ID	Ammonia Value	Humidity Value	Temperature Value	Sensor Time
11488	4	1.4565	24.2	25.4	2018-03-23 10:10:05
11487	4	1.5982	22.7	25.4	2018-03-23 10:00:05
11486	4	1.2708	22.9	25.5	2018-03-23 09:50:04
11485	4	1.3148	19.3	25.7	2018-03-23 09:40:04
11484	4	1.1926	20.9	26	2018-03-23 09:30:04
11483	4	1.4516	21.7	26.2	2018-03-23 09:20:03
11482	4	1.4858	21.7	26.1	2018-03-23 09:10:03
11481	4	1.3539	22	26	2018-03-23 09:00:03
11480	4	1.3148	22.1	26	2018-03-23 08:50:02
11479	4	1.3587	22.4	25.9	2018-03-23 08:40:02

Fig. 2 Web page of the air quality sensor

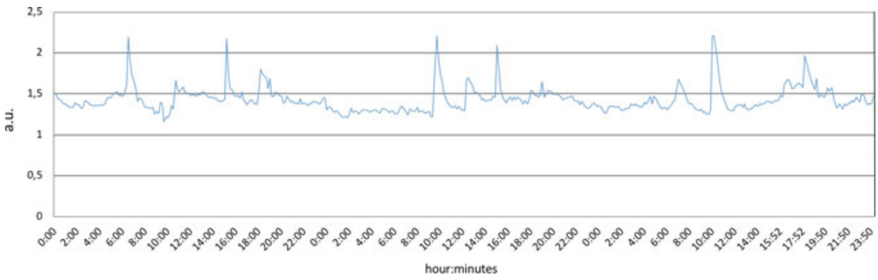

Fig. 3 Daily evolution of ammonia/VOC

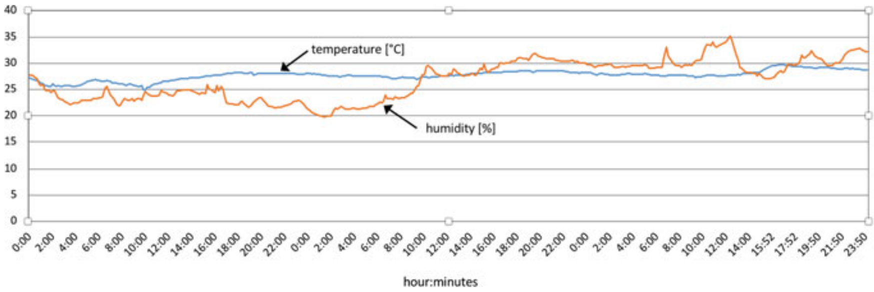

Fig. 4 Daily evolution of temperature and humidity

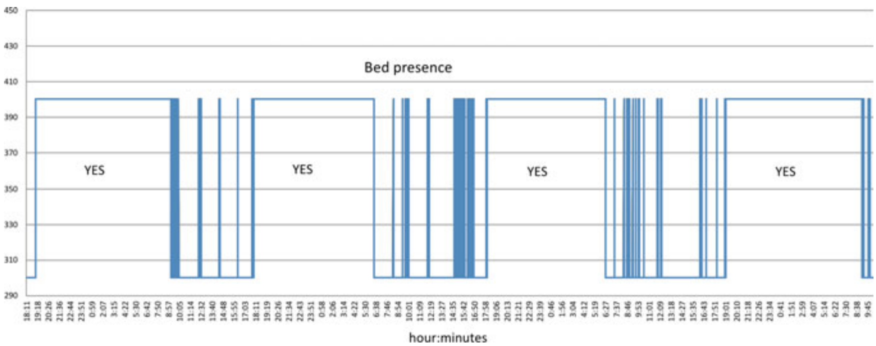

Fig. 5 Daily bed occupancy

caused by movements from the bed due to cleaning operations or in any case from involuntary interactions of the operators with the bed.

Figure 6 describes the trend of the Heart rate value measured by the sensor during the user's stay in bed. The figure shows plausible heart rate values, even if no validation of these values has yet been reached. However, it may be noted that during the night hours the measured heart rate value changes. This variation is caused by the sensitivity of the sensor according to the position taken by the user. In fact, when

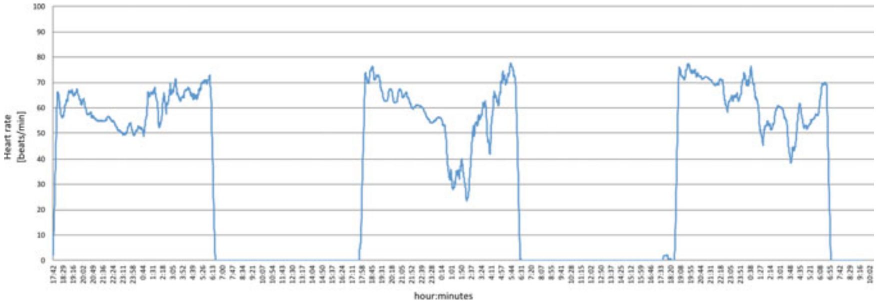

Fig. 6 Heart rate monitor

the patient is lying on one side, the received signal level is reduced, giving rise to a high measurement error.

4 Conclusion

This paper describes the state of the art of the OPENCARE project activities. The motivations and aims of the project were highlighted, and the technological platform implemented for data acquisition was examined in detail. After a year of activity, a consolidation of the platform was achieved, for what concerns both the data acquisition from the sensors and through the interactive interfaces on tablets.

In this way, the technological base was built to provide families of guests of residential facilities with information on the health status of their loved ones, and on the level of assistance that is provided to them. Such a kind of information will be obtained through a proper elaboration aiming at the fusion of the acquired data, in order to show an overall frame about health, general condition and assistance level. In the same way, a different processing of the same data allows to generate alarm information that can be used by the operators to improve the level of assistance.

References

1. Lee L, Heckman GA (2012) Meeting the challenge of managing seniors with multiple complex conditions: the central role of primary care, UWSpace
2. Morin L, Laroche ML, Texier G, Johnell K (2016) Prevalence of potentially inappropriate medication use in older adults living in nursing homes: a systematic review. J Am Med Dir Assoc 17(9):862.e1–862.e9. https://doi.org/10.1016/j.jamda.2016.06.011
3. Lattanzio F, Abbatecola AM, Bevilacqua R, Chiatti C, Corsonello A, Rossi L, Bustacchini S, Bernabei R (2014) Advanced technology care innovation for older people in Italy: necessity and opportunity to promote health and wellbeing. J Am Med Dir Assoc 15(7). https://doi.org/10.1016/j.jamda.2014.04.003

4. Spinsante S, Stara V, Felici E, Montanini L, Raffaeli L, Rossi L, Gambi E (2016) The human factor in the design of successful ambient assisted living technologies. In: Ambient assisted living and enhanced living environments: principles, technologies and control, pp 61–89. https://doi.org/10.1016/b978-0-12-805195-5.00004-1
5. Rossi L, Belli A, De Santis A, Diamantini C, Frontoni E, Gambi E, Palma L, Pernini L, Pierleoni P, Potena D, Raffaeli L, Spinsante S, Zingaretti P, Cacciagrano D, Corradini F, Culmone R, De Angelis F, Merelli E, Re B (2014) Interoperability issues among smart home technological frameworks. In: Proceedings of 10th IEEE/ASME international conference on mechatronic and embedded systems and applications. https://doi.org/10.1109/mesa.2014.6935626
6. Cippitelli E, Gasparrini S, Gambi E, Spinsante S, Wåhslény J, Orhany I, Lindhy T (2015) Time synchronization and data fusion for RGB-depth cameras and inertial sensors in AAL applications. In: Proceedings of IEEE international conference communication workshop (ICCW). https://doi.org/10.1109/iccw.2015.7247189
7. Smith S, White P, Redding J, Ratcliffe NM, Probert CSJ (2010) Application of similarity coefficients to predict disease using volatile organic compounds. IEEE Sens J 10:92–96
8. Galassi R, Ricci S, Burini A, Macchioni A, Rocchigiani L, Marmottini F, Tekarli SM, Nesterov VN, Omary MA (2013) Solventless supramolecular chemistry via vapor diffusion of volatile small molecules upon a new trinuclear silver(I)-nitrated pyrazolate macrometallocyclic solid: an experimental/theoretical investigation of the dipole/quadrupole chemisorption phenomena. Inorg Chem 52(24):14124–14137. https://doi.org/10.1021/ic401948p
9. http://mqtt.org
10. Capelli L, Taverna G, Bellini A, Eusebio L, Buffi N, Lazzeri M, Guazzoni G, Bozzini G, Seveso M, Mandressi A, Tidu L, Grizzi F, Sardella P, Latorre G, Hurle R, Lughezzani G, Casale P, Meregali S, Sironi S (2016) Application and uses of electronic noses for clinical diagnosis on urine samples: a review. Sens 16:1708. https://doi.org/10.3390/s16101708
11. http://eph.ccs.miami.edu/precise/GasSensorSpecs/NH3.pdf
12. https://akizukidenshi.com/download/ds/aosong/AM2302.pdf

A Non-invasive Method for Biological Age Estimation Using Frailty Phenotype Assessment

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Abstract The human body has two different ages: a Chronological Age (CA), the actual time a person has been alive, and a Biological Age (BA), the real age that indicate the decline in health and in function ability during aging. Among previous studies, some authors proposed methodologies to estimate the Biological Age starting from non-invasive frailty measurements to evaluate the Frailty Index, others proposed invasive and expensive methods to measure the biological aging. Conversely, in this paper we propose a method to estimate the BA of a subject based on the assessment of the Frailty Phenotype. This type of evolution allows an efficient estimation of the frailty in contrast with the Frailty Index which is composed by a long checklist of clinical conditions and diseases to be evaluated from medical staff. We developed a cloud application, able to store and elaborate the data acquired during the evaluation protocol of the Frailty Phenotype, and also able to automatically provide the state of phenotypic fragility, and finally the Biological Age of a subject.

Keywords Biological Age · Frailty phenotype · Cloud application

1 Introduction

Recently, two themes have been of primary interest to global public opinion: on one hand, the debate on how to measure the well-being of individuals and societies; on the other hand, the so-called active and healthy aging. Active and healthy aging is not just about working life, but also social. The population is living longer and in good health, thanks to adapted housing and infrastructures that guarantee the possibility to live independently and healthy. In the last twenty years, the population structure

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across EU Countries has changed. The EU is particularly sensible to the issue of aging society, as proven by its decision to declare the 2012 as the EU Year for Active Aging and Solidarity between Generations. In fact, understanding how the aging process will affect different countries having different cultural and societal structures as well as distinct public policy approaches, is an important task. Thus, monitoring the aging phenomenon is crucial and challenging.

Aging is a complex phenotype characterized by the gradual and progressive deterioration of integrity across multiple organ systems, accounting for the decline of biological functions [25]. From the fifth decade of life, advancing age is associated with an exponential increase in burden of many different chronic conditions, sharing a common pro-inflammatory condition [6]. The most effective means to reduce disease burden and control costs is to delay this progression by extending "healthspan", i.e. the period of human life during which one is generally healthy and free from serious diseases. The need for biological measures of age, and more precise screening tests for age-related diseases, is increasingly becoming urgent.

The human body has two different ages: a Chronological Age (CA) and a Biological Age (BA). CA refers to the actual time a human has been alive, while BA refers to how old that human seems. The real BA is different to the CA because it includes the speed at which each person is aging and, for this reason, it is dramatically difficult to estimate. At the same time, the knowledge of an accurate BA index for each individual is of vital importance because it can be used to identify causes of aging and evaluate rejuvenation therapies and, thus, it impacts on different spheres of the society, including, among others, health, economics, political and welfare strategies and decisions.

However, since the average health-life expectancy varies from community to community, reflecting a mix of genetics, epigenetics environmental and others randomly determined factors, until now there has been no reliable way to measure how well a person is aging compared with their peers. Physical capacity, such as strength, or onset of disease, is often used to assess healthy aging in the elderly, but it is difficult to measure aging before symptoms of decline or illness occur. Even if CA is actually considered as the major risk factor for the development of disease and death, BA should be taken into account to accurately predict illness and mortality. CA does not parallel the BA during life-time, and several efforts have been made to identify the parameters that better contribute to measure BA [2].

Research studies for the estimation of BA are of primary interest and directly impacts one of the societal challenges and priorities of the "health, demographic change and wellbeing" EU H2020 Programme for Research and Innovation. In this context, the Multidisciplinary Innovative Research Actions on AGE (MIR-AGE) project was funded by the Polytechnic University of Marche, Italy. MIR-AGE project has the ambitious and challenging goal to propose, and experimentally validate, an innovative tool for accurately estimating and predicting the BA of each individual. Based on the research activity of the MIR-AGE project, in this paper we propose a simple and non-invasive method for BA estimation of elderly people via the support of Information and Communication Technology (ICT).

The paper is organized as follows. The review of the relevant literature is presented in Sect. 2. The Frailty Phenotype, the evaluation protocol and the cloud application are illustrated in Sect. 3, while the results of the proposed method are reported in Sect. 4. Conclusions and future work end the paper.

2 Related Works

BA is characterized by a complex remodelling of thousands of variables necessary for maximizing the probability of survival, depending principally from environmental and genetic factors, and to a lesser extent from stochastic ones. Several studies have underlined that age-related effects on specific biological functioning variables arise from common causal mechanism and may explain many of the outcomes predominantly observed in old age [22]. This study shows that exceptional survival requires dynamic maintenance of physiological variables at "optimal values". These parameters are not fixed for the entire life course but change over aging, suggesting that the determinants of exceptional survival could have "age-related trajectories" rather than fixed values. Different age-related trajectories of blood-based parameters (i.e., glucose levels or inflammatory biomarkers) and new discovered epigenetic biomarkers, in healthy and diseases were described [1].

The main methodologies used today to estimate a subject's BA are essentially based on the measurement of certain biomarkers that are closely related to CA. The World Health Organization has defined biomarkers as the measurements that indicate an interaction between a biological system and a potential danger, which can be chemical, physical or biological. According to the study by Karasik et al. [10], biomarkers should:

- predict the deterioration of one or more organ systems and the probability of a pathological event;
- be highly correlated with loss of functionality, rather than just Chronological Age;
- be easily observable with minimally invasive acquisitions.

According to the state of the art, several biomarkers have been proposed for BA assessment, mainly based on biological parameters [11, 18]. Unfortunately, the previous developed indexes for predicting the BA, show moderate performance to predict illness and mortality or to quantify the effect of anti-aging interventions. Furthermore, due to the complexity of the aging process, a single biomarker is not yet found to provide a precise measure of the biological aging rate.

To the classic phenotypic biomarkers, usually used in scientific research, new molecular biomarkers based on DeoxyriboNucleic Acid (DNA) and RiboNucleic Acid (RNA) have added. Recently, many studies defined the age measurement of DNA methylation (DNAmAge), also called epigenetic clock, as a valid predictor of the Biological Age. Two of these measures, Horvath's and Hannum's clock, are currently the most powerful to predict Chronological Age. Their main feature is the ability to predict mortality, due to various causes, regardless of the classic risk factors. Although the epigenetic clock is a valid predictors of the Biological Age, this method is invasive and very expensive.

In another study, Breitling et al. [4] discovered that the Horvath's clock was directly related to the increase in the number of deficits accumulated by a subject. The deficits of a subject are the basis of another methodology to estimate the BA considering the state of frailty of the individual as the state in which an elder shows greater vulnerability to adverse events [21]. This widely developed methodology is based on the estimation of the Frailty Index of a subject q_i which is considered as the proportion of the deficits in the i-th subject [13]. Therefore, the Frailty Index of a subject q_i can be defined as the ratio of deficits present with respect to the total number of considered deficits:

$$q_i = \frac{Number\ of\ deficits\ present}{Number\ of\ deficits\ total} \quad (1)$$

with q_i between 0 and 1. Comparing q_i with a model obtained by analyzing the Frailty Index of a reference population will be possible to estimate the BA of the examined i-th subject.

A study conducted by Mitnitski [13] has analyzed the Frailty Index (q) of a group of Canadian individuals over the age of 65 considering 20 deficits with a binary evaluation: 1 score is assigned if the deficit is present, 0 if is not present. In this study, the authors calculated the Frailty Index of the 2914 subjects who underwent the clinical examinations foreseen by their evaluation protocol. The authors analyzed the Frailty Index averaged across all subjects at the same age and, assuming a linear increase of $ln(q)$ with age and using linear regression techniques, they provided a model valid for the examined population. The obtained model corresponds to the following equation

$$ln(q) = -4.23 + 0.03 \cdot t \quad (2)$$

where t = CA. From this model, it is possible to derive the line of the CA as a function of the Frailty Index. As shown in Fig. 1, when the Chronological Age increases, the deficits accumulate and the value of the Frailty Index increases.

This definition of frailty depends on two factors: the Chronological Age and the percentage of deficits. The log-linear relationship between these values can be used in the calculation of the Personal Biological Age (PBA) by applying an inverse regression:

$$PBA = 126 + 26.09 \cdot ln(q) \quad (3)$$

Chronological and Biological Age coincide when the subject's deficit number corresponds to the age given by the Eq. (3). Otherwise, it can be said that the subject is younger (healthier) or older (more frail) than her/his CA, and the degree of frailty will be defined by the difference between BA and CA.

In a similar study, Goggings [8] took into consideration the Chinese population, therefore subjects with different lifestyles and diets compared to the Canadian population. In this study, a multivariate analysis was performed by calculating the mean value of the Frailty Index for each age and sex. Multiple linear regression was used

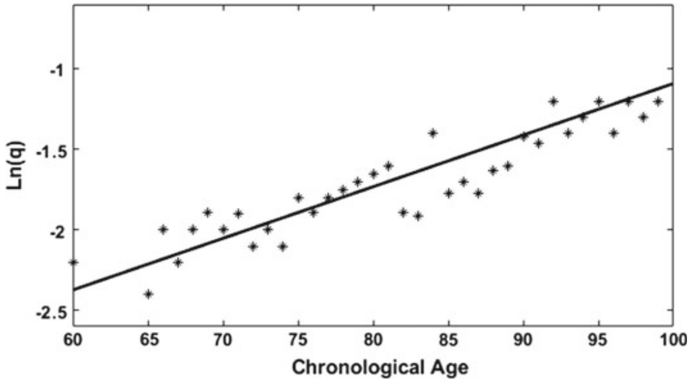

Fig. 1 Biological Age estimation using the model based on Frailty Index

to evaluate the relationship between age and average frailty by discriminating by gender. Finally, the square root transformation of the mean Frailty Index and age was performed to improve the adaptability of the model. In further studies it was defined that the rate of deficit accumulation exponentially increases with the Chronological Age, at a rate of 3% per year [13].

The Frailty Index is defined as an accurate and precise predictor for its detailed risk scale, but has some drawbacks: the lack of a univocal definition of the deficits that must be taken into account (which and how many), and the large number of deficits (at least 30/40) that have to be assessed during the clinical examinations [3, 20]. These drawbacks make the Frailty Index evaluation impractical in scenarios where the assistance of a qualified medical staff is not required.

Moreover, the previous studies did not emphasized the complex integration with diet, habits and, in general, lifestyles information of each individual.Since each individual cannot control the genetics she/he was dealt at birth, let's focus on what he/she can control to make herself/himself feel younger and live a better quality of life. Daily habits and lifestyle monitoring are important to analyze people's lives within structural, social, and cultural contexts. Thus, daily life monitoring plays a key role and has an important impact on determining indicators to estimate their BA.

For the BA estimation, ICT plays a key role because it is the means by which it is possible to acquire clinical data as well as the lifestyle information of each individual, acquired via suitable wearable [16, 17] and unwearable devices, also installed in the living environments [15].

3 Method and Materials

The use of frailty measurements in clinical practice is crucial for estimating the age-related conditions in elderly people. In previous studies, the main methodologies used to estimate the BA starting from frailty measurements, are based on the evaluation of the Frailty Index. Conversely, in this paper we propose a method to estimate the BA of a subject based on the assessment of the Frailty Phenotype. This instrument are well established in literature and universally accepted, allowing a rapid estimation of the frailty in contrast with the Frailty Index which is composed by a long checklist of clinical conditions and diseases to be evaluated from medical staff. In this section, after describing the Frailty Phenotype, the related evaluation protocol, and the proposed cloud application to evaluate it, a model for estimating the Biological Age is defined, as already done in the literature with the Frailty Index.

3.1 Frailty Phenotype

Two fundamental methods emerged in literature for the estimation of fragility: the Frailty Index and the Frailty Phenotype. The Frailty Index is based on the evaluation of unspecified number of deficits during comprehensive clinical assessment [13]. Instead, Frailty Phenotype defines fragility as a clinical syndrome based on the evaluation of certain criteria which are evaluated through the presence or absence of certain symptoms.

The Frailty Phenotype methodology has been extensively validated in the scientific community for its easy reproducibility and the possibility of being used without preliminary clinical evaluation or the presence of medical staff. One of the most commonly accepted definitions of the Frailty Phenotype, is the classification proposed by Fried which taken into account 5 phenotypic criteria: involuntary weight loss, weakness, breakdown, slowness, and low level of physical activity [7, 24]. These 5 criteria represent the predictors of fragility [7] classifying a subject as frail (frail respect three or more criteria), prefrail (frail respect one or two criteria) or nonfrail (no criterion is respected). In order to estimate the Frailty Phenotype of a subject, Fried proposed a unique definition of each criterion and the relative cut-off value to evaluate it. The description of Fried's criteria is as follows:

1. *Shrinking*: unintentional weight loss of 4.53 kg or of 5% of body weight in prior year. If one of the two conditions is verified, the individual is considered frail respect to this criterion.
2. *Weakness*: maximum grip strength measured in kg. The cut-off values are reported in Table 1 as function of the gender and the different ranges of Body Mass Index (BMI), that express the thresholds below which the subject is frail.
3. *Poor endurance and energy*: self-report exhaustion level. In order to evaluate this criterion, the subject must answer two specific questions from the Center for Epidemiological Studies-Depression (CES-D) scale [19]:

    1. I felt that everything I did was an effort?
    2. I could not get going?

    The possible answers that each subject can give for each question are:

    A. Rarely or none of the time (less than one day)
    B. Some or a little of the time (1–2 days)

Table 1 Cut-off values below which a subject is defined frail respect the *Weakness* criterion

Man		Woman	
	Cut-off value (kg)		Cut-off value (kg)
BMI $\leq$ 24	29	BMI $\leq$ 23	17
24.1 $\leq$ BMI $\leq$ 28	30	23.1 $\leq$ BMI $\leq$ 26	17.3
		26.1 $\leq$ BMI $\leq$ 29	18
BMI $\geq$ 28.1	32	BMI $\geq$ 29.1	21

Table 2 Cut-off values above which physical performance and walking speed decrease

Man		Woman	
	Cut-off value (s)		Cut-off value (s)
Height $\leq$ 173 cm	7	Height $\leq$ 159 cm	7
Height $>$ 173 cm	6	Height $>$ 159 cm	6

C. Occasionally or a moderate amount of time (3–4 days)
D. Most or all of the time (5–7 days)

If both answers are C. or D. the subject is frail respect *Poor endurance and energy* criterion.

4. *Slowness*: elderly's mobility monitoring, based on time to walk 4.57 m at the rhythm chosen on the basis of individual skills. The cut-off parameters are reported in Table 2 as function of the individual's gender and height, above which the subject is frail.
5. *Low Physical Activity Level*: based on self-assessment of the short version of the Minnesota Leisure Time Activity questionnaire, a weighted score of kilocalories expended per week was calculated about 18 carried out activities. The cut-off values as function of the gender are:

A. Men, with calories of physical activity per week less than 383 kcal, are considered frail.
B. Women, with calories of physical activity per week less than 270 kcal, are considered frail.

3.2 Evaluation Protocol

Following Fried's recommendation, an evaluation protocol is developed in order to assess the Frailty Phenotype of a subject. The first phase of the protocol consists in collecting the personal and clinical data of each individual, then the tests for the assessment of the Frailty Phenotype are carried out. The protocol includes 5 different tests in which the five criteria of the Frailty Phenotype are evaluated. The tests, called

Table 3 Cut-off values, considered in our protocol, above which the physical performances and the speed of the walk decrease

Man		Woman	
	Cut-off value (s)		Cut-off value (s)
Height $\leq$ 173 cm	15.5	Height $\leq$ 159 cm	15.5
Height $>$ 173 cm	13.5	Height $>$ 159 cm	13.5

the Frailty Evaluation Test (FET), provide a good basis for a screening and an overall assessment of the risk of frailty in the elderly. The criteria taken into consideration in each FET are:

1. *Weight Loss*: assessed by direct measurement of weight in periodic FETs or explicit question asked to the subject. If the subject has a decrease of at least 4.53 kg in the last year, is considered frail.
2. *Weakness*: assessed by the use of a hand dynamometer. The subject performs 3 tests, if the average of the measured force is lower than the cut-off values of Table 1, is considered frail.
3. *Tiredness*: evaluation through the administration of the CES-D questionnaire. A score from 0 to 3 to the four answers previously listed is assigned as output of the test. If the subject totals a value equal to or greater than 2 is considered frail.
4. *Mobility*: the subject carries out the Timed Up and Go test (TUG) twice. In this session, the subject must stand up from a chair, walk about five meters, turn at a designated point, return to the seat and sit [12]. The execution times of the two tests are also estimated through the stopwatch. If the average of the time taken to complete the exercise is higher than the limit value shown in Table 3 is considered frail for this criterion.
5. *Low phisical activity Level*: evaluation through the administration of the short version of the Minnesota Leisure-Time Activity Questionnaire. The weekly consumed kilocalories are estimated, using the following formula [23]:

$$\frac{Kcal}{week} = MET \cdot \frac{Times}{2} \cdot \frac{Duration}{60} \cdot Weight \tag{4}$$

   where the *Metabolic Equivalent of Task (MET)* represents the physiological measure of the physical activity's energy cost [9]. If the consumption is lower than the cut-off value previously described, the subject is defined frail for this criterion. *Times* represents the number of times the activity is performed, *Duration* defines the duration of the activity in minutes, and *Weight* is the subject's weight in kilos.

3.3 Cloud Application

The evaluation protocol for the assessment of Frailty Phenotype is in general composed by simple tasks, but its administration and meaningfulness could be problematic if no efficient support tools are used by the assessor. Furthermore, the application of the Frailty Phenotype to a large population may become unfeasible if the direct contact between the subject and the assessor is required [5]. Therefore, an online automatic assessment tool for Frailty Phenotype evaluation could be an optimal solution that could be used by both an assessor or a subject during a self-reported evaluation protocol.

In order to efficiently store and analyze the information acquired during the Frailty Phenotype evaluation protocol, a cloud application is developed. It was designed to be indifferently used by authorized user or medical staff. Cloud computing technologies are widely used to efficiently manage resources and information involved in health processes. Nowadays, doctors confide in this system to remotely monitor patients, find personalized treatments, and early-diagnose diseases.

The need of a backend system that guarantees high scalability, reliability, interoperability and flexibility, drive us to design a cloud application. We used MEAN, a fullstack JavaScript platform for web applications, which components are MongoDB, Express, AngularJS and NodeJS. In this work, a user-friendly cloud application is created to historicize data of the medical records and data acquired during the evaluation protocol, such as weight, questionnaire, TUG, and hand dynamometer. Handling these data, the cloud application automatically provides the results for each criterion (Weight Loss, tiredeness, mobility, and Kcal/week) and calculates the relative state of phenotypic frailty. This architecture needs to manage and store an enormous amount of clinical data based on the Health Level 7 (HL7) format, the main reference worldwide standard to share hospital data [14]. For this reason, we use MongoDB, an open source, NoSQL database, that provides support for JSON-styled, document-oriented storage systems. In order to store and analyze HL7 messages in MongoDB, we firstly need a conversion from XML to JSON format. The realized application allows the user to perform the questionnaires, enter personal data and weight, upload data of the medical records and, finally, store results of the evaluation tests. This allows to collect a history for each person and an assessment of progress over time, and thus to evaluate each year the user's Biological Age of individual.

The main characteristic of the cloud application is its modularity and interoperability, allowing to directly interact with the doctor, caregiver or patient. The cloud application could be also a potential follow-up in other connected areas, such as telemedicine and telerehabilitation.

3.4 Biological Age Estimation

The proposed work focuses on the use of the Frailty Phenotype assessment for estimating the BA. As was done for the Frailty Index, even with the Frailty Phenotype, it would be possible to derive a model to estimate the BA. In fact, processing data of the Frailty Phenotype of a given population and using linear regression techniques, it would be possible to derive a valid model for BA estimation. For example, taking into account the data on the Frailty Phenotype analyzed by a previous study [24], we would obtain the model illustrated in the Fig. 2. The reference study conducted

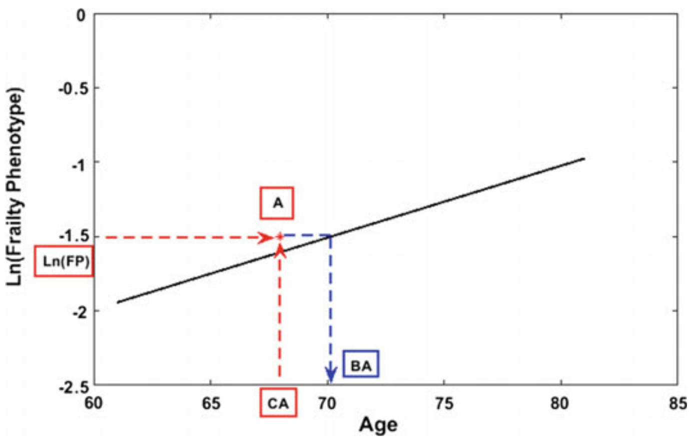

Fig. 2 Biological Age estimation using the proposed model based on Frailty Phenotype

by Theou et al. aimed to compare several frailty scales, in particular, the Frailty Phenotype has been evaluated by faithfully following the Fried's study. The work was applied to a sample of 27527 middle-aged and older European participants.

Using the model presented in Fig. 2, it is also possible to estimate the Biological Age; starting from subject's CA, the natural logarithm of the subject's Frailty Phenotype is calculated and the point A is found (defined by the red dashed line). From A, the corresponding point belonging to the model is found, and taking it on the X-axis (described by the blue dashed line), the Biological Age is determined.

4 Results

The goal of the presented work is to develop an efficient method for estimating the BA of a subject using the Frailty Phenotype assessment. Thereby, the used method was tested during the data-collection session in which 15 elderly subjects (8 males and 7 females) aged from 61 to 81 years took part.

This section shows the results obtained from tests carried out on the 15 subjects. The evaluation of the Frailty Phenotype of each subject is obtained using the evaluation protocol and the cloud application described in Sect. 3.2 and in Sect. 3.3, respectively. For each enrolled subject, Table 4 shows the results achieved in the data-collection session with regard to Frailty Phenotype assessment. In detail, the Table 4 shows the personal parameters, the results obtained from the evaluation of the 5 criteria and the computed state of frailty. The asterisk identifies the criterion for which the subject was frail beyond the established cut-off value. The last column of Table 4 represents the state of phenotypic frailty and in brackets the number of criteria for which the subject is considered frail. Note that in the Table 4, the subjects enrolled to perform the protocol are ordered by state of fragility. Results show that in the considered samples, 3 subjects are considered nonfrail, 2 are frail and the others are prefrail. Patients without any criterion of frailty lead an active life, perform

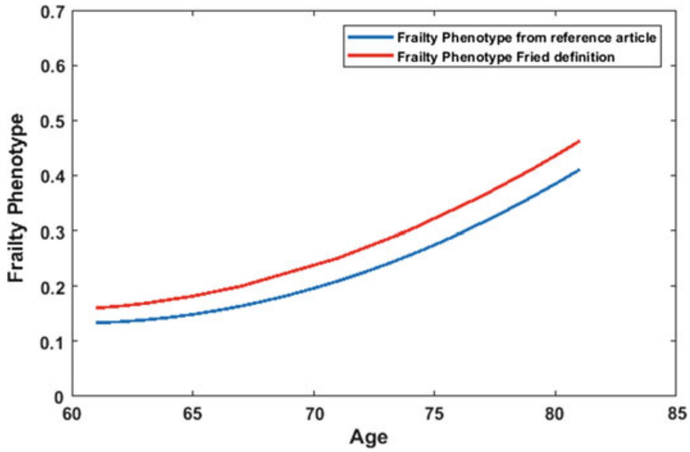

Fig. 3 Estimation frailty phenotype

physical activity, have a higher grip strength than the cut-off values, and short TUG test's times. The subjects identified as frail, have a medium-low grip strength, have a weekly consumption of kilocalories lower or close to the pre-established cut-off values, and have performed the TUG test in times longer than the limit ones. After the data-collection session, the value of the Frailty Phenotype is estimated for each subject and is calculated as a weighted average for each age.

In order to validate our methodology, the study proposed by Theou et al. [24] is taken as a reference. This study is the only one which carried out similar assessment of the Frailty Phenotype using a reference population comparable to the one taken into consideration in our work. In fact, we evaluated a sample of Italians elderly, which is a subset of the European elderly population considered in the Theou's work. In detail, in Fig. 3 the curve of the Frailty Phenotype obtained in the Theou's study is shown in blue and the red curve represents our results elaborated by the cloud application during the evaluation protocol. From Fig. 3, it is possible to observe that the red and blue curves are close to each other; probably the red curve is higher than the reference one due to the limited number of examined subjects.

As indicated in Sect. 3.4, a model for estimating the BA can be derived from processing the data related to the Frailty Phenotype of the data-collection session. For the population taken into consideration, the model proposed is shown in Fig. 4 together with the reference model of the Sect. 3.4. The model proposed in Fig. 4 estimates the BA through subject's CA and the natural logarithm of Frailty Phenotype.The obtained model corresponds to the equation:

$$BiologicalAge = 88.30 + 22.08 \cdot ln(FrailtyPhenotype) \tag{5}$$

The trends show that the loss of biological functions increases with age at a rate of 4–5% per year.

Table 4 Frailty Phenotype evaluation obtained from a group of 15 subjects

Personal details				Weight loss	Tiredness		Weakness (kg)	Mobility (s)	kcall/week	Frailty status
Age	Sex	Height (m)	BMI		1	2				
71	M	1.85	29.22	No	0	0	43.6	9.8	4108.00	Nonfrail(0)
71	M	1.86	30.06	No	0	0	42.5	8.8	3900.00	Nonfrail(0)
67	M	1.83	34.34	No	0	0	51.5	10.5	1265.00	Nonfrail(0)
61	F	1.70	27.68	No	0	0	24.7	11.0	230.00[a]	Prefrail(1)
62	M	1.65	30.12	No	1	0	35.2	11.4	287.00[a]	Prefrail(1)
77	M	1.75	23.18	No	2[a]	3[a]	31.9	10.4	1438.13	Prefrail(1)
74	M	1.72	19.61	No	0	0	27.1[a]	12.0	406.00	Prefrail(1)
65	F	1.58	32.05	No	0	0	27.8	11.50	240.00[a]	Prefrail(1)
77	M	1.75	22.53	Yes[a]	2[a]	2[a]	32.6	11.70	1145.63	Prefrail(2)
71	F	1.72	18.59	Yes[a]	1	1	19.2	11.50	233.75[a]	Prefrail(2)
63	F	1.58	34.05	No	3[a]	3[a]	18.4[a]	13.50	308.13	Prefrail(2)
81	F	1.57	29.62	No	1	1	22.5	28.0[a]	146.00[a]	Prefrail(2)
81	F	1.58	29.64	No	1	0	22.1	24.5[a]	222.00[a]	Prefrail(2)
79	M	1.73	26.06	No	2[a]	2[a]	25.2[a]	20.0[a]	399.75	Frail(3)
80	F	1.56	30.82	No	1	1	19.4[a]	31.0[a]	150.00[a]	Frail(3)

[a]The values for which the subject is frail for that criterion are highlighted

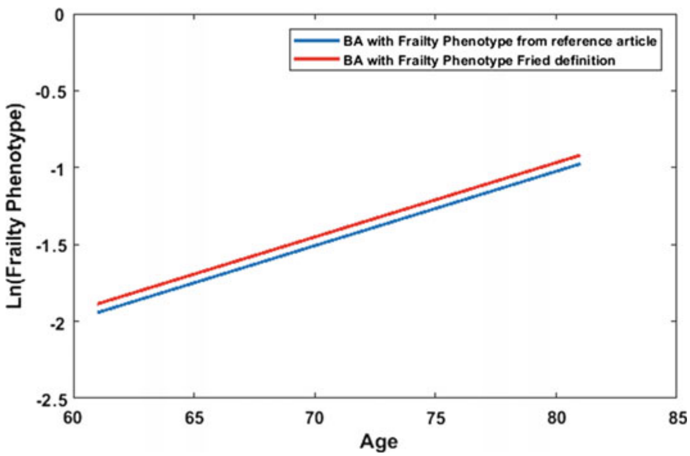

Fig. 4 Biological age estimation

5 Conclusions and Future Developments

In this paper a non-invasive method for BA estimation via an evaluation of Frailty Phenotype has been presented. The proposed solution consists of a protocol for the evaluation of the five phenotypic criteria, a developed cloud application to automatic elaborate the acquired data and provide Frailty Phenotype assessment and an BA estimation. The implemented solution has been validated through an experiment data-collection session in which 15 elderly subjects took part. The analysis of the information gathered during the session shows that the proposed method for Frailty Phenotype assessment has achieved results comparable with those obtained from previous studies. In this way we will have a large amount of data available to further validate the model for the estimate of the BA via Frailty Phenotype assessment.

References

1. Arbeev KG, Cohen AA, Arbeeva LS, Milot E, Stallard E, Kulminski AM, Akushevich I, Ukraintseva SV, Christensen K, Yashin AI (2016) Optimal versus realized trajectories of physiological dysregulation in aging and their relation to sex-specific mortality risk. Front Public Health 4:3
2. Bacalini MG, Friso S, Olivieri F, Pirazzini C, Giuliani C, Capri M, Santoro A, Franceschi C, Garagnani P (2014) Present and future of anti-ageing epigenetic diets. Mech Ageing Dev 136:101–115
3. Bergman H, Ferrucci L, Guralnik J, Hogan DB, Hummel S, Karunananthan S, Wolfson C (2007) Frailty: an emerging research and clinical paradigm–issues and controversies. J Gerontol Ser A: Biol Sci Med Sci 62(7):731–737
4. Breitling LP, Saum KU, Perna L, Schöttker B, Holleczek B, Brenner H (2016) Frailty is associated with the epigenetic clock but not with telomere length in a german cohort. Clin Epigenetics 8(1):21

5. Cesari M, Gambassi G, van Kan GA, Vellas B (2013) The frailty phenotype and the frailty index: different instruments for different purposes. Age Ageing **43**(1), 10–12
6. Franceschi C, Bonafè M, Valensin S, Olivieri F, De Luca M, Ottaviani E, De Benedictis G (2000) Inflamm-aging: an evolutionary perspective on immunosenescence. Ann N Y Acad Sci 908(1):244–254
7. Fried LP, Tangen CM, Walston J, Newman AB, Hirsch C, Gottdiener J, Seeman T, Tracy R, Kop WJ, Burke G et al (2001) Frailty in older adults: evidence for a phenotype. J Gerontol Ser A: Biol Sci Med Sci 56(3):M146–M157
8. Goggins WB, Woo J, Sham A, Ho SC (2005) Frailty index as a measure of biological age in a chinese population. J Gerontol Ser A: Biol Sci Med Sci 60(8):1046–1051
9. Haskell WL, Lee IM, Pate RR, Powell KE, Blair SN, Franklin BA, Macera CA, Heath GW, Thompson PD, Bauman A (2007) Physical activity and public health: updated recommendation for adults from the american college of sports medicine and the american heart association. Circulation 116(9):1081
10. Karasik D, Demissie S, Cupples LA, Kiel DP (2005) Disentangling the genetic determinants of human aging: biological age as an alternative to the use of survival measures. J Gerontol Ser A: Biol Sci Med Sci 60(5):574–587
11. Levine ME (2012) Modeling the rate of senescence: can estimated biological age predict mortality more accurately than chronological age? J Gerontol Ser A: Biomed Sci Med Sci 68(6):667–674
12. Mathias S, Nayak U, Isaacs B (1986) Balance in elderly patients: the" get-up and go" test. Arch Phys Med Rehabil 67(6):387–389
13. Mitnitski AB, Graham JE, Mogilner AJ, Rockwood K (2002) Frailty, fitness and late-life mortality in relation to chronological and biological age. BMC Geriatr 2(1):1
14. Orgun B, Vu J (2006) Hl7 ontology and mobile agents for interoperability in heterogeneous medical information systems. Comput Biol Med 36(7–8):817–836
15. Palma L, Pernini L, Belli A, Valenti S, Maurizi L, Pierleoni P (2016) Ipv6 wsn solution for integration and interoperation between smart home and aal systems. In: IEEE sensors applications symposium (SAS), pp 1–5
16. Pierleoni P, Belli A, Maurizi L, Palma L, Pernini L, Paniccia M, Valenti S (2016) A wearable fall detector for elderly people based on ahrs and barometric sensor. IEEE Sen J 16(17):6733–6744
17. Pierleoni P, Belli A, Palma L, Pernini L, Valenti S (2014) An accurate device for real-time altitude estimation using data fusion algorithms. In: IEEE/ASME 10th international conference on mechatronic and embedded systems and applications (MESA), pp 1–5 (2014)
18. Putin E, Mamoshina P, Aliper A, Korzinkin M, Moskalev A, Kolosov A, Ostrovskiy A, Cantor C, Vijg J, Zhavoronkov A (2016) Deep biomarkers of human aging: application of deep neural networks to biomarker development. Aging (Albany NY) 8(5):1021
19. Radloff LS (1977) The ces-d scale: a self-report depression scale for research in the general population. Appl Psychol Meas 1(3):385–401
20. Rockwood K, Mitnitski A (2007) Frailty in relation to the accumulation of deficits. J Gerontol Ser A: Biol Sci Med Sci 62(7):722–727
21. Searle SD, Mitnitski A, Gahbauer EA, Gill TM, Rockwood K (2008) A standard procedure for creating a frailty index. BMC Geriatr 8(1):24
22. Spazzafumo L, Olivieri F, Abbatecola AM, Castellani G, Monti D, Lisa R, Galeazzi R, Sirolla C, Testa R, Ostan R et al (2013) Remodelling of biological parameters during human ageing: evidence for complex regulation in longevity and in type 2 diabetes. Age 35(2):419–429
23. Taylor HL, Jacobs DR Jr, Schucker B, Knudsen J, Leon AS, Debacker G (1978) A questionnaire for the assessment of leisure time physical activities. J Chronic Dis 31(12):741–755
24. Theou O, Brothers TD, Peña FG, Mitnitski A, Rockwood K (2014) Identifying common characteristics of frailty across seven scales. J Am Geriatr Soc 62(5):901–906
25. Weidner CI, Wagner W (2014) The epigenetic tracks of aging. Biol Chem 395(11):1307–1314

Enabling End Users to Define the Behavior of Smart Objects in AAL Environments

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Abstract In Ambient Assisted Living (AAL), Internet of Things (IoT) technology is exploited to equip living environments with smart objects that communicate with the outside world in an intelligent and goal-oriented manner and can support the occupants' activities. Currently, providing such objects with new capabilities requires several programming efforts. In this paper, we present an approach to combine IoT technologies and End-User Development (EUD) paradigms and tools to identify innovative scenarios where end-users are directly involved in the creation and customization of the AAL systems they use. We will present EFESTO, a Task Automation tool that offers novel visual interaction paradigms to enable end users to easily express rules for smart object configuration and discuss how the overall approach can support daily practices of non-frail elderlies.

Keywords Internet of Things · End-User Development · AAL · Task Automation tool

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1 Introduction and Motivation

Our current research aims at bringing innovation in Ambient Assisted Living (AAL) contexts, with a specific focus on the elderly's activities, by proposing new approaches to build spaces equipped with technology for monitoring older people behavior while fostering an independent lifestyle and health preservation.

The new approaches capitalize on years of experience on End-User Development (EUD), a research area whose goal is to support non-technical end users (or end users for short) in the creation of products and services tailored to their needs and desires [1, 2, 15, 18]. Specifically, our research aims to empower end users to co-design, customize and evolve computer systems by flexibly composing services and smart objects that are now available on the Web.

The design approaches and interaction paradigms we have been developing in the last years may also be applied in Ambient Assisted Living (AAL) contexts. AAL is a challenging application field for EUD. Specifically, AAL entails technological interventions in the home, the most intimate and personal of the living spaces. Internet of Things (IoT) technology is exploited to equip living environments with smart objects that communicate with the outside world in an intelligent and goal-oriented manner and can support the occupants' activities [4]. Currently, providing such objects with new capabilities requires several programming efforts. A challenge of our research is to investigate how IoT and EUD can be combined to identify innovative AAL paradigms where end users are directly involved in the creation and customization of the systems they use.

Smart homes form networks between people and objects that can be conceptualized as "information ecologies". This concept stresses the situated entanglement between people (their values and behaviors) and technologies (their requirements and functionalities). Moreover, older age is a period of strong inter-individual differences claiming for highly flexible and customizable solutions.

Despite a financial support of up to 700 million Euros from the AAL EU program (2008–2013), little social and practical benefits emerged so far and population aging is still one of the main challenges for Europe. Such failures have been associated with a major focus on technological solutions and a substantial lack of understanding of older people, their evolving needs and desires.

The solutions proposed so far in AAL are still technology-centric and consist of monolithic, rigid systems that cannot be adequately customized to support the information flow needed for care provisioning. Moreover, elderly people can live in very different situations and can have variable needs and behavior; thus a one-size-fits-all system would not work [19]. Also, current interventions addressing safe and independent living have designed their deliverables around the dominant stereotype of older adults as people in need, and technology as the solution to their problems [27–29]. However, there is evidence that this stereotype leads to the inappropriate design of artifacts, which older people may refuse to use, or, in the worst case, may be hampered by [11]. More importantly, it may easily lead to a reinforcement of ageism and possibly discrimination.

Our aim is to empower end users and other stakeholders of AAL to co-design, tailor and evolve the technology they use by flexibly composing services and smart objects. The focus is on end users that base their daily practices also on the interaction with the surrounding environment. Non-frail elderlies are in particular addressed. Frailty in elderly people is a state of vulnerability with an increased risk of adverse health outcomes, caused by the cumulative decline in multiple physical and psychological areas [12]. We target "non-frail" elderlies who lie on the borderline between "active" elderly people, who still maintain good relational involvement and high motivation for an independent life, and "fragile" elderly people, who start to perceive the physiological and cognitive decline in their capabilities and feel insecure in their living alone.

Our research adopts a socio-technical paradigm claiming that technology consists of social and technical systems interacting with an external environment (where people live or work). We investigate how to design products and services for and with older users. In this paper we describe how a platform recently developed can be used to support non-technical people to tailor AAL applications to their needs.

2 A Quick Look at the State of the Art

A number of European research projects have been recently funded in the field of AAL. However, to the best of our knowledge, the proposed solutions merely address technological issues (e.g., sensor interoperability) or some specific accessibility aspects, while none of the projects faced with EUD challenges, as this proposal aims to do. Actually, several AAL projects (see for example ALFRED (www.alfred.eu/project), GIRAFF+ (www.giraffplus.eu), DREAMING (www.age-platform.eu/all-projects/658-dreaming) and inCASA (www.incasa-project.eu) identified the interaction paradigm as a critical factor for lay users. They, in particular, focused on either adaptivity or adaptability of AAL systems; however, none of the solutions they offered came to completely solve the challenge of spreading the adoption and the personalization of the new technology among the end users.

An AAL environment for the elderly population we address is a smart home where several smart objects are available. A smart object is a device equipped with embedded software that is typically connected to the Internet [5]. It exploits sensors to "feel" the environment/users and/or actuators to communicate with the environment/users. Examples of sensors are those measuring light intensity, the physical pressure of an object, and also air humidity. Actuators can be light and sound emitters, electric valves, motor servos, relays, etc. Smart objects can foster important changes in people lives and in particular in elderly lives. If enabled to exploit the abundance of resources (the object functionality, the produced data, the related applications), non-technical people could compose the "behavior" of the surrounding environment to accommodate their everyday needs, and even visualize the data produced by sensors in the environment [8]. However, while research on the Internet of Things (IoT) [5] has devoted many efforts to the technological aspects characterizing smart objects, little social and practical benefits have emerged so far. Programming the behavior of smart objects is currently a prerogative reserved for professional developers, as it requires the use of scripting languages that can also vary depending on the underlying hardware. Another aspect is that often the available objects expose a very specific functionality that does not result in useful services able to accommodate users' needs. The opportunities offered by IoT can be amplified if new approaches are conceived to enable non-technical users to be directly involved in "composing" their smart objects by synchronizing their behavior.

Recently, some approaches have been proposed to support non-technical users to configure the behavior of smart object behavior. Many such tools, however, provide pre-packaged solutions, e.g., vendor- and device-specific apps for remotely controlling single smart objects that cannot be easily adapted to the requirements deriving from specific domains and contexts of use. Task-Automation (TA) tools that combine social services, data sources and sensors, are also gaining momentum [9, 13, 20]. They are gaining attention as they offer alternative paradigms to synchronize the behavior of objects and applications [21]. In particular, users can specify object behavior by either: (a) graphically sketching the interaction among the objects, for example by means of graphs that represent how events and data parameters propagate among the different objects to achieve their synchronization, or (b) defining event-condition-action (ECA) rules [25], a paradigm largely used for the specification of active systems (see for example [10, 14]), that in the IoT domain can be fruitfully exploited to express how and when some object behaviors have to be activated in reaction to detected events. An example of a graph-based tool is Node-RED, an open-source Web platform to compose both smart objects and Web services [24] by wiring nodes representing smart objects, control statements, functions written in JavaScript, and debug procedures. An example of TA tool based on ECA-rules is IFTTT (If This Then That), a free Web platform that, by means of a wizard-based composition paradigm, guides end users to create simple chains of conditional statements called "apps" [3]. Each app consists of (1) a service that IFTTT tracks to detect if a specific event is triggered (e.g., the position of an Android Device is within a specific area) and (2) another service that reacts to the triggered event by executing a specific action (e.g., switch on the smart Vacuum Cleaner).

However, the adoption of TA tools is still limited. Indeed, on one hand tools based on graph metaphors do not match the mental model of most users because, as demonstrated in different works on visual service composition [23, 30], they do not think about "connecting" services. On the other hand, tools implementing ECA rules, which are typically suitable for non-technical users, allow a trivial synchronization of smart-objects behaviors, without the possibility to define powerful constraints on events activation and actions execution. For example, in [6] authors discuss the importance of temporal and spatial conditions to create ECA rules that better satisfy users' needs. Specifying temporal conditions also emerged as an important requirement in home automation, to schedule rules for appliance activation [26]. Some of the available TA tools based on ECA rules allow the definition of such spatial and temporal conditions, but only by means of workarounds, for example by considering additional events to monitor the system time, or by creating filters on smart device data (e.g., in Zapier [31]). Obviously, such workarounds complicate the rule creation, thus resulting into a scarce adoption of the available tools, especially by non-technical users, or in their adoption only for very simple tasks. Others adopt a formal language to define complex behavior of devices; however, the composition of rules may easily become difficult to follow for a casual user [7].

At the IVU Lab, we have implemented the EFESTO platform, which actually is a TA tool that offers a visual interaction paradigm in order to enable end users to easily express rules for smart object configuration that are more powerful than the rules created by other TA tools like IFTTT. The paradigm is based on a model, called 5 W, which defines some specification constructs (Which, What, When, Where, Why) to build rules coupling multiple events and conditions exposed by smart objects, and for defining temporal and spatial constraints on rule activation and actions execution. Such paradigm has been designed during an elicitation study involving 25 participants, compared with other solutions during a controlled experiment with 40 users, and evaluated during a utilization study with 15 experts of both IoT and home automation [16].

3 Using the EFESTO Platform in an AAL Scenario

In order to describe how the EFESTO platform can be used in an AAL context in order to allow end users to specify the behavior of smart objects, let us consider the following scenario. Alfredo, aged 80 years old, lives in the city's outskirts and is retired. In spite of his physical limitations, he lives alone because his home is prepared to provide daily life assistance to an elder person. A system installed in his house provides an environment with a range of interconnected sensors, devices and smart appliances working together to provide a safe and secure place to live. These appliances allow Alfredo an easy utilization due to their customized interfaces and are connected to the smartphones of Pedro and Joana, his children. When Alfredo goes to the five o' clock walk, his absence from home is detected by the changing position of the smart bracelet he wears. Thus, the vacuum cleaner robot starts its work. Later, Alfredo comes back home. At seven o' clock, the doorbell rings. The devices positioned at the door detects that there is nothing to worry about as it is Alfredo's sister, identified by her smart-watch. The door automatically swings open, as the house already knows she has permission to get in.

We now illustrate how EFESTO allows a person to create one of the rules involved in the above scenario. In particular, Joana wants to create the following rule: "turn on the vacuum cleaner robot when Alfredo's bracelet detects that he is outdoor for the five o'clock walk".

On the main window of the EFESTO platform, Joana clicks the "New Rule" button in the navigation bar (Fig. 1, circle 1) and the "Creating Rule" window appears, as shown in Fig. 1, showing the main area in which a rule is defined. The left side is for specifying the triggering events, and the right side is to define the actions to be activated by the appropriate services.

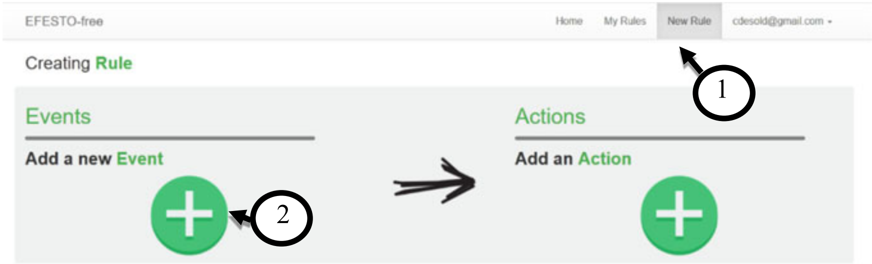

Fig. 1 EFESTO: the interface for rule creation

To add an event, the user clicks on green "+" button highlighted by circle 2 in Fig. 1. This activates a wizard procedure that guides Joana in defining the rule event. Specifically, the wizard sequentially shows some pop-up windows in which services, events and temporal and spatial conditions can be specified (see Fig. 2a, b, c). More in details, the user defines an event by selecting Which is the service to be monitored for detecting the triggering event (Fig. 2a), What service event has to be monitored (Fig. 2b), When and Where the event has to occur (Fig. 2c). Actually, the specification of When and Where conditions is optional. By referring to the example in Fig. 2, Joana by a simple click, selects the Android Wear object (bracelet) in the window in Fig. 2a (Which) and the "Position changed" event in the window in Fig. 2b (What). This because the event that activates the rule is that Alfredo, who wears the bracelet, is now outdoor. By operating on the window in Fig. 2c, she also specifies that the event activates the rule if the Alfredo's position is outdoor (Where) and if it happens in the time interval from 5.00 to 6.00 p.m. (When). At this point, the wizard procedure ends and the defined event is shown in the "Events" area (Fig. 2d, circle 1).

After the event definition, Joana starts the creation of an action by clicking on the "Add an action" button in the Actions area (Fig. 2d). Similar to what happens for the event, the button activates a wizard that helps the user define an action in terms of Which service will execute the action as a consequence of the event(s), What action the service has to perform and When and Where the action can be performed. In this scenario, Joana chooses the vacuum cleaner robot (Which) and the "Start Cleaning" as action to be activated (What), without specifying any spatial or temporal constraint. Joana can enrich her rule by adding further events and actions. More details on this rule composition paradigm implemented in the EFESTO platform can be found in [16] and will also be discussed at the conference.

4 Conclusion and Future Work

Population aging, the increasing cost of formal health care, the caregiver burden, and the importance that the individuals place on living independently, all motivate

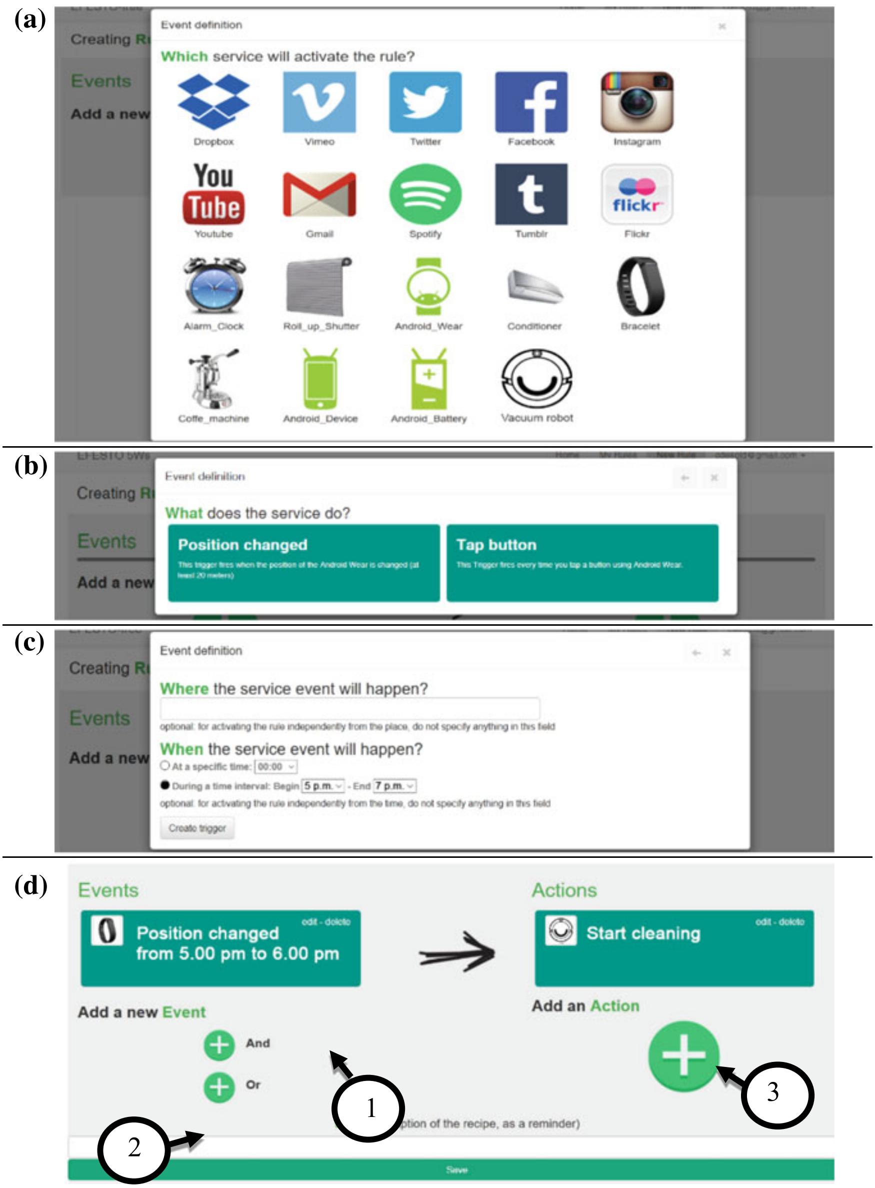

Fig. 2 Event specification: **a** the wizard first asks to select the service that will activate the rule; **b** as second step, the event is selected among those related to the chosen service; **c** temporal and spatial constraints are defined; **d** the event has been defined and the user can define further events or actions

the development of innovative Assisted Living technologies (AAL) for safe and independent aging.

The widespread of AAL applications will reduce admission to hospitals or nursing homes, permitting a better quality of life and savings for the community [22]. So far, several AAL projects have been proposed. While the technology is already well advanced, the major challenge for the success of AAL projects comes from the Human-Computer Interaction (HCI) point of view, i.e., enabling even non-technical users to manipulate data and functionality of things in a simple way, without having to refer to traditional approaches [17], as we have shown in this paper.

The AAL domain presents several HCI challenges, including system acceptability by the elderly, who often perceive an AAL system as a threat to both domestic privacy and her/his freedom and independence. This is a psychological factor that varies widely, as also high is the variability of the home physical space, the technology available there or that can be installed, and the specific needs of elderly. We believe that an approach based on a combination of EUD practices and IoT technology will maximize the appropriation of AAL technology by the elderly, making it an active part not only in the use but also in the creation and customization of useful and usable products (services and smart objects).

References

1. Ardito C, Buono P, Desolda G, Matera M (2017) From smart objects to smart experiences: an end-user development approach. Int J Hum Comput Stud 114(2017):51–68
2. Ardito C, Costabile MF, Desolda G, Latzina M, Matera M (2015) Making mashups actionable through elastic design principles. In: Díaz P, Pipek V, Ardito C, Jensen C, Aedo I, Boden A (eds) End-user development—Is-EUD. LNCS 9083. Springer Verlag, pp 236–241
3. AtomGraph. https://github.com/AtomGraph/Web-Client. Last accessed 12 Feb 2018
4. Atzori L, Iera A, Morabito G (2010) The internet of things: a survey. Comput Netw 54(15):2787–2805
5. Atzori L, Iera A, Morabito G (2010) The internet of things: a survey. Int J Comput Comput Netw 54(15):2787–2805
6. Barricelli BR, Valtolina S (2015) Designing for end-user development in the internet of things. In: Díaz P, Pipek V, Ardito C, Jensen C, Aedo I, Boden A (eds) International symposium on end-user development, IS-EUD. LNCS 9083. Springer International Publishing, pp 9–24
7. Buono P, Cassano F, Legretto A, Piccinno A (2018) A homemade pill dispenser prototype supporting elderly. In: Garrigós I, Wimmer M (eds) ICWE 2017: current trends in web engineering. LNCS 10544. Springer International Publishing, pp 120–124
8. Buono P, Costabile MF, Lanzilotti R (2014) A circular visualization of people's activities in distributed teams. J Vis Lang Comput 25(6):903–911
9. Caivano D, Fogli D, Lanzilotti R, Piccinno A, Cassano F (2018) Supporting end users to control their smart home: design implications from a literature review and an empirical investigation. J Syst Softw 144:295–313
10. Ceri S, Daniel F, Matera M, Facca FM (2007) Model-driven development of context-aware web applications. ACM Trans Internet Technol 7(1):2
11. Clarkson J, Dong H, Keates S (2003) Quantifying design exclusion. In: Clarkson J, Keates S, Coleman R, Lebbon C (eds) Inclusive design. Springer, 422–436
12. Clegg A, Young J, Iliffe S, Rikkert MO, Rockwood K (2013) Frailty in elderly people. Lancet 381(9868):752–762

13. Coronado M, Iglesias CA (2016) Task automation services: automation for the masses. IEEE Internet Comput 20(1):52–58
14. Daniel F, Matera M, Pozzi G (2008) Managing runtime adaptivity through active rules: the Bellerofonte framework. J Web Eng 7(3):179–199
15. Desolda G, Ardito C, Jetter H-C, Lanzilotti R (2019) Exploring spatially-aware cross-device interaction techniques for mobile collaborative sensemaking. Int J Hum-Comput Stud 122:1–20
16. Desolda G, Ardito C, Matera M (2017) Empowering end users to customize their smart environments: model, composition paradigms and domain-specific tools. ACM Trans Comput-Hum Interact 24(2):52 p
17. Fernández-Sáez AM, Genero M, Chaudron MRV, Caivano D, Ramos I (2015) Are forward designed or reverse-engineered UML diagrams more helpful for code maintenance?: a family of experiments. Inf Softw Technol 57:644–663
18. Fischer G, Fogli D, Piccinno A (2017) Revisiting and broadening the meta-design framework for end-user development. In: Paternò F, Wulf V. (eds) New perspectives in end-user development. Springer International Publishing, pp 61–97
19. Fischer G, Piccinno A, Ye Y (2008) The ecology of participants in co-evolving socio-technical environments. In: Forbrig P, Paternò F (eds) Engineering interactive systems. LNCS 5247. Springer, pp 279–286
20. Fogli D, Lanzilotti R, Piccinno A (2016) End-user development tools for the smart home: a systematic literature review. In: Streitz N, Markopoulos P (eds) Distributed, ambient and pervasive interactions, in DAPI 2016. LNCS 9749. Springer International Publishing, pp 69–79
21. Lucci G, Paternò F (2015) Analysing how users prefer to model contextual event-action behaviours in their smartphones. In: Díaz P, Pipek V, Ardito C, Jensen C, Aedo I, Boden A (eds) International symposium on end-user development—IS-EUD. LNCS 9083. Springer International Publishing, pp 186–191
22. MIUR—Art. 185 (ex 169) del Trattato UE—Ambient Assisted Living (AAL). http://hubmiur.pubblica.istruzione.it/web/ricerca/ricerca-internazionale/art169/aal. Last accessed 8 Jan 2016
23. Namoun A, Nestler T, De Angeli A (2010). Service composition for non-programmers: prospects, problems, and design recommendations. In: Proceedings of IEEE European conference on web services (ECOWS '10). IEEE Computer Society, Washington, DC, USA, pp 123–130
24. Node-RED. http://nodered.org/. Last accessed 10 Sept 2018
25. Pane JF, Ratanamahatana CA, Myers BA (2001) Studying the language and structure in non-programmers' solutions to programming problems. Int J Hum-Comput Stud 54(2):237–264
26. Rode JA, Toye EF, Blackwell AF (2004) The fuzzy felt ethnography—understanding the programming patterns of domestic appliances. Pers Ubiquitous Comput 8(3–4):161–176
27. Sixsmith A (2013) Technology and the challenge of aging. In: Sixsmith A, Gutman G (eds) Technologies for active aging, vol 9. Springer, US, pp 7–25
28. Vines J, Pritchard G, Wright P, Olivier P, Brittain K (2015) An age-old problem: examining the discourses of ageing in HCI and strategies for future research. ACM Trans Comput-Hum Interact 22(1):1–27
29. Wilkinson CR, De Angeli A (2014) Applying user centred and participatory design approaches to commercial product development. Des Stud 35(6):614–631
30. Zang N, Rosson MB (2008) What's in a mashup? And why? Studying the perceptions of web-active end users. In: Proceedings of IEEE symposium on visual languages and human-centric computing (VLHCC '08). IEEE Computer Society, Washington, DC, USA, pp 31–38
31. Zapier. https://zapier.com/. Last accessed 9 May 2018

Smart Objects and Biofeedback for a Pediatric Rehabilitation 2.0

Paolo Meriggi, Martina Mandalà, Elena Brazzoli, Tecla Piacente, Marcella Mazzola and Ivana Olivieri

Abstract The progressive miniaturization of electronic devices and their exponential increase in processing, storage and transmission capabilities, is opening new scenarios in pervasive computing, like the Ambient Assisted Living (AAL) and Internet Of Things (IoT). Although most of the investigations in the recent years focused on remote monitoring and diagnostic efforts, rehabilitation too could be positively affected by the use of these solutions, since these small Smart Objects may enable novel quantitative approaches. In this paper, we present the preliminary efforts in designing a pediatric rehabilitation protocol based on Smart Objects and biofeedback, which we administered to a small sample of hemiplegic children. Despite the few treatments (not suitable to assess any change in the subjects' abilities), children enjoyed participating in the study, and the initial qualitative/quantitative results highlight that such approach could represent an interesting starting point to fuel the scientific and clinical discussion towards a Pediatric Rehabilitation 2.0.

Keywords Smart objects · Biofeedback · Pediatric rehabilitation · Internet of things

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1 Introduction

Despite the increasing availability of small and compact devices and the widespread diffusion of AAL, Smart Home, IoT and distributed systems that affects all our daily lives, these systems are not yet largely used in rehabilitation settings. They are still matter of research projects, investigating the potential role of environment [1] or even objects themselves [2], generally being conceived for personalized eHealth monitoring services [3] or assessments of Active Daily Living (ADL) [4, 5].

AAL researches as well are still mostly focused on the assessment of the health conditions of the persons under monitoring, the adherence to medical treatments [6], the patients empowerment toward a more conscious healthy lifestyle [7], etc. Moreover, it is to be noted that most of the studies reported in literature, are targeted to the adults and elderly population, while very few studies foster the effects of smart environments on children.

Also in the Pediatric Rehabilitation (PR) field, there are yet several studies regarding the use of advanced technology (Virtual Reality—VR—in particular) and other quantitative approaches, but often they are limited to the assessments of kinematic quantities. On the contrary, the rehabilitation process, to positively affect subjects' daily life, should cope also with real objects (and their shape/weight) with which children deal. Hence the idea to investigate, in a rehabilitation perspective, the interaction of children with common real objects, by "smartifying" them. The idea stemmed from our recent clinical and research efforts, that lead to the building of the Computer Assisted REhabilitation (CARE) Lab, and its related theoretical founding pillars, which we summarized in the acronym EPIQ (Ecological, Personalized, Quantitative, Interactive) [8].

In this paper, we reports some preliminary results about an explorative and feasibility study around the use of smart objects in pediatric rehabilitation. Such results highlight the great potential of this approach, where the rehabilitation efforts can be fully personalized to the specific capabilities and needs of the child, thanks to an intrinsic ecological approach and exploiting the interactive and quantitative nature of smart systems.

2 Methods

For this preliminary study, 10 children were enrolled: 7 males and 3 females, aged between 3 and 16 years, with cerebral palsy (hemiplegic form) and Intelligence Quotient (IQ) higher than 80. The exclusion criteria were: severe hypovision or hypoacusia or the administration of pharmacological or surgical treatments in the six months before the beginning of the study. Caregivers gave their informed consent to the study and each child performed three session of exercises with smart objects. The duration of each treatment varied from child to child, and the session number: the first ones were usually longer (about 40 min) compared to the second and third (20–30 min) ones.

We studied a set of simple exercises, based on the interaction with simple objects, while doing common activities. We identified a sponge ball as the central element, around which to design all the activities, and we studied the way to measure the motion information in an unobtrusive, continuous, simple and safe way. The result was to use small sized IMUs, to be placed close to the center of the ball, and on the hands and the trunk of the child, as in Fig. 1. The general aim of the exercises was to promote the movements of both hands in handling the ball, while taking into consideration their position and trunk's inclination.

The experimental setup was realized in one of the rooms of the CARE Lab, and a set of 6 exercises was defined, to explore a broad range of manipulations and movements, involving mostly the upper limbs and also related to the whole body.

In order to save the quantitative information measured by the sensors, and to give an audio and video feedback to the user, a custom software was developed, named PRESO (Pediatric Rehabilitation Exercises with Smart Objects).

The experimental setting was built around a set of miniaturized wireless inertial sensors (Cometa Wavetrack—Cometa S.r.l., Bareggio, Italy), as reported in Fig. 1.

These sensors were placed into a sponge ball and into specially designed pockets on custom adjustable straps with Velcro ® (Fig. 1D), to be firmly placed on the back of both hands and on the chest of the child. These last three inertial units were used to measure the angle of the hands and trunk with respect to the vertical axis. Finally, two big colored buttons (yellow and red) were wireless connected to set the start and stop position in the time based exercises. The information acquired by sensors was conveyed to the computer running the PRESO software via the WaveTrack receiver.

All the rehabilitation activities took place in the "Low Tech" room in the CARE Lab. The room setting consisted in the following items (see Fig. 2):

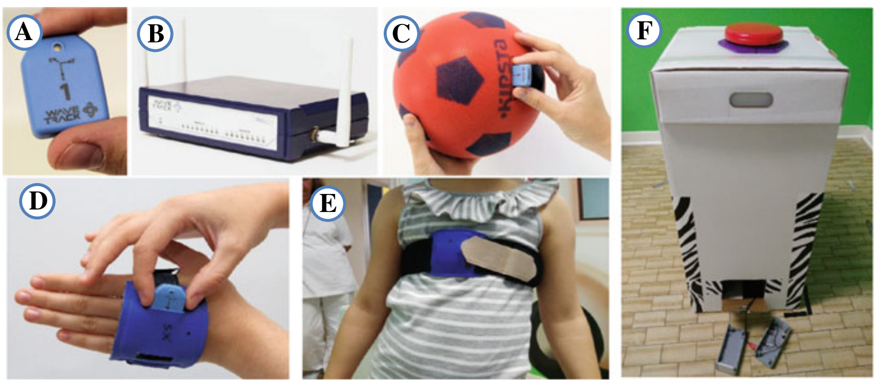

Fig. 1 **A** A Wavetrack sensing unit. **B** Wavetrack receiver. **C** Setup of the IMU sensor in the ball. **D** Placement of the IMU sensor in custom pocket on the back of the hand. **E** Positioning of the IMU sensor in a belt attached to the chest of the subject. **F** Plastic enclosure to hold a Cometa footswitch device to monitor the state of a big button (on the top of the cardboard box)

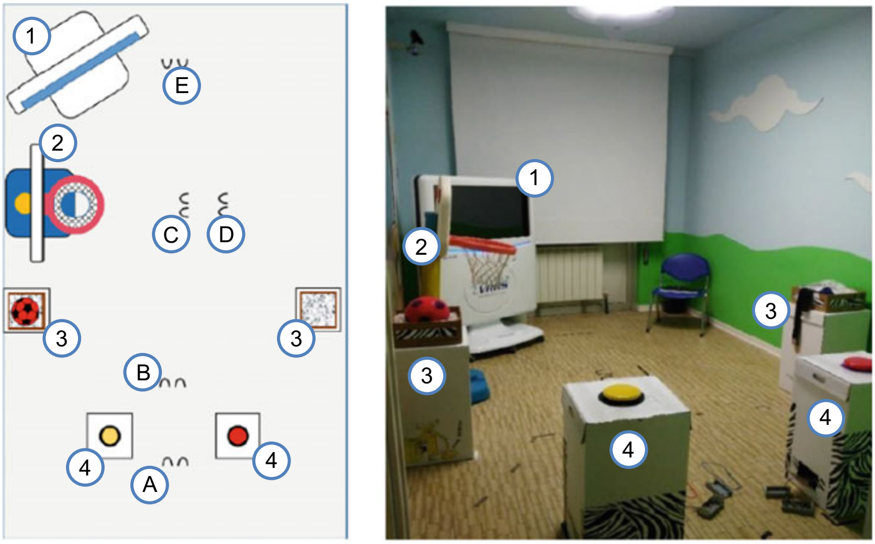

Fig. 2 On the left a schematic view of the room. On the right, a picture of the actual setup

(1) Computer with a wide screen monitor (40”), equipped with loudspeakers, to ensure an appropriate perception of the biofeedback by the children in all the room. The computer run the PRESO custom developed software, for the data acquisition and production of biofeedback. The computer and the wide screen were placed in a corner of the room, to avoid the need to relocate them for the different exercises, thus leaving the therapist always in position E (Fig. 2)
(2) Toy basketball hoop
(3) Two cardboard boxes, to hold the smart ball
(4) Two cardboard boxes holding the start/stop big buttons.

Some special signs were placed on the room’s floor (items A–E in Fig. 2) to indicate the start positions for the various exercises, as further described in the following paragraphs. Two big colored buttons were placed on top of cardboard boxes and connected to the footswitch devices (Cometa FSW) to signal the pressing of each button.

The PRESO software was developed using Microsoft .NET C#, to perform data acquisition from the sensors, processing and production of the suitable triggers audio/video and biofeedback. PRESO consisted in two different screens (see Fig. 3), one to select the exercise and verify in real-time that the data acquired from the sensors are ok, and one containing the visual feedbacks related to each exercise. This latter was composed of:

- two rectangles (items 4 in Fig. 3) representing the right and left hand which could color (green, yellow or red) and rotation, depending on the inclination of the hands detected by the sensors.

Fig. 3 Pictures of the user interface of PRESO software. (1) Round number of the exercise (if organized in rounds). (2) Score (in blue) and high-score (in white). (3) Countdown time in seconds, for the timed exercises. (4) Rectangles representing the inclination of the inertial sensors placed on the back of the hands. (5) Puppets reporting trunk's inclination measured by the chest's inertial module. (6) Smiles to give a nicer feedback about the inclination of the hands (smiling when in correct position, red and disappointed when not upright). (7) Parameter setup window, used by the therapist to check the information received from the sensors and to adjust the exercise parameter and select the exercises

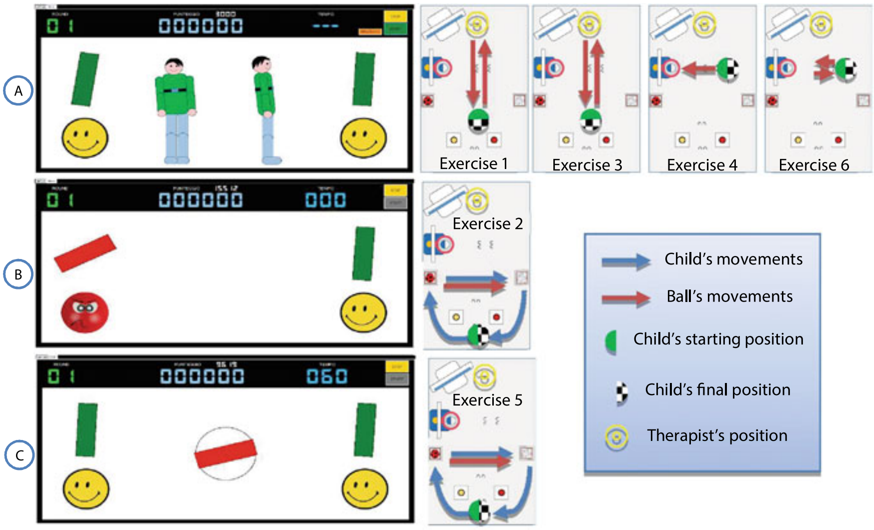

Fig. 4 Pictures of the actual screen of the PC (on the left), and the schematic representations of the movements (on the right) during each exercise

- two smilies that change expression (happy or angry) and color (yellow, red), according to the same logic previously reported for the rectangles.
- two puppets reporting the bending angle to the front and to the side, as detected by the chest sensor.
- a circle in the central position (Fig. 4C), that was used to report the ball's orientation, as reported by its internal sensor,

Beside the visual cues (Figs. 3 and 4), PRESO software produced also an acoustic feedback and could also play background entertainment music (selectable by the operator). The first audio cue was a whistle, used to start the activities, then a high frequency beep feedback sound that was produced if one of the sensors on the hands and/or on the chest were outside the maximum angle with the vertical axis.

In the time-based exercises, the child was asked to wait the so-called "trigger" condition before starting the action to be performed. Such condition consisted of having both hands and trunk upright (the angle is calculated from the 3D accelerometer), and the child is not moving (standard deviation of accelerometer and gyroscope moduli is less than a given threshold), for a given percentage of time in a time-window (usually 80% of 1.5 s, but the figure was fully customizable to each children capabilities).

Each Exercise begun after the therapist pressed the "start" button and could be interrupted through the "stop" button in case of any problem.

The six exercises administered are described in Table 1 and Figs. 4 and 5.

Table 1 List of the exercises performed in the protocol

Exercise	Type (time or round based)	Description
1—Roll the ball	Time based (1 min)	Physiotherapist (PT) stands in position E, and the child stands in position B. PT starts rolling the ball on the floor in the direction of the child, who grabs the ball as soon as it gets closer. The child lifts up the ball and stands still waiting for the software to signal the feedback due to the correct ball position and steadiness, then the child bends again and spins the ball, rolling it back toward the PT *Objective*: children need to stay for the predefined amount of time (5 s) in the correct upright position, with both hands extended in vertical position and the trunk upright, before letting the ball to roll back to the PT. They should try to complete the sequence as many times as possible in one minute
2—Transfer the ball still from one basket to the other	Round based (6 rounds)	The therapist places the ball in one of the two baskets, and the child stands in position A (Fig. 2) pressing the buttons (Fig. 5B) with both hands. Once the child hear the beginning whistle, she/he goes to get the ball in the basket to bring it into the other, and then the child have to return to the starting point and press both buttons again. In the next round the child perform the same exercise, along the reverse path *Objective*: the child must be careful to keep his hands in the correct position for the whole duration of the exercise, using the visual feedback given by the monitor while completing the exercise as soon as possible. If the hands are not in the correct position, an acoustic feedback is produced (a continuous hi-frequency "beep")

(continued)

Table 1 (continued)

Exercise	Type (time or round based)	Description
3—Launch the ball	Time based (1 min)	The child stands in position B (Fig. 2). The therapist, who stands in position E, passes the ball towards the child. The child must catch the ball and has to hold it with the hands in the correct upright position, waiting for the visual and acoustic feedback (a trumpet sound and a green flag). Then the child passes the ball back to the therapist. The exercise continues according to the same procedures for one minute *Objective*: the child must be able to reach the correct position and must complete the game, passing the ball to the therapist, as many times as possible in the time interval of one minute
4—Throw the ball into the basket hoop	Time based (1 min)	The child stands in position C or D according to her/his height (Fig. 2), turned towards the basket hoop (Fig. 5D). When she/he hears the acoustic signal indicating that she/he has his hands and trunk in the correct position she/he can throw the ball into the hoop. Then she/he must retrieve the ball and return to the start position to try to reach the trigger due to the correct position and restart, continuing in the same way for a minute *Objective*: the child must be able to reach and keep the correct upright position while holding the ball before launching it to the basket hoop, and should totalize the greatest number of launches and scores in one minute
5—Transfer the ball in a given position	Round based (6 rounds)	Therapist places the ball in a basket in an "incorrect" position (the rectangle into the ball—Fig. 4C—should be yellow or red). The child starts from position A (Fig. 2) and press both buttons, releasing them only after hearing the whistle indicating the start of each round. The child then picks up the ball in the basket (Fig. 5), turns the ball (with finger and/or pronation and supination movements of the forearms) until the bar on the monitor turns green, then moves the ball into the second basket. Then the child can return to the starting point and press the buttons again to end the exercise. The next round the child would follow the reverse path *Objective*: the child must be able to manipulate bimanually the orientation of the ball. Then she/he must be careful to keep his hands and the ball at the same time in the correct position while transferring it to the opposite basket. If the hands or the ball are not in the correct position, a feedback is produced (a continuous high frequency "beep")
6—Bounce the ball	Time based (1 min)	The child can be placed anywhere in the room (Fig. 2), and must hold the ball with hands and trunk in upright position. When she/he hears the starting signal, indicating the correct position has been reached and kept for enough time, she/he must bounce the ball onto the ground and then grab it again (Fig. 5F) *Objective*: the child must be able to reach the correct position looking at the visual feedback given by the monitor (Fig. 4A) and performing the highest number of rebounds in a minute of time

Fig. 5 **A** Exercise 1: the child is rolling the ball toward the therapist. **B** Exercise 2: the child is about to move from the initial position. **C** Exercise 3, the child is receiving the ball from the therapist. **D** Exercise 4: the child is throwing the ball into the basket hoop. **E** Exercise 5, the child is picking up the ball from one cardboard basket to bring it to the opposite one. **F** Exercise 6: the child is preparing to bounce the ball onto the ground

3 Results

As previously described, due to the limited sample size and the small number of treatments, the results here reported focus on the potential of such approach rather than on actual quantitative findings. The potential is double fold: on the one side from the pleasantness and appeal of such a treatment (all children reported they happily participated in the study, with great interest in the performed activities); on the other side its intrinsically quantitative nature, based on the sensors' readings, may be easily exploited to sustain activities specifically focused on the child's rehabilitation needs and abilities.

In this paper we present some graphical results of the acceleration and angular velocity moduli, easily segmented in different phases, summarizing one sample for each exercise, just to highlight the capabilities disclosed by such an approach. It will be easy to notice the bold difference in the movements performed by the normal and plegic arms, as well as the ease to identify the key instants when the hands and the ball may be considered as moving "together" and the phases where the arms are moving separately.

In each chart, a green line represents the ball, a red line the left hand and a blue line the right hand. Time (X axis) is expressed in seconds, while the Y axis represents respectively the acceleration modulus in g, and the angular velocity in degree per second (dps).

The graphs shown in Fig. 6 represent a single action in Exercise 1, in which the child and the therapist pass the ball to each other by rolling it on the ground. In this case in particular, we report what happens between the second fifth and the eleventh.

Observing the traces it is possible to identify 6 phases, after the trigger condition (red line) is met:

A. *Child's reaction time*: acceleration and angular velocity of the inertial moduli remain stable until the beginning of the movement, identified with dashed line 2.
B. *Child prepares to launch*: there are fluctuations of both parameters, due to the subjective strategy with which the child performs the movement, up to a sharp increase at point 3, when the ball is released. In this phase the hands and the ball move together.
C. *Ball is rolling*: the ball's acceleration oscillates consistently between negative and positive values, probably due to the position of the sensor, not exactly placed in the center of the ball. Angular velocity modulus reaches a high positive value describing a plateau, remaining constant until the therapist stops the ball.
D. *Ball is caught by the therapist, and the child prepares to receive it*: at point 4 the ball is stopped by the therapist who in turn throws it, releasing at point 5.

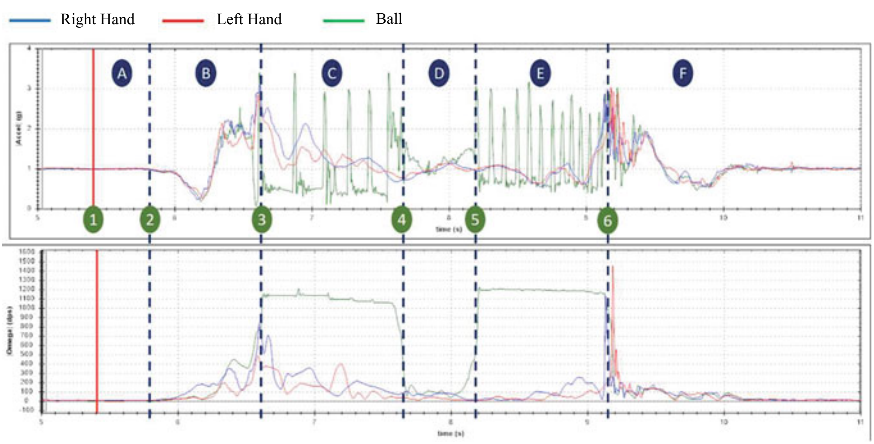

Fig. 6 Tracings acquired during Exercise 1 for a left hemiplegic child

E. *Therapist rolls the ball back to the child*: we see again the fluctuations in the acceleration modulus of the ball, and a plateau for its angular velocity
F. *Child catches the ball (point 6) and returns to the rest position*: note that in this phase the hands and the ball move together, as reported by the overlapping tracings

The graphs shown in Fig. 7 represent the tracings acquired during the execution of a round of the Exercise 2. It is possible to divide it into 4 phases.

A. *Reaction time*: line 1 indicates when the therapist clicks the start button on the monitor, then the tracings remain steady up to point 2, which represents the beginning of the movement.
B. *Beginning of the movement*: the child moves from the starting position towards the basket containing the ball, and she/he grabs it (point 3). In this part, we see that there are accelerations and rotations of the hands, while the ball is laying still.
C. *Ball carried from one basket to another*: after the child has taken the ball, this too begins to report variations of the parameters similar to those of the hands, since they are moving together.
D. *Child returns to the start position*: the child puts the ball in the basket (point 4), easily detectable since the ball shows negligible acceleration and angular velocity. At the point 5 the child gets back to the start position and pushes both buttons.

Note that since Exercise 5 was similar to Exercise 2, and hence we did not reported a specific example for it.

The traces shown in Fig. 8 were recorded between the second 49 and 55 of Exercise 3, in which the child and the therapist throw each other the ball. Six phases may be identified:

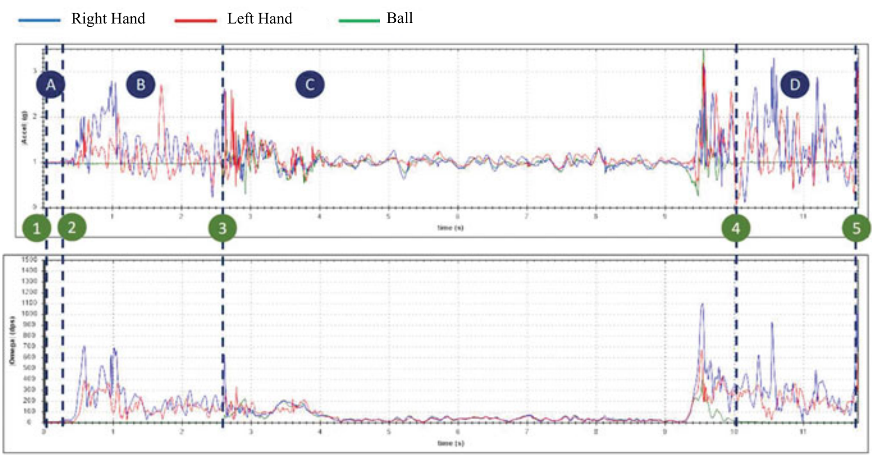

Fig. 7 Tracings of Exercise 2 for a right hemiplegic child

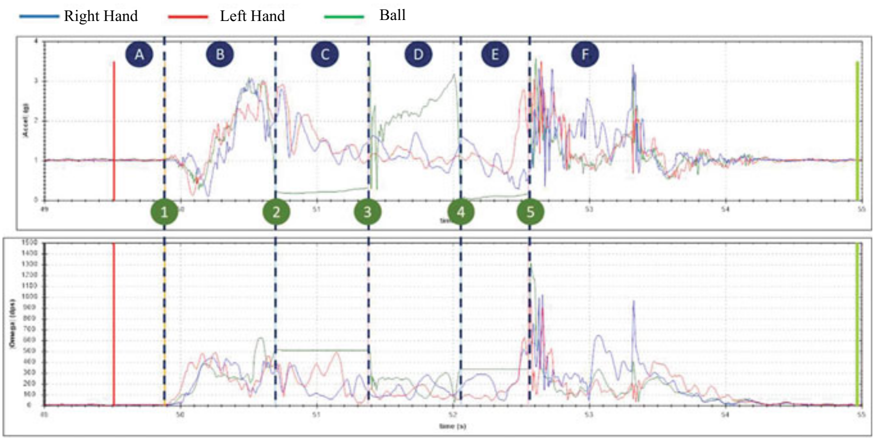

Fig. 8 Tracings of Exercise 3 for a right hemiplegic child

A. *Reaction time*: the parameters do not change significantly from the red line (trigger) to line 1, indicating that the child has not yet started the movement.
B. *Child gets ready to launch*: we note that the three elements (hands and ball) have similar behavior, since they are moving together.
C. *Ball in flight*: at point 2 the child throws the ball which then undergoes a deceleration until point 3, in which it is taken by the therapist. In this case, we are observing the tracings of a left-hemiplegic patient, since we may note that the pathological limb is characterized by lower values of the acceleration and angular velocity moduli with respect to the non-pathological one.
D. *Ball is caught by the therapist, the child prepares to receive it*: at point 3, the ball is stopped by the therapist who then throws it (point 4) towards the child.
E. *Ball in flight*: after the therapist's launch, the ball is in flight and is caught by the child at point 5.
F. *Return to the rest position*: the child, after taking the ball, makes adjustments to return to the rest position.

In Fig. 9 we report the traces of a child with right hemiplegia, recorded between the second 10 and 17 of the Exercise 4.

A. *Reaction time*: from the red line (trigger) to line 1 there are no changes in acceleration or angular velocity, meaning that the child is still in a resting condition.
B. *Preparation to launch*: there is an increase in both acceleration and angular velocity moduli, especially for the left hand (non-pathological limb) and the ball, which follows the movement of the non-pathological limb.
C. *Ball flying towards the basket and subsequent rebounds*: starting from line 2, the hands and the ball are separated, then we observe different acceleration peaks for the ball, given by the rebounds against the basket and then onto the ground, and also an increase in the angular velocity.

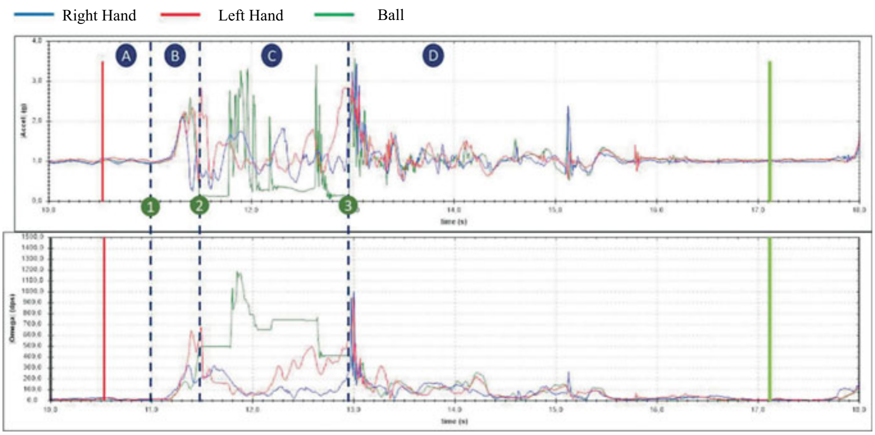

Fig. 9 Tracings of Exercise 4 for a right hemiplegic child

D. *Return to the rest position*: from line 3, the acceleration and angular velocity tracings of the hands and the ball describe similar patterns until a stationary condition is reached.

The tracings in Fig. 10 represent the acceleration and angular velocity moduli between the second 24 and 27 of Exercise 6, in which the child bounces the ball on the ground continuously for one minute. In this case, the graph of a child with left hemiplegia is taken as an example and it is observed that the blue line (right hand) assumes, for most of the time, greater values both in terms of acceleration and angular speed.

For this graph, six phases have been identified.

A. *Reaction time*: parameters remain stable from the trigger line (leftmost part of the graph) to line 1.
B. *Preparation to launch*: in this phase, hand and ball sensors have similar traces, since they all move together. In particular, in the graphs of the majority of children a reduction in the acceleration's module was noticed before an increase. This means that the child elevates the hands and the ball before pushing down and throwing the ball.
C. *Ball pushed downward*: at the point 2 the ball is released from the hands of the child and begins the flight phase downward, then the hands and the ball tracings are distinct either for the acceleration and angular velocity (as in phases D, E).
D. *Ball touches the floor*: a sudden increase in acceleration's module is observed.
E. *Ball bounces up*: from the line 4 the ball bounces from the floor and we may observe the flight condition of the ball by the sharp reduction of its acceleration module.
F. *Return to the rest condition*: in point 5 the child grabs the ball, and since then the traces of the three sensors return to have similar behavior, for they are moving again together, to reach the rest condition and wait for the next trigger.

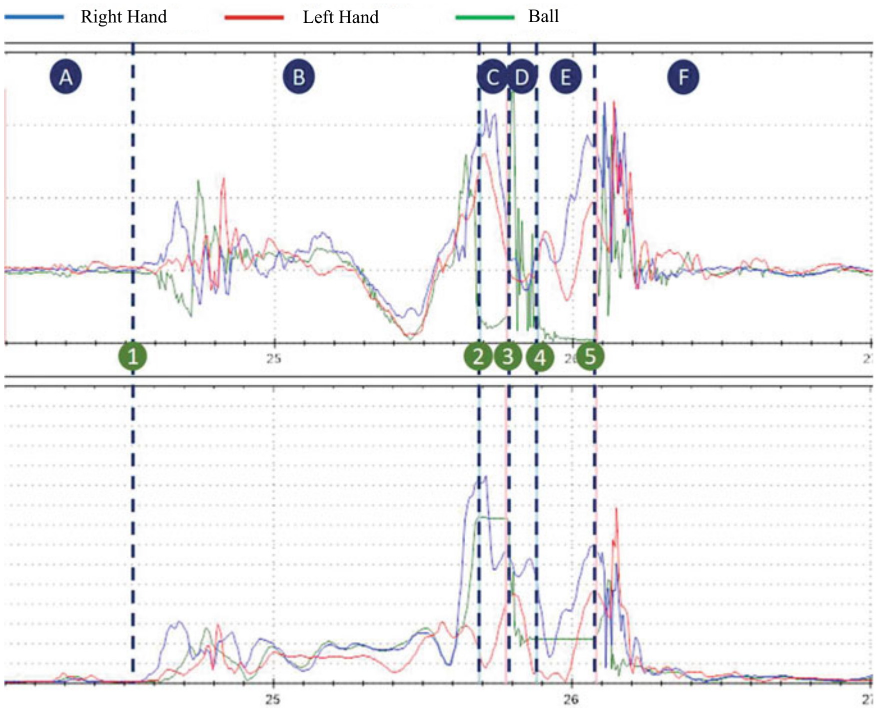

Fig. 10 Tracings of Exercise 6 for a left hemiplegic child

4 Discussion

Despite the small number of subjects and sessions involved in the protocol, and the lack of a real quantitative analysis of data, the semi-quantitative results reported show interesting perspectives that deserve to be further fostered. From the measures of the acceleration and angular velocity of the inertial sensors (segmented as reported in the past paragraph), we may derive several indexes, like reaction times, estimates of lateralization, quantitative indication about the child's motor strategies, etc. The measures acquired and the indexes calculated (in real-time) may also open novel forms of biofeedback-driven exercises that may increase the efficacy of the rehabilitation process.

It is however important to highlight some other limitations of the present study:

- The sensor in the ball was not always placed exactly at its center, resulting in an erroneous reading in the acceleration while the ball was rolling, and not all the interactions were instrumented (i.e. we do not have quantitative readings about the basket hoop, the pressure on the buttons and/or under the cardboard basket the hold the ball).

- The segmentation of the tracings has been performed manually, while it would be advisable to have an automatic (or semi-automatic) assessment tool to analyze the tracings.
- The user interface of PRESO application still needs be further simplified and improved, both for the therapist and for the child.
- The bands used to hold the IMUs on the back of the hands and on the chest were a bit too bulky, resulting difficult to be placed correctly and to be worn firmly (due to sweat) during the whole exercise, especially for younger (smaller) children.
- Finally, the setup was a bit too complex for younger kids, resulting in the need to redesign the overall exercise sequence and look and feel to be used by youngest ones (less than 4 years).

Nevertheless, the tracings reported in paragraph 3 clearly show that novel scenarios where suitably "smartified" common objects (toys, pencils, cutlery, glasses, etc.), may be used to record the interactions with the subject's limbs, and possibly being included in a gamification process of the rehabilitation, that could in turn enhance the recovery or the improvement of impaired functions.

5 Conclusions and Future Work

From the experience so far gathered with this feasibility study, it appears that "smartified" objects present great potential in (pediatric) rehabilitation, not only in terms of appeal and engagement, but also from a quantitative and personalized perspective. Moreover, their intrinsic ecological and interactive nature could definitively boost the "last mile" in the rehabilitation process, for the strong relationships with usual daily activities. This holds especially true if we consider the increasing demand for continuity of care and quality home-based rehabilitation services.

Of course, further improvements are needed either in defining proper indexes, designing the more appropriate exercises (i.e. throwing the ball into the basket hoop led to somewhat fuzzy results for the lack of information regarding the interactions of the ball with the environment), and possibly by introducing new ones.

New "smartified" objects could also be designed and used, also with the aim of replacing (if and when possible) or hiding into nicer and better looking objects instead of the straps needed to place the sensors on the hands and on the chest.

Important improvements are also required for the graphics and sounds used by PRESO software, and its usability for the operator, possibly including cloud-related extensions. Regarding the sensors, an important improvement would be to identify cheaper devices, even if with lower precision and resolution. These two last items are mandatory to extend the rehabilitation process at home, even if bridging such a gap will require also further investigations about the absence of the therapist and the on the role of caregivers.

All these development perspectives are intrinsically multidisciplinary, and would require the collaboration of several different expertise, technical and clinical, not only to further design the exercises and protocols, and evaluate them in the clinical practice, but also to define suitable training and educational path for therapists and clinicians about the use of this novel approach.

As reported in [8], a Pediatric Rehabilitation 2.0, based on the Ecological, Personalized, Interactive and Quantitative keywords, will very likely become routine, and the use of smart objects is indeed one of the key steps in this process.

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References

1. Jekel K et al (2016) Development of a proxy-free objective assessment tool of instrumental activities of daily living in mild cognitive impairment using smart home technologies. J Alzheimers Dis 52(2):509–517
2. Jovanov E, Nallathimmareddygari VR, Pryor JE (2016) SmartStuff: A case study of a smart water bottle. Conf Proc IEEE Eng Med Biol Soc 2016:6307–6310
3. Pharow P et al (2009) Portable devices, sensors and networks: wireless personalized eHealth services. Stud Health Technol Inform 150:1012–1016
4. Sacco G et al (2012) Detection of activities of daily living impairment in Alzheimer's disease and mild cognitive impairment using information and communication technology. Clin Interv Aging 7:539–549
5. Prioleau T, Moore Ii E, Ghovanloo M (2017) Unobtrusive and wearable systems for automatic dietary monitoring. IEEE Trans Biomed Eng 64(9):2075–2089
6. Roy PC, Abidi SR, Abidi SSR (2017) Monitoring activities related to medication adherence in ambient assisted living environments. Stud Health Technol Inform 235:28–32
7. Grace SL et al (2017) Perceptions of seniors with heart failure regarding autonomous zero-effort monitoring of physiological parameters in the smart-home environment. Heart Lung 46(4):313–319
8. Olivieri I et al (2018) Computer Assisted REhabilitation (CARE) Lab: A novel approach towards Pediatric Rehabilitation 2.0. J Pediatr Rehabil Med **11**(1):43–51

The Use of Smart Tools for Combined Training of People with MCI: A Case Report

Gianmaria Mancioppi, Emanuela Castro, Laura Fiorini, Martina Maselli, Cecilia Laschi, Francesca Cecchi and Filippo Cavallo

Abstract Dementia and Alzheimer's Disease affects more than 35 million people worldwide. The onset and the development of this pathological condition are generally subtle and progressively. Nevertheless, is often possible identifying some precursors symptoms of the disease. A nosographic entity, which describes this condition between healthy and pathological aging, is called Mild Cognitive Impairment (MCI). Over the last years, several new technologies are entering in the field of medicine and neuropsychology, especially, Information and Communication Technologies (ICT). Today ICT are more and more being recognized as a valid instrument for assessment, treatment, and assistance of subjects who are suffering from MCI. This paper reports two case studies about the use of two new technological tools for the cognitive assessment and stimulation of elderly healthy people or subjects suffering from MCI. This study purpose is to investigate the peculiarities, in terms of cognitive performances, highlighted by the use of these smart systems, namely SmartWalk and SmartTapestry system.

Keywords Neuropsychological assessment · Cognitive stimulation · Mild cognitive impairment · Information and communication technology

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1 Introduction

Over the last years, we witnessed the massive increment of elderly people suffering from neurodegenerative diseases, such as Alzheimer's disease (AD). The World Alzheimers Reports have revealed that, in the last few years, the global cost associated with AD increased by approximately +34%, and will reach $ 1 trillion within the next 3 years [1]. The ADs impact is enormous, economically and socially. Indeed, it represents one of the most remarkable causes of disability in older age [13] and, moreover, to date there is no pharmacological treatments able to arrest the disease [1].

Several studies on patients suffering from Mild Cognitive Impairment (MCI), a condition which is deemed a harbinger of dementia [17], have demonstrated that cognitive training (CT) has a healthy effect on various cognitive functions, including attention and memory, but also mood and psychological well-being [19]. Also, aerobic and non-aerobic exercises have been recently used in the treatment of people with MCI. The exercise, in fact, seems to have a positive impact on the cognitive and emotional sphere [1].

Over the last years, new technologies, especially Information and Communication Technologies (ICT), are entered, more and more, in the field of neuropsychological treatment for dementia [5, 7]. This paper describes the use of two ICT smart tools, namely SmartWalk and SmartTapestry, developed as instruments for the neuropsychological assessment and the training of elderly people and subjects with MCI. These tools were minded to combine cognitive tasks with physical exercise, so to exploit the virtuous circle defined by the mutual effect of cognitive stimulation on physical performance [20], and vice versa, the beneficial effect of exercise on cognitive performances [12].

Here are displayed two case studies, with the purpose to highlight the subjects' cognitive performances and process detectable during the use of two alternative smart systems. This study aims to investigating in details how a healthy subject and an MCI subject perform with the two system and which supports and which difficulties they meet in their use.

2 Related Works

The interest in investigating how ICT can be used to tackle dementia is growing faster. Researchers and clinicians believe that thanks to the combination of technological and clinical progress, it will be easier identifying subjects with MCI in a more accurate way [8]. For example, concerning the assessment of MCI patient, several types of ICTs are already available. In their systematic review, Garcia-Casal et al. [8], state that nowadays there are four categories of ICT instruments for cognitive impairments early detection and assessment, such as (i) personal devices; (ii) internet-based devices; (iii) monitoring devices; (iv) virtual reality. They summarize that PC is the most common ICT used in this field and its applications are widely diffuse to assess several neurocognitive functions, among which memory and attention. In addition, in another review emerges that computer-based test could help the clinician in several ways, such as more severe control of assessment condition, which leads to greater psychometric reliability; quick and easy recording of latency and response types; reduce the examiners' subjectivity effect and enable automatic performance correction [5]. ICTs could also be utilized to assess behavioral changes in affective disorders due to MCI, as reviewed in [9].

With regards to ICT for cognitive intervention, Cognitive Training (CT) protocols were implemented with ICT to stimulate the subject intensively, ecologically, economically and in a customizable fashion. Cognitive training (CT) is defined as "*guided practice on a set of standard tasks designed to reflect particular cognitive functions*" [2]. Usually, such tasks are administered by paper and pencil protocols or, recently, by computerized tools [11]. Charchat-Fichman et al. reviewed the literature concerning cognitive rehabilitation and ICT. The authors affirm that new technologies applied to neuropsychological rehabilitation have facilitated the development of compensatory strategies and real-world simulations, leading to greener training procedures [5].

In a more recent review, drafted by Ballesteros et al. [3], the authors report that ICTs furnish great opportunities to improve or facilitate the implementation of multi-domain interventions in aging. The authors mentioned computerized training as the preferred option in most of the intervention studies. This solution is really useful since the program can automatically adapt to the trainees daily performance. Moreover, through the use of video games, it is possible to train only a target domain or simultaneously several cognitive domains.

A recent Garcia-Betances review tries illustrating the ICT application with MCI subjects. The authors sustain that advanced ICT-based tools, such as virtual and augmented reality technologies, are the most fitting platforms for applying nonpharmacological computerized neurocognitive interventions as a means to assess, maintain or improve cognitive functions. Moreover, the authors assert that a synergic application of multicomponent and multimodal neuro-technological intervention seems to be a promising approach. In fact, the application of ICT to MCI subjects can lead to significant improvement in the treatment of memory, sustained attention, executive ability to make a decision, spatial orientation and time and visual perception [7].

Our work aims to introduce the use of two new smart systems in that framework.

3 Materials and Methods

The two developed smart tools are based on neuropsychological task used for assessment and rehabilitation. In particular, was used the "Batteria Computerizzata di Test per l'Esame dell'Attezione" (TEA)[1] to stimulate the auditory sustained attention.

[1] Italian version of TAP "Test battery for attention performance."

TEA is a computerized technique composed by various subtests able to assess different aspects of the attentional domain including sustained attention. Particularly, the task took into account is composed of a sequence of alternated high and low tone. The subject had to detect each irregularity which occurs in the sequence pushing a button, while he is sitting in front of a computer. The output measures that neuropsychology uses to assess the users' performance are related to three main scores: (i) Correct answers, which is defined as the number of changes in the audio track correctly identified. (ii) Omitted answers, which is defined as the number of changes in the audio track not identified. (iii) Error, which is defined as the number of changes identified in absence of changes in the audio track. Other parameters are related to the reaction time of the correct answer, and it includes the mean and the standard deviation (SD) [21].

The SmartWalk system is the TEA litmus test, but its novelty is that it was designed to require a commitment to the subject both on motor side (walking, and mobility of lower limb articulation movement) and cognitive side (attention in relation to the reference standardized test) [6].

The other neurocognitive ability took into account was verbal episodic memory. The cognitive exercise chosen for the stimulation of this cognitive domain was the subtest Verbal Paired Associated (VPA) Learning Task of Wechsler Memory Scale-Fourth Edition WMS-IV, in double condition: immediate (VPA immediate recall subtest) and delayed recall (VPA delayed recall and VPA recognition subtests) [10]. In particular the immediate recall subtest measures the immediate verbal memory of the associated word pairs. 14 or 10 word pairs are read to the subject (the WMS-IV provides an adult version and one for the elderly aged 65 and older, respectively). Later the examiner reads the first word of each pair and asks the subject to recall the associated word. In the subtest there are four versions of the same list of word pairs presented in a different order. The examiner will read these 4 versions and every time, after presenting each list, proceed to the recall (from here reported as Imm1, Imm2, Imm3, and Imm4). The raw score is the sum of the correct answers to the four versions. The delayed recall subtest, indeed, is administered 20–30 min after the subtest Immediate recall condition. The deferred condition evaluates the long-term memory for word pairs. The raw score is the sum of the correct answers. Finally the recognition subtest is a list of word pairs is read to the subject and asked to identify each pair as one of those already present in the previous subtest or as a new couple. The raw score is the sum of the correct answers.

The ICT counterpart developed to stimulate verbal episodic memory by using verbal pair associated is SmartTapestry. Similarly to SmartWalk System, the novelty of this tool is that it was designed to require a commitment to the subject both on the cognitive (memory in relation to the reference standardized tests) and on the motor side (upper limb articulation movement). Specifically, the subject placed standing in front of the system will have to raise the upper limb to perform the exercise. This task involves flexion and rotation (internal and external) movements on the frontal plane. If the subject is placed as to have the side system, he can carry out the same exercise by performing abduction and rotation (external and internal) movements on the sagittal plane [14].

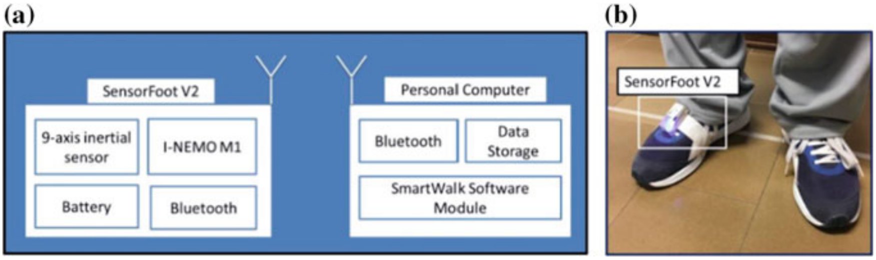

Fig. 1 **a** SmartWalk tool main components. **b** SensorFoot V2 mounted on the users dominant foot [6]

SmartWalk

SmartWalk system is composed of a wearable inertial sensor placed on the dominant foot (SensorFootV2) and a software which collect the data (see Fig. 1). SensorFoot V2 (see Fig. 1a) is able to collect a 9-axis inertial system (3-axis accelerometer, a 3-axis gyroscope, and a 3-axis magnetometer) at a frequency of 100 Hz. The data is filtered on-board with a fourth-order low-pass digital Butterworth filter with a 5 Hz cut-off frequency. The core of this device is represented by the iNEMO-M1 system on board (STMicroelectronics, Italy) with a Cortex-M3 family microcontroller [18]. SensorFoot V2 has a small battery that supplies the system. Data are collected and transmitted via Bluetooth protocol to the software module installed on a computer. The software module is developed with Visual Studio 2013 (c# language) and it is able (i) to collect and store SensorFoot V2 data, (ii) to autonomously administrate the exercise and (iii) to reproduce the audio track for testing the sustained attention (the same of TEA subtest).

SmartTapestry

SmartTapestry is a sensorized tapestry, designed and developed to be used in a combined rehabilitative protocol involving both motor and cognitive functions, as described in [14]. More specifically, SmartTapestry allows the administration of standardized psychometric tests with modalities that are alternative respect to the traditional approach. In particular, since the useful movement for the shoulder is over the 90 line, more frequent letters were placed in that area. On the basis of clinical requirements provided by the psychologists, SmartTapestry was designed with the following elements:

1. A sensitive base (60 × 90 cm) containing: (i) 24 sensitive elements (15 × 15 cm each one) arranged to create a 4 × 6 matrix. Each sensitive element was obtained with a double sheet of conductive textile (Adhesive Conductive Fabric—ACF by Mindsets Ltd.) divided by a 1.5 cm thick foam layer. In correspondence with each unit, holes were performed into the foam for allowing the contact of the two fabric layers to detect touch by the user (the sensing units work like on–off switches); (ii) electronic hardware for data acquisition (Multifunction DAQ System NI USB-6218 by National Instruments), connected to the fabric patches with conductive threads sewn in the foam, and a USB connection to the laptop;

2. interchangeable layers to be placed above the sensitive base with velcro hooks, containing the various targets of the exercises. For instance, in this study the 21 letters of the Italian alphabet were arranged to cover the sensitive units: the system actually works like a wide keyboard;
3. a laptop with a custom LabVIEW graphic user interface to select the desired exercise (tests are administrated through the software) and acquire data from the tapestry (sequence of correct answers and total test score);
4. a mobile support structure for the tapestry, able to adjust the height according to the subject's requirements.

3.1 Protocol

The subjects involved in this study were asked to perform 4 tests, administrated randomly; the traditional neuropsychological task and the equivalent exercise with the smart tools.

At the beginning of the experimental session, written informed consent was obtained from the participants. Study design and protocol, including subject privacy and sensitive data treatment, were approved by the Ethics Committee of the Scuola Superiore SantAnna, Pisa. All methods included in the protocol were carried out in accordance with the guidelines laid down in the Declaration of Helsinki. For further details check [6, 14].

SmartWalk During the traditional test, a neuropsychologist administered the exercise as required by the traditional protocol. Whereas, during the SmartWalk test, firstly the participant was asked to wear the SmartFoot on the dominant foot (see Fig. 1b). As soon as they was ready, they pressed start on the software module thus the instructions were autonomously administrated by SmartWalk software. If they did not understand properly they can listen again the guidelines. Each test lasted about 30 min and was supervised by psychologists and engineers who were ready to intervene in case of necessity. The user was asked to walk at its own natural velocity for the entire test. The acquired data were stored in a computer to be off-line analyzed.

As regards the traditional test, in this study we reproduced a parallel version of the TEA subtest: as soon as the user detected an irregularity in the auditory sequence, they had to click the mouse.

SmartTapestry Each task session took about 1 h, and was supervised by psychologists and engineers in a laboratory setting. The traditional test (VPA-WMS) is administrated by a psychologist that reads a list of word pairs. Whereas during the SmarTaperstry test the participant was asked to stand in front of the system. As soon as they was ready, they pressed start on the software module thus the instructions were autonomously administered by SmartTapestry software. If they did not understand properly they can listen again the guidelines. The instructions and the list of word pairs are provided by the software, while the subject has to type the remembered word by touching letters displayed on the tapestry (See Fig. 2). The data were acquired and stored by a computer.

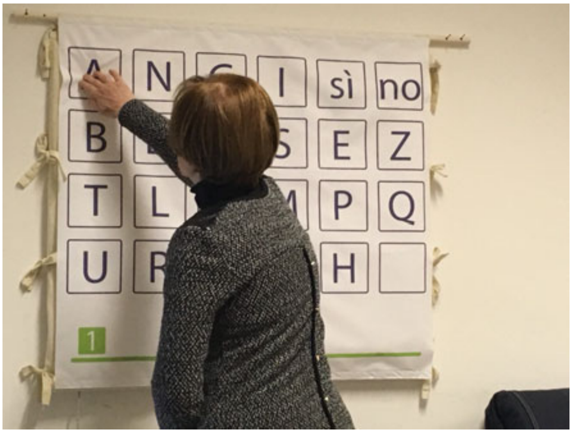

Fig. 2 Participant while performing SmartTapestry test [14]

3.2 Participants

The subjects selected for the case report belong to two different group of participant, one clinic and the other of control, from two feasibility studies about smart tools for assessment and cognitive training of subjects suffer MCI [6, 14]. It was decided to select one healthy elderly subject and a subjects whom is suffering from MCI. MCI diagnosis was carry out by Petersen criteria [17] and deemed to be fit to take part in the study by a neurologist and a neuropsychologist.

The Petersen criteria: (i) subjects who suffer from a cognitive impairment not normal for age; (ii) they are not demented; (iii) whose change in cognition does not cause a significant impairment in functional activities.

Moreover, were verified other further inclusion criteria for the study: (i) ability to walk at normal speed for 30 min without any help; (ii) right foot dominance; (iii) absence of hearing loss; (iv) absence of depression and other psychopathological issues; (v) absence of other neuromotor impairment.

In the two following boxes are reported information about the two chosen subjects. In the case of the subject suffering from MCI also a short medical report was presented.

Anamnesis D. P.

The participant D. P. is a 63 year-old Caucasian woman. She attended 8 years of school and had reported to the experimenter to be in full neuropsychological and medical health.

The subject reported to never have experience of psychiatric disorders, such as mood alterations or anxiety. Moreover, the subject does not believe to forget things or to go towards changing in her way to think.

The subject is oriented, aware, collaborate, and with full insight.

Considered all the aspects listed above, it was decided to consider the subject D. P. as the control subject.

Anamnesis M. R.

The participant M. R. is a 70 year-old Caucasian woman with a diagnosis of MCI. She had several cognitive and behavioral limitation based on neuropsychological assessment, neurological examination and instrumental exams (TC and echo-Doppler).

Mrs. M. R. reported that since a couple of years is suffering from forgetfulness episodes recognized by the clinician as an index of episodic anterial-grade memory issues. These problems began in a subtle manner and got worse over time. In fact, she referred that 1 year after the memory impairment begins she had experienced an episode of topographic disorientation, coming back home from the dentist. In the meanwhile, it started also absent-minded episode, a forgetfulness and/or inattentive behavior, such as forget where she parked the car or left the house key.

In the last 3–4 months the memory problems are getting worse and for this reason, the subject decided to turn to a neurologist. Moreover, simultaneously with the memory deterioration, M. R. started to show some behavioral changes, such as initial insomnia, negative thoughts, irritability, mild agitation and amotivational syndrome, a condition characterized by apathy, abulia anhedonia. In relation to these symptoms, the subject was treated for two months with Zoloft, Samyr, and Illumina, prescribed by the neurologist. As result of an interview about her relatives was been reported that in her father's family branch there were been two cases of Alzheimer's disease. In general, there were not referred cases of mood disorder or depression among family members.

The neurologist assessment and the instrumental exams reported a couple of newsworthy parameters: an enlargement of apical liquor system and a carotid siphons calcification. A complete neuropsychological assessment was prescribed to avoid misdiagnosis, between MCI and depression, and clarify the case.

During the neuropsychological assessment the subject appears vigilant, collaborative and with full insight. The assessment consisted of a comprehensive battery of neuropsychological tests, such as Milan Overall Dementia Assessment (MODA); Wechsler Memory Scale IV (WMS-IV); prospective memory task of Rivermead Behavioural Memory Test (RBMT); Attentional Matrix; Stroop Test; Trail Making Test A and B; Boston Naming Test (BNT); Street Test; Birmingham Object Recognition Battery; Brixton Test; Tower of London Test; Verbal Judgments Test.

Based on the performance shown throughout the neuropsychological assessment was expressed the following clinical opinion: the subject manifested a global cognitive functioning placeable at inferior limit of normality. The study of Memory domain depict a weakening of visuospatial information treatment in all the dimension (short-term, long-term, working memory), but the global performance deposes against a true amnesia. The examination of attentional skills describes a selective impairment on dual task, in part attributable to an increased share of anxiety. The deep study of executive functioning displays an inefficient planning skill and a weak conceptual elaboration of verbal material. In definitive the neurocognitive profile and the clinical observation are deposing to a diagnosis of MCI instead of Depression.

4 Results

In this section will be reported the result of the two selected subjects on the four aforementioned cognitive tests: TEA, Verbal Paired Associated, SmartWalk system, and SmartTapestry system. Two of this concerning the attention domain (TEA and SmartWalk system), whereas the other two concerning the memory domain (Verbal Pair Associate and SmartTapestry system).

Table 1 reports the results related to attention domain, in particular concerning the sustained axis of attention. Both for TEA, the traditional test, and the SmartWalk system, the novel one, is possible to observe a general tendency of the clinical subject to show worse performances, as compared to the control one. The clinical subject, indeed, exhibit a lower number of correct responses both in TEA and SmartWalk system, whereas presents, systematically higher number of errors and omitted response in both the tests. Furthermore, the clinical subject has the tendency to respond slower and with higher variability as compared to the control subject, even though the differences are in the range of millisecond. In Table 2 are reported the results of the two test used to probe the functioning of memory domain, in particular, the episodic component of long-term memory. For the assessment of this neurocognitive skills are generally used two parallel forms of the test, according to the subject age. People under 65 years old are put through on a test composed of 14 pairs of words to remem-

Table 1 Subjects result to attention tasks

Test results	Clinical subject	Control subject
TEA correct	29	35
TEA errors	31	21
TEA omitted	5	0
TEA response Mean (s)	2.31	2.14
TEA response SD (s)	0.68	0.43
SmartWalk system correct	16	33
SmartWalk system errors	10	1
SmartWalk system omitted	13	1
SmartWalk system response mean (s)	2.25	1.98
SmartWalk system response SD (s)	1.52	0.57

Table 2 Subjects result to memory tasks

Test results	Clinical subject	Control subject
Verbal paired associated Imm1	0	1
Verbal paired associated Imm2	6	5
Verbal Paired associated Imm3	4	6
Verbal paired associated Imm4	6	8
Verbal paired associated delayed	5	5
Verbal paired associated recognition	30	28
SmartTapestry system Imm1	3	4
SmartTapestry system Imm2	6	9
SmartTapestry system Imm3	6	8
SmartTapestry system Imm4	6	8
SmartTapestry system delayed	7	6
SmartTapestry system recognition	27	30

ber. On the other side, people over 65 years old are put through on a test composed of 10 pairs of words to remember. So to may compare the results of the two subjects, a normalization based on the maximum score was done. In this way, all the subjects have a range of possible score from 1 to 10 for the subtest: Imm1, Imm2, Imm3, Imm4 and Delayed. And a range of possible scores from 0 to 30 for the Recognition subtest.

As reported in Table 2, the clinical subjects achieve frequently lower scores as compared to the control subject. Especially using the SmartTapestry system. Moreover, on the contrary compared to the performances related to the attention domain, the results accomplished with the traditional form of the exercise are lower, for the clinical subject, if compared to the results achieved with the smart system. Quite the same of the control subject which seems to take advantage of the smart system procedure, using both the systems.

5 Discussion

In this section, the result obtained by the trial will be debated. The clinical judgment about the performance of the MCI subject itself, regarding, her clinical records, and about the comparison with the control subject, will be made. The scores attained in the tests show some interesting patterns. At first, the control subject seems to be facilitated in both the tasks, attention, and memory, using the smart tools systems. On the other hand, the introduction of new technologies, or even the motor exercise, seems to drain the clinical subject performances. The subjects suffering from MCI, in fact, obtained lower scores using the new technology concerning the attention domain, and essentially the same results using traditional and new approach concerning the memory domain. As just said, the differences between the subjects and a discussion about their results will be held in the following.

SmartWalk and SmartTapestry, introduce a physical activity during the execution of the cognitive task. Particularly, in the first case, using SmartWalk, is required to pay attention to a monotonous auditory stimulus meanwhile the subject walk. In the presence of a specific changing in the stimulus tonality, the subject has to stop his/her walking and do an exercise for the mobilization of the lower limb. On the other hand, using SmartTapestry, it is required to carry out an auditory-verbal memory task using a sensorized tapestry to deliver the response. This tapestry is thought to stimulate the use of upper limbs, in particular, to encourage the shoulder girdle mobilization during this cognitive task. Despite the introduction of this physical tasks, the results of the two different subjects, in the two test typologies, are comparable. In fact, as well as using the traditional forms of the tests, the clinical subject shows lower scores in all the sub-tests, both in attention and memory tasks, as compared to the healthy subject.

Furthermore, the clinical subject shows very different performances in regard to the two typologies of the test. As already said, regarding the use of the SmartWalk system, the clinical subject seems to be challenged by the use of the new approach. This result could be explained by the increasing difficulty to accomplish the dual task for the older adult, and, even more for the older adult suffering from some cognitive impairment, such as MCI. As reported by Brustio and collaborators [4], in fact, the addition of exercise, on cognitive tasks, could improve the cognitive effort required to the subject. A subject suffering from MCI possess lesser cognitive reserve, and this aforementioned depletion could show its effects if is required for the subject to complete dual tasks, such as a cognitive task combined to exercise. The difficulties show on the SmartWalk system, are moreover explained by the documented impairment of the subject in dual-task attention, assessed using Trailing Making Test form A and B, and by a general ipoefficiency in executive function. In fact, is just becoming more clear the correlation between impairment in executive functions and difficulties in walking. In particular, it seems that amnestic MCI, which show executive impairment and loss of neuron in hippocampal and cingulate anterior cortex, exhibit greater difficulties during fast-paced walk [15]. On the other hand, the combination of cognitive tasks and exercises seems to facilitate the healthy subject. In fact, as reported in Table 1, the numbers of errors using SmartWalk decrease from 21 to 1. Furthermore, she reported that using the SmartWalk system, the action to walk helped she to focus her attention on the task. This statement, carried out thanks to an essay giving feedback about the system, reflects the sharp false response reduction in the comparison between performances of the subject on the traditional test and the SmartWalk system.

Looking at the performances using SmartTapestry system it is possible to observe that both, the clinical subject and the healthy subject, show a systematically improving about the majority of the performance using this new approach, as compared to the traditional test for auditory-verbal memory assessment. This could be explained by the multimodal nature of the exercise [18], but also by the mild presence of exercise in the smart system. In fact, the task include verbal information that the subject must remember, but also a visual support, provided by the SmartTapestry, used to emit the response. So the information undergoes to two kinds of treatment, first as verbal information, then as visual information. This multiple treatments of the mnemonic trace could be the reason why, both clinical and control subjects, are facilitated by the use of SmartTapestry system [18]. Another explanation could be attributed to the role of implicit memory. The output channel for the response, using SmartTapestry system, in fact, impose that the subject pushes some part of the tapestry, where letters are printed, so to form the right word. The repetition of this task could recruit neural networks involved in implicit memory. The combined effect of explicit and implicit memory may be an explanation for the improvement of the performance, also for the clinical subject, using SmartTapestry system. Furthermore, it is important to remember that in SmartTapestry task is required less dual-task ability.

The two system, as all new technology, possess also some limits. The main purpose of this study is to sound out how these systems work with subjects with cognitive impairment. The partial results inferable by this previous study suggest that the SmartWalk system represents a more complex system as compared with SmartTapestry system, it seems to require a greater cognitive effort from the subjects respect the other. As observed during the discussion the healthy subject had shown a significant improvement in his performance using the SmartWalk system, particularly referred to numbers of false alarms. It seems that the system helps him to stay more focus on the task. On the other and the system seems to require too much effort to the MCI subject. It is possible to think that SmartWalk system could be more useful with people with a very mild impairment, or even with people that showed an age-related cognitive impairment and that want to train their cognitive abilities. The use of this system could be not optimal for people that have deficit related to executive functions or difficulties with divided attention. That is why the task required is more complex, demand the ability to pay attention, planning the gait and remember how to do when the stimulus change. The rate of task impurity is higher and for this reason, considerations referred to subject's strength and weakness are essential.

By the other side, the SmartTapestry system has proved to be useful also for people with MCI, enhancing the ability to encode, store and retrieval the information provided, at the same time, the possibility to do some exercise.

6 Conclusion

According to [6, 14] the two instruments are capable to properly discern between a healthy subject and a subject suffering from MCI, with regard to sustained attention and episodic verbal memory. Moreover, through their use is possible to combine cognitive tasks with exercise. This possibility represents a crucial point thinking to rehabilitation. In fact, is well known that cognitive training combined with exercise determine a greater effect than just cognitive training itself. The benefit is not related only to cognitive functioning but also with the increase of quality of life and reduction of behavioral abnormalities and psychiatric symptoms.

In regard to our tools, previous works, and this report case, suggest that SmartWalk seems to be useful for people complain attention lacks, but that shows a global endurance in cognitive activities. That system could be appropriate for people with a very mild cognitive impairment or for people going through physiological age-related cognitive decline. Besides the SmartTapestry system, because of a less dual-task activity and a less task impurity presence, seems to be appropriate also for people with a more severe cognitive impairment. Furthermore, the physical demand is less lavish compared to SmartWalk.

Further works will outline condition and patients typologies which could represent the best clinical target. The hints coming from this work persuade us that an evaluation of strength and weakness subjects point will be compulsory so to find the best approach for the right patient.

The development of new technologies for the assessment, and assistance of people suffering from MCI and, more general, neurodegenerative disease, represent a huge field of interesting and advancement. Nowadays the priority in this field is to take into account of the specific necessity of single subject, even more, when the object of intervention is related to cognition, mood and in general with psychological dimension. The point, in fact, is not to develop the smarter technology, but rather use the technology developed in the smarter way.

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References

1. Association Alzheimers (2017) Alzheimers disease facts and figures. Alzheimer's Dement 13:325–373
2. Bahar-Fuchs A, Clare L, Woods B (2013) Cognitive training and cognitive rehabilitation for mild to moderate alzheimers disease and vascular dementia: a review. Alzheimer's Res Ther 5:35–49
3. Ballesteros S, Kraft E, Santana S, Tziraki C (2015) Maintaining older brain functionality: a target review. Neurosci Biobehav Rev 55:453–477
4. Brustio PR, Magistro D, Zecca M, Rabaglietti E, Liubicich ME (2017) Age-related decrements in dual-task performance: comparison of different mobility and cognitive tasks. a cross sectional study. PLoS One. https://doi.org/10.1371/journal.pone.0181698
5. Charchat-Fichman H, Uehara E, Fernandes dos Santos C (2014) New technologies in assessment and neuropsychological rehabilitation. Trends Psychol 22:539–553
6. Fiorini L, Maselli M, Castro E, Tocchini S, Sportiello MT, Laschi C, Cecchi F, Cavallo F (2017) Feasibility study on the assessment of auditory sustained attention through walking motor parameters in mild cognitive impairments and healthy subject. In: EMBC. https://doi.org/10.1109/EMBC.2017.8036969
7. Garca-Betances RI, Cabrera-Umpirrez MF, Arredondo MT (2018) Computerized neurocognitive interventions in the context of the brain training controversy. Rev Neurosci 29:55–69

8. Garcia-Casal JA, Franco-Martin M, Parea-Bartolome MV, Toribo-Guzman JM, Garcia-Moja C, Goni-Imizcoz M, Csipke E (2017) Electronic devices for cognitive impairment screening: a systematic literature review. Int J Technol Assess Health Care 33:1–20
9. Gros A, Bensamoun D, Manera V, Fabre R, Zacconi-Cauvin A, Thummler S, Benoit M, Robert P (2016) Reccomendations for the Use of ICT in eldery populations with affective disorders. Front Aging Neurosci 8:269–281
10. Hartman DE (2009) Wechsler adult intelligence scale IV (WAIS IV): return of the gold standard. Appl Neuropsychol 16:85–87
11. Kueider AM, Parisi JM, Gross AL, Rebok GW (2012) Computerized cognitive training with older adults: a systematic review. PLoS One 7:1–13
12. Law LLF, Barnet F, Yau MK, Gray MA (2014) Effects of combined cognitive and exercise interventions on cognition in older adults with and without cognitive impairment: a systematic review. Ageing Res Rev 15:61–75
13. Lee TMC, Chan FHW, Chu LW, Kwok TCY, Lam LCW, Tam HMK, Woo J (2017) Auditory-based cognitive training programme for attention and memory in older people at risk of progressive cognitive decline: a randomised controlled trial. Hong Kong Med J 23:12–5
14. Maselli M, Fiorini L, Castro E, Baldoli I, Tocchini S, Sportiello MT, Cavallo F, Cecchi F, Laschi C (2017) Development and testing of a new cognitive technological tool for episodic memory: a feasibility study. In: EMBC. https://doi.org/10.1109/EMBC.2017.8036968
15. McGough EL, Kelly VE, Weaver KE, Logsdon RG, McCurry SM, Pike KC, Grabowski TJ, Teri L (2018) Limbic and basal ganglia neuroanatomical correlates of gait and executive function: older adults with mild cognitive impairment and intact cognition. Am J Phys Med Rehabil 97:229–235
16. Murphy SL, Kochanek KD, Xu J, Heron M (2015) Deaths: final data for. Natl Vital Stat Rep 63:1–117
17. Petersen RC, Smith GE, Waring SC, Ivnik RJ, Tangalos EG, Kokmen E (1999) Mild cognitive impairment: clinical characterization and outcome. Arch Neurol 56:303–308
18. Shams L, Seitz AR (2008) Benefits of multisensory learning. Trends Cogn Sci 12:411–417
19. Talassi E, Guerreschi M, Feriani M, Fedi V, Bianchetti A, Trabucchi M (2007) Effectiveness of a cognitive rehabilitation program in mild dementia (MD) and mild cognitive impairment (MCI): a case control study. Arch Gerontol Geriatr 44:391–9
20. Verghese J, Robbins M, Holtzer R, Zimmerman M, Wang C, Xue X, Lipton RB (2008) Gait dysfunction in mild cognitive impairment syndromes. J Am Geriatr Soc 56:1244–1251
21. Zimmermann P, Fimm B (1995) Test battery for attention performance. Psytest, Wuerselen

Designing and Implementing a Transferability Testing Methodology for AAL Systems Dedicated to Integrated Care Services

Massimiliano Malavasi, Evert Jan Hoogerwerf, Valentina Fiordelmondo, Lisa Cesario, Carlo Montanari and Lorenzo Desideri

Abstract Implementing a multi domain ICT system for integrated care is a complex process, dependent from many different factors. The purpose of this paper is to describe the design and implementation plan for testing the transferability of an ICT based solution for Integrated Care (the ProACT system). The transfer Trial of the system will be held in Italy, while Main Trial in Ireland and Belgium. This paper outlines the details of the implementation plan, including the aims and objectives of the trial, the study methodology and design, the recruitment procedures and data collection and analysis. The target participants will be older persons with multimorbidity (PwMs), informal carers (ICs), formal carers (FCs) and healthcare professionals (HCPs). This paper also outlines the practicalities needed in preparing for the trial, such as the deployment of technology to participants, a key factor to ensure that this complex multi domain trial can run smoothly over all the one-year duration.

Keywords Integrated care · Active Assisted Living · Transferability study

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1 Study Overview

The ProACT project partnership has developed a multi domain (home, community, social and hospital) ICT based integrated care system [1, 2]. The system is based on cloud services and analytics and specific care apps that can be used both by final and professional users directly on mobile devices. The system includes a kit of personal device/sensors that can provide more information about the health conditions and the daily behaviors of users with multimorbidity [3]. The transfer study (mainly based in Bologna, Italy) has an explorative approach and will follow a mixed quantitative-qualitative research design. Three groups of users with different user scenarios are foreseen at this stage. Three local service provider organizations will participate in the trial: AIAS Bologna, ASP Città di bologna and Azienda USL di Bologna (the Local Health Trust, LHT). Overall, based on the ProACT Project's aims and a review of the information gathered from potential stakeholders performed previously in collaboration with the local stakeholders and the wider project consortium [1], the objectives of the transferability study can be outlined as follows:

1. To collect preliminary information on the usability and acceptability of the system;
2. To identify weaknesses and strengths of the system used in a specific context and within specific use scenarios;
3. To identify physical (technical), cultural, and personal barriers for the adoption of the system;
4. To evaluate the interoperability of the system.

In a preliminary testing phase, defined as T0, the ProACT system will be localized to the trial region. In this phase, AIAS professionals will pilot the System for a sufficient amount of time (3 months) in order to ensure its proper functioning in a variety of contexts. During this period, professionals from both the Local Health Trust and ASP will identify and approach potential study participants and their caregivers. After T0, the ProACT system will be transferred within 3 distinct users' scenarios. Figure 1 provides a general overview of the procedure that we aim to follow for each user scenario. In detail:

- The first phase, called T1, will involve recruitment of selected participants, the gathering of informed consent and the administration of baseline questionnaires. At this stage, with prior consent, the System will be delivered, installed and made functional within the users' contexts.
- In the next phase, called T2, users will use the ProACT system in their daily living environment for a month.
- In the last phase, called T3, a comprehensive assessment of the users' experience with the ProACT system will be conducted using both quantitative and qualitative approaches. For the quantitative assessment, a battery of questionnaires will be administered to assess the experience in using the system. A broad spectrum of items will be tested. Next, focus groups or interviews are foreseen, both with users and caregivers, to deepen the experience of use with the ProACT system by those

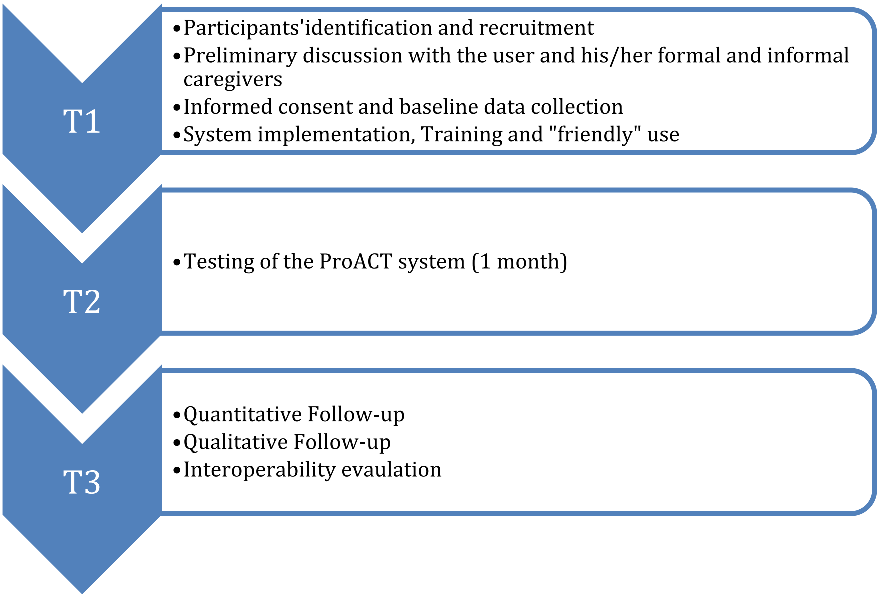

Fig. 1 Overview of the transferability study procedure

who participated in the T2 phase. For the same purpose, formal carers involved in T2 will also be interviewed. Additional formal (e.g., pharmacists) and informal (e.g., friends) support actors will be interviewed if they will be involved by the PwM during the testing period. Only GPs working in the Proximity Outpatient Clinics that will be involved in the testing of the ProACT system will be also interviewed.

2 Pre-study Activities: Localization and Recruitment

2.1 System Localization

Before the testing period begins, a series of friendly trials (FT) will be conducted over a period of 3 months to assure the proper functioning of the whole system. Such FT will involve 5 participants recruited from the AIAS research team, in collaboration with professionals from LHT and ASP. Each participant will perform one role. This will allow researchers at the transferability site to gain experience in using and deploying the ProACT ecosystem before involving the target users.

2.2 Inclusion and Exclusion Criteria

The final users target group of the studies are people with multimorbidity (PwM). As a first step, the inclusion/exclusion criteria for both final users and care network participants have been defined:

2.2.1 PwM Participants

- Aged over 65 years.
- Must have at least 2 of the following conditions: Diabetes, Chronic Obstructive Pulmonary Disease (COPD), Chronic Heart Failure (CHF) or Chronic Heart Disease/Coronary Artery Disease/Cardiovascular Disease (including Hypertension, Atherosclerosis, Angina, Arrhythmia), or any other chronic health condition that impacts on his/her daily life.
- Capable of giving written informed consent.
- Accessibility to broadband services or live in an area with sufficient coverage for mobile Internet.

2.2.2 Care Network Participants

- Aged over 18 years old.
- Providing care or support to a PwM participant with at least 2 of the conditions listed above, or any other chronic health condition that impacts on his/her daily life.
- Care network participants will be defined by the PwM, who may elect to include individuals who provide emotional support, such as family members living at a significant distance, as well as those providing immediate or regular (daily or weekly) personal care.
- Access to a computer, tablet or smartphone with an internet connection.
- Capable of giving written informed consent.

2.3 Recruitment Procedures

Participants involved will be representative of wider user groups that can benefit from the ProACT System in the local context. These are divided into 3 groups each related to a specific scenario of use of the System. Each scenario has been development in strict collaboration with the health and social care services involved in ProAct. In total, at least 15 PwM users will be involved, in addition to their family members and informal caregivers and health professionals, for an estimated total of at least 36 participants. The three recruitment (final users and caregiver) scenarios are:

2.3.1 Users Recruitment Scenario 1

The first scenario will include older adults (>65 years) at risk involved by LHT in the so called "walking groups". Walking groups are organized by LHT health professionals, in collaboration with the municipality of Bologna, to stimulate older adults to engage in physical activities (i.e. walking) in order to reduce the risk of developing or worsening chronic health conditions. For the scope of the ProACT project, those who are involved in the walking groups and are compliant with the inclusion criteria outlined in the previous section will be asked by an LHT health professional to participate to the transferability study.

2.3.2 User Recruitment Scenario 2

The second scenario will include older adults (>65 years) who had a myocardial infarction (heart attack) and, for that reason, are included in a specific clinical pathway (for sake of simplicity, Chronic Heart Disease Clinical Pathway) to assure the regular monitoring of their health conditions once dismissed from the hospital. Such patients are invited to attend regular meetings at the hospital to check their health and receive advice on how to change health-related behaviours (e.g., quit smoking). Between the meetings there are no contacts with the health professionals. For the scope of the ProACT project, those who are involved in the heart attack clinical pathway and have also one further health condition among those listed in the previous section, will be asked by an LHT health professional to participate in the transferability study.

2.3.3 User Recruitment Scenario 3

The third group will include elderly users from the sheltered apartments of ASP Città di Bologna, that meet the inclusion criteria outlined previously.

2.3.4 Formal and Informal Caregivers Recruitment Scenario

The recruitment of formal and informal caregivers will be performed following the identification, selection and recruitment of PwM participants. It is foreseen to involve at least 6 formal caregivers (two for each User Recruitment Scenario) among the following health and social professionals: care professional (Italian, OSS), nurse, and primary care physician. Similarly, informal caregivers will be recruited among those indicated by the PwM in compliance with the inclusion criteria.

2.4 Informed Consent Procedures

Fifteen days before the beginning of each study scenario, selected participants will be required to provide informed consent. PwMs will be first approached by a formal care professional from the LHT or ASP asking for their willingness to participate in the study. After informal consensus is given, a preliminary interview with the PwM will follow, conducted by a representative of the AIAS research team, in which the objectives, methodologies and timing of the project and trial will be outlined. Detailed information will then be left to participants in written format. If the person feels in the condition to be able to take an informed decision during this meeting, the informed consent form will be obtained. If necessary, a second meeting can be organized with the person and his/her informal caregivers to provide additional information and/or to sign the consent forms. In addition to the PwM user, the presence of at least one family or a caregiver during the initial interview will be requested. PwM users and their informal caregivers will fill in separate consent forms already approved by the local ethical committee. For the formal caregivers and health professionals (LHT, ASP), participation in the Trial will be preceded by a preliminary interview which will follow the delivery of the information sheet and the informed consent form as outlined for the PwM above.

2.5 Baseline Assessment

The questionnaires for the collection of baseline information will be administered to PwMs at a separate visit after the informed consent has been obtained. These metrics will be adapted to the needs and practices of the Italian health and social care context, as well as specific requirements of the transferability study. PwM and informal caregivers will be assessed in individual sessions conducted in different days. A summary of the tools is shown in Table 1.

3 System Testing

3.1 Introducing and Implementing the System

Once accepting to participate in the Project, PwM users and their families, as well as selected professionals, will receive the System for a period of 1 month, at the end of which they will be asked to evaluate the accessibility, usability and utility perceived through validated questionnaires.

The system will be delivered in the form of a modular kit according to the needs of each specific user. In general, the basic kit includes the devices listed in Table 2. The list of devices was prepared following a systematic review of the products currently

Table 1 Tools administered in T0 and T1

Tool	Assessment domain	Who			When	
		PwM	Informal	Formal	T0	T1
Socio-demographic questionnaire (WHODAS)	Socio-demographic information	●	●	●	●	
WHO disability assessment schedule 2.0	General health condition	●			●	
Kaufman brief intelligence test, second edition (Italian version)	Global intellectual functioning	●			●	
Warwick-Edinburgh mental well-being scale	Psychological well-being	●	●		●	
Physical Activity Scale for the Elderly (PASE)	Physical activity	●			●	●
General self-efficacy Scale	Self-efficacy (PwM)	●	●		●	●
ZARIT Caregiver Burden	Caregiver burden		●		●	●
Revised scale for caregiving self-efficacy	Self-efficacy (caregiver)		●		●	●
Self-efficacy for managing chronic disease scale	Self-efficacy	●	●		●	●
Lubben social network scale	Social network	●			●	
Multidimensional scale of perceived social support	Perceived social support	●			●	●
System usability scale	Usability	●	●	●		●
Mobile device proficiency questionnaire	Digital skills	●	●	●		
Net promoter score	Perceived utility	●	●	●		●

available and laboratory tests carried out during the development of the ProACT interface. As the kits and the system are completely modular, for specific user needs or transferability study purpose, more different smart sensors could be provided to the users.

PwM participants will be trained the week before the beginning of the study period and after their baseline assessment. Formal and informal caregivers will have access to a customised interface for the ProACT CareApp, that they can access on their own devices (smartphone, tablet or computer). These customised interfaces will allow those in the PwM's care network to view relevant data from the PwM and educational materials specifically related to their disease management and care. Formal and informal caregivers will be introduced to the CareApp and before the ProACT testing.

Table 2 Devices from which the modular ProAct kit will be composed for each user

Application	Products
Domotic applications, home monitoring and presence sensors	• Samsung SmartThings Home Monitoring Kit
Digital weight scale	• Philips body analysis scale • Nokia Body+
Smartwatch/Activity tracker	• Nokia Steel • Philips health watch
Sphygmomanometer/Glucometer/Oximeter	• Philips wrist blood pressure • Nokia BPM • iHealth Gluco • iHealth PO3M
Tablet or smartphone	• Android (es, Samsung) • iOS (IPad)

3.2 Using the System

All participants will be involved in three successive cycles each corresponding to a given scenario. In each scenario, 5 users will be involved, together with one family member or other informal caregiver. In addition, the scenario will include at least 1 formal caregiver from either ASP or LHT involved in the care or assistance path of the recruited users.

During the testing period (1 month), PwM participants will be asked to use the system at least once a day and to explore all its functions. For any technical problem or difficulty of use, a member of the research team will be reachable by phone. Flagged data presenting potential health risks during the entire trial period, will be forwarded to the LHT on the basis of a collaboration protocol. During the testing period, a researcher will contact the participants once every 3 days to receive updates on the use of the System and resolve any difficulties not communicated by the user. Participants will be asked to use the System to record information and measure key parameters related to their health and wellbeing on a regular basis. This will be achieved by using sensors/devices and by answering self-report questions presented in the ProACT CareApp. The same App can provide simple report and allows to view educational materials and training videos, tailored to the preferences of the PwM and support actors respectively.

All users in the care network, including formal (LHT and ASP) and informal caregivers (those indicated by the PwM), will be asked to view relevant data for the PwM participant and relevant training/educational content via their customised interface for the ProACT CareApp. The purpose of involving the caregivers is to evaluate experiences of people within the care network using the ProACT system, and to understand whether they would find this type of system and data useful to them in their role supporting the PwM with their self-management, care and treatment plans, as well as understanding whether such devices can be implemented within already available service procedures.

3.3 *Trial Logistics*

Logistics for the transferability study of such a complex system was identified as a key factor for Trial success and was planned over a series of 3 meetings involving representatives from ASP, LHT and AIAS. In order to tailor the Proact system on the characteristics of the transferability study context, decisions were taken at local level concerning the following topics: broadband and internet connection; smart sensors; users' assistance and maintenance services.

3.3.1 Broadband Connection and Personal System Setup

Where a PwM participant does not currently have broadband, a mobile (3G/4G) connection will be provided. Where a PwM already has broadband, permission will be required to use their existing broadband.

For each participant an account on each 3rd party device application will be setup prior to deployment. This is necessary for linking data from those devices with the ProACT server. The ProACT CareApp(s) will be installed on the trial trials prior to deployment, while care network members accessing the CareApp through their own device will be provided with a link and login details for access. Trial tablets will be open to allow PwMs to add apps for their own use and a set of interesting apps will be initially installed to further promote PwM's engagement with technology.

3.3.2 Users' Assistance and System's Maintenance

A contact number will be provided allowing trial participants to have assistance for any technical problem or difficulty. A number of researchers will be, on a rotation system basis, responsible of the contact center. Trouble-shooting electronic docs/information for deployment and maintenance of devices will be created and be easily available for the support team members. Critical technical elements, such as batteries will be managed to remove any concerns for participants and final users and informal carers will receive full training about the correct procedures to manage devices and Care Apps.

4 System Evaluation

4.1 Quantitative Follow-up

A battery of questionnaires will be administered to assess the experience in using the system. A broad spectrum of items will be tested (see Table 1) with a view to collect quantitative data on the perceived usability of the ProACT system, as well as to monitor any changes in terms of participants' health-related habits, self-efficacy, burden, and perceived support. Due to the relatively short period of deployment and to the small sample size (which lacks statistical power) outcomes from the assessments will not be able to validate the system but can be used in a descriptive context to provide an understanding of the potential effectiveness of the system and whether a large trial is recommended. Finally, usage of devices and the ProACT CareApp will be monitored via system usage statistics and data collected by the ProACT system for analysis.

4.2 Qualitative Follow-up

At the end of each testing scenario, PwM and informal caregivers will be involved in distinct focus groups or face-to-face interviews. On this occasion, participants will be given the chance to share their experience with the ProACT system to identify any critical issues and to define possible solutions or objectives for further development of the platform. The procedures for carrying out the focus groups and interviews will be defined at the end of the T0 phase, once the AIAS research team together with professionals from LHT and ASP have the opportunity to use the ProACT system and test all its functionalities.

4.3 Interoperability Evaluation

In parallel to the experimentation phase with users, a technical evaluation of the interoperability will be carried out through the monitoring of the daily usage data of the ProACT kits, the possible interruptions of data flows and all the criticalities related to their transmission.

5 Results and Conclusions

Designing and implementing a multi domain ICT system for integrated care, such as the ProACT system, is a complex process.

Many factors can impact on the final results both in positive and negative way.

The transfer trial described in this paper has been designed to access as widely as possible the main factors that can impact the implementation of such a system in a real and precise context.

Following a full user (both final and professional, including informal carers) centered design approach and using a model that can involve all principal actors and stakeholders, has allowed to design a methodology, that is able to detect and analyze many parameters and criticalities related to the implementation of a complex integrated care system.

Many aspects related to the real transferability of the system in a highly complex context, with a partial integration of healthcare and welfare services, such as the ones active in the territorial reference area, can be analyzed by highlighting the main critical points and strengths, in addition to the basic performance of the system itself: a result that was among the main objectives of the trial methodology design.

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References

1. Murphy E, Doyle J, Hannigan C, Smith S, Kuiper J, Jacobs A, Brady AM (2017) Perceptions and use of technology to support older adults with multimorbidity. Stud Health Technol Inf 242:160–167
2. Doyle J, Hoogerwerf EJ, Kuiper J, Murphy E, Hannigan C, Dinsmore J, Desideri L, Fiordelmondo V (2017) Designing a proactive, person-centred, digital integrated care system. Int J Integr Care 17(5)
3. Tedesco S, Barton J, O'Flynn B (2017) A review of activity trackers for senior citizens: research perspectives, commercial landscape and the role of the insurance industry. Sensors 17(6):1277

The Design, Implementation and Evaluation of a Mobile App for Supporting Older Adults in the Monitoring of Food Intake

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Abstract Older adults are required to adjust their eating habits to maintain a good health status. However, they may struggle to adopt these new practices. Given their increasing spread, smartphone-based interventions may be a good option for providing older adults an aid to keep track of their food intake. In the present work we adopted a user centered design approach to implement and evaluate a mobile app, i.e., 'Salus', to support older adults in the monitoring food intake.

Keywords Older adults · User centered design · Nutrition

1 Introduction

The role played by nutrition on our health and general wellbeing is widely recognized [15]. The impact of food becomes even more relevant for older adults, whose health conditions tend to become frailer. In addition, perceptual changes due to normal aging contribute to alter older adults' food intake [19]. Therefore, it may become challenging for older adults to comply with the new nutritional needs [15]. Yet, a balanced diet acts as a protective factor against a number of diseases, e.g., cardiovascular disease [20].

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Nutrition-related mobile apps were found to be effective in supporting young adults to adopt healthier eating behaviors [7]. The percentage of older adults using smartphones on a daily basis is constantly increasing. Thus, smartphones are a good platform to foster healthy nutrition behaviors among elderly. In the present study we aimed at investigating whether older adults would benefit of the assistance of a mobile app to monitor their food intake. To this end we developed a mobile app ad hoc, i.e., ‘Salus’, following a user-centered design approach. Data comprising video-analysis, questionnaires and interviews suggest that the final app was usable and well-received by older users. Usage data automatically logged during the trial however show the tendency to reduce the frequency to access the app.

1.1 Changes in the Nutritional Needs of Older Adults

As we age, nutritional needs change as a consequence of the various alterations amounting to the normal aging process, life-style and even medical conditions [4].

A decline in the lean mass and the tendency to be physically less active are associated to a reduced amount of calories intake [6]. At the same time the need for proteins increases, because of the changes affecting the protein metabolism [10]. In addition, the reduction in mass muscle can lead to a gain in the total amount of body fat and can be linked to a reduction of the total volume of body water content. Various changes also occur throughout the digestive system that can limit the absorption of specific nutrients, e.g., iron and vitamins [4]. The number of taste buds decreases, thereby tastes are perceived less intense [4, 10]. Physical and social barriers also contribute to alter food-related behaviors. Tooth loss and ill-fitting dentures may cause unconscious changes in eating patterns. Furthermore, tiredness and loneliness can lead elderly to disinterest in eating and ultimately neglect food preparation [10, 12].

Taken together all these conditions put older adults at risk of not meeting the right nutrients and micronutrients requirements, thereby weakening their immune system and muscle [4].

1.2 Changes in Physical and Cognitive Skills

The normal aging process leads to numerous changes affecting the physical and cognitive abilities, which draw a new set of needs. Typical age-related alterations in the cerebral structures affect the speed of processing stimuli. In addition, losses in memory skills are frequent [27]. Attentive abilities seem to undergo a decline as well [17]. The most evident deteriorations generally regard the perceptual abilities, with the loss of visual acuity and a reduced sensitivity to contrast. A general loss in hearing is also observed. Furthermore, a general loss of mass muscle and joint flexibility cause a reduced speed of movements and loss of dexterity [13].

This constellation of new characteristics requires special attention when we design for senior users [9].

1.3 Supporting Older Adults' Food Intake

Interventions targeting older adults are based on mobile app, paper-based materials or interactive TV app. Salim et al. [23] developed Nutrihealth, which allows users to directly input what they eat and receive suggestions on food. Similarly, Ali et al. [3] proposed a digital nutrition educational package on a tablet, comprising a healthy eating guide, a quiz module, a body mass index calculator and a demonstration video for physical exercises. Hakobyan et al. [12] devised a diet diary app addressed to older adults suffering from age-related macular degeneration. The design of the interface met the specific requirements imposed by the target users' health conditions. The app provided older adults tailored suggestions on the food to consume and allowed them to record food intake, monitor progress and take personal notes. A similar purpose was addressed by Shahid et al. [24] with Friend Forever, which had as main focus to improve the quality of food intake, providing details on nutrients and general effects of a given food on health. Fernández et al. [8] applied a more comprehensive approach with the general purpose to promote self-care and self-reflection using a paper-based diary. Kimura et al. [16] experimented an intervention addressed to community dwelling seniors that was meant to instruct them to eat healthy and to promote physical exercises. Rodrigues et al. [21] planned an intervention based on an interactive TV app with educational and motivational content aiming at promoting food literacy and physical exercise in older adults. Finally, van der Mark et al. [25] compared older and younger adults' compliance to a weight loss program requiring participants to record their food intake and to follow specific recommendations for eating and physical activity.

2 The Research

The research comprised three studies. The first study had the twofold aim to select the best rated apps available on the app store and to have a group of older users to evaluate them. In the second study older adults were involved to collect their requirements, which subsequently informed the design of the mobile app to support food intake monitoring. Finally, in the third study the usability of the app implemented, i.e., 'Salus', was tested by a sample of senior users in a one-week trial.

2.1 Study 1: App Selection and Preliminary Evaluation

The first study aimed at identifying the best rated apps for monitoring water and food intake available on the app store. Secondly, a preliminary usability evaluation of those apps was conducted with a group of older adults to highlight the strengths and flaws.

2.1.1 Initial Identification of the Apps

A total of 700 apps were examined on the Google Play Store in the categories "Eat and Drink" and "Health and Fitness", and searching the keywords "diet" and "nutrition" in "Other categories". We selected 11 of them satisfying the following requirements: (a) being in Italian, (b) having a Google Play Score of at least 4 computed on at least 1000 reviews (c) keeping track of food and water intake, (c) the possibility to monitor body weight. The 11 apps were Perdere Peso Senza Dieta, Fitbit, MyFitnessPal, EasyFit, Yazio, Lifesum, S-Health and FatSecret. In our search we could not identify any app for monitoring food intake that addressed specifically older adults, consistently with [26]. The identification of the apps was run in May 2017.

2.1.2 Selection of the Apps Preferred by Users

In order to reduce the number of mobile apps to be evaluated by older adults, we had a group of users ($N = 48$, mean age 25 years, $SD = 3.5$) to select the two they considered the most usable. To this end, we devised two questionnaires. One survey collected demographics (name, surname, date of birth, education level), their previous knowledge of the apps presented and their level of interest toward such kind of mobile apps. The second questionnaire was meant to investigate participants' impressions of the apps presented investigating the pleasantness of use [5], the ease of use and the perceived efficiency (all items had 6-point Likert response scale). Finally, participants were asked to choose the 3 apps they preferred.

Participants were debriefed on the purpose of the study and were then administered the first questionnaire. After that, they were asked to briefly try out each of the eight mobile apps (counter-balanced presentation). The apps were displayed on a smartphone OnePlus X (5″). Once both tasks were completed, they were asked to fill in the second questionnaire. This procedure was repeated for each app. After having tried all the apps, participants were asked to choose the 3 they liked the most. The whole experimental session lasted about 15–20 min.

Table 1 An overview of the features in the identified apps

	M	SD	YAZIO ($M = 4.81$, $SD = 1.20$, mean rank = 249)			
			Mean rank	z	p	p(BH)
Fitbit*	4.33	1.368	203	−2.32	0.020	0.024
MyFitnessPal*	4.25	1.391	196	−2.66	0.008	0.014
PerderePesoSenzaD*	3.65	1.329	141	−4.54	0.000	0.000
Easyfit*	386	1.494	165	−4.01	0.000	0.000
Fatsecret*	4.28	1.382	198	−2.26	0.024	0.024
Lifesum*	4.24	1.307	193	−2.57	0.100	0.014
S—Health*	4.29	1.169	195	−2.75	0.006	0.014

* $p < .05$

2.1.3 Analyses and Results

As a criterion to identify the preferred apps, we considered those indicated by at least the 50% of the sample. Only the app named "Lifesum" was compliant ($n = 27$).

A second analysis compared the average score gained by each app at the questionnaire. A Friedman test revealed a statistically significant difference in the mean ranks of the scores gained by the apps ($X^2 = 36.187, gdl = 7, p < 0.001$). We selected the app with the highest rating, i.e., Yazio, and compared the mean ranks using the Wilcoxon test. The analysis highlighted that Yazio was rated more positively as compared to all the other apps (Table 1). Therefore, Lifesum and Yazio were selected for the usability test.

2.1.4 Preliminary Usability Evaluation

The preliminary evaluation aimed at revealing the usability strengths and flaws of the apps selected from the standpoint of senior users.

2.1.5 Materials

Participants were given two questionnaires. The first one collected demographics (name, surname, date of birth, educational level, visual impairment level) and respondents' interest to monitor their eating habits. The post-experience questionnaire consisted of 30 items investigating 9 dimensions. Two items investigated the extent to which participants considered the app easy to (learnability). The ease of use, that is the perception of simplicity while using the app, was investigated by 5 items. Two items explored the extent to which respondents felt the app was helpful in preventing and solving mistakes (error prevention). Commands and functions accessibility concerned the extent to which selecting the elements was straightforward (4 items). Two items concerned the quality of the feedback. Four items inquired participants regarding the quality of the experience while using the app (user experience). Three items were devised ad hoc and looked into respondents' willingness to use again the app, namely satisfaction. Information presentation (5 items) concerned the appearance of the app and organization of the elements. Finally, "Intuitiveness" (3 items) explored the straightforwardness of the comprehension of the meaning of the elements. Respondents were asked to answer on a 6-point Likert scale. All items were adapted from [1, 5, 22]. The 'Not Applicable' option was also available. The apps were presented on a Samsung Galaxy S3 smartphone (4.8″).

2.1.6 Procedure and Participants

Participants were debriefed on the overall activity and gave their informed consent to partake in the experiment. They were trained to use the app until they felt confident in using it. Next, participants read a scenario to help them contextualize the tasks required. The actual experimental session began with the experimenter presenting the first task, i.e., to input the food eaten. The second task concerned the insertion of the user's body weight. In the third task participants registered the consumption of a glass of water. After that, they were asked to read what was recorded as the previous day's lunch or dinner. Finally, participants had to consult the trend of their body weight. Participants were instructed to tell the experimenter when they thought they had accomplished a task. Participants were free to ask for the experimenter's help.

Once the task list was completed, users filled in the post-experience questionnaire. After that, the entire procedure was repeated for the other app. The app presentation was counterbalanced. The experimental session lasted about 1 h and was video-recorded to allow offline computer-supported video-analysis. The evaluations were run in a place that was convenient to participants and made them feel at ease.

In total, 12 older adults (6 women) volunteered in the experiment (mean age $=$ 69.7, $SD = 4.5$). They were Italian and owed a smartphone with Internet connection. All participants but two used glasses ($n = 9$) or a magnifier ($n = 1$). None of them reported to have ever used apps for monitoring food intake before. Nevertheless, 7 participants reported to be quite interested in monitoring their food habits, three were very interested and two were not interested at all.

2.1.7 Data Analysis

Data from video-recordings were analyzed using the software The Observer XT 12 by Noldus. Computer-supported video-analysis allowed to code the duration of each event and the frequency with which specific events occurred. We identified four types of relevant events: (1) 'task outcome', which exemplified whether a task was accomplished successfully or not; (2) ‘resolution attempts’, referring to participants’ efforts to accomplish the task; (3) ‘help request’, amounting to the requests of help; (4) ‘actions on the device’, which comprised all the actions participants made on the different elements of the app.

2.1.8 Results

No significant difference between the two apps emerged in the completion time in any of the tasks examined. Furthermore, the majority of the tasks was accomplished autonomously or with help by all users, with the only exception regarding the consultation of the trend of the body weight. This task was completed without help by 4 participants using Yazio and by 8 using Lifesum. We compared the number of incorrect attempts to solve the tasks with Yazio and Lifesum using the Wilcoxon test (BH correction). The analysis revealed that the only statistically significant difference amounted to the task requiring to consult the trend of one’s body weight ($z = -2.684$, $p = 0.007$, $p_{(BH)} = 0.035$). A lower number of incorrect attempts was made when using Yazio ($M = 0.16$, $SD = 0.57$) as compared to Lifesum ($M = 1.08$, $SD = 1.62$).

The analysis on the elements selected by users revealed that with both apps participants made 30% of incorrect selections with Lifesum and 35% with Yazio. More specifically, the incorrect selections were on incorrect buttons (19% with Lifesum and 24% with Yazio), on unselectable areas (7% with Lifesum and 8% with Yazio) or simply ineffective (4% with Lisefum and 3% with Yazio). Such difficulties were probably due to the complexity of distinguishing the elements that were selectable from those that were not. Additional observations revealed that navigational buttons were troublesome because their placement in the lower area led to unwilling selections or their disappearance when not in use. Furthermore, the size of the buttons was too small and the graphs were difficult to interpret.

Regarding respondents’ opinions collected with the post-experience questionnaires, we found no significant difference in any of the dimensions investigated (Table 2).

2.2 Study 2: Design Requirements and Implementation

This stage had the purpose to involve older adults to highlight their habits, interests and preferences with respect to the tracking of their eating-related behaviors. A focus group was run, which had a threefold aim. First, we wanted to understand whether older adults were interested in monitoring specific food categories. Secondly, we explored whether they tended to value more the type or the quantity of food consumed. Finally, we investigated whether older adults employed some strategies to monitor food intake. The information collected informed the implementation of the app, i.e., Salus.

Table 2 The post-experience questionnaires: mean, median and standard deviations and the values of the Wilcoxon tests

	Yazio		Lifesum		z	p
	M(SD)	Mdn	M(SD)	Mdn		
Learnability	4.04(0.92)	4	3.88(0.88)	4	0.97	0.33
Ease of use	4.25(0.9)	4	4.55(0.62)	5	−1.14	0.26
Error prevention	3.88(0.61)	4	4.04(0.69)	4	−0.88	0.38
Accessibility	4.83(0.73)	5	4.65(0.48)	5	−1.07	0.28
Feedback	4.79(0.86)	5	4.96(0.72)	5	−0.97	0.33
Quality of the experience	4.52(0.71)	5	4.4(0.76)	4	−1.17	0.24
Satisfaction	4.64(0.54)	5	4.58(0.57)	5	−0.31	0.76
Information presentation	4.3(0.89)	5	4.07(0.70)	4	−1.39	0.17
Intuitiveness	4.83(0.58)	5	4.72(0.63)	5	−0.68	0.5

2.2.1 Materials and Procedure for the Users' Requirements Collection

The activity started with a brief introduction. The actual focus group consisted of three main phases: a warming up phase, a group activity and a final discussion. In the warming up phase the topics of the discussion were introduced and participants were invited to share their ideas and their usual habits to monitor food intake and whether they focused more on the quantity or type of food. Next, they were split into two groups and each group received a paper representation of a smartphone and twelve cards representing different categories of food (there were also blank cards to add some food categories). In this phase each group was asked to discuss the types of food that were more important to monitor and to rank them within the smartphone frame. In the final stage each group was invited to share the outcome of their discussion and to find a shared ranking with the other group of the most important categories of food to monitor. The entire activity was carried out by a trained moderator and was video-recorded.

In total, three men and five women took part to the focus group session (mean age $= 68.8$, $SD = 3.9$). The meeting was organized at a time and location convenient for the group.

2.2.2 Results

Participants were rather interested in their food intake, reporting to be generally careful of what they eat and to actively seek information. Most of the sample was aware of the need to limit salt and dressings. In addition, they seemed especially careful to eat a variety of different food and they tended to limit some types of food, i.e., red meat. The strategies they reported for controlling food intake consisted of the complete exclusion of some categories of food (e.g., cheese) or to establish a fixed routine to control the intake of specific nutrients, e.g., fish. For what concerns the categories of food older adults would like to monitor, they included those type of food that they considered harder to control: sweets, pasta and bread, cheese and red meat.

2.2.3 The Implementation of the Mobile App

We considered the findings emerged from the preliminary usability evaluation, the users' requirements and the general guidelines from the literature [2, 9] for the implementation of the app. The resulting prototype of the app, that we named 'Salus', was structured in three main pages: the home page, the 'All' page and the 'Body Weight' page. In the home page the user has direct access to the food categories selected in the participatory design activity. Here s/he records food servings by tapping on the 'plus' and 'minus' buttons within the category of interest. The user can go back to the previous days by selecting the date on the top of the page. In the 'All' page the user can find the list of all the food categories. Finally, in the 'Body weight' page the user can add his/her body weight by tapping on the dedicated button and visualize of previous values in a list.

2.3 Study 3: Usability Evaluation

Study 3 aimed to assess the usability of the app implemented. The evaluation was divided in two sessions, one week apart. The first session consisted of a usability evaluation similar to that of Study 1. Participants then installed Salus on their personal smartphones and were invited to use the app for a week. After the trial, participants' impressions regarding the app were collected using a questionnaire.

2.3.1 Materials

A total of three questionnaires were employed. A first one collected demographics, respondents' interest in using systems for monitoring food intake (7 items; adapted from [11]) and information on their health status. The same post-experience questionnaire of the preliminary usability evaluation was used. Finally, the Persuasive Potential Questionnaire (PPQ; [18]) was administered. A shorter version of the PPQ was also devised and administered after the one-week trial.

2.3.2 Procedure

In the first session participants were debriefed on the purpose and unfolding of the activity. Next, they received a training on how to use Salus, and when they felt confident with the app the experimental session begun. Older adults were presented a scenario and then asked to carry out a set of tasks with the app installed on a OnePlus X smartphone. The tasks were (a) food input, (b) water input, (c) body weight input, (d) reading data of the day before and (e) reading body weight data. Participants had to inform the experimenter when they thought the task was completed. The experimental session was video-recorded to allow off-line analysis. Older adult then filled in the post-experience questionnaire and the PPQ. Next participants had Salus installed on their personal smartphones and committed to use it during the following seven days. This session lasted about 30 min. During the second experimental session participants filled in again the PPQ. On average the second session lasted 10 min. Usage data were automatically logged by the app.

We recruited 14 older adults (7 women), with an average age of 67.3 ($SD = 4.48$). Participants were all Italian and owned a smartphone with Internet connection. Three participants wore reading glasses and three bifocal glasses. None of them had ever used a food-monitoring app before. Concerning their health, eight seniors reported to be overweight and five affirmed that they had been under some kind of controlled diet for four years on average. Finally, only two participants reported not to have any health problem requiring special nutrition control.

2.3.3 Results

The data from the video-recordings were analysed following the same coding scheme employed in Study 1. All participants completed the task requiring to input food without help from the experimenter. The tasks requiring to input water, read data of the day before and the body weight data were completed autonomously by 13/14 users, and in one case all the three tasks were accomplished with the experimenter's help. The most difficult task was reading the data pertaining the day before, which was accomplished by half of the participants, while the other half failed. Those who failed either read the food of the current day ($n = 3$) or they consulted only the servings in the home page of the day before ($n = 4$). However, considering the actions made by users on the elements of the app we find that 89% of the actions were targeted to the correct ones. This suggests that the design implemented improved the comprehension of the selectable elements and of the buttons to press.

Concerning the post-experience questionnaire, Salus received positive evaluations on all the dimensions addressed (Table 3).

We split the sample into two sub-groups, based on their self-reported interest toward food-related behaviors (items 1–8 in the pre-experience questionnaire). In Group A fell eight participants who were very interested in the topic (average score 3.2, $SD = 0.21$), while Group B comprised six older adults with low interest in the topic ($M = 2.4$; $SD = 0.22$).

Firstly, we compared the scores at the PPQ given by each group in the first and second experimental session using a Wilcoxon test. No significant difference emerged.

The comparisons run between groups using Mann Whitney tests revealed that Group A ($M = 4.7$, $SD = 0.98$) reported a significantly higher score for the intention

Table 3 The scores at the post-experience questionnaire for Salus, means, standard deviations and medians *$p < 0.05$ for one-sample t-test against the mid-point of the response scale, i.e., 3.5

Dimension	M(SD)	Mdn	p
Learnability	4.04(0.92)	3.50	0.005
Ease of use*	4.25(0.90)	4.20	0.001
Error prevention	3.88(0.61)	4.00	0.063
Accessibility*	4.83(0.73)	4.90	0.001
Feedback*	4.79(0.86)	5.00	0.001
Quality of the experience*	4.52(0.71)	4.60	0.001
Satisfaction*	4.64(0.54)	4.70	0.001
Information presentation*	4.30(0.89)	4.50	0.001
Intuitiveness*	4.83(0.58)	5.00	0.001

Table 4 Comparison of the PPQ between groups A and B after one-week trail

PPQ dimension	Group A post-test		Group B post-test		z	p	p(BH)
	M(SD)	Mdn	M(SD)	Mdn			
General persuasive potential	4.8(1.15)	5	3.6(1.19)	3.5	−1.819	0.081	0.081
Individual persuasive potential	4.7(1.15)	4.8	3.2(1.03)	3	−1.949	0.059	0.081
Intention of use	4.7(0.98)	5	3.1(1.18)	3	−2.469	0.013*	0.039*

of use with respect to Group B ($M = 3.1$, $SD = 1.18$) $z = 2.469$, $p_{(BH)} = 0.039$ after the one-week trial (Table 4).

The logged data pertaining the use of Salus were analyzed. Considering the two sub-groups, we found that they did not differ over time in the number of accesses or actions on the app. However, in both groups the frequency of accesses decreased at day 7 ($M = 1.5$) compared to day 1 ($M = 2$).

3 Discussion and Conclusions

Healthy eating has a great impact on older adults' wellbeing, nevertheless only limited interest has been devoted to this topic. Here we designed and tested a mobile app meant to support senior users to monitor the food they eat daily. We started with a systematic inspection of the mobile apps available on the app store. We found no app specifically addressed to the target user group on the app store, consistently with [26]. The preliminary usability evaluation run by older users revealed that it was not obvious for them what were the elements in the page that could be selected. Moreover, the tasks that were highly fragmented resulted challenging, whilst one-tap input modality was easier. Finding and reading the data was complex, when the navigational menu remained not always visible and when the data were plotted in a graph. By involving older adults in the design of the app, we understood that they were interested in their nutrition and that they valued more important to track those types of food that are harder to limit. In addition, they valued important to assume a wide variety of different types of food. We considered the findings emerged from the preliminary evaluations together with design guidelines [2, 9] to implement 'Salus'. The app had a lean structure allowing the user to immediately visualize and record servings for the main food categories. The usability evaluation carried out by a group of older adults revealed that the app was user friendly and that it was received positively. However, data logged during the one-week trial revealed that older adults tended to reduce the usage and that this trend was more pronounced for those who were less interested in tracking their food intake. This finding suggests the need to include persuasive messages to engage elderly [14].

References

1. Al-Razgan MS, Al-Khalifa HS, Al-Shahrani MD (2014) Heuristics for evaluating the usability of mobile launchers for elderly people. In: International conference of design, user experience, and usability. Springer, Cham, pp 415–424
2. Al-Razgan MS, Al-Khalifa HS, Al-Shahrani MD, AlAjmi HH (2012) Touch-based mobile phone interface guidelines and design recommendations for elderly people: a survey of the literature. In: International conference on neural information processing. Springer, Berlin, Heidelberg, pp 568–574
3. Ali NM, Shahar S, Kee YL, Norizan AR, Noah SAM (2012) Design of an interactive digital nutritional education package for elderly people. Inf Health Soc Care 37:217–229
4. Amarya S, Singh K, Sabharwal M (2015) Changes during aging and their association with malnutrition. J Clin Geron Geriatr 6:78–84
5. Chin JP, Diehl VA, Norman KL (1988) Development of an instrument measuring user satisfaction of the human-computer interface. In: Proceedings of the SIGCHI conference on human factors in computing systems. ACM, pp 213–218
6. Cialfa E, D'Amicis A, Leclercq C et al (2003) Linee guida per una sana alimentazione italiana. Istituto nazionale di ricerca per gli alimenti e la nutrizione, Roma Italia, p 86
7. Elbert SP, Dijkstra A, Oenema A (2016) A mobile phone app intervention targeting fruit and vegetable consumption: the efficacy of textual and auditory tailored health information tested in a randomized controlled trial. J Med Int Res 18(6)
8. Fernández M, Rodríguez I, Rossel PO et al (2017) InMyDay: a digital diary to promote self-care among elders. In: International conference on ubiquitous computing and ambient intelligence. Springer, Cham, pp 486–497
9. Fisk AD, Czaja SJ, Rogers WA et al (2004) Designing for older adults: principles and creative human factors approaches. CRC Press
10. Giacalone D, Wendin K, Kremer S et al (2016) Health and quality of life in an aging population—food and beyond. Food Qual Prefer 47:166–170
11. Graham EC (2003) Development of the eating habits questionnaire. Doctoral dissertation. Texas A&M University
12. Hakobyan L, Lumsden J, Shaw R et al (2016) A longitudinal evaluation of the acceptability and impact of a diet diary app for older adults with age-related macular degeneration. In: Proceedings of the 18th International conference on human-computer interaction with mobile devices and services. ACM, pp 124–134

13. Hawthorn D (2000) Possible implications of ageing for interface designers. Interact Comput 507–528
14. Herrmanny K, Schwarz M, Paldán K et al (2017) Designing a holistic behavior change support system for healthy aging. i-com 16:99–111
15. Keller HH (2007) Promoting food intake in older adults living in the community: a review. Appl Physiol Nutr Metab 32:991–1000
16. Kimura M, Moriyasu A, Kumagai S et al (2013) Community-based intervention to improve dietary habits and promote physical activity among older adults: a cluster randomized trial. BMC Geriatr 13:8
17. McDowd JM, Craik FI (1988) Effects of aging and task difficulty on divided attention performance. J Exp Psychol Hum Percept Perform 14:267
18. Meschtscherjakov A, Gärtner M, Mirnig A et al (2016) The persuasive potential questionnaire (PPQ): challenges, drawbacks, and lessons learned. In: International conference on persuasive technology. Springer, Cham, pp 162–175
19. Pirlich M, Lochs H (2001) Nutrition in the elderly. Best Pract Res Clin Gastroenterol 15:869–884
20. Reedy J, Krebs-Smith SM, Miller PE et al (2014) Higher diet quality is associated with decreased risk of all-cause, cardiovascular disease, and cancer mortality among older adults. J Nutr 144:881–889
21. Rodrigues AM, Gregório MJ, Gein P et al (2017) Home-based intervention program to reduce food insecurity in elderly populations using a TV app: study protocol of the randomized controlled trial saúde. come senior. JMIR Res Protoc 6(3)
22. Ryu YS (2005) Development of usability questionnaires for electronic mobile products and decision making methods. Faculty of Virginia Polytechnic Institute and State University, Blacksburg, Virginia
23. Salim M, Hidir M, Ali NM et al (2017) Mobile application on healthy diet for elderly based on persuasive design. Int J Adv Sci Eng Inf Technol 7:222–227
24. Shahid S, Mubin O, Al Mahmud A (2008) Friend forever: a healderly partner. In: Proceedings of the 10th international conference on human computer interaction with mobile devices and services. ACM, pp 485–486
25. van der Mark M, Jonasson J, Svensson M et al (2009) Older members perform better in an internet-based behavioral weight loss program compared to younger members. Obes Facts 2:74–79
26. Watkins I, Kules B, Yuan X et al (2014) Heuristic evaluation of healthy eating apps for older adults. J Consum Health Internet 18:105–127
27. West R, Jakubek K, Wymbs N (2002) Age-related declines in prospective memory: Behavioral and electrophysiological evidence. Neurosci Biobehav Rev 26:827–833

Reasoning in Multi-agent Based Smart Homes: A Systematic Literature Review

Dagmawi Neway Mekuria, Paolo Sernani, Nicola Falcionelli and Aldo Franco Dragoni

Abstract Multi-agent systems are widely used to model components of a smart living environment as autonomous intelligent agents. Accordingly, its advantages to achieve the comfort and efficiency goals of smart home systems are well-documented in many studies. However, there is a clear lack of systematic investigation targeted at exploring the reasoning modules integrated into these systems. To close this gap, this paper examines the literature on multi-agent based smart home systems and provides a comprehensive overview of the essential requirements, assumptions, strengths, limitations, challenges and future research directions of their proposed reasoning systems. Moreover, it identifies the main technologies used to represent the home environment as a multi-agent system and the reasoning approaches utilized to bring decision-making ability into the smart living environment. As a result, this systematic literature review identifies the ability to learn, plan, predict, explain and reason with incomplete knowledge as the major elements of a smart home reasoning system. In addition, the findings of this work revealed the application of standard rule conflict resolution strategies and sensor data contextualization as principal solutions to address some of the problems caused by conflicting rules and agent goals. Further, it underlines the importance of utilizing hybrid reasoning approaches and the need to handle overlapping multi-inhabitant activities to realize the true potential of smart homes.

Keywords Smart homes · Multi-agent system · Reasoning system

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1 Introduction

The term "smart home" refers to a residence equipped with technology that facilitates monitoring of residents, promotes independence and increases residents' quality of life [16]. Recently, smart homes have been widely used to provide services such as energy management [34], healthcare [17], comfort [20] and entertainment [38]. To deliver these services, the home system must be able to perceive the state of the home through sensors and adapt the environment to its inhabitant needs through effectors.

One key feature of a smart home is the ability to reason, which enables the home system to make an appropriate decision towards achieving comfort and efficiency goals of its inhabitant and their surroundings. With this in mind, various artificial intelligence techniques have been applied to bring decision-making ability into the home environment. Among them, multi-agent system (MAS) architecture, which is based on the interaction of autonomous intelligent agents, is considered as an ideal candidate to cope with the dynamic and distributed nature of a smart home environment. As stated on [39], intelligent agents possess the following characteristics:

- **Autonomy**: agents operate without the direct intervention of humans or others, and have some kind of control over their actions and internal state.
- **Social ability**: agents interact with other agents (and possibly humans) via some kind of agent communication language.
- **Reactivity**: agents perceive their environment and respond in a timely fashion to changes that occur in it.
- **Pro-activeness**: agents do not simply act in response to their environment, they are able to exhibit goal-directed behaviour by taking the initiative.

Many studies have utilized these key properties of intelligent agents to demonstrate the advantages of modeling smart environments using MAS approaches. However, there is a clear lack of systematic investigation targeted at exploring their integrated reasoning systems. Most existing reviews present a comprehensive overview of the smart home system such as [3, 12] or explore in detail a specific smart home technology such as [8, 16]. While few others tailored their surveys to investigate the application of agent-based decision support system for specific domains such as medical data classification [30] and clinical management [18]. And, to the best of our knowledge, none devoted their work to examine the reasoning approaches of multi-agent based smart homes. To close the gap, this paper reports the preliminary results of a systematic literature review conducted to examine the previously mentioned domain. In this regard, it aims to explore:

- the main requirements of MAS based smart home reasoning system.
- the tools, technologies and methodologies used to develop the MAS environment, and the reasoning approaches integrated into it.
- the principal assumptions, strengths and limitations of the proposed techniques.
- and, the reported challenges and future research directions of the field.

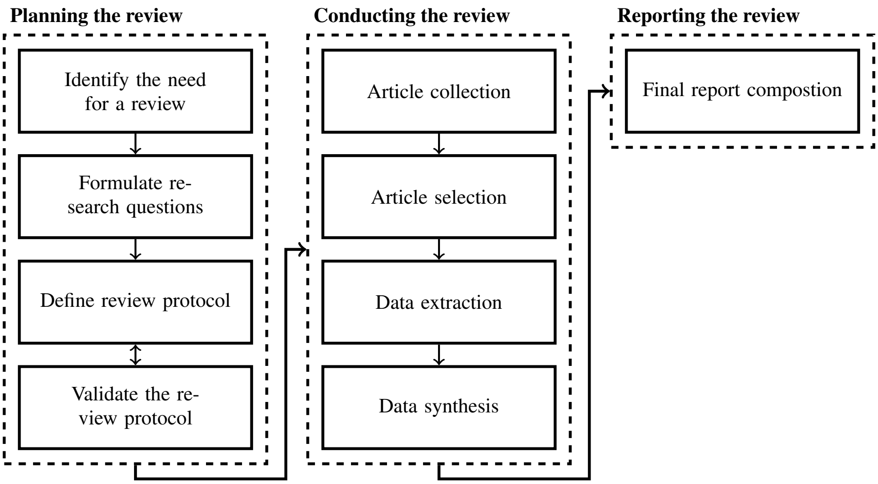


Fig. 1 The systematic review process

The rest of the paper is organized as follows: Sect. 2 describes the review process and the protocol underlining this systematic review. We present and discuss the review results and findings in Sect. 3 and we conclude and discuss future works in Sect. 4.

2 The Review Process

A systematic literature review (SRL) is a method that enables the evaluation and interpretation of all accessible research relevant to a particular research question, subject matter, or event of interest. It aims to present a fair evaluation of a research topic by using a trustworthy, rigorous, and auditable methodology [24]. Most common reasons to perform an SRL are:

- The need to evaluate and summarize existing evidences concerning technology.
- And, to identify gaps in the technology that will potentially lead to topics for future investigations.

In this study, we have carried out an SRL by adapting the guidelines proposed in [24]. The review process (shown in Fig. 1) consists of three main phases: Planning the review, Conducting the review, and Reporting the review. The rest of this section discusses in detail our adopted approach and its principal components.

2.1 *Planning the Review*

Before conducting a systematic review, researchers should identify and examine existing systematic literature reviews on topic of interest, and ensure the need for a systematic review. However, the most important pre-review activities are defining the research question(s) that the review will address and producing a review protocol (i.e. plan) by defining the basic review procedures [24].

2.1.1 Formulating Research Questions

The most important activity during an SRL is to formulate the research questions [24]. Hence, we defined the goal of this review through Goal-Question-Metrics approach [37] as follow:

- **Purpose**: *Explore, Analyze, Characterize, and Compare*
- **Issue**: *Reasoning Systems*
- **Object**: *Multi-agent based Smart Homes/Smart Living Environments*
- **Viewpoint**: *Researcher's point of view*.

To identify the major requirements and purposes of MAS based smart homes reasoning systems, and to assess the contributions presented in the literature, based on the above-defined goal, we formulated the following six research questions (RQ).

RQ1: What are the central purposes of the smart home systems?
RQ2: What are the primary requirements of multi-agent based smart home reasoning system?
RQ3: What are the major technologies used to develop the multi-agent based smart home system? And, which reasoning approaches are used to provide agents decision-making ability?
RQ4: Which of the proposed systems are tested and/or integrated into a real-world living environment?
RQ5: What are the strengths, limitations and assumptions of the proposed (MAS based) reasoning systems?
RQ6: What are the main challenges and future research directions stated in the literature?

2.1.2 Define the Review Protocol

The review protocol specifies the methods to be followed while conducting the systematic review. Based on [24], a review protocol should define the following activities of the SRL: the strategy that will be used to search for primary studies selection; study selection criteria; study quality assessment criteria; data extraction and dissemination strategies. In the rest of this section, we discuss how we specify and perform each of these activities.

2.2 *Conducting the Review*

This phase is composed of the following main activities: article collection, article selection, data extraction and synthesis, where each of them is composed of several sub-activities.

2.2.1 Article Collection

The aim of an SRL is to find as many primary studies as possible related to the research question, using a repeatable search strategy [24]. Accordingly, to carry out a comprehensive and exhaustive search for the primary studies, it is necessary to define a search strategy and strictly apply it. Our article collection process consists the following two main sub-activities:

I **Definition of the search query**: to build the search query[1] shown in Fig. 2, we adopted the following steps recommended in [6].

- Derive major search terms from the research questions.
- Collect keywords from known primary studies for additional main search terms.
- Identify synonyms of the main search terms.
- Construct search strings using Boolean "AND" to join the main terms and "OR" to include synonyms.

II **Conduct the search**: with the aim of performing an exhaustive search, we identify the following six electronic databases: ScienceDirect, SpringerLink, IEEExplore, ACM Digital Library, Google scholar and Semantic scholar. Then, we perform an automated search on each of them, except ACM Digital Library.[2] When required, we adopt the basic search string to the search engine of each source.
The automated article collection is done through an in-house web crawler that able to detect and ignore article repetitions. It also stops the gathering process after detecting a sequence of ten articles that are unrelated to the query of interest. The crawler detects the "unrelatedness" of an article by matching the title of the paper with a predefined set of keywords.[3]

[1]The search query is defined for a larger SRL, that we are conducting on smart home reasoning systems. Therefore, it does not explicitly include MAS.

[2]ACM End-user policy specifically prohibits automatic downloading of articles.

[3]The set of related keywords was defined according to the reviewers' subjective knowledge and experience on the field.

(("smart home" OR "smart building" OR "smart house" OR "smart living environment" OR "connected home" OR "context aware home" OR "context aware building" OR "context aware living environment" OR "building automation", "home automation" OR "domotic" OR "ambient assisted living" OR "active assisted living" OR "ambient intelligence") AND ("reasoning system" OR "decision support" OR "expert system"))

Fig. 2 Basic search strings

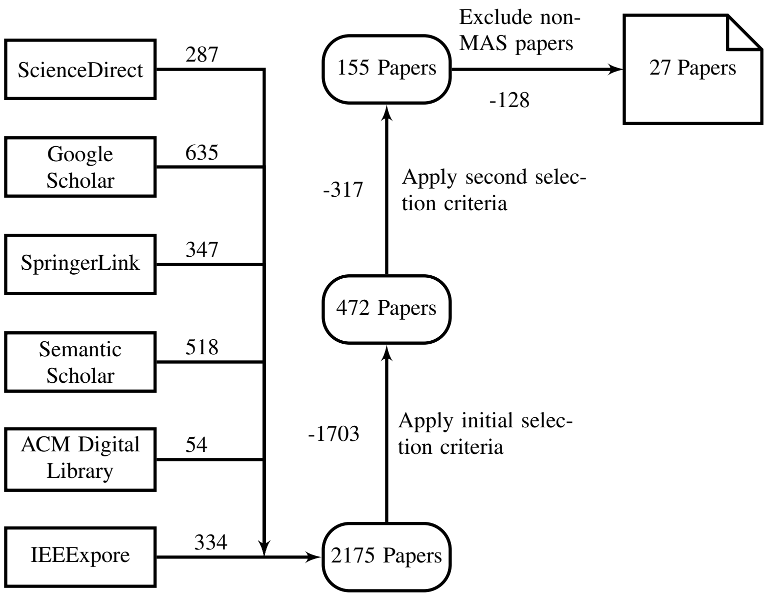


Fig. 3 Article collection and selection process

2.2.2 Article Selection

As shown in Fig. 3, our search process elicited 2175 articles. To select appropriate studies for inclusion in the review the following two sets of inclusion and exclusion criteria were specified:

I **Initial Selection**: as the number of collected papers are vast to consider for full text analysis, in this phase we evaluated the papers based on their abstract, title and list of keywords. The inclusion and exclusion criteria applied for this phase of selection are listed below. A paper was included if it met all inclusion criteria and eliminated if it met any exclusion criterion.

Inclusion criteria:

- Papers whose title indicates that it deals with reasoning systems in smart living environments.
- Papers whose keywords match with some of the search terms defined.
- Studies which presented very general decision support techniques for pervasive/ubiquitous environments and that can be directly applied to smart living environments.
- In addition, articles that focus on smart home inhabitants activity recognition, learning and monitoring are included as potentially relevant articles, to determine if their proposed technique can be applied to the problem domain.
- Similarly, studies on home appliance optimization, planning and scheduling are included, only if the results of these studies are used for decision making/reasoning processes in the home environment.

Exclusion criteria:

- Duplicates reports of the same study, in this case only the most recent and complete version is included.
- Papers that are not published in the English language.
- Studies that focused on smart grids, smart cities, non-residential buildings, and applied for outdoor intelligence services.
- Studies tailored for smart home appliances (e.g. smart fridge, smartphone, smart mirror, domestic robots…), but do not generalize their solution for smart living environments.
- Grey literature.

As abstracts might be insufficient to rely on when selecting, if there was any doubt whether a study should be included, it was added to the list of potentially relevant studies. The outcome of this selection stage was 472 papers, i.e., we have excluded 1703 papers.

II **Secondary Selection**: in this phase, the potential of an article to be included as a primary study assessed by skimming over the full-text of the contribution.An article must satisfy both of the following criteria to be part of in the primary study.

A **Contribution**: The primary contribution of the study should be towards the definition of theoretical foundation and/or the provision of empirical evidence (through implementation, tests, critical analysis, or critical evaluations) for constructing a reasoning system.

B **Context**: the study should be defined in the context of domotics and/or other closely related domain. In addition, a study proposed to address a broader concept but can be mapped into a smart home scenario, is considered to meet this criterion.

After the execution of this selection stage, we remain with 155 papers. However, as this SRL scopes on articles presented based on Multi-agent approaches, another 128 papers were excluded. Consequently, the articles to be explored reduced into 27 papers.

2.2.3 Data Extraction

To extract the data needed to answer our research questions the selected primary studies were read in-depth. Then, we kept a record of the extracted information in a spreadsheet for subsequent analysis. Some of the fields of our data extraction form are: *paper ID, publication year, targeted purpose, article abstraction, MAS technologies (i.e. tools, frameworks and techniques), reasoning technologies (i.e. approach, methodology, and tools), strengths, assumptions, limitations, future works and challenges*. The assumptions, limitations and strengths of an article were determined based on the knowledge of the reviewers, who are experts both in MAS and reasoning systems.

2.3 Data Synthesis

During an SLR, the extracted data should be synthesized in a manner suitable for answering the questions that an SLR seeks to answer [24]. For this SLR, we perform descriptive synthesis of the extracted data and present part of the result in a tabular and diagrammatic form.

To answer RQ1 (Sect. 3.1), we grouped purposes of the contributions into three categories. For the purpose of answering RQ2 (Sect. 3.2), “requirement” was considered as any property, characteristics or feature of the smart home reasoning system. And, to answer RQ4 (Sect. 3.3.1), we grouped the way an article is presented into three groups and explored in detail the employed MAS technologies and their reasoning systems. Whereas, RQ3 (Sects. 3.3.2–3.3.4), RQ5 and RQ6 (Sects. 3.4 and 3.5 respectively) are answered by performing descriptive synthesis of the extracted data and summarizing the results.

3 Review Results and Discussion

This section presents and discusses the findings of this review.

3.1 Purposes of Smart Homes

As shown in Fig. 4, the majority of the analyzed papers are designed with the aim of providing classical home automation services. Mainly, they tackle the control

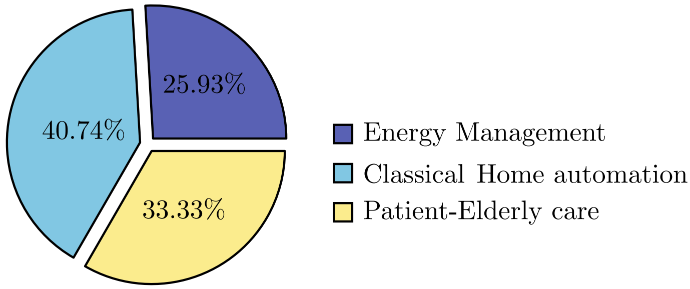


Fig. 4 Main purposes of smart homes

and management of context-aware lights, HVAC systems, consumer electronics and entertainment devices. In addition, our study identified home energy management, patient care and elderly assistance as the other most popular smart home services addressed by the examined articles.

3.2 Requirements of a Smart Home Reasoning System

A review on agent technologies application [22], stated the ability to perceive its environment and respond in a timely fashion to the changes that occur in it, as well as the ability to exhibit goal-directed behaviour by taking the initiative, as two most important properties of an intelligent agent. That means, an intelligent agent which controls a smart home has to be capable of selecting the most appropriate decisions based on the circumstances in the home environment, and autonomously work towards fulfilling its inhabitant preferences (e.g. thermal comfort) while maintaining its design objectives (e.g. energy efficiency). To realize such an intelligent behavior, it is necessary for an agent to possess a diverse set of reasoning skills. In the aim of identifying these fundamental expertises a smart home intelligent agent should be equipped with, we carefully gathered and summarized the following list of requirements from the primary studies investigated:

- **Learning ability**: the analysis of the studies highlights that self-learning is an essential component to be integrated into smart home reasoning system. Thus, the system will suit the dynamic household living patterns and adapt to small changes without being explicitly requested.
- **Planning ability**: some of the studies underlined on the need to integrate a planning component into the agent reasoning system. As a result, it will be able to develop task plans and provide proactive solutions.
- **Ability to predict**: many examined studies stressed that an agent should be able to make a prediction of inhabitants behaviour in the smart home environment.
- **Ability to explain**: few of the examined primary studies outlined the ability to explain its decision as another key requirement of an agent's reasoning system.

Specifically, they stated that an agent should be able to explain its behaviour by revealing relevant facts of its decision.

- **Ability to reason with incomplete knowledge**: examined studies [14, 33] describe the open and dynamic nature of the ambient assisted living environments and, the incomplete and ambiguous contextual knowledge generated from it. And, stressed the importance of integrating different reasoning strategies to make the agent reason with incomplete and inconsistent knowledge about the environment.
- **Adaptability**: though the ability to adapt hugely overlaps with learning abilities, some of the analyzed studies specifically pointed out on the need for an agent's decision-making system to perceive environmental changes and provide adaptive and proactive services to its users.
- **Configurability**: some of the investigated articles insisted that majority of smart home users are non-technical people. As a result, they recommended the reasoning system of a smart home to be highly customizable and easy to configure. Therefore, it will allow the user to express his/her desires in a simple and natural way, and integrate those changes with the rest of its behaviours.
- **Context-awareness**: almost all of the examined studies identified context-awareness as a fundamental attribute of a smart home reasoning system, despite the fact that, it highly overlaps with most of the aforementioned features. A specific reason for this can be the need for a reasoning system to acquire and utilize information about the context of the home environment. So that, it can provide efficient services that are appropriate to the particular people, place, time and event.
- **Non-disturbance**: another interesting but roughly defined concept for a reasoning system in a living environment by [20] is non-disturbance. The study insists on the fact that an agent should be non-disturbing. As a result, the agent should not bother the user more than necessary.
- **Conflict Resolution Strategy**: usually a multi-agent system environment is packed with autonomous agents, which work towards attaining conflicting objectives (e.g. a comfort agent tries to preserve inhabitant comfort by turning on a heater, while an energy saving agent attempts to turn it off). In order to avoid such conflicting situation [5, 34] underline on the need to have a global conflict resolution strategy in multi-agent systems. Whereas, many others stressed on the need to implement local conflict resolution strategy for the agent's own decision support system. So that, execution of conflicting actions that may result in an inconsistent state will be avoided.

Moreover, the analyzed studies specified other non-functional requirements to be considered including reliability, fast performance, satisfactory response time, extensibility, usability and interoperation with other already active client applications. Since also the computational capabilities of most devices in ambient environments are very restricted, [5] points on the need to keep the communication load not too heavy, so that the system can quickly reach a decision, taking into account all the available context information that is distributed between the ambient agents. In addition, [35] listed communication protocol, collaboration scheme, and resource management as the major issues need to be addressed when designing a multi-agent based smart home system. Whereas, [2] shares an interesting point of view, on assessing psychology and social sciences aspects of a reasoning system while designing ambient assisted living environments. It also points on the importance of some additional scientific backgrounds, which are necessary to model the emotional and psychological state of a generic user that interacts with an immersive computing framework.

3.3 Technologies for Multi-agent Based Smart Homes

This section discusses the technologies employed for building a multi-agent based smart homes. Specifically, it explores the development methodologies, frameworks and the reasoning approaches proposed to be integrated into it.

3.3.1 Article Abstraction

To better study the feasibility of the research contributions, they were categorized into the following three groups:

- **Conceptual**: articles which presented only theoretical contribution.
- **Proof-of-concept (PoC)**: articles that illustrated the feasibility of its theoretical contribution with a PoC implementation.
- **Tested in a real-world environment**: articles that integrated and tested its proposed solution in a real-world environment.

And, as shown in Fig. 5, 44.44% of the examined studies presented an entire theoretical contribution, without any feasibility assessment of their proposed solution. Whereas, 29.63% of the articles experimented their contribution in a simulated environment. The rest 25.93% of the examined articles integrated their proposed multi-agent architecture either into a testbed or an actual home environment, and run a series of experiments.

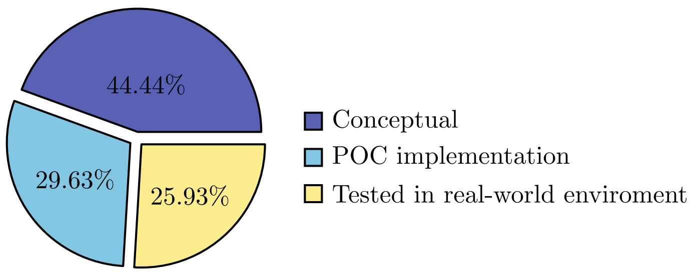


Fig. 5 Distribution of article abstraction

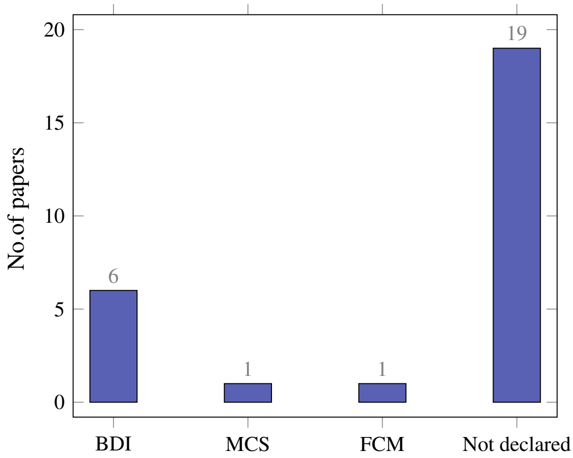


Fig. 6 Utilized multi-agent paradigms

3.3.2 Agent Models and Methodologies

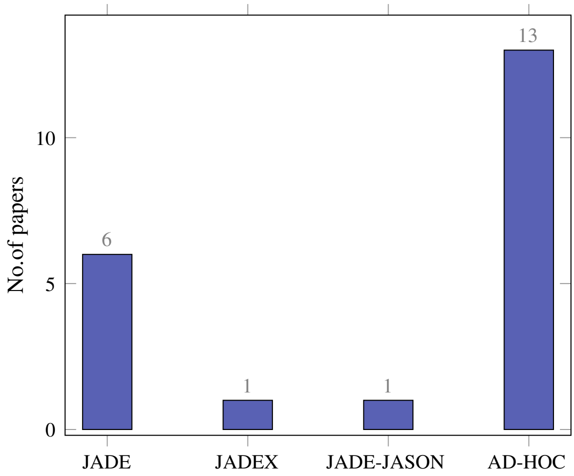
Agent models are essential to describe the agent's internal structure (belief, plans, goals…), and their interaction in the environment [11]. Hence, six of the examined articles utilized BDI agent model [9] to design their proposed system in a standard way. On the other hand, [5] builds its solution based on Multi-Context Systems paradigm [21], in which local knowledge of ambient agents is encoded in rule theories (contexts), and information flow between agents is achieved through mapping rules. Whereas, agents in [2] are modeled as Fuzzy Cognitive Maps. As depicted in Fig. 6, none of the other examined articles specified the agent modeling technique adopted for their work.

In addition, [26, 29], which adopted ASEME and Prometheus methodologies respectively, were the only two articles claimed to design their solutions by adopting a standard agent-oriented methodology.

3.3.3 Frameworks

As depicted in Fig. 7, six of the proposed solutions were built on top of the well-known Java Agent Development Framework (JADE) [4]. And, [19] demonstrated its multi-agent based smart home system using Jadex agent framework [7]. Whereas, [31] developed a PoC implementation of their systems by combining JASON [10] and JADE technologies. However, the majority of the examined contributions were presented as ad-hoc. Their choice of using tailor-made solution was justified by successfully achieving the objectives of their study. Nonetheless, not embracing a proven framework (e.g. JADE) will restrict the robustness, scalability, and interoperability of the proposed solution.

Fig. 7 Multi-agent frameworks



3.3.4 Reasoning Approaches

To effectively present the reasoning approaches integrated into the examined multi-agent based smart home systems, we categorize them into the following three groups:

- **Symbolic approaches**: This group contains all symbolic artificial intelligence techniques used to provide decision support abilities for the proposed systems. Knowledge-based systems, Semantic web and ontology technologies, Search, Optimization, and Planning techniques, are all grouped here.
- **Statistical approaches**: this group contains all modern decision support techniques based on statistical artificial intelligence such as Artificial neural networks, Bayesian networks, and Machine learning algorithms.
- **Hybrid approaches**: this group comprises reasoning techniques, which utilized a combination of the above two approaches.

As shown in Fig. 8, this result is unsurprising, considering the strong and long-established bond between knowledge-based systems and multi-agent technologies. And, the fact that statistical approaches suffer from the problem of reusability and scalability, … i.e a model for an inhabitant may not be applicable for another, and since every activity needs to be learned makes the adoption of such approaches limited.

3.4 Evaluation of the Presented Solutions

This section summarizes the assumption made by the analyzed articles and discusses the strengths and limitations of the proposed multi-agent based reasoning systems.

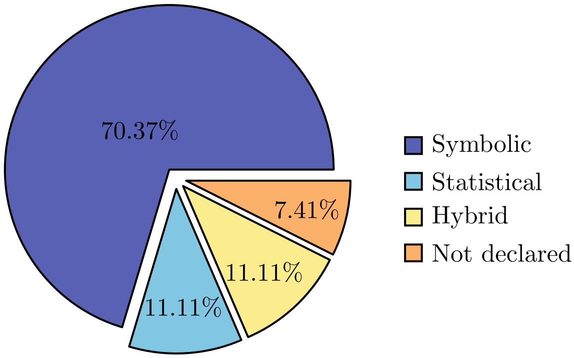


Fig. 8 Reasoning approaches in smart homes systems

Table 1 Summary of assumptions

Assumption	Class	Assumption	Class
Collaborative	Agent	Ability to reason	Agent
Ability to predict	Agent	No conflicting context	Reasoning system
Rationality	Agent	known inhabitant state	Agent
Ability to send unlimited messages	Agent	Single inhabitant	Reasoning system
Reliable communication channel	Agent	Consistent context	Reasoning system
Willingness to share information	Agent		

3.4.1 Assumptions

Table 1 shows the summary of assumptions made by the examined studies. To effectively denote wherein the system these assumptions are made they are marked either as agent or reasoning system. The ones marked as an agent are the assumptions listed in some of the papers to describe the behaviour of the intelligent agents in the proposed smart living environment. Moreover, as most of the evaluated papers neither address conflicting agent interests nor consider multiple inhabitants behaviour, the assumptions marked as reasoning system were made to present their solutions.

3.4.2 Strengths

Most of the articles reviewed highlights the advantages of modeling smart home environment as a Multi-Agent System by mapping some key features of ambient intelligence such as autonomy, distribution, adaptation, proactiveness, interoperability and responsiveness with the properties of software agents. Cavone et al. [13] states that decentralized solution is a suitable alternative given the largely open and pervasive nature of smart environments. It has also some clear advantages, such as system scalability and the benefits to avoid a single point of failure. Further, [1] took the full advantages of MAS, by proposing an open and extendable solution, which allows new devices to join and leave the system without completely redefining the control mechanism. Another reviewed paper, [32] applies the concept of agent negotiations for the decision-making purposes. Whereas, [5] attempts to deal with some key concerns in ambient intelligent environments such as uncertainty, ambiguity, and conflict in intelligent environments by proposing a solution based on argumentative agents. In addition, [34] demonstrated how agent-based systems enable simultaneous usage of distinct technologies by integrating two complementary but mutually exclusive rule-based approaches to enforce energy saving policies.

Fraile et al. [19] proposed a solution to enhance the planning and learning abilities of agents. To achieve its objective, it incorporates Critical Path Method (CPM) into the case-based reasoning—belief, desire, intentions (CBR-BDI) agents. Some other reviewed articles approached the issue of rule conflicts by applying defeasible logic techniques [28] and by defining superiority relation between them. To deal with a similar problem, [5] proposes four alternative conflict resolution strategies, which vary in the type and extent of contextual information that is used to evaluate the quality of imported knowledge. Whereas, agents in [23] utilized semantic web technologies to contextualize low-level sensor data into more meaningful outputs. It also utilized the same technologies to develop ontologies which provide a context model for supporting information exchange and interpretation of contexts. On the other hand, agents in [2] exploit a novel extension of Fuzzy Cognitive Maps benefiting from timed automata and formal method theories to represent human moods and enhance users' comfort accordingly. In addition, it uses emotional, environmental and temporal features of the ambient environment to distribute the most suitable and personalized smart home services.

3.4.3 Limitations

The imperfect nature of contextual information generated within the AmI environment causes serious problems such as uncertainty, ambiguity, inconsistency and, conflicting rules and agents goals. However, the majority of the reasoning approaches investigated in this study either simply neglect the need to address these problems or handle them with ad-hoc solutions that cannot deal with the problem inherently. For instance, the algorithm proposed by [36], picks one rule randomly, if two or more rules have the same priority value. If not addressed properly using a standard conflict resolution strategy this kind of solution can raise several issues. In addition, most of the articles presented the decision process of an agent that can handle only a single inhabitant situation and do not put into consideration multiple inhabitants and overlapping user activities in the living environment. And, almost all of the examined contributions do not mention about sensor data contextualization. This most likely leads to the generation of massive amounts of data, that needs to be handled by the reasoning system.

In addition, most symbolic reasoning systems proposed in the reviewed literature, are based on the assumption of perfect knowledge of the environment with a set of predefined static rules, and no self-learning capabilities. This makes achieving the above-mentioned requirements of smart home reasoning systems very difficult, if not impossible. On the other hand, the investigated statistical approaches require a suitably large amount of dataset to learn from. Moreover, the reusability of the generated activity is limited to the environment and scenarios that have produced the dataset.

Therefore, in order to achieve all the above-identified requirement and make the smart home environment adaptable to its user's need, it is essential to combine the advantages of both approaches.

3.5 Challenges and Future Research Directions

Most of the conceptual contributions examined in this study identified as their immediate future work the PoC implementation of their proposed architectures using standard multi-agent design methodologies (e.g. Prometheus) and frameworks (e.g. JADE and EMERALD). Whereas, the evaluated empirical studies targeted to perform extensive experiments on the testbed. In addition, [25] aims at the development of user behaviour pattern recognition agents and the integration of existing medical and smart environments domain ontologies into the system. [15, 19] plan to test their solutions on increasingly complex environments with multiple inhabitants.

Among the other investigated articles, [27] describes the need to include self-learning abilities in the AAL system. And, it plans to apply data mining techniques to automatically extract context patterns from the occupant's habits. On the other hand, [33] aims to integrate statistical artificial intelligence techniques for the integration of hybrid agents into its proposed architecture. And, [5] outlines the need to deal with incomplete, ambiguous, inaccurate and erroneous context knowledge in ambient intelligence domain as the key subjects to be addressed in the near future.

The other most critical challenges of contextual reasoning in smart living environments are the heterogeneity of local context theories and the potential conflicts that may arise from the interaction of different agents [5]. On top of this, [34] insists conflict resolution is the biggest challenge for agent scheduling and resource allocation in the ambient assisted domain. It also aims to explore the applicability of agent negotiation strategies for conflict resolution, by integrating more instances of the same or different agent. Specifically, each agent will be assigned a sub-task or a region within the building, and negotiate with the others towards achieving a certain goal (e.g. comfort and/or energy savings).

Furthermore, [14] identifies an explanation feature, through a mechanism of queries, where users cannot only trace the internal reasoning of agents but also ask them for specific explanations as part of its future works.

4 Conclusion

This paper presents the preliminary results of a systematic literature review in the smart home domain. The review was performed to identify and characterize the reasoning systems of multi-agent based smart homes. It was focused to answer six research questions and our main findings are:

- Most smart homes are designed to provide classical home automation services such as light and HVAC control. Nevertheless, patient-elderly care and energy management are also the most popular services of smart homes.
- The main requirements of a smart home reasoning system include the ability to learn, plan, predict, explain and reason with incomplete knowledge. In addition, the reasoning system should be context-aware, adaptive, configurable and non-disturbing. Moreover, it needs to be equipped with standard conflict resolution strategy.
- Most proposed solutions are presented as conceptual contributions. Whereas, a great deal of the empirical contributions were presented as ad-hoc solutions, i.e. without adopting any standard agent models and frameworks. In addition, most of the reasoning systems integrated into the MAS were based on symbolic approaches, while few others presented their contributions based on either statistical or hybrid approaches.
- And, most studies presented their solution by making an assumption of single inhabitant behaviour and non-conflicting contexts in the home environment.

In performing this review we also noted a clear need:

- To address conflicting rules and agents goals, which is caused by the imperfect nature of the data generated in smart homes. A starting point in overcoming these problems can be the application of standard conflict resolution strategies and contextualizing sensor outputs.
- To integrate the best of symbolic and statistical reasoning techniques, thus most of the above-mentioned requirements will be successfully achieved.
- And to propose more solutions which are capable of handling overlapping multi-inhabitant behaviours.

The results reported in this paper are preliminary results of a larger systematic review of smart home reasoning systems. In our future analysis, we aim to further evaluate the remaining 128 articles of our primary studies and present a more fine-grained view of the reasoning techniques proposed to give true intelligent behaviours for the home.

References

1. Abras S, Pesty S, Ploix S, Jacomino M (2008) An anticipation mechanism for power management in a smart home using multi-agent systems. In: Information and communication technologies: from theory to applications. IEEE, pp. 1–6
2. Acampora G, Liao V, A V (2011) Distributing emotional services in ambient intelligence through cognitive agents. Serv Oriented Comput Appl 5:17–35
3. Alam MR, Reaz MBI, Ali MAM (2012) A review of smart homes-past, present, and future. IEEE Trans Syst Man Cybern Part C (Appl Rev) 42:1190–1203
4. Bellifemine F, Bergenti F, Caire G, Poggi A (2005) JADE-a java agent development framework. In: Multi-agent programming. Springer, pp 125–147

5. Bikakis A, Antoniou G, Hassapis P (2011) Strategies for contextual reasoning with conflicts in ambient intelligence. Knowl Inf Syst 27:45–84
6. Brereton P, Kitchenham BA, Budgen D, Turner M, Khalil, M (2007) Lessons from applying the systematic literature review process within the software engineering domain. J Syst Softw 80:571–583
7. Braubach L, Lamersdorf W, Pokahr A (2003) Jadex: implementing a BDI-infrastructure for JADE agents. Citeseer
8. Brownsell S, Bradley D, Blackburn S, Cardinaux F, Hawley MS (2011) A systematic review of lifestyle monitoring technologies. J Telemed Telecare 17:123
9. Burmeister B (1995) BDI agents: from theory to practice. ICMAS 95:312–319
10. Bordini RH, Hübner JF, Wooldridge M (2007) Programming multi-agent systems in AgentSpeak using Jason, vol 8
11. Birgit B (1996) Models and methodology for agent-oriented analysis and design. Work Notes KI 96:06–96
12. Calvaresi D, Cesarini D, Sernani P, Marinoni M, Dragoni AF, Sturm A (2017) Exploring the ambient assisted living domain: a systematic review. J Ambient Intell Humaniz Comput 8:239–257
13. Cavone D, De Carolis B, Ferilli S, Novielli N (2011) An agent-based approach for adapting the behavior of a smart home environment. In: WOA, pp 105–111
14. Chen L, Nugent CD (2010) Situation aware cognitive assistance in smart homes. J Mob Multimed 6:263–280
15. Cook DJ, Youngblood M, Heierman EO, Gopalratnam K, Rao S, Litvin A, Khawaja F (2003) MavHome: an agent-based smart home. In: Proceedings of the first IEEE international conference on pervasive computing and communications. IEEE, pp 521–524
16. Demiris G, Hensel BK, and others (2008) Technologies for an aging society: a systematic review of "smart home" applications. Yearb Med Inform 3:33–40
17. Falcionelli N, Sernani P, Brugués A, Mekuria DN, Calvaresi D, Schumacher M, Dragoni AF, Bromuri S (2017) Event calculus agent minds applied to diabetes monitoring. In: Agents and multi-agent systems for health care. Springer, pp.40–56
18. Foster D, and others (2005) A survey of agent-based intelligent decision support systems to support clinical management and research. In: Workshop on multi-agent systems for medicine, computational biology, and bioinformatics
19. Fraile JA, De Paz Y, Bajo J, De Paz JF, Pérez-Lancho, B (2014) Context-aware multiagent system. Plan Home Care Tasks 40:171–203
20. García-Herranz M, Haya PA, Esquivel A, Montoro G, Alamán, X (2008) Easing the smart home: semi-automatic adaptation in perceptive environments. J UCS 14:1529–1544
21. Ghidini C, Giunchiglia F (2001) Local models semantics, or contextual reasoning = locality + compatibility. Artif Intell 127:221–259
22. Iglesias CA, Garijo M, González JC (1998) A survey of agent-oriented methodologies. In: ATAL, pp 317–330
23. Jih W-R, Hsu JY-J, Lee T-C, Chen L-L (2007) A multi-agent context-aware service platform in a smart space. J Comput 18
24. Kitchenham B (2004) Procedures for performing systematic reviews, vol 33. Keele, pp 1–26
25. Kuusik A, Reilent E, Lõõbas I, Parve M (2010) Software architecture for modern telehome care systems. In: 2010 6th international conference on networked computing (INC). IEEE, pp 1–6
26. Marcais J, Spanoudakis N, Moraitis P (2011) Using argumentation for ambient assisted living. In: Artificial intelligence applications and innovations. IEEE, pp 410–419
27. Muñoz A, Augusto JC, Villa A, Antonio J (2011) Design and evaluation of an ambient assisted living system based on an argumentative multi-agent system. Pers Ubiquitous Comput 15:377–387
28. Nute D (2001) Defeasible logic. In: International conference on applications of prolog. Springer, pp 151–169

29. Reinisch C, Kofler MJ, Kastner W (2010) ThinkHome: a smart home as digital ecosystem. In: Digital ecosystems and technologies (DEST). IEEE, pp 256–261
30. Salem H, Attiya G, El-Fishawy, N (2015) A survey of multi-agent based intelligent decision support system for medical classification problems. Int J Comput Appl 123
31. Sernani P, Claudi A, Palazzo L, Dolcini G, Dragoni AF (2013) Home care expert systems for ambient assisted living: a multi-agent approach. In: Technological roles and opportunities for artificial intelligence
32. Sierra E, Hossian A, Rodríguez D, García-Martínez M, Britos P, García-Martínez R (2008) Intelligent systems applied to optimize building's environments performance. In: IFIP international conference on artificial intelligence in theory and practice. Springer, pp 237–244
33. Stavropoulos TG, Rigas ES, Kontopoulos E, Bassiliades N, Vlahavas I (2014) A multi-agent coordination framework for smart building energy management. In: Database and expert systems applications (DEXA). IEEE, pp 126–130
34. Stavropoulos TG, Kontopoulos E, Bassiliades N, Argyriou J, Bikakis A, Vrakas D, Vlahavas I (2015) Rule-based approaches for energy savings in an ambient intelligence environment. Pervasive Mob Comput 19:1–23
35. Sun Q, Yu W, Kochurov N, Hao Q, Hu F (2012) A multi-agent-based intelligent sensor and actuator network design for smart house and home automation. J Sens Actuator Netw 2:557–588
36. Uddin I, Rakib A, Haque HMU (2017) A framework for implementing formally verified resource-bounded smart space systems. Mob Netw Appl 22:289–304
37. Van Solingen R, Basili V, Caldiera G, Rombach HD (2002) Goal question metric (GQM) approach. Encycl Softw Eng 22:289–304
38. Velasco JR, Marsá-Maestre I, Navarro A, López-Carmona MA, de Vicente AJ, De La Hoz E, Paricio A, Machuca M (2005) Location-aware services and interfaces in smart homes using multiagent systems. PSC 5:104–110
39. Wooldridge M, Jennings NR (1995) Intelligent agents: theory and practice. PSC 10:115–152

Will Robin Ever Help "Nonna Lea" Using Artificial Intelligence?

Amedeo Cesta, Gabriella Cortellessa, Andrea Orlandini and Alessandro Umbrico

Abstract A new generation of Intelligent Robots are entering our working and living environments, taking care of human-level tasks. Such robotic systems are becoming more and more important also in healthcare assistance for elderly. Indeed, recent advancements in Artificial Intelligence and Robotics are fostering the diffusion of robotic agents with the capabilities needed to support both older adults and their caregivers in a variety of situations (e.g., in their homes, in hospitals, etc.). The capability of representing and reasoning about diverse kind of knowledge is crucial for allowing robotic assistants to *understand* the needs of the older persons as well as the status of the working environment. This paper presents a recent research initiative which aims at endowing autonomous robots with the capabilities needed to represent and reason on sensor data and to autonomously make decisions according to the inferred knowledge. The complete approach ends out being a cognitive control architecture, called Knowledge-based cOntinuous Loop (KOaLa) whose main aspect are described in this paper. The application of KOaLa to our Robin telepresence robot is also exemplified to enhance the services of older people assistance.

Keywords Assistive robotics · Knowledge representation and reasoning · Ambient intelligence · Automated planning and scheduling · Artificial Intelligence

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1 Introduction

Nowadays, there are many widely diffused commercial robotic solutions like e.g., robot vacuums or industrial lightweight robots, while a new generation of Intelligent Robots are entering our working and living environments, taking care of human-level tasks. Such robotic systems are becoming more and more important also in elderly healthcare assistance. Indeed, recent advancements in Artificial Intelligence (AI) and Robotics are fostering the diffusion of robotic agents with the capabilities needed to support both older adults and their caregivers in a variety of situations (e.g., in their homes, in hospitals, etc.).

Among many technological skills, the ability of representing and reasoning diverse kind of knowledge constitutes a key feature for allowing intelligent robotic assistants to *understand* the actual (and possibly time changing) needs of older persons as well as the status of the environment in which they are acting and infer new knowledge to adapt their behaviors and better assist humans. On the other hand, the need of supporting long-term monitoring and deploying personalized services for different users opens to the exploitation of sensor networks to gather information about the status of the assisted persons and their living environments. A Proper management of this information would allow an intelligent assistive robot to autonomously recognize the actual situation and determine which kind of assistance can be provided. New social robots are entering the market (e.g., Pepper by SoftBank Robotics) but they still lack advanced reasoning capabilities to provide well suited and effective impact in healthcare assistance, contributing in prolonging elderly independence as well as increasing their quality of life.

AI techniques constitute a key enabling technology for realizing personalized assistive services and enabling continuous monitoring and support of daily-home living of seniors. GiraffPlus, a research project [6] funded by the European Commission, is a concrete and successful example of the use of AI in such a context. GiraffPlus generated an integrated system composed by a sensor network and a telepresence robot aimed at supporting and monitoring the daily-home living of a senior person directly in his/her house. Several pilot studies have been made during this project [3] during which a telepresence robot (the Giraff) has been actually deployed in the house of people for several months. Among these, particularly relevant was the case of "Nonna Lea" who represented an ideal and inspiring user for the project.[1] This paper describes a follow-up research initiative, called KOaLa (*Knowledge-based cOntinuous Loop*), which introduces a semantic representation of environmental data and knowledge processing mechanisms to enhance the autonomy and proactivity of the GiraffPlus assistive robot (or Robin as nicknamed by "Nonna Lea"). The paper provides an overview of KOaLa and shows its assistive capabilities through a narrative of some everyday life situations that are typical to "Nonna Lea" and many other elderly people.

[1] https://youtu.be/9pTPrA9nH6E.

2 An Intelligent and Friendly Robot for "Nonna Lea"

There are many common situations in which a person may need personalized and dedicated assistance in order to successfully carry out and perform daily-living activities. This is especially true with seniors or persons that have cognitive and/or physical impairments with limited independence. Let us consider as an example, the story of "Nonna Lea", a 94-years old woman with physical impairments who is living alone in her house. These impairments complicate daily-living activities in her home. Diabetes forces "Nonna Lea" to constantly follow a dedicated therapy and strict dietary restrictions. Mobility impairments do not allow her to move nimbly and easily inside her house. She needs a walking stick to support her gait. "Nonna Lea" lives alone and her two sons work and live far away from her. Thus, "Nonna Lea" often feels alone and depressed because of the distance between her and her sons. In addition, "Nonna Lea" does not feel safe in going out from her house to meet friends due to her physical conditions. As a consequence, "Nonna Lea" spends most of her time alone, sitting on her sofa watching the TV or in front of a PC. In such a situation, also her sons are worried about the life conditions and health status of their mother. Their state of anxiety is further increased by the fact that they are not able to be present as they would in the daily life of their mother, because of the distance and related working commitments. In particular, they are seriously worried after an event that occurred some days ago when "Nonna Lea" fell inside her house and remained on the floor for several hours before being able to reach the telephone and alert someone.

"Nonna Lea" (and also her sons) cannot be left alone. An *intelligent* assistive robot is needed to support her daily-home living, mitigate her sense of isolation and therefore, enhance her quality life. Such a robot should provide services capable of continuously monitoring and supporting "Nonna Lea" directly at her home considering different aspects. For example, the assistive robot could remind the therapy and the dietary restrictions that "Nonna Lea" must follow. They can have a *real-time feedback* about the health status of their mother and intervene in case of need. For example, an assistive service can remind her sons of calling their mother after lunch in order to check whether she has actually taken the pills or not.

To address this challenging problem and provide a robotic agent with such envisaged assistive services, it is necessary to integrate different techniques and technologies. Artificial Intelligence, Internet of Things (IoT) and Robotics represent important research areas that deal with different but correlated problems. The recent advancements in these fields are producing robust and reliable solutions that have shown to be successful in many real-world applications. These techniques can play a key role in enhancing the quality of domestic care technologies. Our research objective is to realize the envisaged assistive service by integrating at different levels these technologies in order to realize an *intelligent and friendly social robot* capable of taking care of the daily-living of elderly directly at their home. Sensors and IoT technology provide the physical support needed to gather and *share* data about a domestic environment through sensor networks. A telepresence robot plays the role of *actuator* by interacting with a person inside his house and implementing all the functionalities needed to *actuate* the desired services like e.g., phone calls, voice interaction or audio message recording and reproduction. Finally, AI provides the capabilities needed to properly *interpret* and process sensor data coming from IoT devices, recognize activities and situations and coordinate a telepresence robot for actually supporting and interacting with the assisted person in a robust, safe and flexible way. These are exactly the challenging research objectives pursued by KOaLa.

3 KOaLa: Knowledge-Based Continuous Loop

GiraffPlus envisages an application context consisting of a mobile telepresence robot capable of autonomously interact with an older person through audio/text messages and gestures [7] as well as navigate the home environment. The robot is also endowed with videoconferencing functionalities that allow a user to communicate with a caregiver in the "external world" (e.g., a relative or a doctor). The robot is supposed to move inside a sensorized environment that can produce data about the status of the house as well as the status and activities of the user. The cognitive architecture of the robot must continuously process sensor data in order to understand the status of the person (with her specific needs) and the environment (its operative context) and, then, dynamically synthesize the actions needed to better support the user. The improvement introduced by KOaLa consists of the integration of a knowledge processing module, called the *KOaLa Semantic Module*, and a planning and execution module, called the *KOaLa Acting Module*. The integration of these two modules realizes a cognitive high-level control loop enhancing the capabilities of GiraffPlus. Figure 1 shows a conceptual representation of the envisaged cognitive architecture and highlights the different phases of the *control flow* which starts with the gathering of data from the sensor network and ends with the execution of actions in the environment.

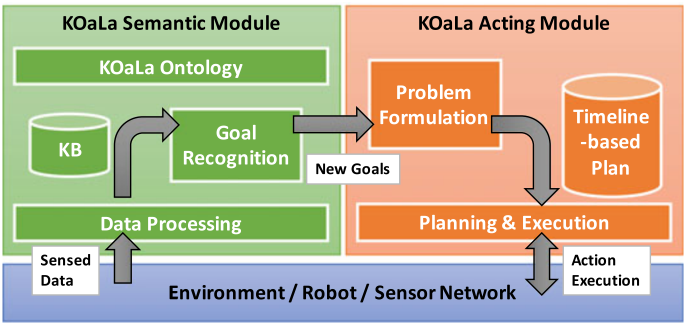

Fig. 1 Expanding the semantic and acting modules of the KOaLa *sense-reason-act* cycle

3.1 The Semantic Module

The *KOaLa Semantic Module* is responsible for interpreting data gathered from the sensor network and managing the resulting *knowledge*. This module relies on the *KOaLa Ontology* to provide sensor data with semantics and incrementally build an abstraction of the application context i.e., the *Knowledge Base* (KB). A *data processing mechanism* uses standard semantic technologies based on the Web Ontology Language (OWL) [1] to continuously refine the KB and infer additional knowledge (e.g., about user activities). Then, a *goal recognition process* analyzes the KB to identify specific *situations* that require a proactive "intervention" of the robot and generate high-level *goals* for the acting module.

3.1.1 The KOaLa Ontology

The KOaLa ontology has been defined by leveraging SSN [5] and DUL,[2] two stable and publicly available ontologies. It has been structured according to a context-based approach which characterizes the knowledge by taking into account different levels of abstraction and perspectives. Specifically, three levels (i.e. contexts) have been identified: (i) the *sensor context*; (ii) the *environment context*; (iii) the *observation context*. The *sensor context* characterizes the knowledge about the sensing devices that compose a particular environment as well as, their deployment and the properties they may observe. This context directly extends SSN to provide a more detailed representation of the different types of sensor that can compose an environment and the different types of property that can be observed. Leveraging this general knowledge, it is possible to dynamically recognize the actual monitoring capabilities as well as the set of *operations* that can be performed according to the types of sensor available and their deployment. The *environment context* characterizes the knowledge about the structure and physical elements that compose a home environment, and the deployment of sensors. This context models the different *physical objects* that are part of a *home environment*, their properties and the particular deployment of the sensors. Thus, this context provides a complete characterization of a domestic environment and the relate configuration of the sensor network. Finally, the *observation context* characterizes the knowledge about the *features* that can actually produce information in a given configuration as well as the *events* and the *activities* that can be observed through them. This context identifies the *observable features* of a domestic environment as the physical elements that are actually capable of producing information through the deployed sensors. Similarly, this context identifies the *observable property* as the properties of the observable features that can be actually observed through the deployed sensors. In this way, the KB can contextualize received observations according to the associated environmental information like e.g., the zone/area of the house data comes from or the type of object data refers to.

[2] http://www.loa-cnr.it/ontologies/DUL.owl.

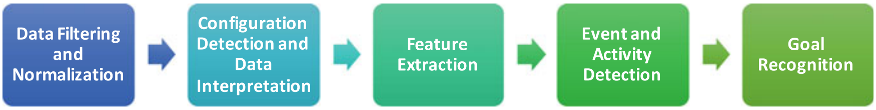

Fig. 2 Data processing pipeline for the knowledge inference and maintenance

3.1.2 Knowledge Processing

Given the semantics defined by the KOaLa ontology, a knowledge processing mechanism elaborates sensor data to incrementally build a KB. The pipeline depicted in Fig. 2 shows the main steps of this knowledge processing mechanism. The pipeline is composed by a sequence of reasoning modules each of which elaborates data and the KB at a different level of abstraction (i.e., ontological context) by means of a dedicated set of *inference rules*. Such rules define a semantics to link different ontological contexts in order to incrementally abstract data and infer additional knowledge.

The KB is initialized on a configuration specification which describes the structure of the domestic environment, the set of sensors available and their deployment. The *Configuration Detection and Data Interpretation* module generates an initial KB by analyzing the configuration specification. Such KB is then refined by interpreting (filtered and normalized) sensor data coming from the environment. The *Feature Extraction* module identifies the observable features of the environment and the related properties. It processes sensor data to infer *observations* and refine the KB accordingly. Finally, the *Event and Activity Detection* module analyzes inferred observations by taking into account the knowledge about the environment. Different inference rules detect different types of events and activities according to the particular set of features and properties involved.[3]

3.2 *The Acting Module*

The *KOaLa Acting Module* is responsible of planning and executing operations according to the events or activities inferred by the semantic module. These events are detected by a *Goal Recognition* module (GR) which is part of the pipeline shown in Fig. 2. GR is a key element of the envisaged cognitive architecture. It is in the charge of providing the link between the semantic and the acting modules of KOala. Specifically, it leverages the inferred KB to connect knowledge representation with planning. It can be seen as a background process that monitoring the KB to generate operations the GiraffPlus robot must perform. GR is the key feature of KOaLa to achieve *proactivity*. Operations that GR generates are modeled as *planning goals* the *problem formulation* process encodes into a planning problem specification. Such a

[3]The knowledge processing mechanism has been developed by means of the Apache Jena software library (https://jena.apache.org/).

problem specification is then given to a timeline-based planner which synthesizes a plan describing the sequences of operations needed to support the user. Then, a *planning and execution* process leverages the timeline-based approach [4] and the PLATINUm framework [9] to continuously execute and refine the plan according to the feedbacks received from the environment.

3.2.1 Planning Model Configuration and Robot Integration

The set of goals the Acting Module can deal with depends on the particular configuration of the environment and the available *capabilities* of the deployed sensors. A *planning model* encapsulates the knowledge about the capabilities of the *controllable elements* that compose the environment and how such capabilities can be coordinated to realize the desired *assistive functionalities*. A planning model must describe the primitive capabilities of an assistive robot like e.g., make a call, send a message or move to a particular location, as well as the primitive capabilities of the available sensors like e.g., turn on, turn off a sensor or set a particular configuration on a sensor. Goals represent high-level assistive functionalities that can be performed by properly controlling and coordinating these primitive capabilities. The planning model can be dynamically configured by analyzing the "static" knowledge about the domestic environment. Figure 3 shows the configuration process pipeline which generates a planning model description by means of mechanisms similar to those described in [2] for a reconfigurable manufacturing system.

The *Configuration Detection* step extracts the configuration of the environment from the KB to identify the set and types of sensor and their deployment as well as information about the capabilities of the GiraffPlus robot. The *Primitive Capability Extraction* further analyzes these elements in order to extract the *primitives* that determine the low-level functionalities available. Two types of primitives can be identified: (i) *environment primitives*; (ii) *robot primitives*. The *environment primitives* represent the capabilities of the elements of the environment that can be controlled. They characterize the controllable elements of the environment and the operations that can be performed with them. It is important to note that they do not model directly the sensors of the environment, but rather they model the elements that can be controlled through the deployed sensors (i.e., the observable features). For example a sensor deployed on the socket where a TV is plugged in can be used to turn off and turn on the TV. In such a case, the TV becomes *controllable* and the related *turn on* and *turn off* capabilities are part of the *environment primitives*. Similarly, the *robot primitives*

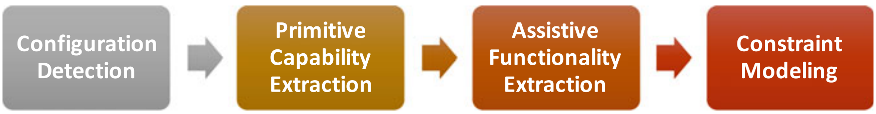

Fig. 3 Configuration pipeline for the generation of a timeline-based planning and acting model

represent the capabilities of the assistive robot available i.e., the GiraffPlus robot. They model the *functional layer* of the robot which provides the basic capabilities that can be used to perform assistive functionalities. For example, the GiraffPlus robot provides *navigation capabilities* that can be used to move the robot inside the domestic environment, *messaging capabilities* that can be used to send/receive messages to/from patient's relatives, *video-calling capabilities* that can be used to make calls or receive calls with or from doctors and patient's relatives. All these functionalities compose the *robot primitives*. The *Assistive Functionality Extraction* step extracts the high-level assistive functionalities the system can perform. This step identifies the types of assistive task (i.e. planning goals) the goal recognition process could generate by analyzing the KB. Finally, the *Constraint Modeling* step finalizes the control model by linking assistive functionalities to the environment and robot primitives. The result of this pipeline is a timeline-based planning model characterizing the high-level assistive functionalities the GiraffPlus robot can perform as well as the operational constraints the system must satisfy to realize them.

3.2.2 Planning and Execution with PLATINUm

The planning and execution capabilities of the acting module rely on a novel timeline-based framework, called PLATINUm [9]. PLATINUm complies with the formal characterization of the timeline-based approach proposed in [4] which takes into account *temporal uncertainty*, and has been successfully applied in real-world manufacturing scenarios [8] recently. Broadly speaking, a timeline-based model is composed by a set of *state variables* describing the possible temporal behaviors of the domain features that are relevant from the control perspective. Each state variable specifies a set of *values* that represent the states or actions the related feature may assume or perform over time. Each *value* is associated with a *flexible duration* and a *controllability tag* which specifies whether the value is controllable or not. A *state transition function* specifies the valid temporal behaviors of a state variable by modeling the allowed sequences of values (i.e., the transitions between the values of a state variable). State variables model "local" constraints a planner must satisfy to generate valid temporal behaviors of single features of the domain i.e., valid *timelines*. It could be necessary to further constrain the behaviors of state variables in order to coordinate different domain features and realize complex functionalities or achieve complex goals (e.g., perform assistive functionalities). A dedicated set of rules called *synchronization rules* model "global" constraints that a planner must satisfy to build a valid plan. Such rules can be used also to specify *planning goals*.

The pipeline described in Fig. 3 produces a timeline-based model which complies with the above description. The state variables model the primitives of the environments defined by the *Primitive Capability Extraction* step and the assistive functionalities defined by the *Assistive Functionality Extraction* step of the pipeline. Given such a model, a PLATINUm planner synthesizes a set of timelines each of which represents an envelope of valid temporal behaviors of a particular state variable. These timelines allow the GiraffPlus robot to perform the desired assistive tasks.

Then, an PLATINUm executive carries out the timelines by temporally instantiating the associated sequences of values, called *tokens*. Namely, an executive decides the exact *start time* of the tokens composing the timelines of the plan. In general, the actual execution of these tokens cannot be controlled by the executive which must dynamically adapt the plan according to the *feedbacks* received during execution. For example, the actual time the GiraffPlus robot needs to navigate the environment and reach a particular location cannot be decided by the planner or the executive. Indeed, the navigation can be slowed-down by obstacles along the path and therefore the actual duration of a *navigation operation* is known only when the executive receives a feedback about its completion.

4 KOaLa in aid of “Nonna Lea”: An Happy Ending Story?

Going back to “Nonna Lea” and her carers, KOaLa and the cognitive services described above would allow Robin, our GiraffPlus robot, to better support “Nonna Lea” through a more proactive and autonomous interaction. We have paved the way to allow Robin to autonomously understand what “Nonna Lea” is doing and what is happening inside her house and proactively make decisions accordingly.

“Nonna Lea’s” house is a single floor apartment composed by a living room, a kitchen, a bathroom, a bedroom and a central corridor connecting all the rooms with the entrance. There are many sensors that have been installed to track activities and events inside the house. Each window and the entrance door have been endowed with a sensor to check whether they are open or close. There is (at least) one sensor for each room to track temperature and luminosity and detect motions. Finally, there are additional sensors to track the usage of electronic devices like e.g., the TV, the oven or the microwave. In addition to these environmental sensors, there are other sensing devices that track physiological parameters of “Nonna Lea” like blood pressure, heart rate, glucose level, etc. All these sensing devices provide a rich and heterogeneous set of data that Robin can continuously analize through KOaLa to recognize activities that “Nonna Lea” is performing, or events/situations affecting the state of the house or the health of “Nonna Lea”. Below there are some examples about typical situations characterizing the daily-home living of a person in need of assistance. These examples want to point out the contribution and the objectives of the enhanced assistive services of Robin:

- *The sensor network detects some activities in the kitchen of the house*. The information gathered from sensors is saying that *someone* is moving inside the kitchen, the TV is on, the luminosity is *high* and also that the temperature close to the flame is a bit higher than usual. Given this information and given the time, Robin understands that “Nonna Lea” is *cooking* and therefore it plans to move towards the kitchen to remind the dietary restrictions she must follows. Then, Robin plans to remind “Nonna Lea” to take her pills for the therapy in forty-five minutes which is the time she usually takes to complete the meal. In addition, Robin plans to send a message to her sons for reminding to call their mother in one hour and a half in order to check whether she has actually taken the pills or not.

- *The sensor network detects some activities in the living room of the house*. The information gathered from sensors is saying that *someone* is sitting on the sofa, the TV is on and that the luminosity of the room is *high*. According to these information Robin understands that "Nonna Lea" is *watching the TV* and therefore it plans to move inside the living room and inform "Nonna Lea" about the TV programs of the day. In addition, Robin notices that "Nonna Lea" has neither made any calls to nor received calls from her sons today and therefore it plans to suggest to "Nonna Lea" to call her sons before going to sleep.
- *The sensor network detects some activities in the bedroom of the house*. The information gathered from sensors is saying that *someone* is moving inside the bedroom and that the light inside the room is on. Robin checks the time and recognizes that it is the time at which "Nonna Lea" usually goes to bed. However, it detects that the window inside the kitchen is open and that the light of the bathroom is on. Thus, Robin plans to move towards the bedroom in order to alert "Nonna Lea" about the fact that the window must be closed and that the light in the bathroom must be turned off before going to bed. After a while, the information gathered from sensors in the bedroom says that *someone* is laying on the bed and that the luminosity of the room is *low*. Robin understands that "Nonna Lea" is *sleeping* and decides to notify her sons about this. In addition, Robin notices that the temperature inside the bedroom is a bit higher than the *ideal temperature* for a good sleep. Thus, it decides to cool down a bit the temperature of the room by *controlling* either the air-conditioner or the heater according to season. The day after, Robin detects that "Nonna Lea" is still *sleeping* at the typical time she wakes up. Thus, Robin plans to send a message to her sons about this unusual behavior within thirty minutes if she does not wake up before.

Such scenarios show ordinary life situations of a senior person like "Nonna Lea" and some roles that Robin, with the help of KOaLa, can play to support her living at home. In particular, these scenarios show that KOaLa, through the combination of simple inference rules like e.g., *someone is moving inside the kitchen* and *the temperature close to the flame is higher then usual*, can endow Robin with the capability of autonomously reasoning on the state of the environment, inferring *complex* situations and dynamically triggering *goals* accordingly. A first set of inference rules has been developed to realize a "stratified" reasoning mechanism capable of abstracting sensor data and inferring situations concerning the status of the environment. Currently an extended set of rules is under development to realize the *goal triggering* mechanism needed to proactively link knowledge reasoning to planning and acting.

5 Conclusions

This paper presented an AI-based cognitive architecture which integrates sensing, knowledge representation and automated planning techniques to constitute a high-level control loop to enhance proactivity features of an assistive robot designed to support an older person in his/her daily routine. A semantic module leverages a dedicated ontology to build a KB by properly processing data collected from a sensor network installed in the environment. An acting module takes advantage of the timeline-based planning approach to control robot behaviors. A goal triggering process acts as a bridge between the two modules and provides the key enabling feature to endow the robot with suitable proactivity levels. At this stage, some tests have been performed to show the feasibility of the approach. Further work is ongoing to enable more extensive integrated laboratory tests and better assess performance and capabilities of the overall system. Future work will also investigate the opportunity to integrate machine learning techniques to adapt the behavior of the assistive robot to specific *daily behaviors* of different targeted people.

References

1. Bechhofer S (2009) OWL: web ontology language. Springer US, Boston, MA, pp 2008–2009
2. Borgo S, Cesta, A, Orlandini A, Umbrico A (2016) A planning-based architecture for a reconfigurable manufacturing system. In: The 26th international conference on automated planning and scheduling (ICAPS)
3. Cesta A, Cortellessa G, Fracasso F, Orlandini A, Turno M (2018) User needs and preferences on AAL systems that support older adults and their carers. J Ambient Intell Smart Environ 10(1):49–70
4. Cialdea Mayer M, Orlandini A, Umbrico A (2016) Planning and execution with flexible timelines: a formal account. Acta Inform 53(6–8):649–680
5. Compton M, Barnaghi P, Bermudez L, García-Castro R, Corcho O, Cox S, Graybeal J, Hauswirth M, Henson C, Herzog A, Huang V, Janowicz K, Kelsey WD, Phuoc DL, Lefort L, Leggieri M, Neuhaus H, Nikolov A, Page K, Passant A, Sheth A, Taylor K (2012) The SSN ontology of the W3C semantic sensor network incubator group. Web Semant Sci Services Agents World Wide Web 17(Supplement C):25–32. http://www.sciencedirect.com/science/article/pii/S1570826812000571
6. Coradeschi S, Cesta A, Cortellessa G, Coraci L, Gonzalez J, Karlsson L, Furfari F, Loutfi A, Orlandini A, Palumbo F, Pecora F, von Rump S, Štimec A, Ullberg J, Ötslund B (2013) GiraffPlus: combining social interaction and long term monitoring for promoting independent living. In: The 6th international conference on human system interactions (HSI), pp 578–585
7. Cortellessa G, Fracasso F, Sorrentino A, Orlandini A, Bernardi G, Coraci L, De Benedictis R, Cesta A (2017) Enhancing the interactive services of a telepresence robot for AAL: developments and a psycho-physiological assessment. In: Cavallo F, Marletta V, Monteriù A, Siciliano P (eds) Ambient assisted living. Springer International Publishing, Cham, pp 337–357
8. Pellegrinelli S, Orlandini A, Pedrocchi N, Umbrico A, Tolio T (2017) Motion planning and scheduling for human and industrial-robot collaboration. CIRP Ann Manuf Technol 66:1–4
9. Umbrico A, Cesta A, Cialdea Mayer M, Orlandini A (2017) PLATINUm: a new framework for planning and acting. In: AI*IA 2016 advances in artificial intelligence: XVth international conference of the Italian Association for Artificial Intelligence, Genova, Italy, 29 Nov–1 Dec 2016, Proceedings. Springer International Publishing, pp 508–522

Part II
Enabling Technologies and Assistive Solutions

Age-Friendly City and Walkability: Data from Observations Towards Simulations

Andrea Gorrini, Luca Crociani, Giuseppe Vizzari and Stefania Bandini

Abstract The use of agent-based simulation systems can provide an innovative framework to support the design of age-friendly cities, focusing on walkability assessment. This is aimed at managing the complex interaction between elderly pedestrians and vehicles at zebra crossings, in which the compliance to traffic norms plays a fundamental role. The data of an observation performed at a non-signalized intersection are presented to provide useful insights for supporting the future development of agent-based models. Results focus on drivers' compliance to crossing pedestrians, describing potentially conflictual interactions among heterogeneous agents. The discussion closes with the potential applications of the collected data set for modelling the phenomenon.

Keywords Ageing · Pedestrian · Crossing behavior · Agent-based modeling

1 Introduction and Related Work

Agent-based modelling and simulations of pedestrian circulation dynamics have been increasingly reported in the technical and scientific specialized literature. Scientific communities started to incorporate agent-based systems to improve the

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expressiveness of traditional approaches and to simulate the complex behaviour of people and traffic in outdoor and indoor urban scenarios. The intrinsically dynamical properties of agent-based models offer a research framework to face the complexity of the future cities [8], offering new possibilities to incorporate and integrate the growing presence of autonomous entities/artefacts both physical (e.g. autonomous vehicles) and virtual (e.g. data coming from heterogeneous sources: social media, distributed sensors etc.).

The development of agent-based models and systems requires to check the quality, robustness and plausibility of the obtained simulations against real data, in order to tackle decision making problems related to urban mobility. Recent literature contains a wide range of methods and study cases supporting this view [1]. The aim of this paper is to present a real case of data collection performed to collect useful insights about pedestrian-vehicles interactions at non-signalized intersections, supporting the future development of a heterogeneous agent-based system to simulate the phenomenon.

From pioneering works, several models have been developed and applied for the simulation of pedestrian and vehicular dynamics, including both Cellular Automata and particles models [3]. These two approaches have, separately and independently, produced a significant impact, yet efforts characterized by an integrated model considering the simultaneous presence of vehicles and pedestrians are not as frequent or advanced. With the notable exception of [7], most efforts in this direction are relatively simplistic, narrow (i.e. targeting extremely specific situations), homogeneous for the simulated entities, and they are often not validated against real data [5, 13]. In this framework, we consider the possibility to model and simulate the complex aspect of drivers' compliance to pedestrian yielding rules in the context of interactions among heterogeneous agents, and its implications on self-organization dynamics.

2 Observation Results

The video-recorded observation was performed in 2015, at a zebra crossing in the city of Milan (Italy). The scenario of the observation has been selected by means of a preliminary analysis which was aimed at crossing the geo-referred information related to the socio-demographic characteristics of the inhabitants of Milan and the localisation of road traffic accidents. Results showed that the chosen residential area is characterised by a significant presence of elderly inhabitants and an high number of pedestrian/car accidents involving elderlies pedestrians in the past years. See [6] for a detailed description of the results of the observation.

A sample of No. 812 crossing episodes has been identified from the video (about one hour and ten minutes), considering only the cases in which one vehicle directly interacted with one or more adult and elderly pedestrians (see Fig. 1). At non-signalized intersections traffic laws require drivers to yield those pedestrians who are already occupying the zebra, but also those who are localized nearby or in correspondence of the curb waiting to cross. The level of compliance of drivers to

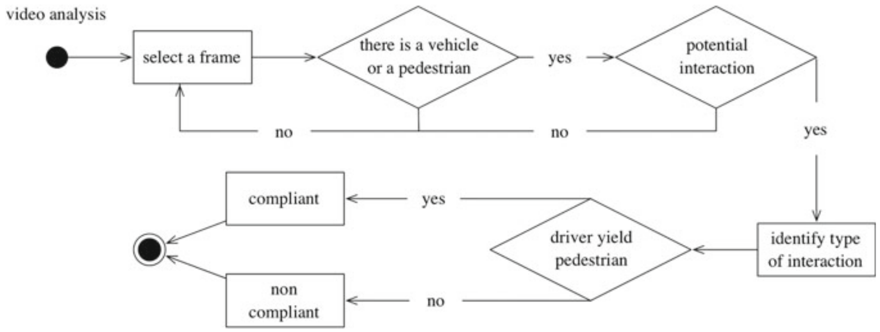

Fig. 1 The work flow for selecting the sample of crossing episodes from the video images

Table 1 Results about the drivers' compliance to the right-of-way of crossing pedestrians

Types of pedestrian/vehicle interaction	Compliant	Non-compliant
Ped. approaching/waiting/crossing from the near side-walk	191 (46.14%)	223 (53.86%)
Ped. approaching/waiting/crossing from the far side-walk	230 (57.69%)	168 (42.21%)

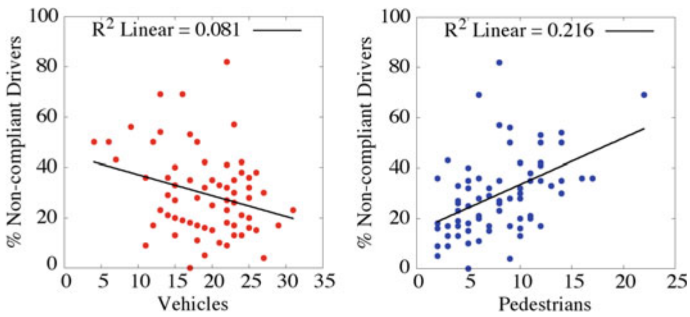

Fig. 2 The relation between non-compliant drivers and the number of vehicles (left) and crossing pedestrians (right) in the observed intersection. Each data refers to one minute of the video

pedestrians' right-of-way have been estimated considering the position of crossing pedestrians with respect to the curb (i.e. pedestrian about 1.5 m far from the curb, waiting at the curb, crossing on the zebra) and to the direction of travel of vehicles (i.e. pedestrian from the near or the far side-walk).

Preliminary analyses on results (see Table 1) showed that 48% of the total number of crossing episodes was characterized by non-compliant drivers with crossing pedestrians from the two side-walks. A multiple linear regression (see Fig. 2) was calculated to predict the percentage of non-compliant drivers per minute based on: (i) number of vehicles per minute (18.89 veh/min in average; $p = 0.007$, significant predictor) and (ii) number of crossing pedestrian per minute (8.01 ped/min in average; $p < 0.001$, significant predictor). A significant regression equation was found [$F(2,70) = 14.526$, $p < 0.001$], with R^2 of 0.293. This demonstrates that the non-compliance of drivers is negatively determined by traffic conditions and positively determined by pedestrian flows on zebra. Despite the low level of drivers' compliance, no accidents or risky situations have been observed, thanks to the self-organization of the system based on pedestrians' yielding/collaborative behaviour to approaching cars.

3 Discussion

The results showed in the previous section represent applicable insights towards the extension of a model for the analysis of pedestrian crossings [2, 4], considering potentially conflictual interactions among heterogeneous agents. As shown in Fig. 3a, the model is based on the integration of two independent models for the simulation of vehicles, moving in continuous lanes, and pedestrians, moving in a 2-dimensional discrete environment. The two environments are superimposed, and car-agents perceive pedestrian-agents while they are crossing or in the nearby of the curb (grey cells in Fig. 3a) and vice-versa. The interactions between them are described in Fig. 3b. Pedestrian-agents consider the speed and distance of cars to avoid collisions, giving way to non-compliant vehicles. The compliance of car-agents is mainly influenced

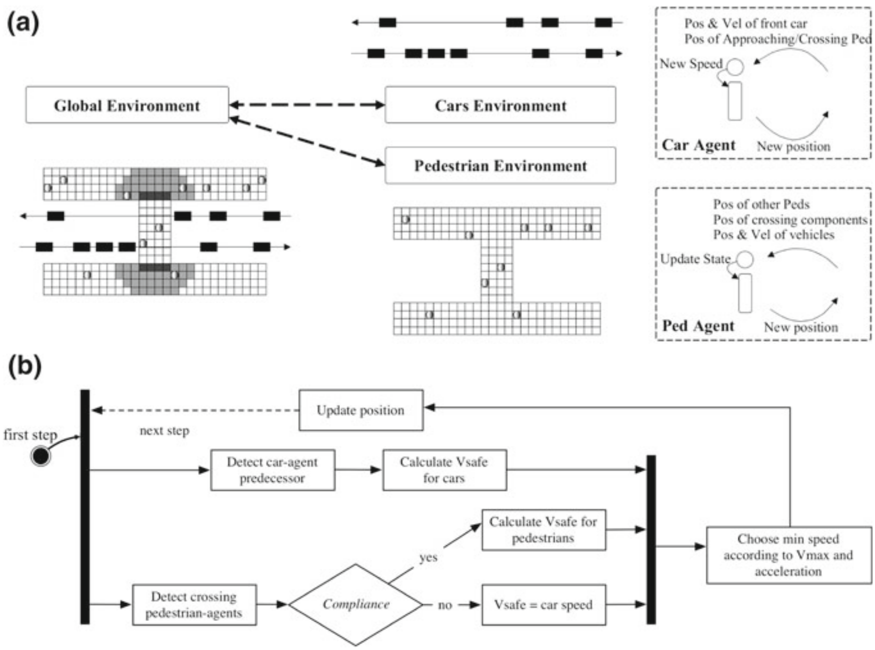

Fig. 3 A description of the environment and the two classes of agents (**a**). Car-agents life-cycle considering their possible non-compliance with respect to the presence of pedestrian-agents (**b**)

by the necessary braking distance. On the other hand, according to a fixed probability that will be set on the collected data on compliance, car-agents can deliberately avoid to stop even if the braking distance is sufficient, requiring pedestrian-agents to yield.

The potential applications of such research are related to the possibility to test the effect of non-compliance on emergent observables like: near accident situations, exposure to accidents, traffic capacity of the road and Level of Service [9]. This is totally in line with the concept of "Age-friendly City" proposed by the World Health Organization [10]: a framework for urban development encouraging an active ageing of the population. The investigation of innovative solutions to enhance the level of walkability of urban areas for the elderly [11] is becoming, in fact, a mandatory requirement for the design of Age-friendly Cities. In addition, despite the specific context of the performed observation, this kind of research is also potentially relevant to test the effects of alternative traffic management solutions (e.g., traffic light systems, speed limits) and to complement studies on autonomous vehicles [12] in order to evaluate future transportation scenarios in Smart Cities.

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References

1. Campanella M, Hoogendoorn S, Daamen W (2014) Quantitative and qualitative validation procedure for general use of pedestrian models. In: Pedestrian and evacuation dynamics 2012. Springer, pp 891–905
2. Crociani L, Vizzari G (2014) An integrated model for the simulation of pedestrian crossings. In: Was J, Sirakoulis GC, Bandini S (eds) Cellular automata—Proceedings of 11th international conference on cellular automata for research and industry, ACRI 2014, Krakow, Poland, 22–25 Sept, 2014. Lecture notes in computer science, vol 8751. Springer, pp 670–679
3. Duives DC, Daamen W, Hoogendoorn SP (2013) State-of-the-art crowd motion simulation models. Transp Res Part C Emerg Technol 37:193–209
4. Feliciani C, Crociani L, Gorrini A, Vizzari G, Bandini S, Nishinari K (2017) A simulation model for non-signalized pedestrian crosswalks based on evidence from on field observation. Intell Artif 11(2):117–138
5. Godara A, Lassarre S, Banos A (2007) Simulating pedestrian-vehicle interaction in an urban network using cellular automata and multi-agent models. In: Traffic and granular flow'05, pp 411–418
6. Gorrini A, Vizzari G, Bandini S (2016) Towards modelling pedestrian-vehicle interactions: empirical study on urban unsignalized intersection. arXiv:1610.07892
7. Helbing D, Jiang R, Treiber M (2005) Analytical investigation of oscillations in intersecting flows of pedestrian and vehicle traffic. Phys Rev E Stat Nonlinear Soft Matter Phys 72(4)
8. Masthoff J, Vasconcelos WW, Aitken C, Correa da Silva F (2007) Agent-based group modelling for ambient intelligence. In: AISB symposium on affective smart environments, Newcastle, UK
9. Milazzo JS II, Rouphail NM, Hummer JE, Allen DP (1999) Highway capacity manual 2000. Transp Res Rec J Transp Res Board 1678(1):25–31
10. Organization WH (2007) Global age-friendly cities: a guide. World Health Organization
11. Speck J (2013) Walkable city: how downtown can save America, one step at a time. Macmillan

12. Tachet R, Santi P, Sobolevsky S, Reyes-Castro LI, Frazzoli E, Helbing D, Ratti C (2016) Revisiting street intersections using slot-based systems. PLoS ONE 11(3):1–9. https://doi.org/10.1371/journal.pone.0149607
13. Zeng W, Nakamura H, Chen P (2014) A modified social force model for pedestrian behavior simulation at signalized crosswalks. Procedia Soc Behav Sci 138:521–530

A Novel Tele-Medicine System to Improve Therapy Monitoring in Chronic Respiratory Diseases

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Abstract In this work we proposed a novel tele-medicine system called Smart Breath Network (SBN) with the perspective to improve the life of patients affected by a well-known respiratory disease called Chronic Obstructive Pulmonary Disease (COPD). The main therapy for COPD is home-assisted ventilation that requires frequent home intervention by specialized hospital staff in order to adjust dispensing and to verify the effectiveness of the therapy. Moreover, healthcare services need to improve the care of patients with difficult access to services, particularly those in rural or remote areas without sustaining high costs of service maintenance. The SBN system tries to fill the gap between healthcare services, that need to take care of a growing number of home-assisted COPD patients due to the today's alarming air pollution. The SBN network gathers all patient's respiratory data from Smart Breath Analyzers (SBAs) devices that are low-cost, simple to use, compact-sized devices that fit to almost any ventilator with bi-tube capabilities.

Keywords Smart healthcare · Tele-medicine · Breath analysis · COPD · Gas sensing

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1 Introduction

Despite years of continuous research towards diagnostic and monitoring technologies, many issues regarding *Chronic Obstructive Pulmonary Disease* (COPD) as an early diagnosis and effectiveness of therapy to recover from acute exacerbations, are still critical points [1]. Home mechanical ventilation is applied to patients with COPD requiring custom dispensing and this can be obtained only by frequent home interventions by specialized hospital staff. On the other hand, healthcare services of industrialized countries still need improving the care of patients with difficult access to services, particularly those in rural or remote areas, without sustaining high costs of health-care maintenance. Hence, in order to improve monitoring of COPD ventilation therapies at home and to reduce health-care costs, we introduced a tele-medicine system called *Smart Breath Network* (SBN), a star-network system strongly based on *Internet-of-Things* paradigm. Leaf nodes of the network, called Smart Breath Analyzers (SBAs), are based on a relatively new concept, the analysis of exhaled air from patients that could be useful as a new non-invasive, safe and fast tool in technologies supporting respiratory diseases screening practices [2, 3].

2 Smart Breath Analyzer (SBA)

As stated before, the leaf node of the SBN network is the SBA device, that is connected to the expiratory path of breathing circuit of the mechanical ventilator, in between the patient's and the expiratory port of the ventilator; the connection was achieved in a straightforward manner, that is through two T-connections. This choice allows the device to be easily used as universal external module for almost any commercial ventilator with a bi-tube capability. Figure 1 shows a photography of a SBA device taken during a preliminary laboratory test; the device is connected to a typical ventilator used in the clinical practice.

From the electrical point of view, the SBA device is made as a modular device to improve design flexibility. In order to make use of the latest market available sensors, shipped with *Surface Mount Device* (SMD) packages, special considerations were taken to carefully design a gas chamber sitting directly, as a sealed lid, on the sensors module's custom *Printed Circuit Board* (PCB) respecting gas-tight condition.

The overall hardware architecture of the SBA device, with all sensors involved, is depicted in Fig. 2.

On-board sensors provide signals of CO_2 and O_2 concentrations, temperature and relative humidity. In addition the SBA has a small e-nose composed by an array of 3 MOX sensors to detect changes in Volatile Organic Compounds (VOCs), CO and NO_X. In order to keep device's costs and simplicity as low as possible, Arduino MEGA 2560 was chosen as main microcontroller board and the Arduino Ethernet Shield 2 was adopted to enable data communication over TCP/IP protocol. In order to allow the use of the SBA device in actual clinical practices, data security over

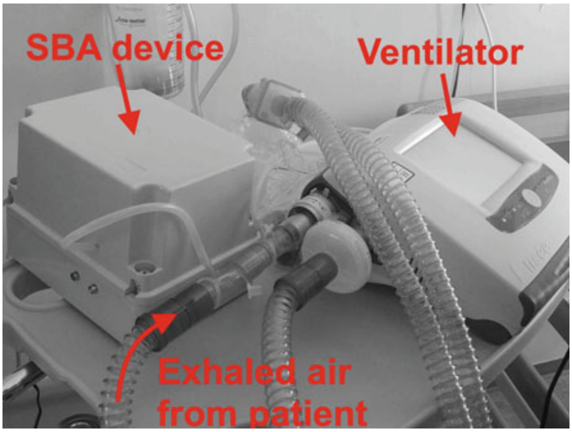

Fig. 1 A SBA device connected to a ventilator during a laboratory preliminary test

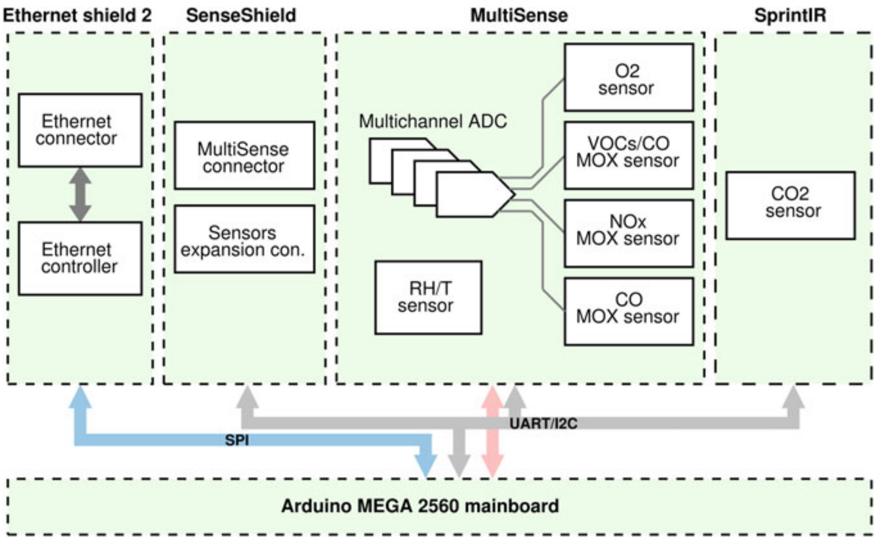

Fig. 2 Overall hardware architecture of the SBA device

Internet must be introduced in the communication and this constitutes a research active branch of this project still in progress. Finally the SBA device exposes two status LED remotely controlled by server.

3 Overall Network Architecture

Every single SBA device is part of the Smart Breath Network, a star network made by a central cloud server and SBA devices connected to some patient's ventilators located in a specific territory area. Careful considerations about data protocol mechanism were carried out during the firmware development stage: two of the most popular protocols for IoT data-exchange are *MQTT* and *HTTP*. Since in most cases patients houses are not provided of ADSL connection, the only way the SBAs have to connect to the central server is the 3G network, hence, a system requirement is to choose a lightweight protocol for sending data. The choice was made on MQTT protocol because, according to measurements in 3G networks, throughput of MQTT is 93 times faster than HTTP [4]. Moreover, MQTT has a very short message header and the smallest packet message size is only of 2 bytes, whereas HTTP formats messages with lengthy headers and text. As remote cloud server, the choice fell on *ThingsBoard*, a relatively new and open-source IoT platform for data collection, processing, visualization and device management. Figure 3 depicts the overall SBN network architecture. Current activity of this research project regards the development of a real-time processing of the collected data on the server side. By using of control charts-based algorithms, the system will automatically infer about the exacerbation of the COPD and will control the effectiveness of the home therapy. In the case of exacerbation, an alert can be sent to both the SBA device and to the hospital staff.

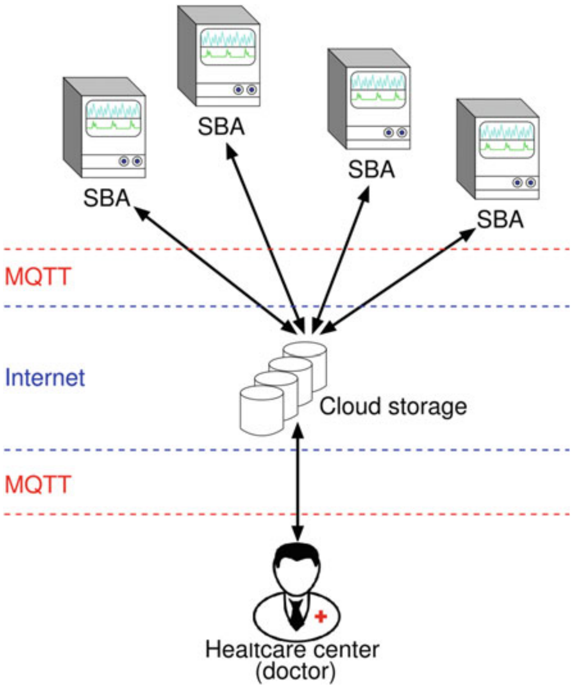

Fig. 3 Smart Breath Network overall architecture

4 Conclusions

A tele-medicine system, called Smart Breath Network (SBN) was designed, realized and verified in laboratory field. This star-based network system has the aim to fill the gap between healthcare services and COPD patients that relies on home-assisted mechanical therapy to cope with the disease. The leaf nodes of the network are the Smart Breath Analyzers (SBAs) devices, modular devices composed by a bundle of various gas sensors, a microcontroller module and finally a communication module. The SBA devices are connected to patient's ventilator to analyze the exhaled air from the patient. The system aims also to be a progress in the field of Ambient Assisted Living (AAL) because of his double aim: improve the life of home-assisted COPD patients and reduce the related costs of healthcare services.

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References

1. Dixon LC, Ward DJ, Smith J, Holmes S, Mahadeva R New and emerging technologies for the diagnosis and monitoring of chronic obstructive pulmonary disease: A horizon scanning review
2. Mathew TL, Pownraj P, Abdulla S, Pullithadathil B (2015) Technologies for clinical diagnosis using expired human breath analysis. Diagnostics 5:27–60
3. Amann A, Miekisch W, Schubert J, Buszewski B, Ligor T, Jezierski T, Pleil J, Risby T (2014) Analysis of exhaled breath for disease detection. Annu Rev Anal Chem 7:455–482
4. Serozhenko M. MQTT vs. HTTP: which one is the best for IoT? Medium.com

The Diabesity Care Project: Diabetes Integrated Monitoring System for Self-care Empowering

Paolo Casacci, Massimo Pistoia and Gianfranco Borrelli

Abstract According to the latest WHO estimates, today, about 50 million people in Europe suffer from diabetes, a disease which the UN have defined as a serious public health problem for the planet, probably destined to worsen in the future. Diabetes is cause for a multiplicity of health complications. Those are mainly related to retinopathy, coronary artery disease, that is, risk of myocardial infarction, and lower limb diabetic complication, more commonly known as "Diabetic Foot" caused by peripheral neuropathy and vasculopathy. It is therefore of fundamental importance for the diabetic patient to perform an accurate and constant monitoring of all those parameters that are of major clinical interest for the disease (blood glucose, creatinine, PA, FC, ECG, dry skin evaluation, alteration of blood pressure in the lower limbs). This, not only to keep the current disease under control, but above all in the perspective of a prevention process from further complications. The Diabesity Care Project intends to implement an integrated system that uses innovative materials (tissues) and multi-sensory platforms for continuous and minimally invasive monitoring of the health status of the diabetic patient and for the prevention of the conditions that cause the diabetic foot problem. This paper describes the work planned for the project, that is still under development at the present time.

Keywords Diabetes · Telemedicine · Prevention

1 Introduction

Diabetes is now one of the major social challenges for the economies in the developing world. In order to foster a process of self-health management and therefore of prevention of further complications, it is of fundamental importance for the diabetic

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patient to carry out an accurate and constant monitoring of the parameters of clinical interest in the pathology, while at the same time to adopt a suitable diet to reduce the risk of obesity. Monitoring of the health status of the lower limbs requires special care, due to complications, more commonly known as "Diabetic Foot" caused by peripheral neuropathy and vasculopathy that represents one of the most common and impactful side effects of the pathology.

In this context, the idea came out for an integrated system that uses innovative materials (fabrics) and multi-sensory platforms. The Diabesity Care Project intends to implement a hardware and software system that uses the following innovative tissues and platforms for continuous and minimally invasive monitoring of the health status of the diabetic patient and for the prevention of the conditions that cause the diabetic foot problem:

a. an antibacterial engineered sock [1] produced with nano-silver and containing yarn electronic devices aimed at remote monitoring of parameters of clinical interest for diabetes;
b. smart wearable, technologically advanced sensors for the detection of blood sugar in a poorly invasive way;
c. a miniaturized molecular device, able to detect the chemical composition and the quality of food, in order to monitor the nutrition of the diabetic subject;

Starting from the experience and research activities that guided previous projects aimed at the development of integrated ICT platforms for remote monitoring and assistance of fragile users, the work meant to extend them with a solution that incorporates new features specifically designed for diabetic patients.

As a collateral effect, the project also intended to promote the development of technical and scientific skills, experimentation activities, opportunities for industrial partnerships and research, as well as growth and competitiveness, of various public and private actors, including end users, in compliance with the now recognized European quadruple helix (PPPP). This goal was facilitated by the fact that Diabesity Care was born under the aegis of the InnovAAL public-private aggregation. InnovAAL promotes the development, testing and validation of innovative technologies and services for the Ambient Assisted Living (AAL) and plays a role as promoter and catalyst of research, bringing together the skills of participating companies, research organizations, and other external subjects, such as spin-offs and start-ups. Moreover, InnovAAL promotes systemic actions in the Apulia Region and leads an ENoLL[1]-member Living Lab called InnovAALab, which counts several interconnected pilot sites. Therefore, InnovAALab constituted the catchment area for the direct involvement of users and patients in the project, since the design phase up to the demonstration and validation phase of products and services.

[1]The European Network of Living Labs (ENoLL) is the international federation of benchmarked Living Labs in Europe and worldwide.

2 Study and Research

As concerns methodologic activities, in the initial phase of the project all partners, in close collaboration, proceeded to the study and definition of the requirements of the system to be developed. Alongside, the study and definition of the system architecture progressed with particular attention to the functional requirements and to the architectural technological specifications necessary for the implementation of the experimental settings envisaged. A thorough analysis of the application scenario of the "Diabesity care" system was performed (regulatory framework, actors, roles, workflows, etc.) and the relevant clinical aspects related to diabetes were defined. Technologies at the state of the art for the implementation of functional requirements and system architecture were identified and analyzed, evaluating all their respective strengths and weaknesses. The project team completed the co-design of custom system user interfaces, based on needs of the different categories of users (patients, doctors, caregivers) and on the acceptability requirements and usability of the system by the end-user, in line with the principles of "User Centered Design (UCD)".

Subsequently, the project leader partner Liferesult defined methods of data acquisition and patterns of data centralized management. Data are collected, conditioned, stored and managed on the OMNIACARE software platform. OMNIACARE is a hardware/software system designed for the social welfare and healthcare. It provides tools to both operators providing assistance and the patients. Its main objective is to improve the quality of life for those who need special attention in the daily activities and those who, day by day, take care of them. The system is aimed to users who do not suffer from serious diseases, have discrete mobility capabilities and are self-sufficient in daily activities, but who may find themselves in difficult situations and may need support. To promote the independence of vulnerable people and to help them having an independent life, as long as possible in their own home, the system makes use of advanced technologies that allow to perform a continuous monitoring of the health state of the patients. Thanks to the system, the caregivers are able to check the patient's situation, receiving alerts in case of critical situations, and to provide remote assistance by communicating directly with patients. The OMNIACARE system is modular, and each element carries out certain specific functions, so that the system can adapt itself to different situations and environments in a dynamic manner. It is therefore possible to implement a higher or lower number of features, using or discarding specific elements without compromising the overall operation of the system in any way. In the project context, OMNIACARE is used as a software platform designed for a tidy and structured information management, under the form of a web application with a front-end consisting of dynamic pages accessible through web browsers. Starting from the data acquisition, even from external and heterogeneous sources, the platform ensures efficient processing and management, fostering an automated and functional approach. It allows interoperability among different systems and, being a software product endowed with very broad characteristics of configurability, scalability and robustness, is apt to act as a middleware integration layer. Actually, all applications and software components that constitute user interfaces, developed within the project, share data with this central architecture component. E.g., it contains the profiles of the individual users, the configuration settings of the various devices and the data received from the sensors and from the handheld devices. It also provides the web interface to access the system, to which the operators use to connect and carry out their activities.

Finally, the project team involved in the specific project task identified technical parameters for an optimal system profiling, based on the specificities of each type of user as well as on the methods of interaction between the system and the different users. A market research was carried out on the main applications available for diabetes monitoring and diet control. The survey produced a review of 16 applications, of which 7 for monitoring of the blood glucose, 5 for dietary control and 4 that integrate the two functions together. The data derived from the evaluation provided by users of Google Play Store and Apple App Store. The results of this analysis, described in a project deliverable, were made available for the realization of the Diabesity Care app for the control of diet and physical activities in diabetic patients. In the meantime, partners carried out a survey among users of social housing interested in monitoring their health conditions at home by particular wearable or mobile technology devices. The survey concerned nutritional behaviors and lifestyles of diabetic users, or at risk of obesity or diabetes, and investigated the availability of users to use wearable smart sensors, technologically advanced and minimally invasive, to detect blood glucose and vital parameters necessary to remotely control the evolution of disease and the health conditions of users at risk. The sample involved 88 families, for a total of 216 users of different age groups, 27% of which over 60 years old. There were 11 cases of confirmed diabetes in the sample. According to the analysis of the body mass index, which relates the weight to the height of the person, 13 cases of obesity and 57 conditions of overweight were also present. The most significant results of the survey were:

- Diabetic people control their blood sugar level, by predominantly using “lancing” devices, rather invasive for users;
- Frequency of control is mostly daily;
- Therapy is taken from 2 to 6 times a day, depending on the severity of the disease;
- Concerns about home care and therapy, mainly concern the possibility of not being aware of situations of hypo or hyperglycemic risk and to take harmful or non-compliant doses of the therapy;
- Medical checks are too distant in time; therefore, immediate feedback is not possible, in case of uncertainty.

The survey also tested the availability to use any devices or applications on smartphones/tablets that allow the continuous monitoring of blood glucose and send data online to the medical center, with immediate alerts for the user:

- 86% of those interviewed consider such devices useful;
- Almost 80% of the sample already owns and declares to use a smartphone;
- 25% of respondents already have some sort of home automation technology (mainly security-related); over 95% consider them particularly useful;

Finally, the survey tested what support to aging and fragility was considered useful at home:

- Prioritization of tele-help services, home care and care (81%)
- Transport and accompaniment (61%)
- Purchase and home delivery (33%).

3 Technical Activities

As concerns hardware and materials, in the initial phase of the project partners focused on the optimization of the antibacterial treatment of the wearable component. This one is a sock that, besides being able to be integrated with the appropriate sensors, is characterized by important antimicrobial properties that prevent bacterial contamination in people with diabetes or affected by a diabetic foot [2]. In fact, this pathology causes insensitivity or loss of the ability to perceive pain and temperature in the lower limbs, with the result that diabetic patients do not notice the presence of skin lesions resulting from, for example, a poor weight distribution on one particular area of the foot. The bacterial infections that can result are one of the main causes of complication and delay in healing. In order to ensure adequate prevention from bacterial infections, the stocking must be characterized by an appropriate degree of antibacteriality.

Later on, project partners conducted study and scouting activities in order to identify the state of the art around wearable technologies for monitoring and eventually treatment of the diabetic foot [3, 4]. Different bio-physical quantities were considered in regard to the health and well-being of a diabetic patient's foot. Among these, temperature, humidity, pressure loads and transcutaneous oxygen saturation. The study of the state of the art allowed verifying the presence of a multitude of devices taxonomically related to:

- Socks: smart devices designed to provide up to 345 pressure measurements (1–8 sensor arrays in the tissue) or only temperature measurements (array of 1–6 thermistors in the fabric);
- Insoles: smart devices designed to provide both pressure measurements (4–13 sensor arrays) and temperature/humidity measurements (2–6 sensor arrays) and related non-electronic control systems integrated into the insole but worn on another point of the lower limb. Such systems exhibit average levels of usability and acceptability;
- Shoes: smart devices that borrow the technologies described in the insoles and integrate them in more bulky feed systems, with scarce usability and acceptability but with prolonged life-time;
- Baro-podometric platforms: instruments for measuring only the pressures exerted by the barefoot, equipped with software packages that can perform different processing automatically.

Only the first three types of technology mentioned above can be used in a real life context (i.e. semi-domestic environment), showing a relative simplicity of use (even in the absence of caregiver or experienced operators) as well as relatively low costs. In fact, baro-podometric platforms can be used exclusively in conditions of clinical laboratory under the supervision of highly qualified personnel. For these considerations and based on the project available resources, the optimal configuration used one sensorized insole designed for this purpose, integrating sensors and devices for the acquisition of the most interesting bio-physical quantities (pressure, temperature, humidity) jointly used with an antibacterial sock. This was something innovative, as no other state-of-the-art solution exploits these two features together.

Next step was to analyze and design the system transmission of data detected by the sensors. After analyzing the specifications of each standard, partners proceeded to choose the most appropriate one for the project. A comparison of the various protocols was performed using appropriate criteria such as energy consumption and bit rate. The chosen technology was Bluetooth 4.2 Low Energy. It is characterized by low energy consumption and adequate bit rate. The first feature makes it suitable for use in wearable devices powered by button batteries; besides, a maximum transmission rate of 2 Mbps is fully compatible with the expected data flows. Moreover, the connection to the host can be established in a direct way, without the need to use an intermediate gateway device.

After selecting the communication protocol, the Research partners moved on to the definition of the architecture hardware of the insole system. A System On Chip (SoC) would manage the acquisition of signals, their processing and subsequent transmission on Bluetooth LE transceiver. The ARM Cortex M3 architecture was chosen because it is specifically designed to be used in real time of power supply and sensors. In the proposed hardware architecture, the force and pressure sensors are both of the analog type. The acquisition of temperature measurements takes place with a period initially set at 1 Hz. In order to minimize consumption, it was decided to "trigger" the acquisition of pressure loads in function of the value of the signal detected by the sensors [5].

As concerns the server software part, data are collected from applications and devices, then sent to leading partner Liferesult's OMNIACARE server platform. The project activity on this part focused on the design of the platform architecture, responsible for managing the core features of the system: from the authentication to the acquisition/processing/storage of data, from the management of the alarm thresholds to the delivery of notifications/alerts to the other components of the system. Within the platform, a monitoring center is being integrated to allow not only data storage, but also a proper production of monitoring logics for use by caregivers to manage individual patient programs, monitor the trend of the styles of life and to intervene in the face of critical events [6]. These events will be managed by execution of specific customizable workflows activated automatically depending on the problem (Fig. 1).

As concerns client software and systems, the goal of the project is to implement effective methods of communication among users, doctors and caregivers to enforce a correct management of diabetic pathology. Given this objective, the partners involved

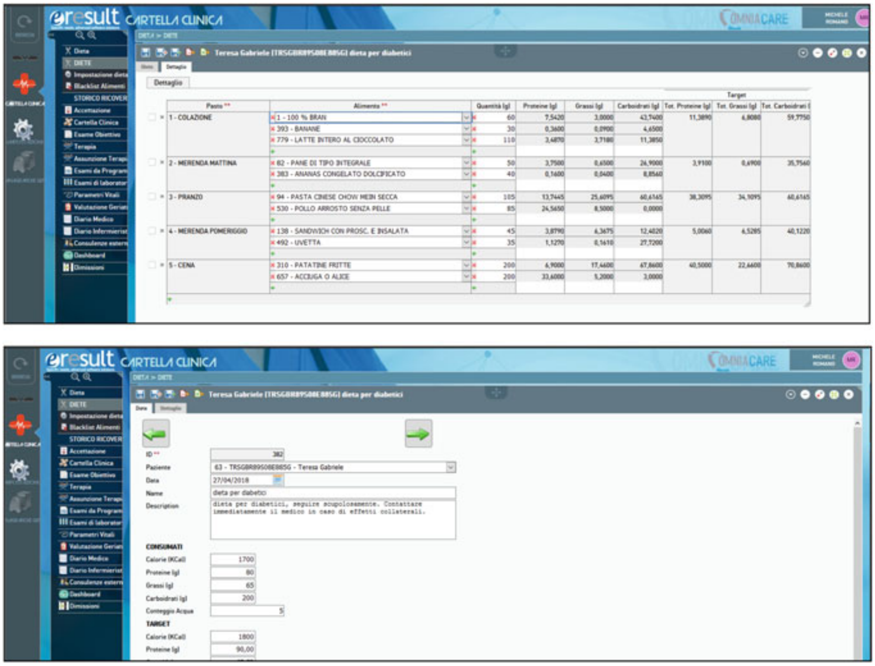

Fig. 1 Diabesity care OMNIACARE server application example screens

firstly provided for a precise definition of the risk situations that the system should detect and the types of medical/assistance intervention, proportionally to the detected risk. Subsequently, the partners concentrated their efforts in the research of the best technological solutions to be integrated in the design and prototype development of the following complementary and cooperating application modules to be realised in Android environment:

- Mobile App for Doctors;
- Mobile App for Patients;
- Mobile App for Caregivers.

A design study was conducted on the interfaces of the mobile applications and on the functionalities of interest to reach the requirements set for the project. The analysis phase of the useful monitoring features to patient, physician and caregivers allowed partners to carry out co-design of customized system user interfaces based on needs of different categories of users.

In the first place, partners established an application scenario of the system with identification of clinical aspects related to diabetes and to the complications of this disease due to obesity. This scenario predicts the situation of an elderly patient with type 2 diabetes, obese and with arterial hypertension. Sedentary habits of the patient reflect in a high body mass index. The patient can follow, through the application, a personalized diet completed by advice on lifestyle, with objectives suited to the type and severity of the disease suffered. Furthermore, patients can check the caloric content of food or view data and clinical parameters related to their pathology, to keep them under strict control. An increased awareness of the glycemic values leads to an improvement in confidence of patients towards their pathology and towards possible improvements in life-style. A highlight of the parameter improvements in the average and punctual values can further push patients to achieve their objectives.

The analysis of the scenario led to the identification of specific parameters to be detected by the Diabesity Care system, with definition of their characterization in relation to the pathology. Studies carried out indicated the value of blood glucose as the main parameter to detect, possibly in a poorly invasive way and with frequent measurements. Cardiac frequency detection right after, as it allows the system to correlate the disease with the risks of hypertension. Moreover, the partners decided to employ a spectrometer for food analysis, as an innovative parameter to favor correct and personalized dietary habits. Following the analysis phase, each of the partners took charge, based on their experience, of the development of a complete set of dedicated functions to each of the Diabesity Care system user profiles.

A Mobile App with functions dedicated to users with a medical profile is under development. This application is intended for professional users and, therefore, will comply with the following guidelines:

- Be adapted to the needs and expectations of "technical" users;
- Be easy and quick to use;
- Facilitate the work of the doctors by simplifying and automating the processes in which they're involved directly;
- Facilitate communication with the patient;
- Be aesthetically pleasing.

Several application layers have been defined with a set of functionalities built specifically for this specific type of user of the Diabesity Care system. The first layer is that of authorization, consisting of authentication and activation profile functions. The functionality of profile activation allows the application to register users. The application layer relating to data transmission includes the reading capabilities of the sensors, as well as pre-processing. Support for the design of the communication modules was provided for data transmission detected by the monitoring sensors to obtain homogeneity in the communication protocols used by all integrated systems. In this way, it is possible to generate an accurate and useful data flow for storage on central archive system based on the second expected functionality, i.e. pre-processing. The mathematical and logical model behind allows the transmission of only indicative and valid data to avoid a massive sending of data containing false alarms or partial or inaccurate findings. Together with the transmission of data, the information layer designed for the Diabesity Care application was envisioned. The features designed for this layer realize a display functionality of historical data, to evaluate the progress obtained by patients with respect to their pathology. Furthermore, the communication application layer for the Patient profile was defined and designed, too. The functionalities envisaged consists in making available a communication channel among the various users of the application and the availability of an emergency call function with a pre-settable fixed number. This feature has been designed to guarantee each user the possibility to be able to immediately communicate by preferential channels, such as messages or calls.

Finally, a mobile App with functions dedicated to users with the "Caregiver" profile is in course of development. The application must allow a quick consultation of the medical records and the insertion of vital parameters acquired from third party sensors. It may also contain a series of graphs created on the basis of the collected data and inserted in a certain period of time so as to allow easy understanding of changes over time. The application will also allow the caregiver to consult both a wiki section to inquire on best practices and a newsletter section focused on the treatment and treatment of the diabetic disease. In addition, the application would integrate a messaging function that allows caregivers to be put in contact with patients. Following is a list of functions realized within the above applications.

Log in. The application will include an initial login screen in which the user inputs access credentials and can reset or changes the password. In addition, this function allows registration whenever the user is not registered yet.

Contact list. Right after the login, the list of patients currently associated with the caregiver is uploaded, showing their name, surname and social security number.

Patient data and clinical records. By clicking on one of the patients, doctors display screens with details about registry and medical records. The clinical record includes all the measurements that have been acquired on the patient. Furthermore, by clicking on one of the values in the list, it will be possible to access the accurate details and history of each transaction and registration. The application also provides a menu that allows sending new measured values to the server simply selecting the type of measurement (Transpiration, Heart Rate, Respiratory Rate, ECG, Weight, Pressure, Physical activity, muscle mass/fat/hydration, muscle strength, blood glucose), the measured value, the date and time of detection.

Patient therapies. The application provides a menu that allows viewing of the therapies that are associated with the patient; the therapy display screen will show the following data: therapy name, date, description of therapy, drugs to be administered, frequency, social assistance activity to be performed. It is also be possible to modify the current therapies, using the appropriate detail screen, and it is possible to insert new ones.

Wiki/Newsletter. The application provides a menu that contains all Wiki articles and Newsletter about the selected domain.

Patient messaging. The application integrates a feature that allows the caregiver to text with their own patients selecting a conversation from the list, or choosing the patient of interest.

Diet management. The purpose of this app is to monitor the diet of diabetic patients in a simple and flexible way. It is possible to modify the diet, according to the needs, and the system will recalculate the daily diet, providing new and daily nutritional information. The use of a miniaturized SCIO molecular scanner device is under investigation for use with an internal food database. The device can detect the

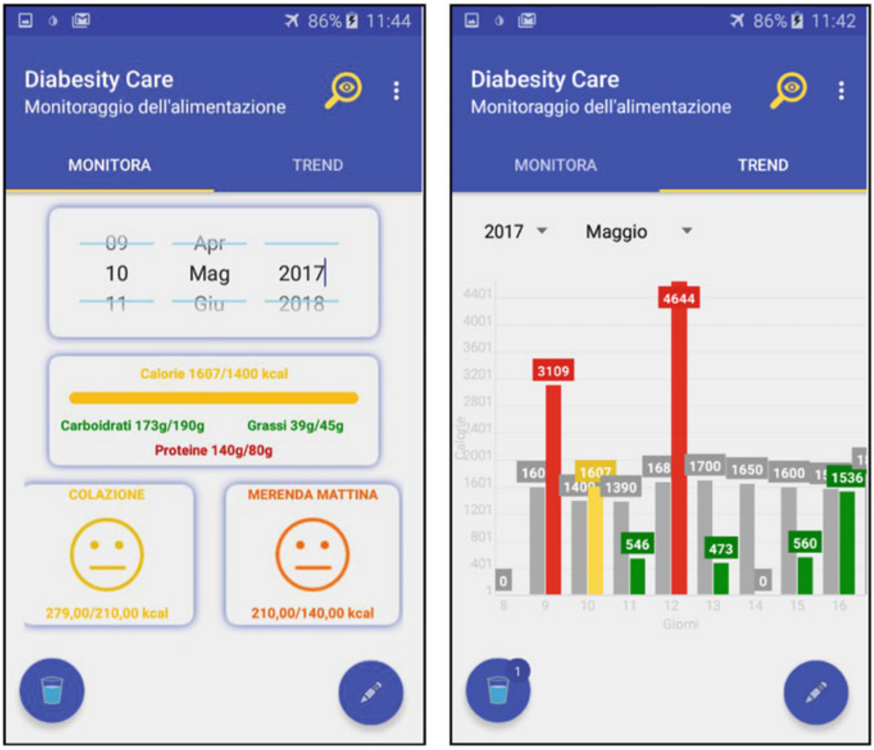

Fig. 2 Examples of diet control screens

chemical composition of a food to monitor nutrition of the diabetic subject. Example screenshots are shown in the Fig. 2.

Physical activity management. The feature detects movement and activity of the patient through an integrated accelerometer in the mobile device and calculates calories burnt during the activity. The use in the accelerometer is compensated with GPS data in case of outdoor activities. Example screenshots are shown in the Fig. 3.

Glucose management. Partners proceeded to design this function whose main purpose is to provide the user with the possibility to continuously monitor the glycemic level through interfacing with the minimally invasive sensor Dexcom G5 Bluetooth. Through this function, the user is able to visualize the graphical trend of the glycemic values acquired over time and set custom alarm thresholds.

4 Future Outcome Evaluation

For the verifiability of project outcomes, the prototype will be tested by end users in a real situation. The so-called UCD—User Centered Design approach will be used during the development of the whole project. UCD implies a direct involvement of

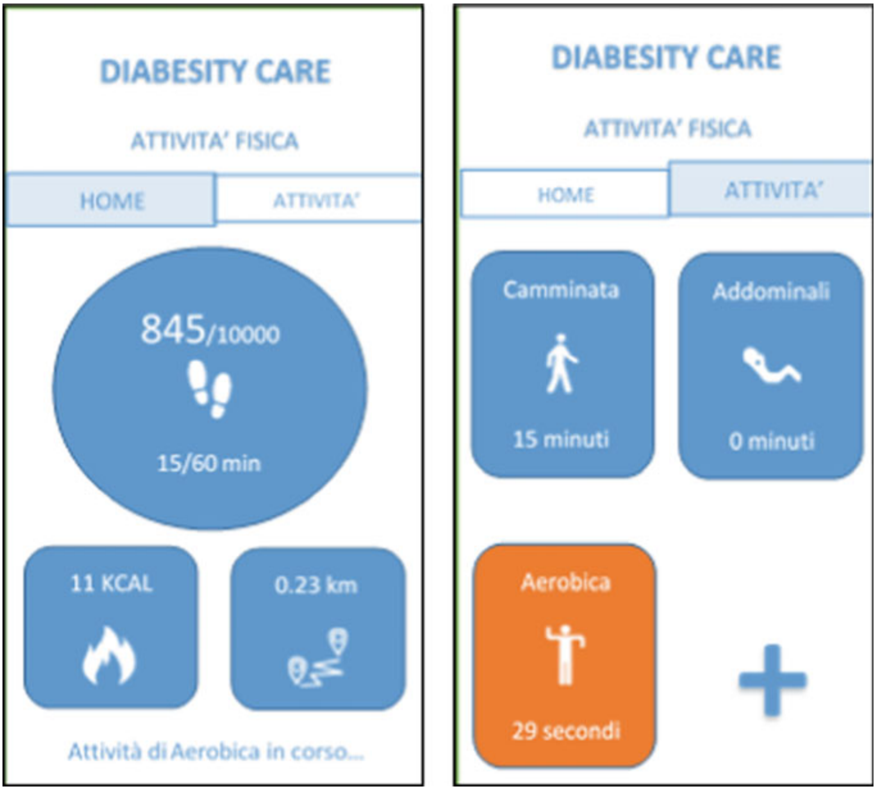

Fig. 3 Examples of physical activity control screens

the user, who stands at the center of the whole solution development process. UCD strongly takes into account the needs of the requests and limits of end users. It is an iterative process based on the structure *design* -> *test* -> *design refining*, applied from the first design stages in a cyclical way throughout the product development. This process requires that the developers directly interact with the end user during each de-sign phase. Each interaction produces a result, which is closer to the real needs of the user. Feedback provided by users during each pilot test will serve as a basis for a new phase of analysis towards the possible development of a new prototype, as long as the needs and requirements expressed by users are fully satisfied. Tests will be carried out to verify:

- The coherence of processed information by the systems, against the requirements collected in the project;
- The ability of the systems to acquire, process, transmit and present data of clinical interest;
- The ability of the systems to facilitate the exchange of useful information among the various actors involved in the assistance and care process;

- The ability of the systems to make remote patient monitoring and remote assistance more efficient.

In this regard, the following quantitative parameters for measurement of project performance have been identified, consistently with the aims, purposes, and activities envisaged for their achievement:

- Use of the molecular scanner for the detection of the chemical components and quantity of food, and use of the applications to support a correct diet for over 50% of the time in which the whole system is used;
- Over 70% of interventions by specialized medical personnel to calibrate the therapy in progress and make any changes, performed remotely;
- Reduced risk of developing complications related to diabetic foot by more than 70%, thanks to the use of the engineered sock;
- Recorded improvement in diabetic foot conditions in more than 70% of cases in which the engineered stocking is used;
- Use of the wearable and poorly invasive smart sensor for the detection of glucose levels through interstitial fluids for more than 50% of cases, during the use of the system;
- Over 25% of users participating in the pilots deciding to keep the system and its components for themselves, at a reasonable cost;
- 85% of pilot participants considered the platform to be easy to use and user-friendly, consistently with the UCD approach used;
- 90% of the pilot participants able to use all the features implemented, finding them easy to access and use and able to meet their needs and requests.

Furthermore, project partners will use the technical data provided to perform appropriate treatment on the finished product. The antibacterial efficacy of the silver coating deposited on textile substrates and on the socks will be evaluated through appropriate qualitative and quantitative microbiological tests (e.g. diffusion test in agar, spectrophotometric analysis of optical density). The scientific partner will then perform impedance measurements on solutions containing known concentrations of glucose to evaluate limits of detention and detection on conventional non-fluids, such as sweat.

5 Conclusions

The strategy pursued by the partners involved in this project stems from the will of create a highly innovative system to deal with needs arising from patients with diabetes and with the socio-economic burden resulting from their disease. The project results aim to induce, on the one hand, the users who suffer from this chronic pathology to become active subjects, aware and autonomous in the management of their own health. On the other hand, to reduce hospitalization or access to public assistance facilities, mainly due to complications. By conveying skills of excellence in different and specific areas, the project aims to the realization of an integrated and highly innovative system, able to allow the diabetic patient to monitor his disease, to implement preventive actions and to receive assistance in real time. This is a project born from the strategic coherency of InnovAAL, in relation to the promotion of re-search and technological innovation at the service of quality of life, and which therefore brings together the expertise and the specific skills of companies, research organizations and spin-offs.

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References

1. Pollini M, Paladini F, Licciulli A, Maffezzoli A, Nicolais L, Sannino A (2012) Silver coated wool yarns with durable antibacterial properties. J Appl Polym Sci 125:2239–2244
2. Giannossa LC, Longano D, Ditaranto N, Nitti M, Paladini F, Pollini M, Rai M, Sannino A, Valentini A, Cioffi N (2013) Metal nano antimicrobials for textile applications (review). Nanotechnol Rev 2:307–331
3. Lin X, Seet BC (2017) Battery-free smart sock for abnormal relative plantar pressure monitoring. IEEE Trans Biomed Circuits Syst 11(2):464–473
4. Reddy PN, Cooper G, Weightman A, Hodson-Tole E, Reeves N (2016) An in-shoe temperature measurement system for studying diabetic foot ulceration etiology: preliminary results with healthy participants. Procedia CIRP 49:153–156
5. Ostadabbas S, Saeed A, Nourani M, Pompeo M (2012) Sensor architectural tradeoff for diabetic foot ulcer monitoring. In: 34th annual international conference of the IEEE EMBS, pp 6687–6690
6. Pistoia M, Parata C, Giugni P, Urlini G, Loi S, Borrelli G (2017) Virtual modeling of the elderly to improve health and wellbeing status: experiences in the active ageing at home project. In: Proceedings of ForITAAL 2017

Fully Integrated Smart Insole for Diabetic Foot

Gabriele Rescio, Alessandro Leone, Luca Francioso, Pierfrancesco Losito, Enrico Genco, Francesco Crudele, Leonardo D'Alessandro and Pietro Siciliano

Abstract Foot ulcer is a severe complication affecting about 25% of diabetes mellitus patients due to a lower blood supply and loss of foot sensitivity (neuropathy). A fast and reliable identification of foot pressure loads and temperature distributions changes on the plantar surface allows to prevent and reduce the consequences of ulceration. Several wearable technologies have been developed and tested by the scientific community, addressing the "diabetic foot" topic. However, the dimensions of the devices and the combined pressure/temperature monitoring capabilities don't accommodate the requirements from both the end-users and caregivers: normally just one information—pressure loads or temperature map—is acquired, moreover the amount of thermal reading points is lower than 5 and the accuracy of thermal sensors is greater than 0.5 °C. This work presents a fully integrated, high accuracy, smart insole in which both temperature and pressure data in 8 reading points are monitored in remote way, for the assessment of the health foot.

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Keywords Wearable device · Diabetic ulcers · Insole

1 Introduction

Diabetes represents one of the main problems in health system and a global public health threat that has increased dramatically over the past 2 decades [5, 6]. The dramatic consequences on the quality of life have favored the widely dissemination of several scientific works about the prevention techniques and medical treatments of diabetes. They have shown that with good self-management and health professional support, people with diabetes can live a long and healthy life. One of the common and serious complication in diabetic patients is the foot ulcers that may affect up to 25% of patients in the course of their lifetime [4]. The main causes of the ulcers arising are due to the neuropathy, peripheral artery diseases and vascular alterations. These diseases induce insensitivity conditions that can cause high plantar pressure, deformity and ischemic wounds on the plantar foot up to the ulcers development [4, 5]. When the ulcers appear, the treatment is challenging, expensive and a long term treatment is required. It might need of podiatrist, orthopedic surgeon, endocrinologist, infectious disease physician and nurses. In this scenario the prevention of ulcers assumes a prominent rule. The prevention could forecast appropriate training of patients in order to assimilate the behaviors necessary to reduce the appearance of ulcers (i.e. the glycemic and blood pressure control, lipid management, smoking cessation, feet drying, wearing special and comfortable shoes, ecc). In addition, the use of technologies for the monitoring of relevant vital parameters on the plantar, as temperature and foot load distribution, may be very important to prevent foot ulcers. They may identify the prolonged and excessive pressure at a point of the foot or recognize anomalies in skin conditions and in bloody circulation. Several methods have been developed to measure the pressures and stresses in the plantar tissue by using mainly sensorized mats and force platforms. These strategies are usually realized following pre-defined scheduled medical visits. This approach could be not very effective because it is desirable to continuously monitor and to detect high pressure values in timely way. Several systems for measuring plantar pressure in the foot are commercially available [1]. These systems are extremely expensive and aim at athletic activities and are not designed for prevention of ulcers. Another useful parameter for assessing the diabetic foot is the temperature. Progressive degeneration of sensory nerve pathways affect thermoreceptors and mechanoreceptors. High temperatures under the foot coupled with reduced or complete loss of sensation can predispose the patient to foot ulceration. So, the foot thermal monitoring may facilitate detection of diabetic foot problems [2]. The most part of the temperature foot measurements for the diabetic foot regarding with non-invasive, and accurate thermal images analysis or thermography inspections. However, as described for the pressure monitoring, the long-term and continuous measurements of temperature may allow for a more effective ulcers prevention.

Several wearable technologies, for the permanent monitoring of the diabetic foot, have been developed and tested by the scientific community. However, the dimensions of the devices and the combined pressure/temperature monitoring capabilities do not accommodate the requirements from both the end-users and caregivers. Indeed, normally just one information (pressure loads or temperature map) is acquired. Moreover the amount of thermal reading points is lower than 5 and the accuracy of thermal sensors is greater than 0.5 °C. This work presents a full integrated smart insole in which both temperature and pressure data in 8 reading points are acquired and then transmitted through a wireless protocol to a gateway in order to monitor foot conditions and inform the caregiver about the health status.

2 Smart Insole System

The architecture of the developed smart insole system consists of three subsystems: (1) sensors system for the temperature and pressure parameters acquisition; (2) wireless transmission module; (3) data aggregation and processing module. The first two subsystems are integrated in the insole, whereas the third subsystem is implemented on a gateway device (Embedded PC) able to send the data to a caregiver through a cloud service. For the sensor positioning and sensor dimensions have to be find the best trade-off through the covering area and accurately measurements at specific points of the plantar. According to the Ferber et al. [3] and the local load foot analysis, performed by using the BTS G-studio [7], the placing of the pressure sensors was designed as shown in Fig. 1. The temperature sensors were located close the pressure sensor in order to monitor the main pressure point of the foot.

2.1 Temperature and Pressure Data Acquisition—Transmission System

The electronic insole system hardware architecture is based on a System on Chip (SoC): Texas instrument's CC2650 with an ARM Cortex M3 core reads, processes and sends temperature and pressure data through a Bluetooth Low Energy (BLE) communication. Information storing in a flash memory was also implemented to prevent data loss in prolonged periods of listener absence. In Fig. 2 a schematic representation of the system is reported.

Both the Force Sensing Resistor (FSR) conditioning circuits and the integrated temperature sensors were selected to minimize the system power consumption indeed all the op-amps are based on nanowatt technology and the temperature sensors have an asynchronous low power consumption sleep function. For the load pressure acquisition, the IEE CP151 FSR sensor (0.43 mm thick and 6% for the accuracy) [8] has been chosen for the low invasive integration. Their dynamic is within 100 N, so

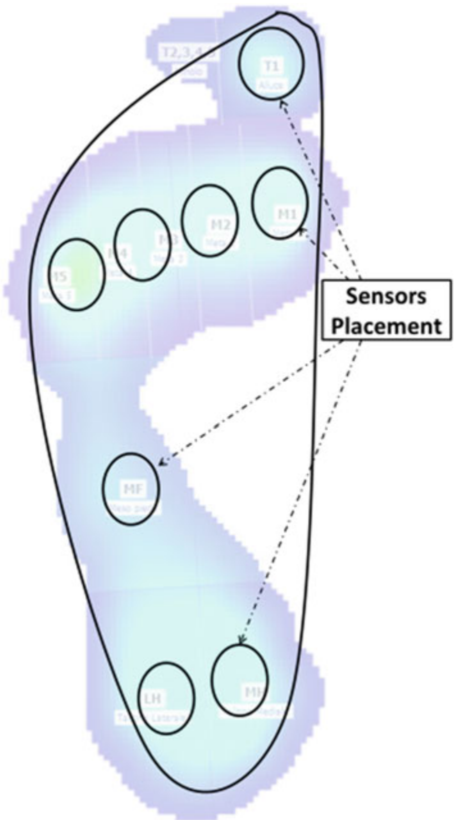

Fig. 1 Temperature and FSR sensors positioning

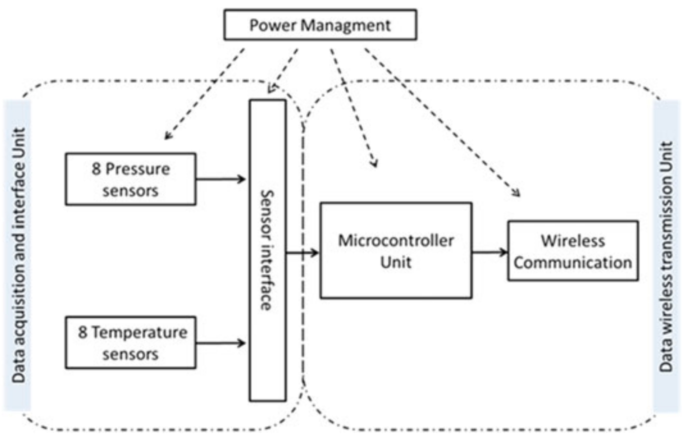

Fig. 2 Block diagram of smart insole system

it is appreciated for dynamic and static foot load pressure measuring. The sensors placement was studied and optimized in order to obtain an accurate monitoring of foot in the 38–43 size range by using only the 39 and 42 foot sizes. While the FSRs are basically analogue sensors and need a conditioning circuit with a converter to digitize pressure info, temperature sensors are fully digital and only need I2C bus and commands to work. Maxim's MAX30205 sensors were chosen due to their high accuracy (0.1 °C) and their number of programmable I2C addresses, more than the eight required. The entire system is powered by a 3 V source such as a primary lithium button cell.

CC2650 firmware was designed following the rules of Texas Instruments Real-Time Operating System TI-RTOS that requires a multi task architecture for the BLE communication. Different tasks were implemented to acquire sensors data and create BLE services. The main data service is divided in two characteristics dedicated to the different sensor types and accessible from any smartphone.

FSR data signal acquisition is made by an eight-multiplexed channel 12 bit Analogue to Digital converter that select and digitize all the on-board sensors signals. It's possible to set sampling frequency in a range of 50–0.01 Hz from the user's smartphone app.

All the FSRs relevant data are grouped in records each containing 8 samples of 16-bit unsigned integer and then stored in circular buffers allocated in the flash memory. With this strategy the system can grant over 40 min of no data loss condition using a 16-Mbit flash and a sampling frequency of 50 Hz. After this time an overrun condition occurs and the last stored data are overwritten. A management algorithm was designed to optimize the flash sectors read/write cycles (strongly related with the memory life) and data loss.

A default sampling period of 60 s was set for the temperature data acquisition then, after reading each sensor status, the samples are stored in a circular buffer of 768 elements in the CC2650 internal SRAM. Like the previous case, each record will contain 16 bytes of data or rather 2 bytes per sensor with the integer part of the temperature sample in the most significant byte and the decimal stored in the least. In those conditions this buffer grant an autonomy of 48 min. Both temperature and pressure records are associated with an index for univocal temporal correlation of all the stored data. Once the first record is stored, the BLE communication starts. As mentioned before, the main algorithm provides two characteristics where temperature and pressure data can be requested. Those two different data types are sent using the 4.2 BLE protocol over a 2.4 GHz connection. In this exchange the smartphone application has the role of "master" and may ask new records anytime. Then, when unsent data are stored, the designed system supplies them on a read only GATT server and acts as a "slave". The slave answers any data request until its queue is empty.

The maximum sampling frequency between sensors types is 50 Hz therefore the smartphone application was designed to ask and receive a single record in less than 20 ms to not occur in overrun conditions. After the communication phase, the system restarts to store data in buffers, meanwhile controls.

A dual-layer circuit board was realized and all components were integrated on the bottom side (apart the flat and very thin FSR sensors) to avoid asperities potentially harmful for the diabetic foot. To measure the foot temperature, a via hole has been realized on the board in correspondence of the sensing pad of each temperature sensor, assuring the thermal transfer between the bottom and the top of the insole, through the application of a silver-based conductive paste. The flexible circuit was incorporated between the first and the second layer of the two antibacterial polyurethane-based layers architecture, designed in accordance with the typical requirements of diabetic foot insoles.

3 Results

In Fig. 3 it is reported the 3D image of the smart insole system, while in the Fig. 4 it is shown the first prototype, realized on a polyamide support, with a dielectric and copper thickness of 360 μm and 18 μm respectively. In the prototype the acquisition and transmission module was realized on an external PCB for the testing. To evaluate the performance, preliminary laboratory testing were performed in order to compare the temperature values measured by the proposed system and an accurate infrared thermometer on the top of insole.

The mean and the standard deviation of the error calculated for 15 measurements for all temperature points are reported in Table 1. Moreover, to assess the load pressure acquisition, five end-users (47.2 ± 12.3 years old and 26.3 ± 2.1 Body Mass Index) performed static and dynamic actions on the BTS baropodometry P-Walk platform, wearing the insoles. The differences between the data acquired with the P-Walk platform and the developed insole are also reported in Table 1 (for the comparison the offset due to the polyurethane layers were evaluated and compensated). Moreover the weight and the power consumption of the system are reported. Based on the results, the developed system shows high performance in temperature/pressure detection.

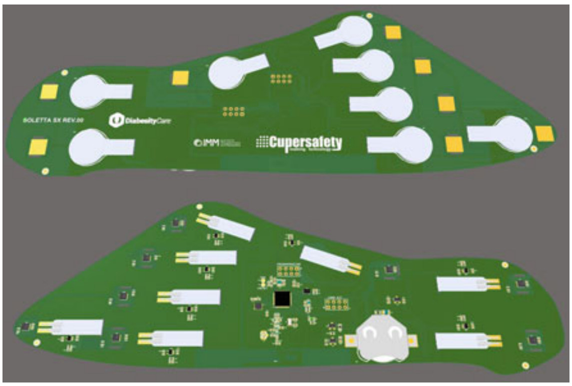

Fig. 3 3D prototype of the smart insole

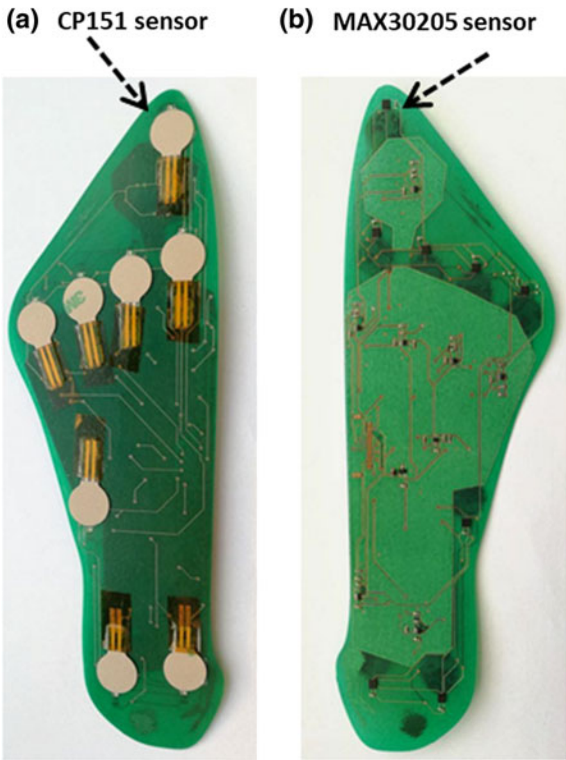

Fig. 4 **a** Top and **b** bottom view of the smart insole prototype

Table 1 Main features of the smart insole

Feature	Smart insole system
Temperature accuracy (compared with infrared thermometer)	0.21 °C (range 25–40 °C)
Max mean peak pressure for all measurements points	8% (range 40–298 kPa)
Insole weight	<90 g
Power consumption	Max 46.3 mW (data transmission mode)
Battery	Lithium-Ion button cell 600mAh

4 Conclusion

A smart insole system for continuous temperature and load pressure foot monitoring in daily activities was presented for diabetes patients. The data were acquired from eight different points on the foot plantar both for temperature and load pressure parameters useful for the ulcer prevention. The preliminary laboratory tests validate high accuracy level in temperature data acquisition. Moreover good performance was obtained for the foot load distribution evaluation by using minimally and passive pressure sensors. Ongoing studies are focused on the integration of a low-power elaboration and transmission unit to allow for a final coupling with antibacterial socks.

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References

1. DeBerardinis J, Trabia M, Dufek JS (2016) Review of foot plantar pressure—focus on the development of foot ulcerations. Open Access J Sci Technol 4(101158):7
2. Etehadtavakol M, Ng EYK (2017) Assessment of foot complications in diabetic patients using thermography: a review. Appl Infrared Biomed Sci 33–43
3. Ferber R, Webber T, Everett B, Groenland M (2013) Validation of plantar pressure measurements for a novel in-shoe plantar sensory replacement unit. J Diabetes Sci Technol 7(5):1167–1175
4. Iraj B, Khorvash F, Ebneshahidi A, Askari G (2013) Prevention of diabetic foot ulcer. Int J Prev Med 4(3):373–376
5. Ogurtsova K, Rocha Fernandes JD, Huang Y, Linnenkamp U, Guariguata L, Cho NH, Cavan D, Shaw JE, Makaroff LE (2017) IDF diabetes atlas: global estimates for the prevalence of diabetes for 2015 and 2040. Diabetes Res Clin Pract 128:40–50
6. Yazdanpanah L, Nasiri M, Adarvishi S (2015) Literature review on the management of diabetic foot ulcer. World J Diabetes 6(1):37–53
7. https://www.btsbioengineering.com
8. https://www.iee.lu/en/technologies/force-sensing-resistor

A eHealth System for Atrial Fibrillation Monitoring

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Abstract In clinical practice the ability to monitor arrhythmia episodes in elderly people is helpful to make an accurate diagnosis and choose the proper therapeutic interventions to reduce potential health risk. In this paper we propose an eHealth system to detect atrial fibrillation events as well as provide information about patient's health status using commercial devices such as a smartphone and a wearable sensor for heart rate monitoring. Our solution consists of a smartphone application able to real time process raw data from the wearable sensor, detect critical events for the patient's health status, and generate remote alert to medical staff. In the smartphone application a SVM-based algorithm to detect arrhythmia episodes by handling electrocardiogram signal is implemented. To test the performance of the developed eHealth system, the proposed algorithm has been evaluated using acquisitions with atrial fibrillation events. The results show a sensitivity of 94% and a specificity of 93%.

Keywords eHealth System · Atrial fibrillation detection · Wearable · Sensors Heart-rate monitoring

1 Introduction

Atrial Fibrillation phenomenon is a very common heart rate alteration which affect about 2% population, taking into account the large number of cases not diagnosed [18]. Atrial Fibrillation episodes can be related to many diseases, and its aftermaths can be very serious. In clinical practice the diagnosis of atrial fibrillation is made by two criteria based on ECG analysis: the heart rhythm irregularity or the P-wave absence [17]. Therefore, a practical system to monitor atrial fibrillation events can be

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helpful to make an accurate diagnosis and choose the proper therapeutic interventions to reduce potential health risk for the patient.

The availability of even more miniaturized and economic electronic allows today the spreading of consumer portable devices. This is very important for the development of solutions for eHealth, mHealth and AAL, and for the biomedical sector in general. Portable devices are gaining an important role in health research and monitoring, allowing a fast measurement of vital parameters, an accurate diagnosis and a reduction of visits to hospitals. The cardiac signal and the breathing signal are the most important vital signs and give lot of information about the person. A continuous and automatic monitoring system can be a needful instrument for medical staff, especially for elderlies and patients affected by cardiac and respiratory diseases. In this work we used the reliable BioHarness wearable sensor [1, 10], and the processing algorithms has been developed in Matlab environment and then implemented into an Android application for real-time usage. The cardiac signal processing is based on the heart rate and intervals between heartbeats, exploiting the potentialities of HRV analysis. Starting from these few data it is possible to obtain information about stress condition, arrhythmic events and energetic consumption, as presented in [13]. In addition to this previous work, we added the possibility to detect also atrial fibrillation events using a SVM-based method. Instead, as regards to the monitoring of breathing activity, we added to the system the capability to reveal apnea status, as presented in [14]. The great advantage of the solution is the integration of different typologies of analysis that give lot of information about the patient allowing a better diagnosis process to the physician. Furthermore, the use of smartphone applications is increasingly widespread and very useful for all those services that involve fragile people such as sick or elderly [15], encouraging self-sufficiency and security through constant monitoring.

2 Materials and Methods

This section presents the acquisition system used and the techniques implemented for the detection of some major disorders related to the variability of the heart rhythm.

2.1 Acquisition System

The BioHarness is a small wearable device: it is attached to a chest strap, and includes electrodes for one-channel ECG, a breathing sensor and a tri-axial accelerometer. In our solution we use all these sensors. To evaluate the ECG we use the pre-processed information of heart rate and interbeat intervals, while for the breathing and acceleration signals we use the raw signals. The signals is acquired by the smartphone through a Bluetooth connection and processed (Fig. 1). Finally the results of the analyses can be stored into an online DB to share data with the medical staff.

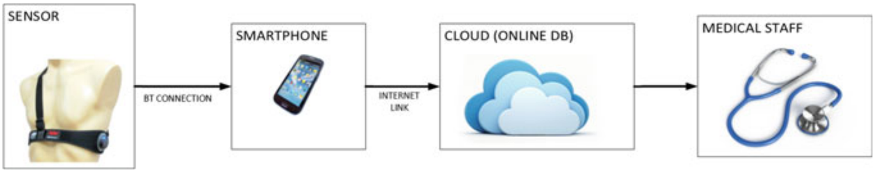


Fig. 1 System architecture

2.2 *Analysis on Heart Activity*

This section describes the algorithms implemented by our research group, some entirely, others starting from algorithms already known, aimed to detect some of the majors disorders related to the hearth rate alterations. Further, is also presented a new one algorithm we developed, for the atrial fibrillation detection.

2.2.1 Stress State Detection

Anxiety disorders and chronic or post-traumatic stress are related to particular behaviors in HRV due to alterations of autonomic nervous system [4, 6]. For the stress detection algorithm, we extracted some HRV features in time domain over a standard period of acquisition (5 min) [3], that are: the $SDNN$ (square root of variance, related to the cyclic components connected to the variability during the observation period, and strongly dependent to this), the $rMSSD$ (square root of mean squared differences of successive RR), the $pNN50$ (the ration between number of interval differenze of successive RR greated then 50 ms and the total number of RR), and the average HR. The algorithm [13] calculates the previous features and compares the obtained values with the thresholds. The decision on the stress state is performed by a majority vote. If at least three of the four features are lower than the thresholds (or greater for the HR average) (Table 1), the patient is considered as stressed [2, 20].

Table 1 HRV features thresholds for stress detection

Variable	Threshold	Unit
HR_{AVG}	>85	beats/min
$pNN50$	<7	%
$SDNN$	<55	ms
$rMSSD$	<45	ms

Table 2 Thresholds for sinus rhythm classification

Sinus rhythm	HR (bpm)
Bradycardia	$HR < 60$
Normal	$60 \leq HR \geq 100$
Tachycardia	$HR > 100$

2.2.2 Sinus Rhythm Classification and Sinus Arrhythmia Detection

The first analysis on cardiac rhythm is the classification of this as bradycardic, normal or tachycardic. For this kind of analysis the patient has to be at rest. The used algorithm is the same developed by us in [13]: it calculates the average heart rate during an observation window (configurable by user in this case). Then the obtained value is compared to two threshold to establish the rhythm (Table 2) [11].

The sinus arrhythmia is very common especially in young people, and it is not considered as pathological. This is related to breathing: the heart rate increases during inspiration due to the Brainbridge reflex, while decreases during expiration due to vagal effect. The used algorithm [13] takes in account RR intervals, and compares the maximum and the minimum RR in the observed period. If the difference is >0.16 s [9] the sinus arrhythmia is present.

2.2.3 Arrhythmias Classification

A more complex algorithm has been implemented to detect and classify various types of arrhythmia. The method, proposed by [19] and already implemented in real-time in Android environment by our previous work [13], is composed by two steps: a first arrhythmia beat classification and a subsequent episode classification (Fig. 2). The arrhythmia episodes that can be detected are: ventricular premature systole, ventricular bigeminy, ventricular trigeminy, ventricular couplet, ventricular tachycardia, ventricular flutter/fibrillation, and 2nd degree heart block. The algorithm uses only RR interval as input, and following 3 different rules it is able to classify beats into: normal beats, premature ventricular contractions, fibrillation and 2nd degree heart block. Then, the classified beats are used to move into states of an automaton for the classification of the episodes.

2.2.4 Atrial Fibrillation Detection

Atrial Fibrillation (AF) is the most common cardiac arrhythmia which can be characterized by a heart rate alteration (Fig. 3). We included in the system an original algorithm for the detection of AF events through the processing of RR intervals. One of the main features of AF is that RR intervals are rather irregular. For this reason our choice was to exploit parameters usually intended for the estimation of HRV and to use them as features in a SVM classifier, as initially proposed by Mohebbi and

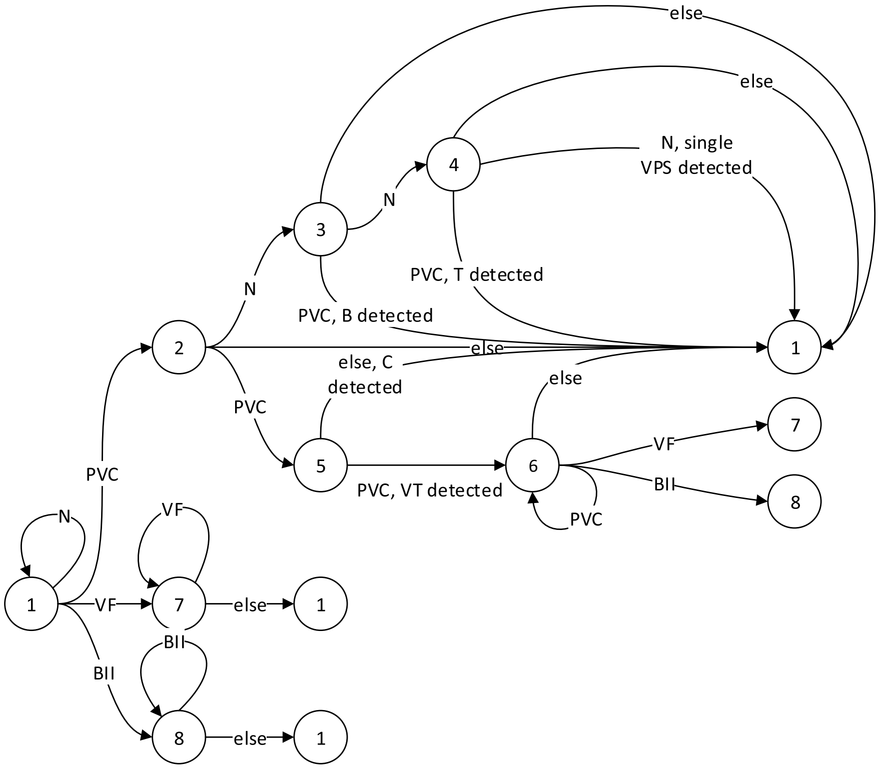
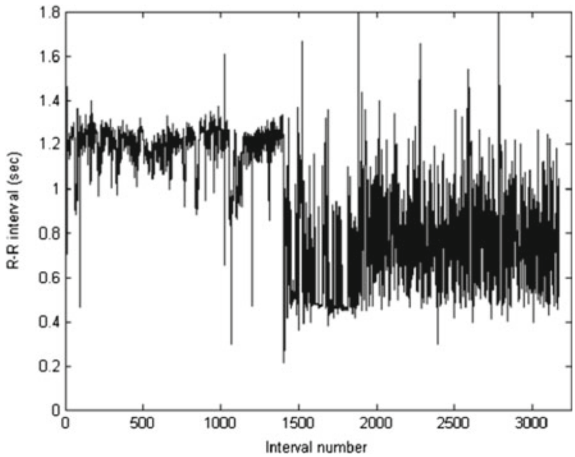


Fig. 2 Automaton for arrhythmic episode classification

Fig. 3 Tachygram of an AF event



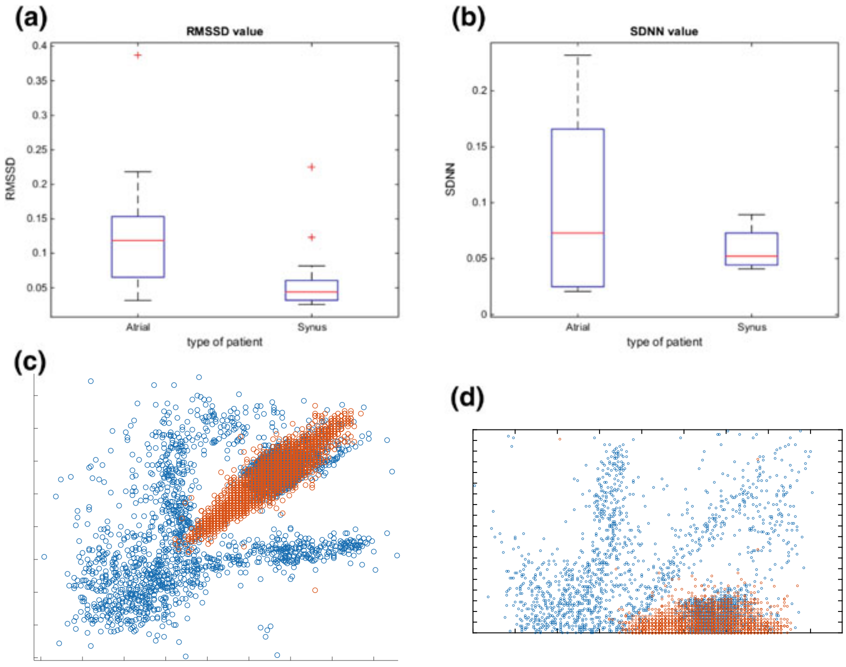


Fig. 4 Representation of selected features for SVM: **a** RMSSD, **b** SDNN, **c** Poincaré plot, **d** dRR plot

Ghassemian [7]. At first we performed an analysis process over lot of AF affected signals collected from MIT-BIH PhysioNet database [8] to detect most significant parameters for the SVM. In particular, we selected Standard Deviation of RR intervals (SDNN), Root Mean Square of Successive Differences (rMSSD), Poincaré Dispersion [12] and Non-Empty Cells (NEC) value [5] (Fig. 4). All parameters have been calculated over periods of 5 min. Then we executed the training of the classifier using 180 known events (intending an event as a 5 min window), 60 with AF events, 120 with Normal Sinus Rhythm (N).

2.2.5 Energy Expenditure Estimation

The last feature related to heart monitoring is the evaluation of the energy consumption of the user. The implemented method is the same of [13] and requires the knowledge of user's characteristics, such as: weight, height, gender, age, at rest HR. The calorie consumption is calculated by integrating the instantaneous HR values over the observation window in real-time. In particular, the method calculates initially the calorie consumption related to the at rest HR. Then calculates the consumption

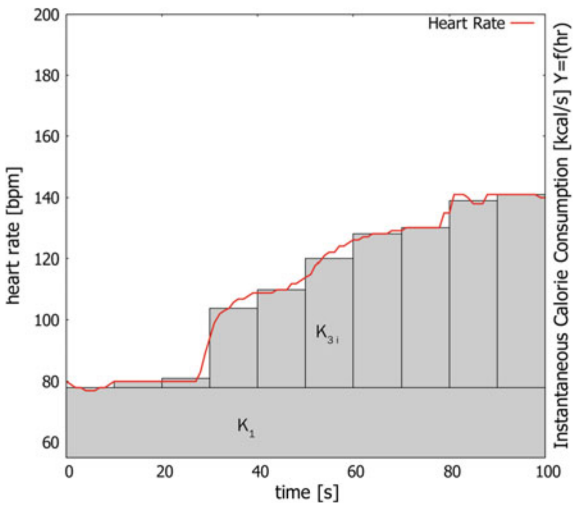


Fig. 5 Graphical representation of the method for the energetic consumption estimation

every 10 s during exercise basing on the mean HR of the window. This second value is periodically added to the total value (Fig. 5).

2.3 Analysis on Breathing Signal: Apnea Events Detection Algorithm

The algorithm for the detection of apnea events can be subdivided into two parts [14]:

- breathing detection over the raw breathing wave signal acquired by the pressure sensor of the BioHarness
- the correction on the results of the first part using the accelerometer of the BioHarness.

Then we realize a data fusion to reach the final result. The first breathing algorithm works on 10 s window. This choice is linked to the minimum duration of an apnea event that is 10 s, and to the features of the data transmitted by the BioHarness (1 packet each 1.008 s). The algorithm includes a first filtering stage (low-pass Butterworth filter with cutoff frequency of 0.45 Hz). Then the average of the signal in the considered window is calculated and subtracted from that signal (to remove zero frequency component). Subsequently DFT is applied to obtain the signal spectrum and to find the major harmonic component and then the breathing rate. The obtained breathing rate value (per minute) is a fundamental value and is used by the algorithm to take a first decision: if the rate is lower than 6 bpm, an apnea status is detected. On the contrary the algorithm proceed to another step, based on time domain. In time domain is performed a discrete derivative operation to find relative maximum

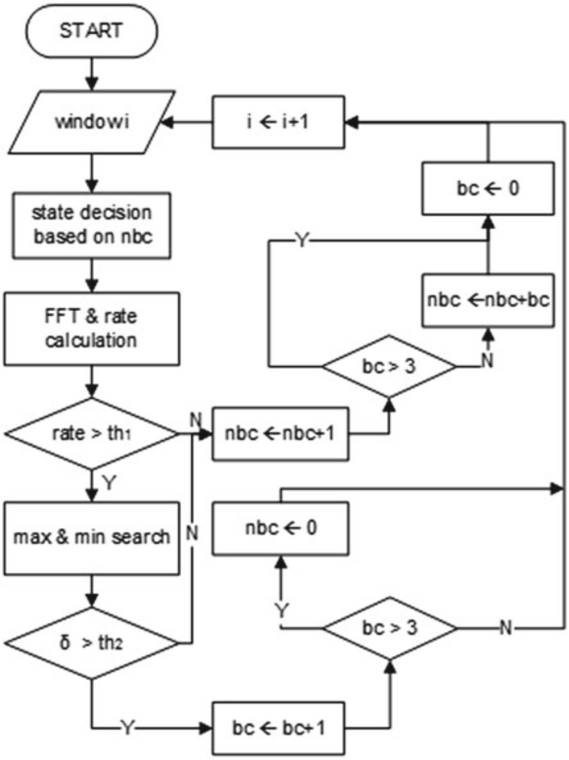


Fig. 6 Breathing algorithm

and minimum and to calculate the amplitude value of these points. The difference between maximum and minimum is compared with another threshold. If the value is lower than threshold the apnea status is detected. This threshold is calculated through an initial calibration procedure and is constantly adapted for the particular breathing pattern of each user. The algorithm is shown in Fig. 6.

The second correction algorithm exploit the information provided by accelerometer. In fact, it is possible to detect movements or positions that causes artifacts into the breathing signal. In the case of the patient lying on his left side, the second threshold is temporarily lowered. This is due to the limits of pressure sensors that measures a signal with lower amplitude variation in this case. In the case of an important movement detection, revealed by the RMS calculation of the three components of the acceleration, the breathing algorithm is not executed for a period of 6 seconds and the new detected state depends on the previous state. An example of the algorithm output is shown in Fig. 7.

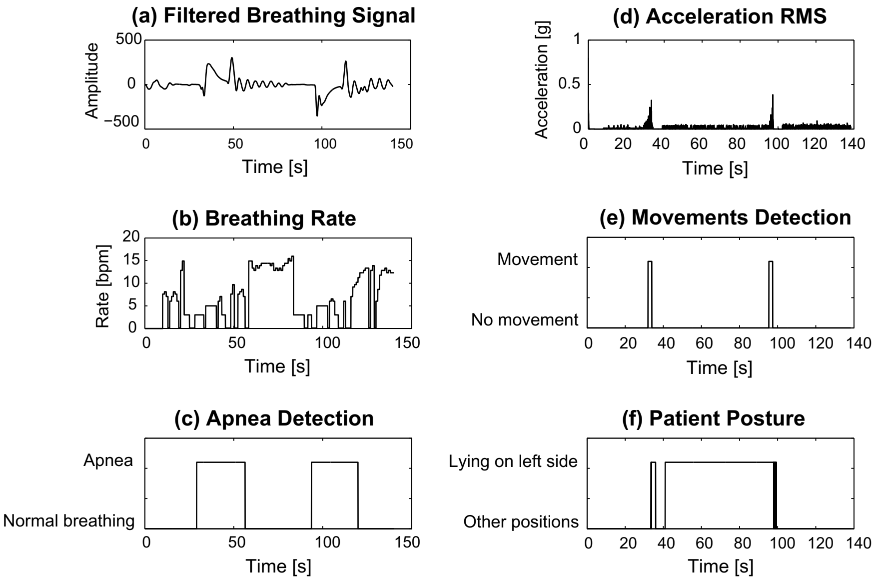


Fig. 7 Example of apnea detection in the cases of two movements

2.4 Application

The developed application includes all the features heart activity and breathing activity analysis, it is composed by various components:

- a Service to handle the Bluetooth connectivity and to extract data needed to the processing algorithms
- a Service that implements all the algorithms on the heart activity
- a Service that implements the algorithms for the apnea detection
- a Class to store locally all the elaboration results and the user characteristics and settings
- a Class to eventually transmit the results of the elaborations to the Cloud
- an Activity that allow the user to start an acquisition by connecting to a previously paired device or to find a new device
- an Activity to start/stop and monitor all the analysis related to cardiac activity
- an Activity to start/stop and monitor the analysis on the breathing activity.

Some example interfaces are shown in Figs. 8 and 9.

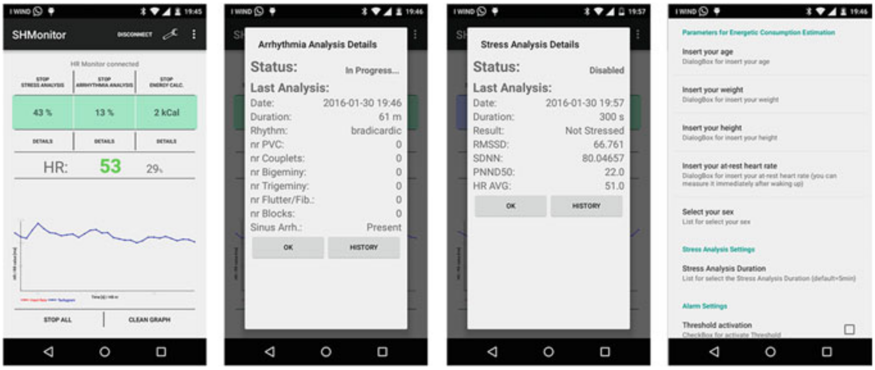


Fig. 8 UI example 1

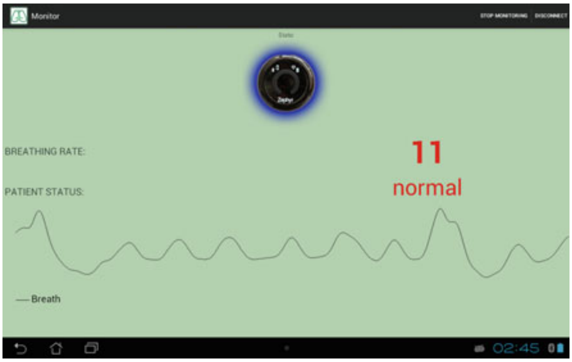


Fig. 9 UI example 2

3 Results

In order to evaluate the performance of the developed application, experimental tests were carried out for the evaluation of the computational load and the battery life consumption of the smartphone in relation to its use. The experimental tests were carried out on a mid-range smartphone and in particular a Xiaomi Redmi Note 4 was used. The evaluation of the computation load was performed by real time analyzing of the resources used by the application during its normal operation. The battery life has been evaluated performing experimental tests in which the application runs in background, with the smartphone screen off and until the battery runs out completely. Experimental evidence shows that the computing load is totally negligible while the battery life was about 16 h. Its battery life is however always higher than that of the BioHarness which on average is about 15 h. The stress state detection, the sinus rhythm classification, the sinus arrhythmia detection, the arrhythmia classification, the energy expenditure estimation and the apnea detection results are already been presented in [13]. About the atrial fibrillation detection the performance of the algorithm has been evaluated using 18 acquisitions from the PhysioNet database with AF

Table 3 AF detection algorithm results

Interval type	Tot	TN	FP
Normal rhythm	127	119	8
AF	89	83	9
Specificity	Sensitivity		
93%	94%		

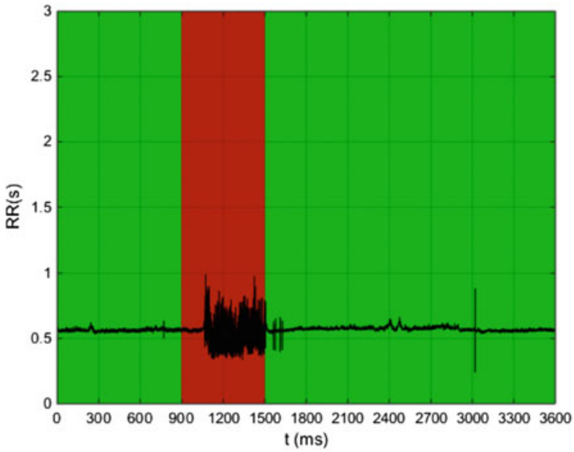


Fig. 10 Graphical output of the algorithm

annotations and containing a total of 216 events to be classifies (89 AF events, 127 normal events). The results of the algorithm in terms of sensitivity and specificity are shown in Table 3.

The results are very good especially because many of the false negative events (AF not detected) are characterized by a very limited duration. An example of the algorithm output is represented in Fig. 10.

4 Conclusion

In this paper an eHealth system to detect atrial fibrillation events and provide information about patient's health status has been presented. The results of the implemented algorithms are good, and the developed smartphone application proved to be able to identify stress conditions, arrhythmias and apnea events. In particular, the algorithm for atrial fibrillation detection has been tested using acquisitions with atrial fibrillation events. The results show that, the algorithm for atrial fibrillation detection has obtained excellent results for the monitoring of this pathology. In future works, it would be interesting to evaluate the performance of our algorithm with patients suffering from different pathologies or arrhythmias generally identified by the analysis of the P-wave. In addition to this, further efforts will be made to implement the proposed solution directly in a Cloud platform and to use tele-counseling service based on the WebRTC technology [16] for data upload of physiological parameters acquired by the BioHarness wearable sensor. It is important to underline that a computer software cannot replace the diagnosis of a physician, but it can be helpful to provide additional information and alerts. Finally, a software that includes such a set of different algorithms, can provide very important information also to relate different symptoms and diseases.

References

1. Agostinelli A, Morettini M, Sbrollini A, Maranesi E, Migliorelli L, Di Nardo F, Fioretti S, Burattini L (2017) Carisma 1.0: cardiac risk self-monitoring assessment. Open Sports Sci J 10(1)
2. Andreoli A, Gravina R, Giannantonio R, Pierleoni P, Fortino G (2010) SPINE-HRV: a BSN-based toolkit for heart rate variability analysis in the time-domain. Wearable and autonomous biomedical devices and systems for smart environment, pp 369–389. Springer
3. Camm A, Malik M, Bigger J, Breithardt G, Cerutti S, Cohen R, Coumel P, Fallen E, Kennedy H, Kleiger R et al (1996) Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task force of the European society of cardiology and the north American society of pacing and electrophysiology. Circulation 93(5):1043–1065
4. Kulmala J, Hynynen E (2011) Heart rate variability in chronic and acute stress
5. Lian J, Wang L, Muessig D (2011) A simple method to detect atrial fibrillation using RR intervals. Am J Cardiol 107(10):1494–1497
6. Licht CM, de Geus EJ, Zitman FG, Hoogendijk WJ, van Dyck R, Penninx BW (2008) Association between major depressive disorder and heart rate variability in The Netherlands study of depression and anxiety (NESDA). Arch Gen Psychiatr 65(12):1358
7. Mohebbi M, Ghassemian H (2008) Detection of atrial fibrillation episodes using SVM. In: 30th annual international conference of the IEEE engineering in medicine and biology society, EMBS 2008, pp 177–180. IEEE (2008)
8. Moody GB, Mark RG, Goldberger AL (2001) Physionet: a web-based resource for the study of physiologic signals. IEEE Eng Med Biol Mag 20(3):70–75
9. Najarian K, Splinter R (2012) Biomedical signal and image processing, 2nd edn. Taylor & Francis
10. Nepi D, Sbrollini A, Agostinelli A, Maranesi E, Morettini M, Di Nardo F, Fioretti S, Pierleoni P, Pernini L, Valenti S et al (2016) Validation of the heart-rate signal provided by the Zephyr BioHarness 3.0. In: Computing in cardiology conference (CinC), pp 361–364. IEEE
11. O'Rourke RA, Fuster V, Alexander R (2003) Hurst. Il cuore, il manuale. McGraw Hill
12. Park J, Lee S, Jeon M (2009) Atrial fibrillation detection by heart rate variability in poincare plot. Biomed Eng Online 8(38):1–12
13. Pierleoni P, Pernini L, Belli A, Palma L (2014) An android-based heart monitoring system for the elderly and for patients with heart disease. Inte J Telemed Appl 2014:10
14. Pierleoni P, Pernini L, Belli A, Palma L (2014) Real-time apnea detection using pressure sensor and tri-axial accelerometer. In: IEEE-EMBS international conference on biomedical and health informatics (BHI), pp 513–516. IEEE (2014)
15. Pierleoni P, Pernini L, Belli A, Palma L, Valenti S, Paniccia M (2015) SVM-based fall detection method for elderly people using android low-cost smartphones. In: 2015 IEEE sensors applications symposium (SAS), pp 1–5. IEEE

16. Pierleoni P, Pernini L, Palma L, Belli A, Valenti S, Maurizi L, Sabbatini L, Marroni A (2016) An innovative webRTC solution for e-health services. In: 2016 IEEE 18th international conference on e-health networking, applications and services (Healthcom), pp 1–6. IEEE
17. Sbrollini A, Mercanti S, Agostinelli A, Morettini M, Di Nardo F, Fioretti S, Burattini L (2017) Athria: a new adaptive threshold identification algorithm for electrocardiographic p waves. Computing 44:1
18. Stewart S, Hart C, Hole D, McMurray J (2001) Population prevalence, incidence, and predictors of atrial fibrillation in the renfrew/paisley study. Heart 86(5):516–521
19. Tsipouras MG, Fotiadis DI, Sideris D (2005) An arrhythmia classification system based on the RR-interval signal. Artif Intell Med 33(3):237–250
20. Yang H, Lee J, Lee K, Lee Y, Kim K, Choi H, Kim D (2008) Application for the wearable heart activity monitoring system: analysis of the autonomic function of HRV. In: 30th annual international IEEE EMBS conference

Assessment of Mental Stress Through the Analysis of Physiological Signals Acquired From Wearable Devices

Matteo Zanetti, Luca Faes, Mariolino De Cecco, Alberto Fornaser, Martina Valente, Giovanni Guandalini and Giandomenico Nollo

Abstract Mental stress is a physiological state that directly correlates to the quality of life of individuals. Generally speaking, but especially true for disabled or elderly subjects, the assessment of such condition represents a very strong indicator correlated to the difficulties, and, in some case, to the frustration that derives from the execution of a task that results troublesome to be accomplished. This article describes a novel procedure for the assessment of the mental stress level through the use of low invasive wireless wearable devices. The information contained in electrocardiogram, respiratory signal, blood volume pulse, and electroencephalogram was extracted to set up an estimator for the cognitive workload level. A random forest classifier was implemented to assess the level of mental stress starting from a pool of 3481 features computed from the aforementioned physiological quantities. The proposed system was applied in a scenario in which two different mental states were elicited in the subject under investigation: first, a baseline resting condition was induced by the presentation of a relaxing video; then a stressful cognitive state was provoked by the

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administration of a mental arithmetic task. The random forest classifier shows an accuracy of 97.5% in discerning between these two mental states.

Keywords Stress assessment · Network physiology · Wearable devices Measurements · Classification · Machine learning

1 Introduction

Ambient Assisted Living (AAL) [1] is a term that encapsulates a set of technological solutions to make the environment in which a person lives smart and cooperative. In this context, accurate measurement of stress and effort can be helpful both to evaluate the status of the individual in performing daily activities and to assess the efficacy of proposed technological aids with respect to their impact and acceptability by users and caregivers [19].

This is the goal of the AUSILIA project [22], whose focus is smart monitoring of disabled users inside a domotic apartment, via the aggregate and remote collection of health related parameters for evaluating their physiological status [8]. In such context, the automatic identification of stressing situations represents a core feature: it simplifies the monitoring by providing to the therapists more detailed, not directly visible by eyes, information about the subject and his/her difficulties.

Other than the clinical application, the proposed research can also be applied to further areas interested in the assessment of mental stress. Examples are the one related to the reduction of stress levels [9], cardiovascular risk [28], work-related stress [15], student stress [29] and environmental stress [27].

Overall, the presence of certain stressors can lead to decrements in performance and give measurable physiological conditions, although there is no a single stress reaction for different stressors [7]. The stress condition is determined by a series of stimuli that can be internal or external, physical, social, or intrapsychic. These factors disrupt the balance of the complex interacting control mechanisms, causing a series of behavioral and physiological activations to restore the theoretical balance.

2 State of the Art

In this section, a brief review of the state of the art about the most used measurements of stress that are based on the acquisition of physiological signals is given [25]. Some of the main parameters used for stress detection are relative to the cardiovascular system activity that is usually measured through blood volume pulse (BVP) and electrocardiography (ECG) signals. In particular, one of the most frequently used physiological indexes exploited to perform stress detection is the heart rate variability (HRV) that refers to the variation in the time interval between heartbeats (the R-R tachogram). The computation of the power spectral density of the HRV makes possible to distinguish stress situations: taking into consideration the low-frequency band (0.01–0.08 Hz) and the high-frequency band (0.15–0.5 Hz), the increase in the LF and in the LF/HF ratio is related to anxiety [16]. Other parameters usually used to perform stress detection are the respiratory system activity, the arterial blood pressure (ABP), the electro-dermal activity (EDA), the facial muscle activity, which is measured through electromyography (EMG), and the electroencephalography (EEG).

A range of studies make use of the aforementioned physiological parameters to assess mental state of individuals, some of which are briefly reviewed in the following. In [32], the impact of a prolonged mental activity is studied, analyzing the strong correlation between the EEG signal and the HRV power spectral density. After the feature extraction, the authors applied a support vector machine (SVM) algorithm to differentiate two mental fatigue states.

In [3], is presented a study in which EEG data and in particular alpha rhythm power at right prefrontal cortex are used to train an SVM algorithm to classify multilevel mental stress.

In [12, 13, 30], combined cardiorespiratory analyses during mental stress are presented. The authors used the information theory to assess the interaction between respiration and HRV.

A comparative analysis of feature reduction and machine learning methods for physiology-based emotion estimation is presented in [17]. In this case, the physiological signals measured by the authors were ECG, respiration, skin conductance and skin temperature. The aim of the paper was to find the best compromise between the accuracy in the classification and the real-time implementation.

In [2], a framework for mental stress monitoring using wearable devices is presented. The authors implemented an SVM classifier to distinguish if a person is stressed or not using features derived from HRV and EDA. Wearable devices can be accessories or clothes that with respect to laboratory instrumentation are less invasive and cheaper. One of the biggest advantages of these systems is the ability to get information without having to reside in a specific place and ensure a certain freedom of movement [21].

In this paper, we apply concepts of network physiology [6] within the general framework of information theory [12] to perform the analysis of physiological signals acquired by wearable devices. The outcomes of the analysis are used to design a random forest (RF) classifier able to distinguish between states of rest and stress in a single subject. The acquired signals are the ECG, the respiratory signal, the BVP and the EEG.

3 Hardware Configuration

The considered hardware for the acquisition of physiological signals consists in a sensorized t-shirt, a wristband and a headset. Figure 1 shows a subject equipped with the devices.

Fig. 1 Wearable devices used to acquire the physiological signals

The t-shirt, by Smartex (Prato, Italy), provides the ECG at a sampling frequency of 250 Hz and the respiration rate at 25 Hz. This last signal is measured by a piezoresistive sensor situated at the level of the ribcage. The BVP, at 64 Hz, was measured using an Empatica (Milano, Italy) E4 wristband. Finally, the EEG was acquired using the 14 channels Emotiv (San Francisco, CA) EPOC PLUS wireless headset, 256 Hz for every channel. The battery life of the Smartex, Empatica and Emotiv devices in streaming mode is respectively of 12 h, 24 h, and 12 h.

For what concerns problems in correct wearing to obtain high accuracy vital signs acquisition, it is important that the t-shirt is the right size to have a good contact with the ECG electrodes and not to have the piezoresistive sensor too much stretched or loose. The wristband should be worn reasonably snugly (but not uncomfortably tight) in order not to be able to see any light escaping from the PPG sensor on the back of the wrist. For the EEG headset, special attention must be paid to the correct positioning of the EEG electrodes. However, thanks to the fixed configuration, the setup time of the EEG headset is about 3–5 min. Smartex and Emotiv devices provide also an interface for verifying the acquired signal quality. All devices were connected to the same PC via Bluetooth.

4 Measurement Protocol

A single subject participated in this preliminary study. Such design choice aims at removing from the analysis possible confounding factors related the inter-subject variability, to optimize the testing protocol and at the same time to focus more in detail on the capability of the classification method. It is clear that the resulting model will be tailored specifically for the subject, but that represents the initial, necessary step for a more wider testing procedure optimized thanks to the results achieved with the proposed analysis.

Twenty recording sessions were performed. These were conducted between 10.30 and 12.00 a.m. in order to avoid differences due to time of day. The subject was seated in front of a PC in a comfortable room at constant illumination. Instructions were given to not speak and not to move except for the dominant hand to use the keyboard. No caffeine had to be assumed at least three hours before a recording session.

The protocol was made of three phases:

- rest (12 min);
- mental arithmetic (7 min);
- rest (12 min).

The rest condition consisted in watching a relaxing video. For the mental arithmetic task we used an on-line tool in which participant had to perform sums and subtractions of 3-digit numbers and write the solution in a text-box using the keyboard. No pen and paper or other supports were allowed for the achievement of the arithmetics. Also finger counting was discouraged.

5 Data Analysis

For each recording session, both rest and arithmetics, 5 datasets were taken at different times spaced out by 10 s. The subdivision was meant to discriminate if any effect is highlighted in the classification process by using data coming from different moments of a namely *constant* state of the user.

Each set contains the cardiovascular data (ECG, respiratory signal and BVP) and the EEG data for a total of 100 datasets (20 recording session per 5 extracted datasets) for the initial rest phase, 100 for the mental arithmetic phase and 100 for the conclusive rest phase.

The data have been analyzed (offline) using Matlab and Python.

5.1 Cardiovascular and Respiratory Data Processing

The baseline wander of the ECG was removed using an high-pass filter with an half power frequency of 1 Hz while the high-frequency noise was removed using a low-

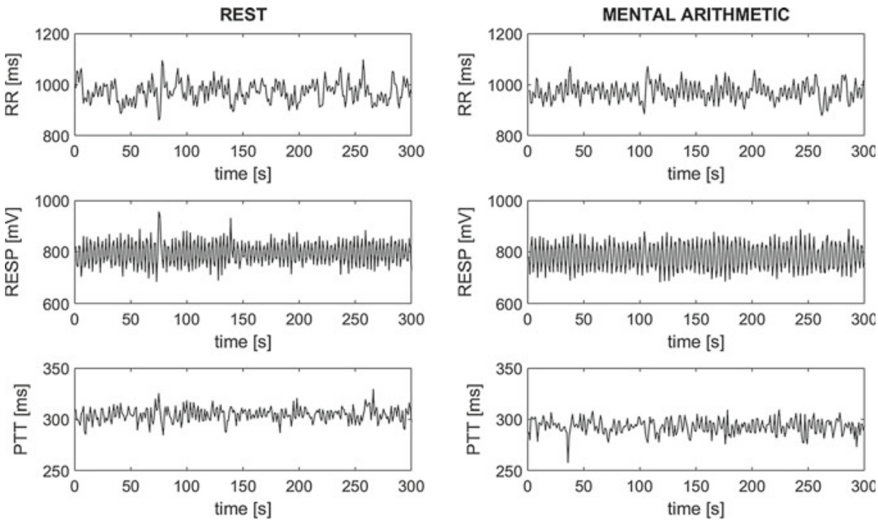


Fig. 2 RR, respiratory and PTT time series during rest and mental arithmetic resampled at 1 Hz

pass filter with an half-power frequency of 20 Hz. The R peaks were detected using the template matching algorithm [26] from the ECG and the respiratory signal was resampled at the R peaks. For what concerns the BVP signal, the points corresponding to the peak of the first derivative were used to obtain the pulse transit time (PTT) [18, 20, 31], computing the time between the R peak of the EEG and the point of maximum derivative of the BVP. The tachogram, the respiratory, and the PTT time series were then extracted.

In order to reduce the transient behaviors, the time series in the rest periods were extracted after at least 3 min passed from the beginning. There is a different situation with the stress intervals: the phenomenon of habituation can occur and therefore the earlier during the task (except the first 1 min of the state change) this happens the higher (usually) the response will be. For this reason, the selected stress intervals were taken starting from 1 up to 2 min after the transition to the mental arithmetic task.

Time series of 300 points were extracted. Their stationarity was tested checking the steadiness of mean and variance [23]. The time series were finally resampled at 1 Hz. Figure 2 shows the RR, respiratory and PTT time series for a subject during rest and performing mental arithmetic.

5.2 EEG Data Processing

For the EEG data, the power spectral density (PSD) was computed in the δ (0.5–3 Hz), θ (3–8 Hz), α (8–12 Hz) and β (12–25 Hz) bands. A sliding windows of 2 s

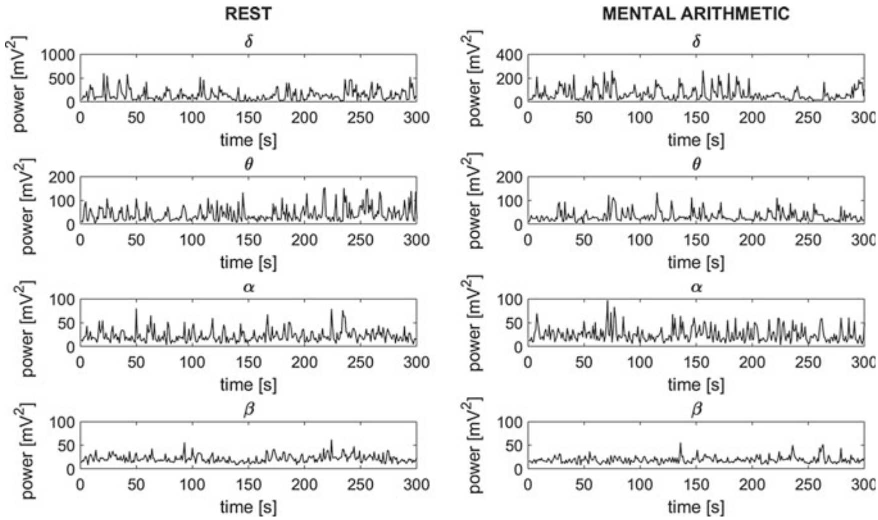


Fig. 3 Power series of the AF3 electrode in δ, θ, α, β bands during rest and mental arithmetic

duration and 50% overlap was used in order to maintain the synchronization with the cardiovascular data. In this manner, it was possible to construct the power series for every band as shown in Fig. 3, using the MATLAB function *bandpower()*, specifying the sampling frequency and the band of interest.

5.3 *Feature Extraction*

Data analysis was performed according to the principles of network physiology. The idea is to look simultaneously at multiple organs, where each one is seen as a node of a complex network of physiological interactions. In particular, it is studied how information is processed in the physiological network using information-theoretic measures, such as the self entropy S_Y, which was used to investigate dynamical activity within a single physiological signal, and the mutual information $I(X;Y)$ and conditional mutual information $I(X;Y|Z)$, which were used to investigate connectivity between two or more signals.

Let us consider a dynamic process Y. Given the present sample Y_n and the past states $\mathbf{V}_n^Y = [Y_{n-1}, Y_{n-2}, ...]$, the self entropy S_Y can be defined as:

$$S_Y = H(Y_n) - H(Y_n|\mathbf{V}_n^Y) \quad (1)$$

where $H(Y_n)$ is the Shannon entropy that is given by $H(Y_n) = -\sum p(Y_n) \ln p(Y_n)$ and $H(Y_n|\mathbf{V}_n^Y)$ the conditional entropy. S_Y is a measure of information storage that quantifies how much information carried by Y_n can be predicted by the knowledge of its own past (S_Y gives an idea on how much the signal under investigation is predictable [12]).

Given two dynamic processes X and Y, the mutual information $I(X_n; Y_n)$ is defined as:

$$\begin{aligned} I(X_n; Y_n) &= H(X_n) - H(X_n|Y_n) \\ &= H(Y_n) - H(Y_n|X_n) \\ &= H(X_n) + H(Y_n) - H(X_n, Y_n) \end{aligned} \tag{2}$$

where $H(X_n)$ and $H(Y_n)$ are the marginal entropies, $H(X_n|Y_n)$ and $H(Y_n|X_n)$ are the conditional entropies, and $H(X_n, Y_n)$ is the joint entropy. $I(X_n; Y_n)$ measures the amount of information that can be obtained about one random variable observing another.

Finally, the conditional mutual information $I(X_n; Y_n|Z_n)$ is defined as:

$$\begin{aligned} I(X_n; Y_n|Z_n) &= I(X_n; Y_n, Z_n) - I(X_n; Z_n) \\ &= I(Y_n; X_n, Z_n) - I(Y_n; Z_n) \end{aligned} \tag{3}$$

and it is the expected value of the mutual information of two random variable X and Y, given the value of a third variable Z.

From a computational point of view, under the hypothesis of joint Gaussian distribution of the variable y, S_Y can be computed as proposed in [5, 24]:

$$S_Y = \frac{1}{2} \log \frac{\sigma_Y^2}{\sigma_\epsilon^2}, \tag{4}$$

where σ_Y^2 is the variance of Y and σ_ϵ^2 is the variance of the prediction error ϵ of an Auto Regressive model fitting Y:

$$Y_n = \sum_{i=1}^{p} a_i Y_{p-i} + \epsilon \tag{5}$$

where p is the model order (in the case of this paper $p = 7$).

Given the covariance Σ and precision Σ^{-1} matrices of X and Y:

$$\Sigma = \begin{bmatrix} \sigma_X^2 & \sigma_{XY}^2 \\ \sigma_{XY}^2 & \sigma_Y^2 \end{bmatrix} \tag{6}$$

$$\Sigma^{-1} = \begin{bmatrix} \gamma_X^2 & \gamma_{XY}^2 \\ \gamma_{XY}^2 & \gamma_Y^2 \end{bmatrix}, \tag{7}$$

$I(X_n; Y_n)$ and $I(X_n; Y_n|Z_n)$ can be computed as [14]:

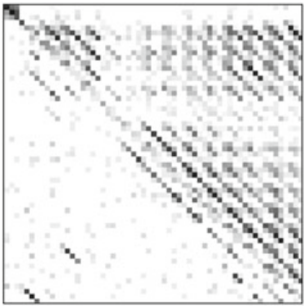


Fig. 4 59 × 59 matrix reporting an example of the values of mutual information, conditional mutual information and self-entropy, respectively on the upper diagonal part, on the lower diagonal part and on the diagonal. The darker the box, the higher the corresponding value

$$I(X_n; Y_n) = -\frac{1}{2}\log\left(1 - \frac{\sigma^2_{XY}}{\sigma^2_X\sigma^2_Y}\right) \tag{8}$$

$$I(X_n; Y_n|Z_n) = -\frac{1}{2}\log\left(1 - \frac{\gamma^2_{XY}}{\gamma^2_X\gamma^2_Y}\right), \tag{9}$$

where Z_n contains all the variables except X_n and Y_n.

For every dataset, 59 time series were obtained: the RR series, the respiratory series, the PTT series, and the δ, θ, α, β power series from the 14 channels of the EEG (for a total of 4 × 14 time series for the EEG signals). For each one of the listed entries, the self-entropy, the mutual information and the conditional mutual information were computed for a total of 3481 (59 × 59) features. Figure 4 shows the extracted features rearranged in matrix form, where, visually, the values of mutual information are reported on the upper diagonal part, the values of conditional mutual information on the lower diagonal part and the values of self-entropy on the diagonal. The signals are ordered in the following manner starting from the left: RR, respiratory series, PTT and δ, θ, α, β power series of the electrodes (in order) AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4.

6 Results

The total number of feature entries for each recording session were 3481 × (2 × 5), 2 classes, 5 different time windows (named W_a, W_b, $\dots W_e$) for each class.

The rest class includes a double amount of data given the double phase in the testing protocol. We decided to use only the data coming from the first phase for the training of the model and leave the second block as an additional control sequence.

As first step the influence of the time window position in the time series was analyzed. Five RF classifiers, from scikit-learn, were trained and tested using the

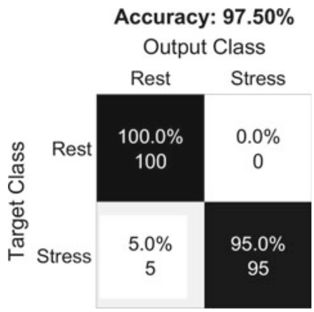


Fig. 5 Confusion matrix showing the result of the random forest classification for a 20-fold cross validation. An accuracy of 97.5% was obtained

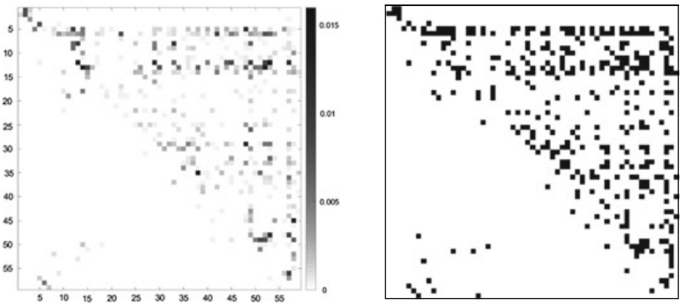
Table 1 The 10 most important features (out of 3481) used by the RF classifier with their relative scores. MI stands for mutual information

Feature	Importance score (%)
MI $\delta_{F3} - \theta_{F8}$	1.84
MI $\delta_{F3} - \theta_{F3}$	1.39
MI $\theta_{FC6} - \alpha_{AF4}$	1.36
MI $\theta_{F3} - \delta_{F8}$	1.17
MI $\delta_{F3} - \theta_{O1}$	1.10
MI $\delta_{F4} - \theta_{F8}$	1.03
MI $\delta_{F7} - \theta_{O2}$	1.02
MI $RR - RESP$	1.02
MI $\delta_{F7} - \theta_{F3}$	1.02
MI $\theta_{F4} - \beta_{F4}$	1.00

data from a defined window W_k. After that, the same models were tested with data this time coming from windows $W_{q \neq k}$. In both testing condition a 20-fold cross validation procedure was applied. A similar accuracy of 98% was achieved in either cases, thus highlighting the marginal or negligible influence of time selection over a constant state of the user. For the above reason, all 5 windows were used in the training of the final model.

The conclusive RF classifier was trained using 19 out of 20 sessions, all completed with their 5 windows, leaving out one session for the validation. Such structure achieved an accuracy in discerning between the two phases of 97.5%. The mean computational time for classifying one sample was up to 108 ms. Figure 5 shows the overall confusion matrix.

From each step of the cross validation, the RF classifier returned a feature importance list in determining the splits that will most effectively help distinguish the classes. The 20 × 3481 resulting entries were analyzed, median and variance were computed for each feature. The 95% of the overall score is reached using only the first 367 features. Table 1 lists in order of importance the top 10 features used by the classifier and relative scores in percentage. Figure 6 shows the median values of feature importance for the 20-fold cross validation. The darker the box, the higher the importance score.



(a) 59 × 59 *matrix reporting the median of feature importance.*

(b) *The first 367 features highlighted. They correspond to the 95% of the overall score of the feature importance.*

Fig. 6 Analysis of the feature importance

From such analysis, key elements can be underlined: (i) the most important features are relative to the mutual information part, (ii) the information between the cardiovascular/respiratory system and cerebral system seems to have the less importance, while (iii) a stronger importance is seen between the cardiovascular and respiratory systems.

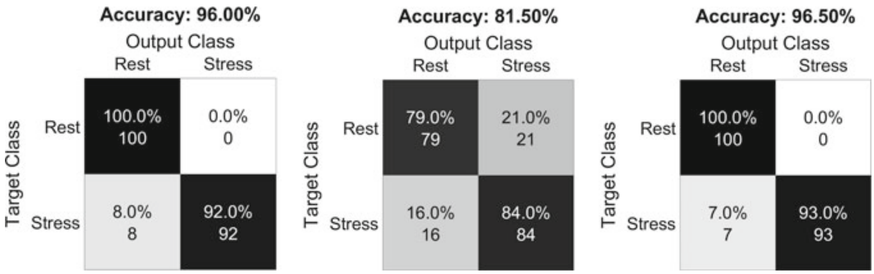
By using only the features provided by the EEG, the achieved accuracy becomes 96.0%, with a new mean computational time of 105 ms equal to a reduction in time of 2.78% with respect to the use of all the 3481 features. By using only the features provided by the cardiovascular and respiratory signals, the obtained accuracy is 81.5%, with a mean computational time of 88 ms corresponding to a reduction in time of 18.52%. If only the 367 most important features are used, the classification accuracy results equal to 96.5%, with a mean computational time of 95 ms equal to a reduction in time of 12.04% (Fig. 7).

As final control, the feature entries computed from the second rest phase, not included in the training, were tested with the trained classifier. All of these were correctly classified with no errors.

7 Conclusions

The paper presented a framework for the analysis of physiological signals acquired by low invasive wearable devices in order to distinguish between rest and stress situations.

The main goal was to design a classifier able to distinguish between a state of rest and stress in a single subject performing repeated experiments under rest and stress conditions. In particular, a data processing and a feature extraction method based on network physiology and information theory was described. The achieved accuracy



(a) *Confusion matrix using only the features provided by the EEG.*

(b) *Confusion matrix using only the features provided by the cardiovascular and respiratory data.*

(c) *Confusion matrix using only the 367 most important features.*

Fig. 7 Classification accuracy using only the features provided by the EEG data, only by the cardiovascular and respiratory data and using only the first 367 important features decreases respectively to 96.0%, 81.5% and 96.5%

was 97.5%. This is a promising result, if compared with the current state of the art [3, 32], even if the analysis was conducted only on a single subject. The use of wearable devices gives also good prospects for the implementation of the presented method in a real-life scenario.

The most important features identified by the classifier are related to the mutual information shared by the various bands and electrodes of the EEG data (in particular the F3, F4, F7 and F8 electrodes) and to the mutual information between the RR and respiratory time series. These results suggest the importance of brain connectivity and cardiorespiratory interactions for the detection of mental stress, confirming recent findings in the literature [4, 30]. On the other hand, lower importance was given to the information shared between the cardiovascular/respiratory system and the cerebral system, suggesting that brain-heart interactions are less involved in the differential characterization of mental stress compared to a relaxed state. Such information represents core elements for the optimization of the measurements system in the form of the number and type of devices that have to be worn by to a subject in order to achieve a reliable identification of the stress state.

Future experiments will foresee the extension of the proposed analysis to a wider pool of testers so as the update of the classification model with the new data collected, focusing also on analyses of dynamic connectivities [10, 11]. The inter-subject performance analysis of the model will represent one of the main topic of the next steps, focusing on the generality of the method and its applicability to different mental load related activities. Also the use of standard features from the physiological signals, such as the mean and the standard deviation, will be taken in consideration, together with the features introduced in this paper.

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References

1. AAL—Active and Assisted Living Programme (2016) AAL programme ojectives. http://www.aal-europe.eu/about/objectives/
2. Acerbi G, Rovini E, Betti S, Tirri A, Rónai JF, Sirianni A, Agrimi J, Eusebi L, Cavallo F (2016) A wearable system for stress detection through physiological data analysis. In: Italian forum of ambient assisted living, Springer, pp 31–50
3. Al-shargie F, Tang TB, Badruddin N, Kiguchi M (2018) Towards multilevel mental stress assessment using SVM with ECOC: an EEG approach. Med Biol Eng Comput 56(1):125–136
4. Alonso J, Romero S, Ballester M, Antonijoan R, Mañanas M (2015) Stress assessment based on EEG univariate features and functional connectivity measures. Physiol Meas 36(7):1351
5. Barnett L, Barrett AB, Seth AK (2009) Granger causality and transfer entropy are equivalent for Gaussian variables. Phys Rev Lett 103(23):238701
6. Bashan A, Bartsch RP, Kantelhardt JW, Havlin S, Ivanov PC (2012) Network physiology reveals relations between network topology and physiological function. Nat Commun 3:702
7. Bourne Jr LE, Yaroush RA (2003) Stress and cognition: a cognitive psychological perspective
8. De Cecco M, Fornaser A, Tomasin P, Zanetti M, Guandalini G, Ianes P, Pilla F, Nollo G, Valente M, Pisoni T (2017) Augmented reality to enhance the clinicianâĂŹs observation during assessment of daily living activities. In: International conference on augmented reality, virtual reality and computer graphics Springer, pp 3–21
9. Eda N, Ito H, Shimizu K, Suzuki S, Lee E, Akama T (2017) Yoga stretching for improving salivary immune function and mental stress in middle-aged and older adults. J Women Aging 1–15
10. Faes L, Nollo G, Jurysta F, Marinazzo D (2014) Information dynamics of brain-heart physiological networks during sleep. New J Phys 16(10):105005
11. Faes L, Marinazzo D, Jurysta F, Nollo G (2015) Linear and non-linear brain-heart and brain-brain interactions during sleep. Physiol Meas 36(4):683
12. Faes L, Porta A, Nollo G, Javorka M (2016) Information decomposition in multivariate systems: definitions, implementation and application to cardiovascular networks. Entropy 19(1):5
13. Faes L, Porta A, Javorka M, Nollo G (2017) Efficient computation of multiscale entropy over short biomedical time series based on linear state-space models. Complexity 2017
14. Gelfand IM, Yaglom AM (1959) Calculation of the amount of information about a random function contained in another such function. American Mathematical Society Providence
15. Kopyt A, Zuzewicz K, Bartuzi P (2017) Experimental identification of a mathematical model of human operator working under mental stress. Acta Bioeng Biomech 19(3)
16. Kreibig SD (2010) Autonomic nervous system activity in emotion: a review. Biol Psychol 84(3):394–421
17. Kukolja D, Popović S, Horvat M, Kovač B, Ćosić K (2014) Comparative analysis of emotion estimation methods based on physiological measurements for real-time applications. Int J Hum Comput Stud 72(10):717–727
18. Masè M, Mattei W, Cucino R, Faes L, Nollo G (2011) Feasibility of cuff-free measurement of systolic and diastolic arterial blood pressure. J Electrocardiol 44(2):201–207
19. Maule L, Fornaser A, Tomasin P, Tavernini M, Minotto G, Da Lio M, De Cecco M (2017) Augmented robotics for electronic wheelchair to enhance mobility in domestic environment. In: International conference on augmented reality, virtual reality and computer graphics. Springer, pp 22–32
20. Orini M, Citi L, Barbieri R (2012) Bivariate point process modeling and joint non-stationary analysis of pulse transit time and heart period. In: 2012 annual international conference of the IEEE engineering in medicine and biology society (EMBC). IEEE, pp 2831–2834
21. Patel S, Park H, Bonato P, Chan L, Rodgers M (2012) A review of wearable sensors and systems with application in rehabilitation. J Neuroeng Rehabil 9(1):21
22. Pisoni T, Conci N, De Natale FG, De Cecco M, Nollo G, Frattari A, Guandalini GM (2016) AUSILIA: assisted unit for simulating independent living activities. In: 2016 IEEE international smart cities conference (ISC2). IEEE, pp 1–4

23. Porta A, D'Addio G, Guzzetti S, Lucini D, Pagani M (2004) Testing the presence of non stationarities in short heart rate variability series. In: Proceedings of computers in cardiology, pp 645–648. https://doi.org/10.1109/CIC.2004.1443021
24. Porta A, Faes L, Nollo G, Bari V, Marchi A, De Maria B, Takahashi AC, Catai AM (2015) Conditional self-entropy and conditional joint transfer entropy in heart period variability during graded postural challenge. PLoS One 10(7):e0132851
25. Sioni R, Chittaro L (2015) Stress detection using physiological sensors. Computer 48(10):26–33
26. Speranza G, Nollo G, Ravelli F, Antolini R (1993) Beat-to-beat measurement and analysis of the RT interval in 24 h ECG holter recordings. Med Biol Eng Comput 31(5):487–494
27. Steinheuser V, Ackermann K, Schönfeld P, Schwabe L (2014) Stress and the city: impact of urban upbringing on the (re) activity of the hypothalamus-pituitary-adrenal axis. Psychosom Med 76(9):678–685
28. Vaccarino V, Sullivan S, Hammadah M, Wilmot K, Al Mheid I, Ramadan R, Elon L, Pimple PM, Garcia EV, Nye J et al (2018) Mental stress-induced-myocardial ischemia in young patients with recent myocardial infarction: sex differences and mechanisms. Circulation 137(8):794–805
29. Vanitha V, Krishnan P (2016) Real time stress detection system based on EEG signals. Biomed Res
30. Widjaja D, Montalto A, Vlemincx E, Marinazzo D, Van Huffel S, Faes L (2015) Cardiorespiratory information dynamics during mental arithmetic and sustained attention. PloS One 10(6):e0129112
31. Ye S, Kim GR, Jung DK, Baik S, Jeon G (2010) Estimation of systolic and diastolic pressure using the pulse transit time. World Acad Sci Eng Technol 67:726–731
32. Zhang C, Yu X (2010) Estimating mental fatigue based on electroencephalogram and heart rate variability. Pol J Med Phys Eng 16(2):67–84

Experimentation of a Low Cost Public Transport System for People with Visual Disabilities

L. D'Errico, F. Franchi, F. Graziosi, C. Rinaldi and F. Tarquini

Abstract According to World Health Organization (WHO), currently in the World there are around 39 million visually impaired persons. These persons have to perform exactly the same daily activities as able-bodied people. These activities can be very difficult or dangerous for visually impaired persons (e.g. using public transport, crossing streets, walking alone, etc.). Public transit is the key to independence for many sightless persons but it still remains a challenging problem despite recent progresses in assistive technology. In this work we present and evaluate a smartphone-based system to improve mobility and transportation access for visually disabled people. A pilot experimentation, carried on with five visually impaired volunteers persons has been carried on end it is here presented in order to evaluate the real feasibility of the proposed approach.

Keywords Navigation system · Blind · Public transportation · Visual impairment · Smartphone based

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1 Introduction

According to the World Health Organization (WHO), in the world there are approximately 285 million persons with visually impairments, of whom 39 million are blind and 246 million have low vision and about 90% of the global burden of visual impairment is concentrated in low-income countries [1, 2]. According to the International Classification of Disabilities [3], the four levels of visual functions are: normal vision, moderate visual impairment, severe visual impairment and blindness. Low vision (moderate visual impairment and severe visual impairment) is 47% caused by refractive errors (nearsightedness, farsightedness or astigmatism), 33% because of non-operated cataract and 2% because of glaucoma [1].

The possibility of using public transports plays a critical role in the independence of blind persons, providing more opportunities for employment, education, leisure, and socialization [4]. Yet, blind travelers continue to face difficulties [5, 6]. In particular, access to travel-related information, which contributes to comfort and safety, might be difficult for those who cannot see. A passenger needs to ascertain which bus, train, or subway line to take, when the vehicle departs, and where to board it. While riding, passengers need to be aware of progress toward their destination so they have sufficient time to prepare to exit the vehicle when it arrives at the desired stop.

The proposed architecture consists of two systems: an accessible route stop assistant that contains all the transport system information such as schedules, stops, routes, etc., and a device that provides information to the bus interior about the stops and the route. These systems rely on tools such as GPS, touchscreens and audiovisual media, and principles such as universal design and accessibility so that there is no better quality of life for visual impaired people, but for the general population.

The rest of this work is organized as follows. In Sect. 2 we briefly describe some related approaches for improving information access to travelers with sensorial impairments. The proposed approach as well as the general system architecture is described in Sect. 3. The pilot experiment and preliminary results are presented in Sects. 4 and 5. Finally, the conclusions and future works are described in the last section.

The proposed project was developed in collaboration with the Italian Union of Blind and Partially Sighted People (UICI—Unione Italiana dei Ciechi e degli Ipovedenti) and specifically with the Section of L'Aquila.

2 Related Works

Several researchers have addressed the problem of improving information access to travelers with sensorial impairments [7]. A large number of device-based hardware and software technologies have been developed in order to assist people who are blind or visually impaired. These technologies have functions such as reading the content found on a screen; expand characters, read printed text, Braille systems, long walking sticks for primary mobility, human-machine robots to bring assistance and systems based on computer vision [8, 9].

Other projects have considered the needs of travelers with cognitive impairments [10, 11]. For example, the Travel Assistance Device [12] used the traveler's GPS device to determine the location of the bus he or she is riding and to inform the traveler when the bus is approaching a desired stop. João de Sousa et al. developed a similar system [13]. Unlike these efforts, we designed our Public Transportation System (PTS) from the ground up with the goal of supporting visually impaired passengers throughout their entire travel, from the moment they arrive in the vicinity of their first bus stop to the time they reach their destination bus stop.

Besides accessing trip-related information, visually impaired passengers often have difficulty recognizing a bus stop or orienting themselves in a transit hub. Standard mapping services such as Google Maps and accessible GPS apps such as BlindSquare or Sendero's Seeing Eye GPS can be used for this purpose, but they have critical shortcomings. For example, Google Maps provides the location of bus stops but not descriptions of their layouts. Also, the relatively low spatial accuracy of GPS (10 m or more) does not allow blind users to, for example, determine whether they are at their desired bus stop or at a bus stop across the street. The StopFinder project [14, 15] created a database of detailed descriptions of layouts of bus stops, collected via crowdsourcing. Markus Guentert designed an iPhone app to allow blind persons to explore the layout of a train station [16]. Kotaro Hara et al. presented a system that uses crowdsourcing to build a database of bus stop locations that includes layout descriptions [17].

Moreover the research topics on context-awareness and localization services were deeply analysed during the experience we gained with the Casa+ project [18]. Casa+ is a smart house that is addressed to people with Down syndrome; through the most recent ICT solutions for Ambient Assisted Living (AAL) it offers functionalities for monitoring the environment and its guests, giving indication signals, audio messages or even alarms in case of incorrect actions. Long lasting experimentation steps have shown a good improvement in guests awareness of their possibility of becoming independent [19].

3 System Architecture

In this section we describe the proposed flexible architecture shown in Fig. 3 based on a remote server and the use of smartphones for the other two components of the system: the bus subsystem and the user subsystem.

The proposed system uses personal smartphones as main devices of the user subsystem because people with visual impairments have an appropriate familiarity with it. A remote server is essential to handle all buses data and to manage users' requests. Smartphone embedded GPS is used to localize the bus and the user, and the embedded Bluetooth module of the user's smartphone is exploited to detect the

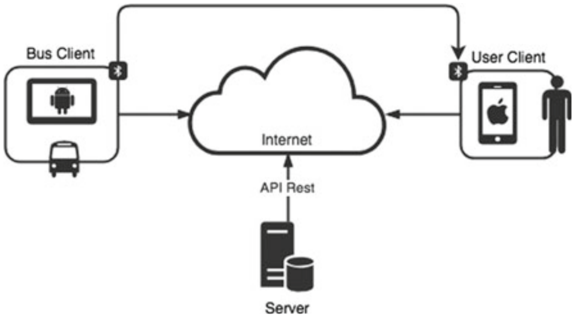

Fig. 1 The architecture of the proposed system

Table 1 The information of the iBeacon

	UUID	Major	Minor	Power
String	BLIND_BUS_UUID	1	1	−59
Hex	0x5f 0x42 0x4c 0x49 0x4e 0x44 0x5f 0x42 0x55 0x53 0x5f 0x55 0x55 0x49 0x44 0x5f	0x00 0x31	0x00 0x31	C5
Length	16 bytes	2 bytes	2 bytes	1 byte

Bluetooth equipped buses. The choice of an Apple based smartphone for the users' system, was required by UICI since it is widely employed by all sightless persons involved in the experimentation (Fig. 1).

The Bus subsystem has been instead developed on an Android based smartphone. The advantages of this choice are: a built-in system with all essential hardware (GPS, Bluetooth, Touch Display, Modem, Audio system, etc.); a simple power-supply available on bus dashboard; no large size; portability; and all utilities of Android OS (push notification system).

In addition to the GPS technology for bus localization along a route, an essential role is assigned to the Bluetooth module. This module allows the user subsystems to detect which bus is approaching. The chosen technology is the Bluetooth 4.0 Low Energy (BLE) called Beacon that allows to send and receive short messages. Beacons periodically send their identifier (they "advertise" their presence), nearby devices that listen to BLE devices properly react (or do not react at all) to the received advertisements. In order to use this technology in both subsystems (Apple based and Android based smartphones) we implemented the Apple Beacon protocol, iBeacon, because it is the only working on Apple smartphones. The iBeacon message is composed by a UUID, a major ID, a minor ID, and the RSSI level measure at a distance of one meter from the device as explained by Table 1. For example: UUID: *5F424C49-4E44-5F42-5553-5F555549445F* Major: 0001 Minor: 0002 POWER: C5.

The system architecture is presented in the following section by separately describing its main components: user application, bus application and server.

3.1 User Application

The user application is a mobile application developed on iOS. Indeed a device such as an iPhone guarantees some accessibility features in order to allow its use by people with impaired vision. The user interface is designed in conjunction with the final users in order to properly respond to their need and ensure all data required. Figure 2 shows services and used technologies.

The application permits the reservation of a bus route, defining its departure and arrival bus stops. When the user selects a destination stop, the application asks to the sever about the possible departure stops in the next two hours and in proximity of the user location. If a proper route is selected and reserved the application may also bring the user to the stop through a navigation system.

Another important feature of this application is the opportunity of identifying those buses which are passing by the user. The application exploits beacon technology to know the buses in its proximity and detects their lines and routes by analysing the major and the minor identifiers in the received beacon payload. Every time a bus is detected the application use text-to-speech to alert the user, specifying the estimated user-bus distance.

A third service available on the application allows the user that is already on board to reserve the destination stop. The application detects the beacon of the bus and shows its next stops.

In every reservation feature, if the user performs a reservation, the application is configured to receive alert notification when the selected bus is coming approaching the departure and arrival reserved stops.

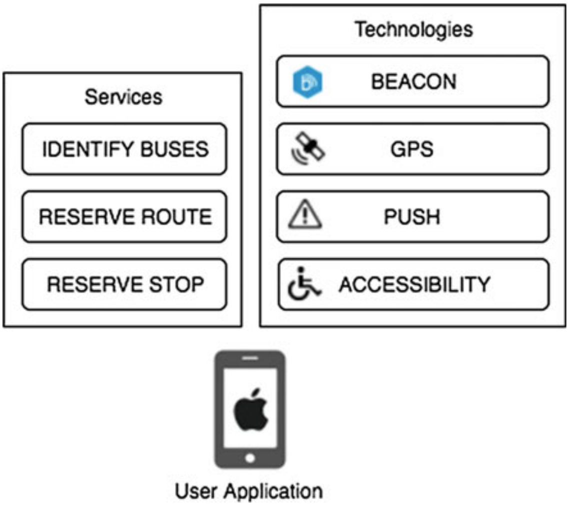

Fig. 2 Services and technologies used in user application

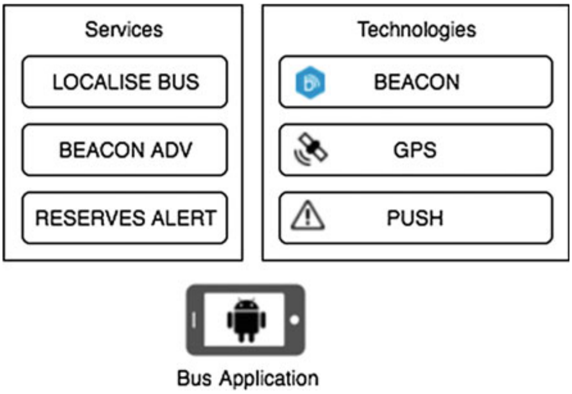

Fig. 3 Services and technologies used in buses application

3.2 Bus Application

The second part of the system is the bus application, whose services and technologies are shown in Fig. 3, for which an Android smartphone has been adopted. This application performs the localisation of the bus using the GPS and sending the position to the main server. The app requires some initial configurations, like the bus identification code, the line and the route it has to cover. The system subsequently localises the device and advertises the identification beacon. As the user application, also this application alerts the user when a reserved stop is approaching with acoustic and visual notifications.

3.3 Server

The last part of the system is the Server on which all data are stored. The Server cross-checks the data to give the right information to the applications. It is the managing director of the alerting notifications. The Server is designed as a web application managed by an administrator in order to check the data and control buses locations.

4 Prototype

This section presents the very first prototype of the system, whose description is splitted into 3 parts following the architecture definition.

The user application is developed for iPhone and iPhone Plus and we adopted the native languages Swift 3.0.

Beacons technology appears to be the best solution to properly develop the proposed services.

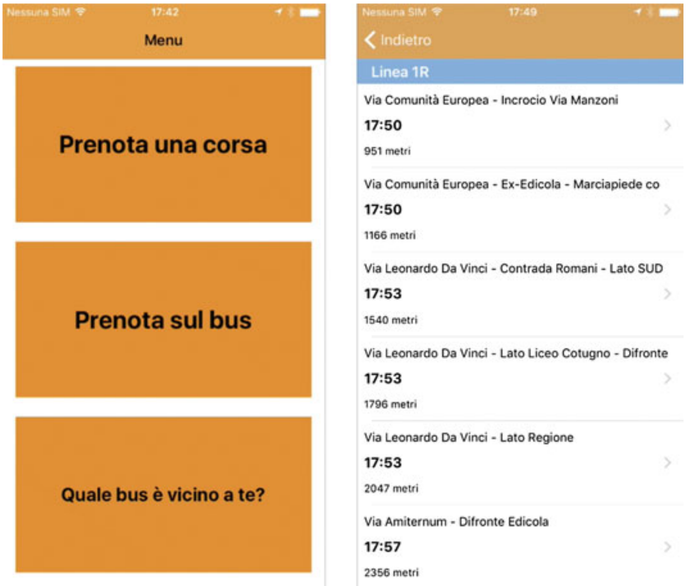

Fig. 4 Screens of the user application: the application will provide functionalities for: (i) book a trip (Button on the top) (ii) book a bus stop (Middle button) (iii) find near buses (Lower button)

For beacon technology exploitation on Apple smartphones the *iBeacon* protocol has been used. This has been developed by Apple and it is supported since iPhone 4S and iOS 7. In addition this is the only beacon protocol allowed on iPhone and it is also supported on Android smartphones (OS version 5.0+). The iPhone application is configured for using *CoreBluetooth* and *CoreLocation* native libraries for iOS App development [20, 21].

CoreBluetooth allows the use of the iBeacon technology, scanning proximity beacons and reading their UUID, major and minor IDs to identify the buses; *Core-Location* allows the GPS to locate user's device when the user looks for the closest departure stop. Finally, alert notifications coming from the server are read by the user application via accessibility embedded services.

Figure 4 shows the accessible user interface (UI) developed of the user application.

The bus application is developed on Android devices. Since its 5.0 version, Android SDK supports iBeacon technology and devices hardware must include at least Bluetooth 4.x [22]. We adopted the line Nexus 6P as smartphone because it supports this technology. The application is configured as an iBeacon Advertiser, in particular when the bus driver selects the line and the route, the system creates the UUID with a unique string of length 16 bytes identifying the main ID registered for the experimentation, a major and a minor ID both of length 2 bytes identifying the line and the route indexes respectively. These indexes are linked to the list of lines or routes the server returns to both user and bus applications. This is described in Table 2. The rest of the iBeacon structure is property of the Apple implementation

Table 2 iBeacon structure

Manufacturer	Service	UUID	Major	Minor	Power
0x004C	0x02 0x15	16 bytes	2 bytes	2 bytes	1 byte

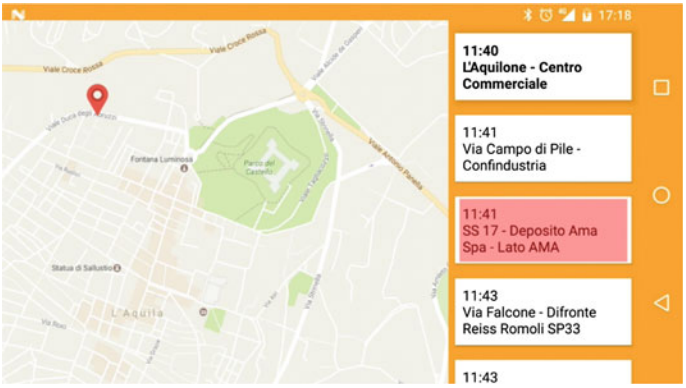

Fig. 5 Screen of the bus application

of the protocol and it refers to the manufacturer identifier and the Power (RSSI) of the signal.

In addition bus application localise the device using GPS feature and send this data to the server via ad hoc developed REST APIs. When the bus moves across the route and the GPS fixes a new location, the application checks if there are some reserved stops and in positive case it triggers an alarm notification to the bus driver. Figure 4 shows the UI of the bus application (Fig. 5).

The last component of the prototype is the Server component. This is the core of the system. This component is designed to store every received data from the two applications and to manage the notification services. It handling the notification process according to the bus location.

Alerting notifications are sent mainly in two cases as shown in Fig. 6: when the bus is approaching the stop preceding the selected one and when the bus is close to the arrival stop. Alerts can also be notified, if the user selects this option, every time the bus approaches a stop of its route.

The alerting system is designed as a Java Web Application, J2EE with Spring Framework and it gives a web user interface to allow a system administrator to manage the data [23, 24]. In order to trigger the notification the system is designed by using the right push services depending on the application: Firebase Cloud Messaging (Android) and Apple Push Notifications (iOS).

Since the server application involves the storage of large amount of data, we adopted a NoSQL solution as database. So we used MongoDB that is efficiently supported and included in Spring framework [25].

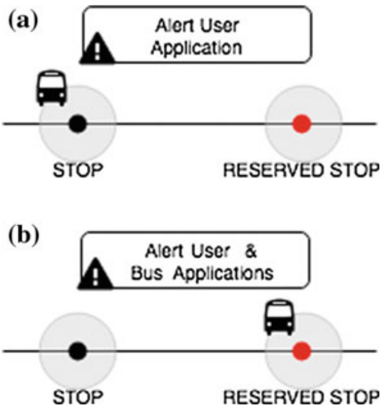

Fig. 6 Alerting system: **a** the system triggers a notification to the user application when the bus is approaching the stop preceding the selected one; **b** the system sends an alert to user and bus apps

5 Pilot Experiment and Preliminary Results

With the aim of determining the real usability of the proposed system, we have conducted two main experiments with the support of five visually impaired persons. Table 3 presents the most relevant details of participants in the pilot experiment. As it can be seen, one subject is sightless whereas four are partially sighted.

The first test phase was carried out totally in the laboratory, emulating the position of the bus on a real bus route using the appropriate tools and a path defined in a GPX file. The emulation of this route allowed us to determine the right distance for a bus to be considered in proximity of a stop of its line. By reproducing the bus position, we also had the possibility to test the stop reservation system. During the second test phase we collaborated directly with the local transport company: "Azienda Mobilità Aquilana" (later on: AMA), installing the dedicated device on the bus and testing the so far only emulated system in the real world. After several meetings with UICI, the transport company selected the "Line 1" for the experimentation, because this line has been detected as the most used one by visually impaired persons. AMA technicians placed a power supply with USB input on the dashboard of the vehicle, where the dedicated Android device was installed. Later, we personally stayed on the bus for some sections of the route in order to better define some fundamental variables for the localization of the vehicle. In addition, we tested the goodness of

Table 3 Participants in the pilot experiment

Subject	Age (years)	Visual condition	Gender
1	50	Blind	Male
2	43	Partially blind	Female
3	51	Partially blind	Male
4	38	Partially blind	Male
5	33	Partially blind	Female

Fig. 7 User n.3 testing the solution

the guidance system using iBeacon technology in stops with several buses close to each other for example in the bus terminal. The last test phase was conducted in collaboration with the personal of the UICI. In this phase we travelled with them to gather requests and suggestions and for better study how they use the system as shown in Fig. 7.

This phase allowed us to define further fixes to the system. The results obtained for both the stops reservation system and the location tracking of both the bus and the user are very good and promising; moreover the feedbacks reported by UICI have been more that good, indeed they asked us to expand the system in order to include the use of smart-watches.

6 Conclusion

In this paper we presented a low cost public transport system for people with visual disabilities. After the analysis of the needs of these people regarding the use of public transportation, we developed a technological solution comprising various kind of aids. Firstly an App for Apple smartphones has been developed to properly guide the users to plan a trip. This app uses the accessibility system provided by the Apples' ecosystem to guide the user to successfully complete the task. Then we designed an easy method to ensure that the planned trip was completed in the correct way;

referring to a companion Android application for the buses the participants of the pilot were guided to hop on the right bus and request for the proper stop. The entire process was tested in a real world scenario involving a significant group of people selected by the local UICI organization with positively results. This work is mainly devoted to visually impaired people, but the proposed solutions may be easily adapted to any kind of users.

Acknowledgements We would like again to remark the irreplaceable help and sustain we gathered by UICI L'Aquila that are representing the fundamental interface to understand the need of people affected by visual impairments, to guide the technological choices and to adapt to continuously arising needs.

References

1. World Health Organization (2018) Blindness and vision impairment prevention
2. World Health Organization (2018) Vision impairment and blindness
3. World Health Organization (2016) International statistical classification of diseases and related health problems 10th revision
4. Golledge RG, Marston JR, Costanzo CM (2001) Attitudes of visually impaired persons toward the use of public transportation
5. Marin-Lamellet C, Pachiaudi G, Le Breton-Gadegbeku B (2001) Information and orientation needs of blind and partially sighted people in public transportation: Biovam project. Transp Res Rec J Transp Res Board 1779:203–208
6. Azenkot S, Fortuna E (2010) Improving public transit usability for blind and deaf-blind people by connecting a braille display to a smartphone. In: Proceedings of the 12th international ACM SIGACCESS conference on computers and accessibility, pp 317–318. ACM
7. Palazzi CE, Bujari A (2016) Fostering accessible urban mobility through smart mobile applications. In: 2016 13th IEEE annual consumer communications & networking conference (CCNC), pp 1141–1145. IEEE
8. Lee YH, Medioni G (2016) RGB-D camera based wearable navigation system for the visually impaired. Comput Vis Image Underst 149:3–20
9. Naranjo L (2015) CRTexter: web-based investigative tool for the blind
10. Fischer G, Sullivan JF Jr (2002) Human-centered public transportation systems for persons with cognitive disabilities-challenges and insights for participatory design, pp 194–198. PDC
11. Livingstone-Lee SA, Skelton RW, Livingston N (2014) Transit apps for people with brain injury and other cognitive disabilities: the state of the art. Assist Technol 26(4):209–218
12. Barbeau SJ, Winters PL, Georggi NL, Labrador M, Perez R (2008) The travel assistant device: utilizing GPS-enabled mobile phones to aid transit rides with special needs. In Proceedings of 15th world congress on intelligent transportation systems, NY
13. Silva J, Silva C, Marcelino L, Ferreira R, Pereira A (2011) Assistive mobile software for public transportation. In: Proceedings of UBICOMM
14. Campbell M, Bennett C, Bonnar C, Borning A (2014) Where's my bus stop?: supporting independence of blind transit riders with stopinfo. In: Proceedings of the 16th international ACM SIGACCESS conference on computers & accessibility, pp 11–18. ACM
15. Prasain S (2011) Stopfinder: improving the experience of blind public transit riders with crowdsourcing. In: The proceedings of the 13th international ACM SIGACCESS conference on computers and accessibility, pp 323–324. ACM
16. Guentert M (2011) Improving public transit accessibility for blind riders: a train station navigation assistant. In: The proceedings of the 13th international ACM SIGACCESS conference on computers and accessibility, pp 317–318. ACM

17. Hara K, Azenkot S, Campbell M, Bennett CL, Le V, Pannella S, Moore R, Minckler K, Ng RH, Froehlich JE (2015) Improving public transit accessibility for blind riders by crowdsourcing bus stop landmark locations with Google street view: an extended analysis. ACM Trans Access Comput (TACCESS) 6(2):5
18. Alesii R. Graziosi F, Marchesani S, Rinaldi C, Santic M, Tarquini F (2015) Advanced solutions to support daily life of people affected by the down syndrome. In: Ambient assisted living, pp 233–244. Springer
19. Franchi F, Graziosi F, Rinaldi C, Tarquini F (2016) AAL solutions toward cultural heritage enjoyment. In: 2016 IEEE 27th annual international symposium on personal, indoor, and mobile radio communications (PIMRC), pp 1–6. IEEE
20. Apple Developer (2018) Core Bluetooth, communicate with Bluetooth 4.0 low-energy devices
21. Apple Developer (2018) Core location, obtain the geographic location and orientation of a device
22. Heydon R (2013) Bluetooth low energy: the developer's handbook, vol 1. Prentice Hall, Upper Saddle River
23. Keogh J, Keogh J (2002) J2EE: the complete reference. McGraw-Hill/Osborne
24. Johnson R, Hoeller J, Arendsen A, Thomas R (2009) Professional Java development with the Spring framework. Wiley
25. Chodorow K (2013) MongoDB: the definitive guide: powerful and scalable data storage. O'Reilly Media, Inc.

Upper Limbs Orthosis for Disability Support: The Areas of Project Development Between Technology and Design

Davide Paciotti, Francesco Pezzuoli and Federica Cotechini

Abstract The ISO 9999: 2016 standard synthetically defines the two different types of artificial support necessary to support or replace the functions of a part of the body, they are indicated as devices applied to the body to support neuromusculoskeletal or movement related functions: the orthosis. They are also referred to as devices applied to the body to replace anatomical structures: prosthesis. The scientific scenario in this field is extremely articulated and invests across many sectors and skills, where the relationship and collaboration systems are substantial for the complexity of the objectives to be achieved. The aid entrusted to a technologically sophisticated system, which represents a substantial functional appendix of the body, implies, for the development of innovation, not only a profound knowledge of the medical, engineering and computer aspects, but also ergonomic, formal, communicative and aesthetic. The project, or the projects that are intended to be presented in the present research work, underline, with the presentation of two case studies, the levels of in-depth analysis of the issues related to the role of design and information technology and robotics. In the following sections two cases of research projects carried out in parallel are proposed. The first "Talking Hands", purely technical and technological, is a completely wearable device for sign language translation. The second "D'Aria" is a glove is aimed at people with rheumatoid arthritis both for the initial stages of the disease (prevention of more serious damage) and for the more advanced phases (a real aid that restores lost grip capacity). Finally, as a research perspective, this article proposes the hybridization of the two case studies. The final objective will therefore be to create an experimental prototype that hybridizes the two characteristics, creating a series of tests on patients affected by these diseases.

Keywords Orthesis · Design · Talking Hands · D'Aria · Language

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1 Research Scenario[A]

1.1 Mobility Level

John Urry formulated the mobility paradigm for the first time at the beginning of the 21st century. Urry [1] postulated that the structuring and transformations of society are linked to an idea of what a member of a given national state should be with certain social rights and duties. The multiple mobility are transforming the historical subject of sociology, that is a "western" individual society with its endogenous social characteristics [1].

Along with social mobility, space mobility should be considered as a structuring dimension of everyday social life. Social structures and dynamics are interdependent with the effective and individual ability to move entities, such as people, goods and information [2]. The context of mobility directs the gaze of sociology towards the greater variety of mobility and the way in which they interact thus constituting the concept of hybrid mobility [1, 3]. The most recent and consolidated version of the typology consists of five modes of movement, five interdependent categories that coexist in everyday life. The category that characterizes man is bodily mobility, which refers to the movement of people in terms of work, family and leisure time.

When the distance traveled is limited and mobility refers to small-scale movements or bodily movements, we talk about micro-mobility. While traditionally, macro-mobility has been extensively studied in many disciplines, a dimension that has only recently been explored is micro-mobility [4]. Micro-mobility revolves around the human body, which is the protagonist of the dynamic between mobility and immobility in a double sense [5]. First of all, immobility is the other side of mobility. Secondly, there is immobility within mobility: when the movement is mediated by means of transport, the body remains stationary, which is an artificial condition for the human body. Life is movement, and to be healthy, humans need to move physically [6, 7].

Other studies suggest some of the pathways of influence that link physical mobility and well-being. Firstly, movement in physical space allows people to meet others and to go to places, so it helps to satisfy basic, social and emotional needs [8]. Secondly, several authors have indicated that changes in people's health, such as physical illness and certain impairments, limit the mobility of people outside the home and thus reduce contact with the wider local community, which can cause or aggravate the isolation, loneliness and depression [9–12].

1.2 Universal Design as User Support

The birth and development of "care robotics" and "disability robotics", while contributing to changing approaches to treatment, is also changing the patient's view of technologies and devices for treating or overcoming disability. In this regard, the diffusion of personal smart devices is only the first evidence of a broader social and cultural transformation process underway: from the passive acceptance of devices connected to it for reasons linked to the treatment or reduction of a disability, we pass the progressive spontaneous request for use that produce not only a monitoring, prevention or treatment action, but also a physical and cognitive enhancement work in a general direction of Human Enhancement [13–15]. The age of technological prostheses, bionic implants and the spread of body artificialization processes calls into question the theme of the acceptance or social exclusion of patients or persons with disabilities (ableism, [16]), which thanks to Future developments in medicine and technology will increasingly consider cyborgs, technologically rehabilitated and empowered individuals who experience the boundaries of what it means to be human [17, 18].

There are therefore many reasons that make it interesting to explore the issue of the artificialization of the human body within the research to see if the technological development and treatment can find a valid response in reality. The theme of human enhancement is certainly an emerging theme even if in the popular imagination it still seems suspended between science and science fiction.

However, perception changes if we try to relate this issue concretely with statistical data on disability. The first World Report on Disability developed in 2011 by the World Health Organization reports the following data: over a billion people, 15% of the world population, live with some form of disability. Of these, at least one fifth has very significant difficulties. In Italy, according to the ISTAT Disability portal in the period 2013–2015, people with disabilities were over three million.

This statistical picture on disability, combined with the themes of new assistive and rehabilitative technologies and the change in the social acceptance of disabilities, generates a useful field of reflection in the research perspective. The first level of reflections goes into the merits of the concept of disability itself. The ICF model—International Classification of Functioning, Disability and Health of 2001, connotes disability no longer as an attribute of the person but as a situation, even occasionally, that occurs whenever the person experiences a gap between their abilities and the environmental aspects that surrounds it, which can then act against the person, giving rise to situations of disability such as to determine restrictions in their quality of life.

Renzo Andrich in "Concetti generali sugli ausili", takes up the definition of technical aid and proposes a classification of the aids based on their role in the process of rehabilitation and social inclusion of the person with disability. Linked to this theme there are therefore reflections on the theme of emerging forms of relationship and empowerment between man and the new types of instruments. The European Commission has developed a 2020 strategy on disability focusing on issues such as access to goods, services and assistance devices, full participation in society, employment and economic autonomy and inclusiveness. The cross-cutting issues highlighted by the new European strategy are: participation, cooperation and coordination universal design, the perspective of gender equality, multiple discrimination, education and training.

From these concepts emerge reflections on three different levels: disability, accessibility and universal design. The first is that disability is the result of the interaction between individual impairments and disability, existing attitudinal and environmental barriers. Disability can hinder the full enjoyment of human rights and fundamental freedoms and prevent effective and fair participation in society. The second consideration is that accessibility challenges can be avoided or greatly reduced through the use of intelligent applications that come from universal design, with a tailored approach. As a last reflection, universal design and the promotion and development of affordable assistive technologies, devices and services aimed at removing existing obstacles should be increasingly supported.

1.3 Orthesis and Prosthesis as Accessory

The containment of disability in order to improve the quality of life is the goal of any rehabilitative action. This result is achieved by implementing the strategies to prevent damage and secondary impairments to the underlying disease subsequently, positively addressing the evolution, and finally using all the devices/devices that regardless of the impairment, make it possible in any case the maximum recovery of autonomy. The use of orthosis, devices that passively maintain certain articular relationships in order to improve a function, limit or enhance a movement, or support a body segment, allows the user to recover lost activities, precociously, even when his level of skill would not allow it, reducing the social weight of different personal skills. The technologies applied in the production of these artificial limbs have made great strides in recent years: yet the aesthetic side has often been neglected.

Analyzing the history of industrial design, it is clear how it manifested itself through the design of external objects independent of the human organism, through the creation of a solution designed to increase the potential of the body, to restore its integrity, or to make up for its physical deficiencies [19].

The concept of orthosis and prosthesis in today's society is increasingly seen as an accessory to be put on display, which does not diminish the person but in some sense adds value. The concept of accessory to show is made possible by the technologically sophisticated system. The development of an unprecedented technological convergence: biotechnologies, A.I. artificial intelligent, ITC technologies, robotics and new manufacturing techniques interact and work together, merge the staff with the artificial, the exact with the sensitive. Orthoses and prostheses are now de-mechanized, and accepted, acting as tools for change and improvement for social integration. The design of the orthoses and prostheses, having overcome the technical aspects of functionality and performance, are addressed with ever more aesthetic, communicative and emotional characteristics.

The orthesis changes role and becomes an art object. An interesting change of perspective if you think that until recently it was only a support that was often ashamed of. As with fashion, where the physical aspect becomes a form of self-expression, one notices the potential of prosthetics as an extension of the wearer's personality.

A very interesting example that works on these concepts is the project called "the alternative limb project". By combining the latest technologies with traditional crafts, artefacts explore themes of body image, modification and evolution, while promoting positive conversations about disability and celebrating body diversity, not as exclusion but as a characterizing element of social inclusion.

1.4 Objectives of the Research Project

The characteristics of humans, which have allowed us to dominate the environment and put us at the top of the evolutionary chain, are the intelligence and the particular conformation of the hand: a very versatile tool, capable of carrying out meticulous and precise operations if properly educated. Arthritis primarily affects the joints of the hands, significantly compromising the functionality and consequently the individual's ability to perform even the simplest tasks, including personal care. There is therefore a drastic loss of autonomy. Hence the importance for the patient to be able to reacquire the ability to use their hands, without this leading to a further damage to the joints or a stigmatization of the disease due to the use of conventional orthosis, bulky and aesthetically unpleasant.

In the following sections two cases of research projects carried out in parallel are proposed. The first "Talking Hands", purely technical and technological, is a tool that might potentially improve the lives of many people, helping their integration in all areas of society by giving them greater autonomy, safety and personal gratification. "Talking Hands" is a completely wearable device for sign language translation. "Talking Hands" does not compromise the tactile sensibility of the user. It is an entire glove: it has ten rings to set the flex sensors, and two light modules for the back of the hand and the wrist. The second "D'Aria" is a glove is aimed at people with rheumatoid arthritis both for the initial stages of the disease (prevention of more serious damage) and for the more advanced phases (a real aid that restores lost grip capacity). The use of air as a source of movement, moreover, to obtain discrete and easily wearable actuators from a hand deformed by arthritis. The intentions of movement are read by electromyographic sensors placed around the forearm, the data are then processed, translating into air flows that will pressurize the pneumatic chambers of the actuators. These controls are designed in such a way that the movements supported by the orthosis do not damage the joints more compromised, relying more on the healthiest ones.

Finally, as a research perspective, this article proposes the hybridization of the two case studies. Taking for the first the ability to read data on the respective movements of individual limbs, exploiting for the second the ability to be an aid to improve articulatory movement. Thanks to "Talking Hands" technology is possible to understand gestures the user is performing, is it possible to activate "D'Aria" actuators (once, or more per time) when the intention of the user is captured by "Talking Hands" algorithm. Using this control system is possible to easily control D'Arias actuators understanding user intentions thanks to a simplified gesture recognition algorithm. In this new system inputs for the gesture recognition algorithm are just data from flex sensors and pressure sensors. If the user cannot move fingers by his own, will be possible to create and associate actuators functions to hand/forearm movements using one or more IMUs inside the new. The final objective will therefore be to create an experimental prototype that hybridizes the two characteristics, creating a series of tests on patients affected by these diseases.

2 Case Study One[B]

2.1 Talking Hands—Background

There are 70 million deaf people worldwide. Deaf people usually communicate through sign languages, they can understand people which don't know sign language reading lips movements. Deaf people experience difficulties developing social, and working relationships. A device able to translate sign language's gestures into voice interpreting sign langue's movements, then transfer the processed information to a device equipped with speakers, such as a smartphone has been developed. This device is called "Talking Hands". Although "Talking Hands" cannot translate a whole sign language, it offers an effective communication to deaf and mute people with everyone through a scenario-based translation. The different challenges of a gesture recognition system have been overcame with simple solutions, since the main goal of this work is a user-based product.

2.2 Introduction

The realization of this device, which will be called "Talking Hands" (see Fig. 1—Talking Hands) from now on, has required advanced skills in electronics for the hardware, math modeling and optimization algorithms for gesture recognition, software and embedded computing for optimized implementation of algorithms and wireless communications of the various components. "Talking Hands" is a tool that might potentially improve the lives of many people, helping their integration in all areas of society by giving them greater autonomy, safety and personal gratification. "Talking Hands" is a completely wearable device for sign language translation. Its main features are: maximum customization, no requirement of external pc or cameras for sign language translation, the possibility to be used everywhere, without any external module. "Talking Hands" does not compromise the tactile sensibility of the user. It is an entire glove: it has ten rings to set the flex sensors, and two light modules for the back of the hand and the wrist. "Talking Hands" is designed for a specific purpose, but it fits the wider category of data gloves. A data glove is an input device that can interact with different systems like a key-board. It uses different kinds of sensors to understand motion of hands (including fingers), and sometimes also arms and shoulders.

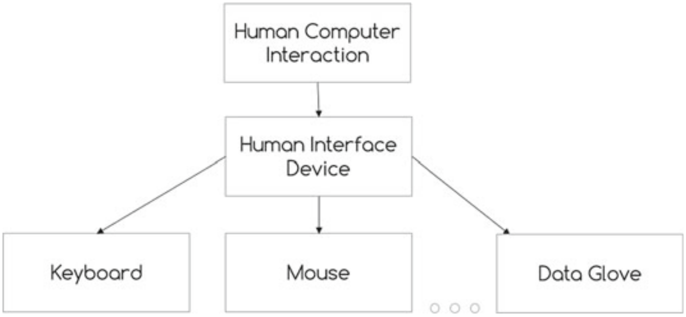

Fig. 1 Data gloves hierarchy

Usually data gloves are connected to other devices, i.e. processors, and give them data about:

- Position.
- Velocity.
- Orientation.
- Acceleration.

Data gloves provides information about hand, arm, shoulder and fingers or some of them. The other component connected to the glove, typically a personal computer or a microprocessor, can elaborate the data and interpret them in different fashions, depending on the specific application.

2.3 Architectural High-Level Design

"Talking Hands" is made of the following components, divided into two main modules:

Hand Module: A 32-bit microprocessor; 10 ex sensors to detect fingers position; one IMU to detect hand orientation; one button to initialize the system. Arm Module: one IMU to detect arm orientation, a led RGB to check the system status, mini-usb connection, a battery and a charge module, Blue-tooth module (Fig. 2).

The High Level Architecture Design the system is shown in Fig. 3—Architectural High-Level Design.

2.4 Software and Firmware

The software of "Talking Hands" is composed by two main modules. The firmware pre-processes the sensors data and establishes if the user is performing a sign, i.e. a

Fig. 2 Talking Hands

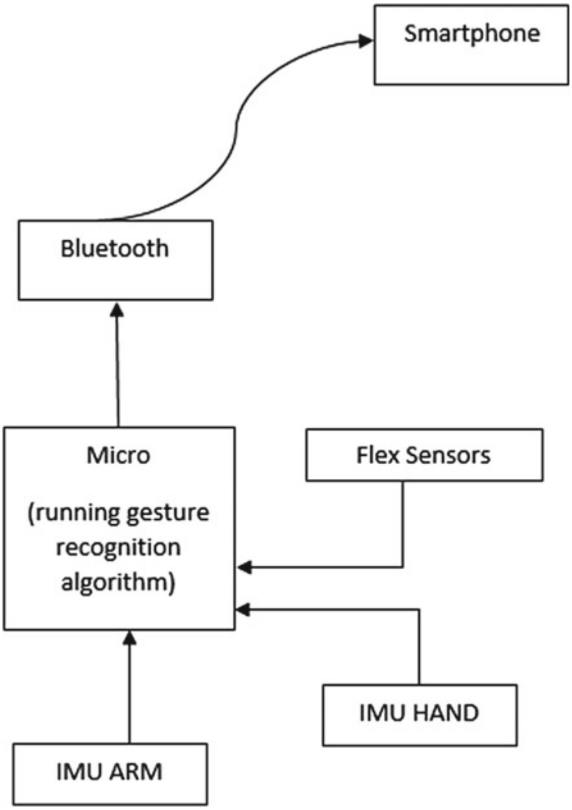

Fig. 3 Architectural high-level design

meaningful gesture. The smartphone receives data from the glove and uses the speech synthesizer to talk. The translation of the sign into a text word can be implemented both on the firmware and the smartphone application, depending on the product version.

2.4.1 Translation Through Scenarios [20]

We define a Scenario a set of signs that "Talking Hands" can translate in a single session. Hence the system can translate the signs of a scenario at time, that can be selected through the smartphone application. The user can switch among the scenarios on-line, i.e. during the usage without the need of re-initializing. This approach leads to some Important advantages. Across the world there are many sign languages, like the spoken ones, and some of them have different dialects, for e ample in the Italian Sign Language. For this reason, it is almost infeasible to realize a pre-build universal system, i.e. a system that can recognize all the sign languages.

In a scenario approach, the signs can be easily recorded by the user through the smartphone application. The user can associate a sign to a word, a letter, a sound or to an entire phrase and then the sign is assigned to one or more scenarios, as shown Fig. 3. This approach enlarges the set of signs that the system can translate, without losing reliability. Hence, the same gesture can have more than one translation in different scenarios. Moreover, similar signs would not be misunderstood if they are not in the same scenarios. Since the number of possible scenarios is limited only by the memory of the smartphone, the user can have a huge set of signs, where the limitation is due mainly to the cognitive load of the user which has to remember and use properly the scenarios and their signs. In the actual prototype, the maximum number of signs in each scenario is about 40–50, but this limitation is due only to the correlations that occurs among large set of signs. Thanks to these advantages, the translation through scenarios others a good communication for the deaf person.

2.5 Wearing System

A detailed study was done also to give to all sensors a long-life cycle reducing stress during the use of TKH. Following the three phases below, a functional prototype of the dressing system has been built. This prototyping phase is important to ensure the realization of a product that can be appreciated by the users. We have taken into consideration many variables, regarding physical constraints of hardware, number of sensors, positioning of the same, dimensions and arrangement of the connection wires and regarding the functionality of use in terms of wearability, transpiration, comfort.

To satisfy these requirements, the system is composed by:

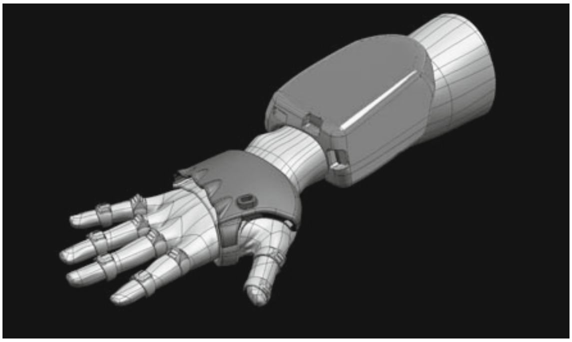

Fig. 4 Cad of Talking Hands. **a** System of rings **b** dorso part **c** arm part

1. A set of rings for housing the different flexion sensors, see a) in Fig. 4—Cad of Talking Hands. (a) System of Rings (b) Dorso Part (c) Arm.
2. The back of the hand; including all cable connections and IMU see (b) in Fig. 4—Cad of Talking Hands. (a) System of Rings (b) Dorso Part (c) Arm.
3. The forearm; connected to the previous via a fabric strap, through which the cables pass, it has the space required to insert the microprocessor, an IMU, the bluetooth communication module, and the battery see (c) Fig. 4—Cad of Talking Hands. (a) System of Rings (b) Dorso Part (c) Arm.

A remarkable innovation of this system is the use of wearable rings where are the spaces for housing the flex sensors. This allows a better use and increase the reliability of data obtained from flex sensors.

A space to communicate the state of the glove via visual protocol, using an RGB led was also been allocated. It gives information on:

- Battery Low state
- Calibration status
- Errors in hardware.

3 Case Study Two[C]

3.1 Research Scenario: The Pathology and the Patient

Rheumatoid arthritis is a chronic degenerative disease, where one's own immune system is induced to attack the joint sheaths, causing swelling and chronic pain until the progressive destruction of the joint itself. Arthritis symmetrically affects various body joints, especially those of the phalanges of the hands. For us human beings, whose hands are the main means of interaction with the surrounding world, the damage caused by the pathology has dramatic implications. The patient witnesses a progressive loss of autonomy even in the simplest daily actions and this heavily compromises both the perception of oneself and social relationships. In fact, arthritis involves the loss of gripping force, due both to a muscle breakdown and to the fragility of the joints. Joint damage also leads to morphological alteration of the hand. Hence the need for a dynamic orthesis capable of restoring the ability to manipulate objects, restoring the strength of the grip, but at the same time helping the joints to work with the right alignment, so as to prevent and delay the onset of deformations (Figs. 5, 6 and 7).

Fig. 5 D'Aria orthoses: prototype

Fig. 6 D'Aria, pneumatic mobile orthosis

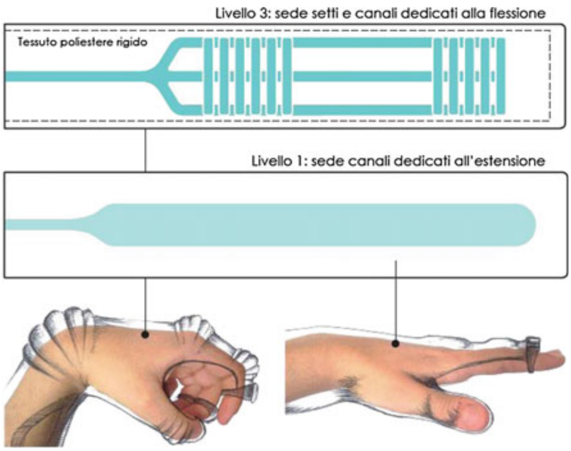

Fig. 7 Pneumatic actuators dedicated to flexion and extension of the fingers

3.2 A New Type of Orthosis: The Role of Design and Technological Contamination

Another problem almost never developed in the field of orthosis, is the stigmatization that these medical objects involve the patient who wears them, always referring to his condition as a patient. Hence the need to replace springs and rods with something more hidden. The adoption of pneumatic actuators, borrowed from the technology of soft robots, has thus made it possible to obtain discrete and soft silicone actuators, therefore very suitable for direct contact with the body and elastic enough to be easily worn even by a deformed hand. This has allowed us to obtain an unconventional aesthetic, capable of giving an orthosis an aspect more similar to a fashion accessory rather than a medical device (Figs. 8, 9, 10 and 11).

In order to prevent the patient from wearing excessively cumbersome elements, all the parts suitable for the function of the glove have been distributed along the entire body of the orthosis, but taking care not to interfere with the flexion of the elbow. Therefore, polypropylene (PP) bodies were obtained, set like silicon stones

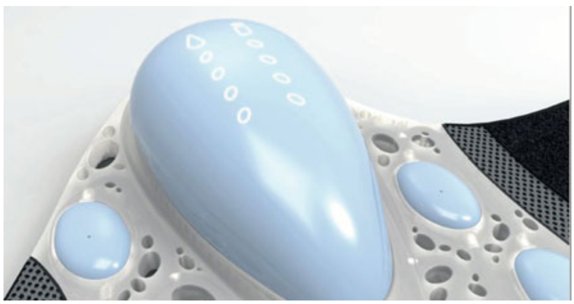

Fig. 8 Headquarters inserted into the silicone body of the glove

Fig. 9 Explanatory diagram of the pneumatic orthosis functions

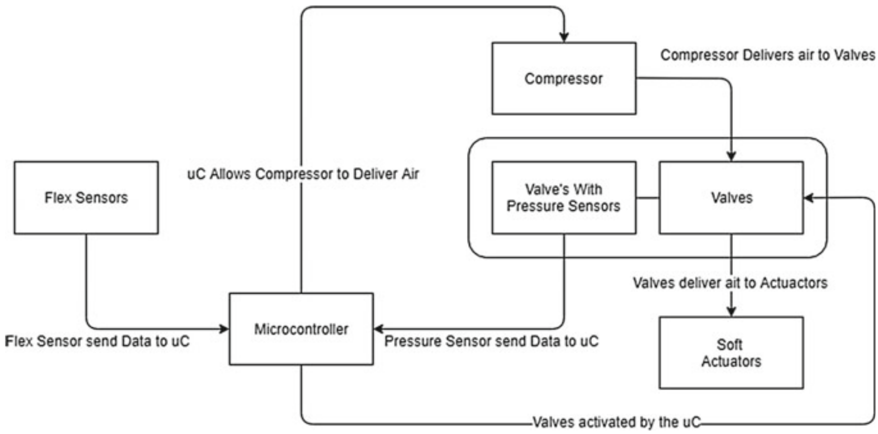

Fig. 10 A new high level architecture is provided

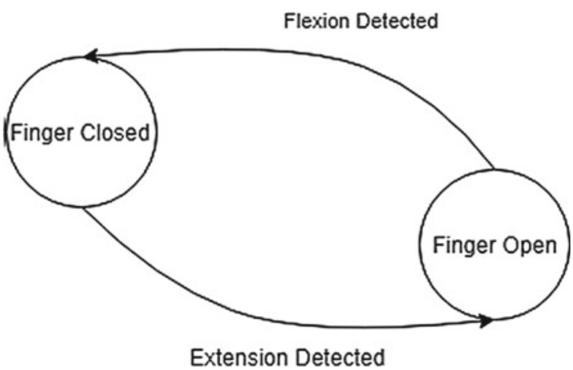

Fig. 11 Algorithm example

that incorporate the actuator supply tubes. The smaller elements house the individual solenoid valves (two for each finger, as one is dedicated to bending and the other to the extension), while the most massive element, containing the lithium battery, a pressure accumulator and the cards electronically, it has been positioned at the shoulder, where its weight is less noticeable.

This last element houses LEDs to provide the user with basic information, such as the battery charge and the pressure level of the battery.

In order to make the object as intuitive as possible, we tried to make its maneuverability quite natural. For this reason the controls have been entrusted to surface electromyographic sensors which, by wrapping the forearm, monitor the electrical activity of the muscles in charge of finger control, translating the signals into precise movements. An object that should be worn in everyday life must first and foremost be easily washable. For this purpose, the glove was divided into two levels. The first is an antibacterial fabric intended to be in direct contact with the skin, which can be easily removed and washed more frequently. The second one, housing all the components, was designed to be taken apart before washing. It has a part in 3D fabric and another in micro-perforated silicone, to allow the skin to breathe as much as possible. The bodies containing the solenoid valves or the control unit can be extracted using the elasticity of the silicone that encloses them in the glove. Even the electric power supply of the solenoid valves has been designed to end up in the washing machine without this causing damage. In fact, the current travels along the edges of silver wire: technology already used in wearable electronics. The closure of the glove around the arm and fingers was achieved by using Velcro, a solution already widely adopted in the field of devices intended to have grip problems, as it does not require a good accuracy of the movements to be used.

3.3 An Orthesis Capable of Evolving with the Course of the Disease

The pneumatic orthesis is able to automatically change its functioning based on the patient's clinical condition. To do this it is necessary that the glove communicate with other external devices. Through the home automation system or an APP installed on the smartphone, "D'Aria" is able to access the medical data that are normally collected and filed by the rheumatologist. Through the processing of information, the glove is able to recognize the different degree of damage suffered by each individual joints of the phalanges and based on this knowledge can act accordingly. The movements controlled by the user are thus corrected, in such a way as to make better use of the healthier joints in favor of the damaged ones, which are thus partially or totally spared from the effort. Rheumatoid arthritis can only be stemmed by a regular monitoring action.

The monthly check-up by the specialist is necessary, but it may be even more useful to have the opportunity to intervene promptly as soon as the further course of the joints begins. A warning sign of the approach of a period of sharpening is the loss of strength in the socket. “D’Aria” never completely replaces the muscular strength of the wearer, on the contrary, it encourages its use in order to prevent muscular atrophy. Therefore, it intervenes only in case of need or to guide the user in the assumption of the most correct posture to perform the task. “D’Aria” is aware of the amount of pressure supplied from time to time to its actuators. But if the user had to request a further increase in pressure compared to the usual one (we are not talking about an exceptional case but of a figure that is repeated almost continuously throughout the day) “D’Aria” interprets the fact as a decrease in strength explicable from the sick hand. The only thing to do is to immediately contact the specialist doctor.

The dedicated APP will therefore warn of the emergency. The alarm will be simultaneously sent to the doctor, together with the data collected by the orthesis. The pneumatic glove “D’Aria” could be the starting point for the development of other similar devices, but intended for different medical fields, such as neuronal rehabilitation.

4 Merging Systems[A-B-C]

“D’Aria” orthesis is controlled using a smartphone application, “D’Aria” system can be improved using sensors and gesture recognition algorithm which will associate actuators functions to user’s intentions. Thanks to this new interaction strategy User Experience will be improved. “Talking Hands” described in Case Study One and “D’Aria” described in Case Study Two were conceptualized for two different aims. The first one to understand sign languages, it means have a full view of our hand, our forearm and fingers, having the exact orientations and fingers position. The second one to help people affected by Rheumatoid arthritis. Merging case study one and two is possible to obtain a new system. In this section is described the conceptualization of the new system.

In “D’Aria” system actuators operates just on fingers, observing finger’s movement is possible to understand user’s intention. Orientations are no more needed so IMUs can be removed. User’s intentions will be provided observing flex sensors and pressure sensors behavior.

Thanks to “Talking Hands” technology is possible to understand gestures the user is performing, is it possible to activate “D’Aria” actuators (once, or more per time) when the intention of the user is captured by “Talking Hands” algorithm.

The algorithm can be also implemented in the microcontroller without interacting with smartphone’s application.

A simple example is provided:

1. User tries to close the index finger, a flex sensor on the index finger will detect the movement and the microprocessor can activate the pneumatic actuator for index finger. The actuator will help user to close index finger.

2. User tries to open index finger increasing pression in the extension camera of the valve, this will be detected from the pressure sensor, this means user wants to open his/her index finger, the pneumatic actuator will help user to open his/her finger.

To detect flexion a flex sensor will be used, to detect extension will be used a pressure sensor inside the valve in combination with finger's flex sensors.

Flex sensor can be used to detect extensions too, but when the user does not have so much strength, a check from pressure sensor is needed, otherwise users intention may be not detected in an effective way.

Using this control system is possible to easily control D'Arias actuators understanding user intentions thanks to a simplified gesture recognition algorithm. In this new system inputs for the gesture recognition algorithm are just data from flex sensors and pressure sensors.

If the user cannot move fingers by his own, will be possible to create and associate actuators functions to hand/forearm movements using one or more IMUs inside the new.

References

1. Urry J (2000) Sociology beyond societies: mobilities for the twenty-first century. Routledge, London
2. Kaufmann V, Bergman MM, Joye D (2004) Motility: mobility as capital. Int J Urban RegNal Res 28:745–756. https://doi.org/10.1111/j.0309-1317.2004.00549.x
3. Urry J (2007) Mobilities. Polity, p 336
4. Sheller M (2011) Cosmopolitanism and mobilities. In: Nowicka M, Rovisco M (eds) The Ashgate research companion to cosmopolitanism. Ashgate, Aldershot, pp 561–589
5. Aday P (2010) Aerial life: spaces, mobilities affects. Oxford, Wiley-Blackwell
6. Markula P (2014) The moving body and social change. Cult Stud Crit Methodol 14:483–495
7. Newman JI, Giardina MD (2014) Moving biopolitics. Cult Stud Crit Methodol 14(5):419–424. https://doi.org/10.1177/1532708614542409
8. Metz DH (2000) Mobility of older people and their quality of life. Transp Policy 7(2):149–152
9. Smith J, Borchelt M, Maier H, Jopp D (2002) Health and well–being in the young old and oldest old. J Soc Issues 58:715–732. https://doi.org/10.1111/1540-4560.00286
10. Mollenkopf H, Kaspar R, Marcellini F, Ruoppila I (2004a) Quality of life in urban and rural areas of five European countries: similarities and differences. Hallym Int J Aging 6:1–36
11. Mollenkopf H, Marcellini F, Ruoppila I, Széman Z, Tacken M, Wahl HW (2004b) Social and behavioural science perspectives on out-of-home mobility in later life: findings from the European project MOBILATE. Eur J Ageing 1(1):45–53
12. Allen J (2008) Older people and wellbeing. Institute for Public Policy Research, London. http://www.ippr.org/publicationsandreports/publication.asp?id=620. Accessed 29 March 2010
13. Wasserman D (2012) Ethics of human enhancement and its relevance to disability rights. Encyclopedia of the life sciences
14. Bose D (2014). Defining and analyzing disability in human enhancement. In: Global issues and ethical considerations in human enhancement technologies. IGI Global
15. Eilers M, Grüber K, Rehmann-Sutter C (eds) (2014) The human enhancement debate and disability. New bodies for a better life. Palgrave MacMillan
16. Wolbring G (2009) What next for the human species? Human performance enhancement, ableism and pluralism. Dev Dialogue 2

17. Tomas D (1995) Feedback and cybernetics: reimaging the body in the age of the cyborg. Body Soc 1(3–4)
18. Swart L, Watermeyer B (2008) Cyborg anxiety: Oscar pistorius and the boundaries of what it means to be human. J Disabil Soc 23(2)
19. Morrone A (2004) "Materiali e protesi" articolo su rivista Diid n°08/2004 Dpress Roma
20. Pezzuoli1 F, Corona1 D, Corradini1 ML, Cristofaro1 A (2019) Development of a wearable device for sign language translation, School of Science and Technology, Unicam, Via Madonna delle Carceri 9, Camerino, Italy

Depth-Based Fall Detection: Outcomes from a Real Life Pilot

Susanna Spinsante, Marco Fagiani, Marco Severini, Stefano Squartini, Friedrich Ellmenreich and Giusy Martelli

Abstract With the increasing ageing population representing a challenge for society and health care systems, solutions based on ICT to prolong the independent living of older adults become critical. Among them, systems able to automatically detect falls are being investigated since several years, because many solutions that appear promising when tested in lab settings, fail when faced with the constraints and unforeseen circumstances of real deployments. In this paper, we present the outcomes resulting from the pilot installation of a fall detection system based on the use of depth sensors located on the ceiling of the monitored apartment, where a 75 years old woman lives alone. We highlight the system design process, moving from the research leading to an original algorithm working offline, preliminarily tested in a lab setting, to the real-time engineering of the software, and the physical deployment of the system. Testing the system in a real-life scenario allowed us to identify a number of tricks and conditions that should to be taken into account since the initial steps, but the lab experimentation alone can barely help to focus on.

Keyword Fall detection · Depth sensor · Machine learning

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1 Introduction

The Ambient Assisted Living (AAL) paradigm encompasses solutions based on ICT to enhance the quality of life of people who need assistance at home. In the last years, because the elderly population is increasing worldwide and the healthcare delivery model is evolving from a hospital-centric approach towards a home-centric one, AAL solutions have been gaining more and more interest within the European scientific community [1].

The increasing ageing population represents a challenge for society and health care systems, due to an increase in health care costs and a decrease in available caregivers. The shortage of professionals trained to work with older people implies that more family members have to take the role of informal caregivers. Given the fact that in many cases older adults are almost self-sufficient and just need occasional visits or help in specific events, so that a full-time caregiver may be even excessive [2], that 89% of them prefer to stay in the comfort of their own homes, and given the costs of nursing home care, it is imperative to develop technologies that help older adults to maintain their autonomy as long as possible, and to age in place [3].

Globally, falls are a major public health problem [4], and an important cause of morbidity and mortality in the elderly. As such, fall detection is one of the most important AAL application areas. Studies report that the majority of falls occur at home, as a person's living environment is filled with potential hazards [5], predominantly in the living room and in the bedroom [6]. In addition, recent studies report that fall kinematics varies depending on the weight and size of the falling person, and that most people fall in the evening or during the night. The risk of falling increases with the number of risk factors present, namely: factors related to the person (e.g. chronic and acute pathologies, gait and balance impairments), factors related to the behavior (e.g. risky ADL—activities of daily living, alcohol, fear of falling), and factors related to the environment (e.g. uneven surfaces, slippery floors, loose carpets, poor lighting) [7].

Fall detection systems are designed to detect falls and issue an alarm aimed to limit the rescue time necessary to reach the victim. In fact, lying on the floor for more than one hour may have several adverse consequences (e.g. dehydration, pneumonia, hypothermia and possible death within 6 months). In [7], fall detection systems are defined as *an assisting device that is capable of sensing, processing and communicating alarm data in the event of a fall under real-life conditions effectively*. This definition focuses not only on the general structure and the purpose, but also on the reliability of a fall detection system when used in real scenarios. In fact, a reliable fall detection system may alert a caregiver just when necessary, thus optimizing the care activity, either for the professional caregivers who can consequently be able to manage several older adults more efficiently, and the informal ones, for whom the impact of the assistance on their daily life can be reduced.

Countless fall detection systems, as well as related classification schemes, exist [7–9]; the solution tested in the pilot herein discussed belongs to the domain of *non-wearable* systems, and specifically in the category of *vision-based* solutions. The developed system exploits a commercial depth sensor located on the room ceiling, to unobtrusively monitor an older adult at home, by means of an inherently privacy-preserving technology, that also ensures adequate robustness to possible occlusions or changes in the environmental conditions. Depth frames captured in top-view configuration are automatically processed by a real-time software, to evaluate the head-to-floor or centroid-to-floor distance (these distances are minimized after a fall), and the inactivity of the subject after a fall [10]. The sensor is interfaced by a mini computer running the real-time software; if a fall event is detected, the system raises an alarm that is delivered to a service center by means of a Wi-Fi connection, to activate proper assistance. The system has been installed in a real apartment and kept running around 4.5 months, to monitor a 75 years old woman who lives in a semi-autonomous manner, i.e. supported by the daily assistance of a social operator.

In this paper we present the most relevant issues emerged during the pilot, and the lessons learned from such an experience, that will allow to improve the next releases of the system, with the aim to achieve a commercial product in the midterm.

The paper is organized as follows: Sect. 2 gives a short description of the fall detection system, the performance of which are discussed in Sect. 3. Section 4 provides details about the specific installation and discusses the most relevant outcomes gained from the pilot. Finally, Sect. 5 concludes the paper.

2 Materials and Methods

In this section we briefly overview the main hardware and software components of the fall detection system.

2.1 Hardware Components

The basic unit of the fall detection system is composed by a commercial depth-sensor, namely a Kinect v1 device, and a mini-computer interfacing the sensor over a USB connection, running the real-time fall detection algorithm, and connected to the home Wi-Fi network. Then, based on the total area to be monitored, and on the arrangement of the rooms within the apartment, the amount of units (sensor + mini-computer) needed may vary. In order to limit as much as possible, the hardware requirements of the system, each mini-computer is configured in such a way as to be able to run up to three independent instances of the fall-detection algorithm, processing the input depth signals generated by up to three different Kinect devices. Two versions of Kinect succeeded over the years: Kinect v1 and Kinect v2. The depth sensor consists of an IR projector combined with an IR camera. Kinect v1 exploits a structured light approach, whereas Kinect v2 uses the Time of Flight (ToF) principle.

Despite the availability of the Kinect v2 at the time of pilot deployment, we opted for the use of the v1 device, as both the depth sensing range and resolution provided by this older version are adequate for the purposes of the project, and, most of all, it is far less computationally demanding than the v2 device. This allows to interface up to three depth sensors to the same mini-computer, and to limit the hardware components requested to deploy the pilot. The mini-computer selected to deploy a single unit of the fall detection system is a NUC7i3BNH by Intel [11], featuring an i3-7100U processor, with 8 Gb DDR4 RAM, a 128 GB SSD, and 6 USB ports, equipped with Ubuntu 17.04 O.S.

2.2 The Fall Detection Algorithm

The real-time algorithm for the automatic identification of falls has been developed first as an offline implementation in Matlab, based on a solution available in the literature [10]. This solution is able to detect a person and monitor it in subsequent frames, and the fall is identified when the distance between the Kinect and the central point associated with the person becomes comparable with the floor distance. This means that in some situations where the person is on the ground but its central point is not sufficiently close to the floor, the fall it is not detected. These conditions may occur in cases of falls on the knees, or when the person falls but ends sitting on the ground and maybe the central point of the blob is placed on the shoulders or on the head.

Figure 1 represents the main steps of the fall detection algorithm, and details a number of parameters (thresholds) that need to be configured according to the specific deployment. Once the algorithm has determined the distance from the sensor of the central point of the human subject blob, additional checks are performed to discriminate between a fall or an ADL. When the condition for a possible fall event is verified, the algorithm also checks how long it holds, with respect to time thresholds (*recovery_time*, *wind_time*, *sit_time*, *shift_time* in Fig. 1) that can be properly configured according to the motion capabilities of the monitored person. This way, a true fall for which an alarm has to be raised, is distinguished from a warning event.

The fall detection algorithm has to work in a real-life installation; as a consequence, it is mandatory to replace the Matlab implementation by a different coding language, able to support the capability to process depth frames and detect possible falls in real-time. The fall detection algorithm has been re-implemented in Python language, for an efficient and timely execution on the selected hardware platform, with some interventions on the original structure of the algorithm. For example, it was necessary to add a new routine to correctly handle the blobs of objects that can move and change their position from one frame to another, to avoid the possibility they get confused with the human blob, being not associated to the static background. An additional check on the position of the tracked subject has been implemented, so that in the case the algorithm loses the subject tracking, a possible warning can be raised. Similarly, additional checks have been implemented in order to avoid the generation of inconsistent messages related to *alert*, *fall*, and *recovery* events.

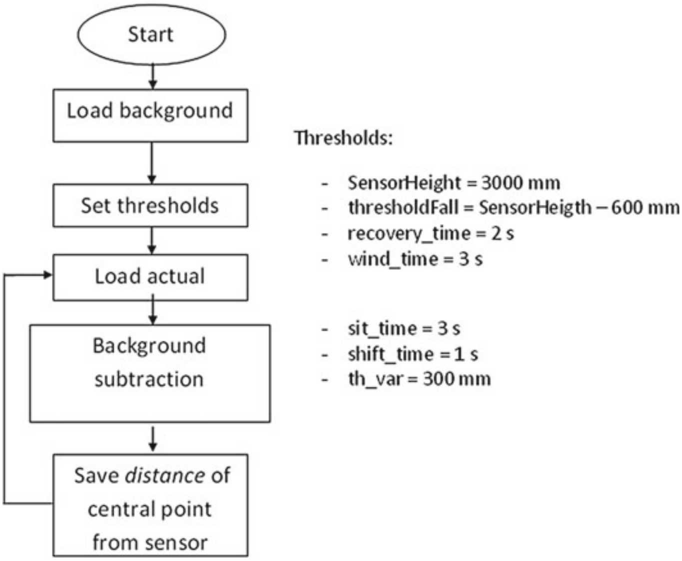

Fig. 1 The main steps of the original fall detection algorithm available in [10], and thresholds configuration

Two main routines have been defined: the former manages the physical interface towards the sensor, the depth frames acquisition and some pre-processing operations on them. The latter deals with the identification of the human subject, tracking of the blob, and detection of falls. This way, the robustness of the system is increased, and it is possible to keep the fall detection routine unchanged even when the physical sensor has to be replaced or modified, or in the case of hardware failures. A schematic view of the Python software architecture is provided in Fig. 2: data related to the events detected by the algorithm are transferred to a remote database (DB) or delivered to a mobile app by means of an MQTT (Message Queuing Telemetry Transfer) session. In case a fall event is detected, the caregiver has the possibility to access a video streaming from the sensor through a web page. Finally, additional operations dedicated to system log and maintenance are enabled.

3 Fall Detection Performance

Before installing the system with the Python version of the algorithm, it is necessary to check its performance against the Matlab implementation. To this aim, a dataset acquired in a laboratory environment was used.

The data collection protocol was defined by taking into account the sensor setup, which must be ceiling-mounted in top-view configuration, and the project requirements, namely: (i) ability to detect falls in which the person ends lying on the ground;

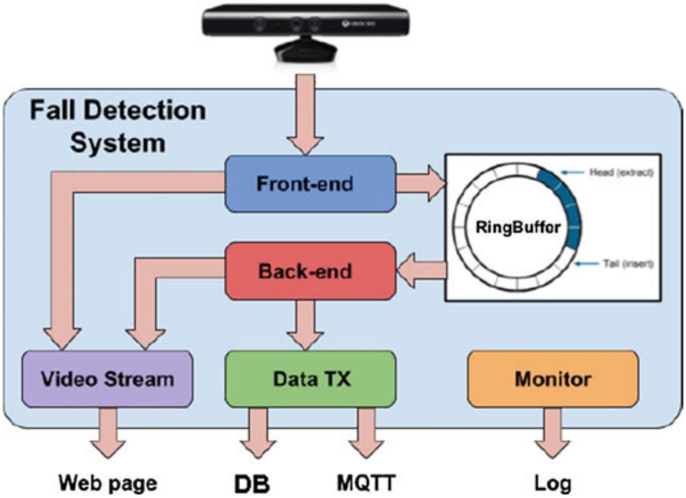

Fig. 2 Logical organization of the Python fall detection system: the two main routines are identified as *front-end* (connected to the sensor) and *back-end* (implementing the core fall detection functions)

(ii) ability to detect falls in which the person ends sitting on the ground; (iii) ability to detect falls in which the person is lying on the ground on his knees, possibly interacting with objects present in the environment; (iv) ability to manage the *recovery* of the person, that is to differentiate a fall in which the subject remains on the ground from one in which the person is able to get up after the fall. The data acquisition protocol included 32 types of falls, and 8 ADLs that can be confused with a fall, like picking up objects from the ground, bending, squatting, sitting down on a chair or sofa. These actions were performed by 20 subjects (5 females, 15 males) of age in 21–55, thus collecting 800 sequences of depth frames (320 × 240 @ 30 fps), with the associated sequences of RGB frames (640 × 480 @ 30 fps) used as ground truth to evaluate the performance of the algorithm.

Using the Matlab code and considering the *warning* case as a distinct class of the dataset from *fall* and *ADL*, we can identify 3 classes and 800 sequences overall, out of which 160 are classified as *ADL*, 319 are classified as *fall* and 320 are classified as *warning*. By this approach the resulting accuracy is 95.5%, taking into account that one sequence of the dataset has not been classified because the person was not recognized at all. Assuming instead of having a system with two possible outputs, and therefore considering *fall* and *warning* within the same class, the system is characterized by the following performance: TP (true positive) = 629, TN (true negative) = 159, FP (false positive) = 1, FN (false negative) = 10, and therefore an accuracy of 98.5%. The confusion matrix resulting from the tests on the complete dataset is shown in Fig. 3a. Most of the errors from the algorithm consist in classifying as a *fall* a depth sequence that is labeled as a *warning*. Other errors are somehow related to the choice of the time thresholds. In other cases, the algorithm cannot correctly locate the head of the subject, thus missing to track the subject when

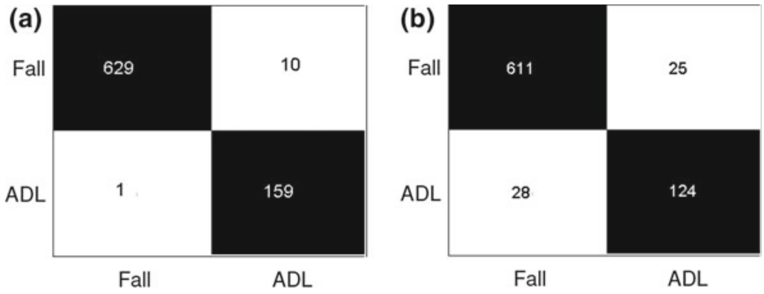

Fig. 3 Confusion matrix obtained by testing: **a** the Matlab code, **b** the Python code, over the complete dataset

recovering after a fall. The tracking of the subject may be lost also when the blob falls at the boundaries of the area covered by the sensor. In this condition, the fall detection algorithm does not work.

In order to limit the impact of tracking loss on the fall detection algorithm outcomes, the performance of the subject identification function and the blob tracking function have been improved during the implementation of the Python version. This way, blobs are identified at each frame and tracked correctly even when a blob fusion takes place. The improvement of this function also allowed to reduce the overall computational burden of the algorithm, by providing a better quality information to the following processing steps. As a further modification, in order to avoid the loss of the subject's tracking due to unexpected situations, an additional check on the user's position has been added, opting for reporting the possible loss of tracking, and documenting the situation with the acquisition of a video, or a frame of the last known position of the subject. Figure 3b shows the confusion matrix obtained by testing the Python code. The overall accuracy is 93.27%: despite the 5% reduction, the performance is still acceptable. The degradation is mostly due to the incorrect detection of *ADL* that are classified as *fall*. Considering that we are working on a system focused on fall detection, this means we are probably going to receive an increased amount of false alarms, but this is practically more acceptable than an increased probability of missing true fall events.

About the real-time behavior of the algorithm, the Python version, tested on the pilot configuration (i.e. Intel NUC i3-7100U, 8 GB RAM DDR4 and 128 GB NVMe SSD) provided 12–22 ms processing time per frame, thus fulfilling the requirement of a real-time frame processing.

4 Pilot Installation

The proposed fall detection system has been deployed in an apartment in the area of Lecco (Italy), to monitor a 75 years old woman who lives independently and alone, but receives daily visits and assistance from social operators. Information about the system functionalities and the types of data collected has been fully provided to the woman, by the help of social operators, and her informed consent to the experimentation has been obtained. The lady received support from the social operators during the pilot, in order to be able to report any possible issue or discomfort due to the presence of the system in her living environment.

4.1 System Deployment

The system has been running from November 16th, 2017 to April 3rd, 2018. In order to provide adequate coverage of the apartment, the system included 2 Intel mini-computers, 2 depth sensors applied on the ceiling, and the necessary cables and accessory devices. The sensors were located in the entrance area, and in the area where both the living space and the bed are present. The apartment is quite small and has one single space hosting both the kitchen and the bedroom, and a small bathroom. Due to the distance between the entrance and the living area, it was necessary to use two separate mini-computers, one for each sensor. A sketch of the apartment is given in Fig. 4. The gray-shaded areas are those covered by the Kinect sensors: one is located at the entrance in front of the wardrobe, the second is centered between the table, the self-catering and the bed. This way, two relevant areas are monitored, where the woman usually spends most of the time. The bathroom has not been instrumented with a sensor due to both practical issues related to cabling, and not acceptance by the woman.

Fig. 4 Plan of the apartment where the pilot has been deployed. The entrance and the window are evidenced. The gray-shaded areas are those covered by the kinect sensors: one is located at the entrance in front of the wardrobe, the second is centered between the table, the self-catering and the bed. Details about the wardrobe, the self-catering and the bed positions are given in the corresponding pictures

The available Wi-Fi connection was exploited to interface both the mini-computers to a remote server, towards which the notifications generated by the software have been delivered, together with short videos recorded in specific conditions (for example, whenever a fall has been notified). Over the pilot lifetime, around 3.1 GB of data have been collected, including event notifications, files listing the coordinates of the subject's positions during each day, short videos, and system log files. It is important to highlight that, differently from the offline implementation of the algorithm that processes a single sequence of depth frames at a time, the real-time Python software has to run on a continuous basis, so it has to be as much as possible robust against any unexpected circumstances, like loss of connection to the remote server, exception raised by a subroutine, ambiguous situations the software is not able to manage (like two or more subjects present in the covered area), power blackout. The system log files collect information about these events, in order to enable the development of suitable patches to correct possible malfunctions.

During the experimentation of the system in the real scenario of the lady's apartment, some issues emerged. The most relevant one is due to the presence of a door on the wardrobe, the position of which may affect the proper detection of the subject within the depth frames captured by the sensor covering that area. In fact, when the door is open, a shade area appears in the depth frame, over which the algorithm is not able to identify the person or maintain the correct tracking. This effect depends on the projection of the IR pattern on the door surface: as shown in the sequence of depth frames in Fig. 5, the black area appearing in the bottom-right side of the frame, when the door is open, corresponds to null depth values. As a consequence, the routines executed by the algorithm raise exceptions and the person's blob detection and tracking fail. Correspondingly, the system generates a number of fall notifications that are not correct.

Another critical situation emerges when the person moves near to the boundaries of the area covered by the sensor. In this case, as shown in the sequence of depth frames in Fig. 6, the tracking is not lost, but the central point of the blob gets misplaced and close to the floor, as the head is not detected. This way, a fall notification is raised, which is not correct.

The problems highlighted above are related to the physical displacement of the sensors, that cannot be arbitrarily chosen as it happens, on the contrary, in a lab setting. When dealing with a pilot installation in a real environment, many constraints are to be faced and traded off, to ensure the least obtrusiveness and the most acceptable performance. In any case, the issues presented can be quite efficiently addressed through additional checks on the position of the subject, or the position of the wardrobe door, within the algorithm.

As a final remark about the pilot, we want to highlight an interesting result emerged after the end of the experimentation, that makes the fall detection system useful also to monitor daily behaviors of the lady. In Fig. 7, the trajectories performed by the subject within the living area, on one day chosen randomly, from 07:00 am to 09:00 am (a), and from 07:00 pm to 09:00 pm (b) are shown, obtained by averaging the coordinates of the positions occupied over 10 s long time intervals. It is possible to see that the movements performed by the lady during the morning are more focused

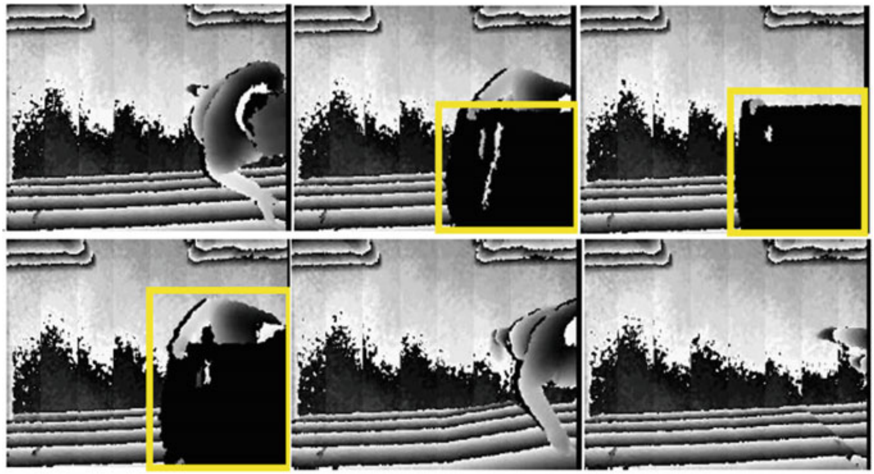

Fig. 5 Sequence of depth frames captured by the Kinect located over the wardrobe (from top to bottom, from left to right). When the wardrobe door is open, the depth sensing fails and the algorithm raises errors

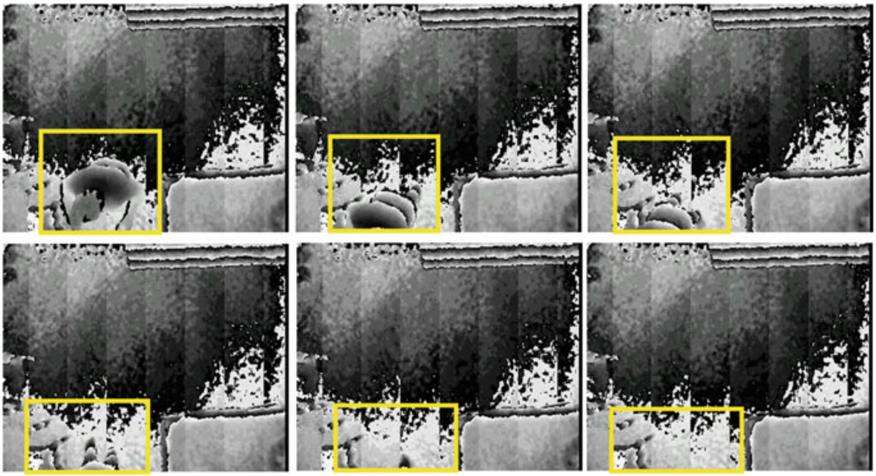

Fig. 6 Sequence of depth frames captured by the Kinect located over the living area (from top to bottom, from left to right). When the person moves near to the boundaries, tracking is not lost but the incorrect placement of the blob central point causes an error fall notification

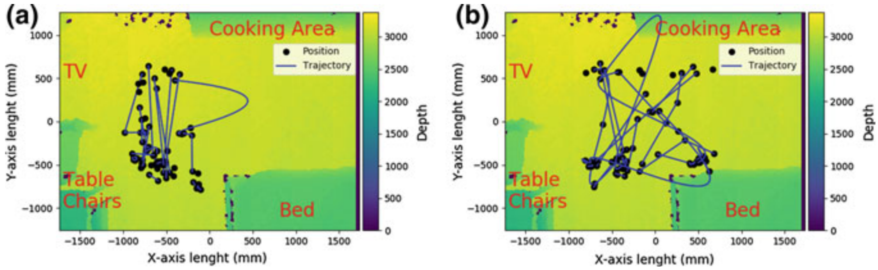

Fig. 7 Trajectories performed by the lady in the living area, on one day chosen randomly: **a** from 07:00 am to 09:00 am, **b** from 07:00 pm to 09:00 pm. Coordinates are given in the relative reference system of the Kinect sensor

around the areas where the table and the TV are located, whereas the movements performed in the evening appear much more chaotic. This feature needs additional investigations and validation, but it could be a possible sign of a discomfort felt by the subject at the end of the day. The additional information obtained by processing the data collected from the fall detection system, from which fall notifications are generated, can be used to implement a long term behavioral monitoring, aimed at prevention and not only detection of possibly dangerous events.

4.2 Main Outcomes

The practical experience performed with the installation of a pilot fall detection system in a real environment brought us a number of outcomes that are summarized here:

- a real-time software aimed at fall detection in a real living environment has to be robust against different possible unexpected events, both related to hardware issues (power blackout, system re-boots, loss of connection to the remote server), and to possible uneven conditions and limitations that can be due to the characteristics of the environment where the monitoring is performed;
- installation constraints are typically ignored when testing a fall detection algorithm in a lab setting. On the contrary, when going into the field, the deployment conditions are usually far from being ideal. It is important to include specific steps within the software, that can help managing these issues in a smart algorithmic way. For example, additional pre-checks on the data collected from the sensors may be applied to avoid getting trapped into conditions that are ambiguous or noisy, and eventually lead to notification errors;
- the logical separation among different functionalities of the system should reflect on a modular design of the software, so that the different modules may be adjusted or replaced without affecting the whole system operation. This way the system is more robust and even scalable, by allowing the addition of new sensors whenever

necessary, without the need to apply any changes to the pre-existing deployment. Specifically, for the system described in this paper, the modular architecture of the software will allow to quite easily replace the front-end routine to accommodate a new depth sensor, as even the last available device (the Kinect for Xbox One) was discontinued by Microsoft in October 2017, thus terminating the Kinect product line;

- the reliability of the system execution must be guaranteed even in the presence of possible critical error conditions, such as: (i) automatic reboot of the system and the fall detection routine following a power down event (the implemented procedure dynamically detects the number of sensors connected to the mini-computer, and for each of them the routine instance is started, loading the appropriate configuration file); (ii) handling errors generated by the sensor driver, or missing acquisitions from the sensor (in both the cases, a proper software library is used to force the disconnection and reconnection of the sensor after 10 s); (iii) correct association of each sensor to a USB port, which is important in the case a sensor gets physically disconnected from the mini-computer due to improper actions by the user. The correct association between each sensor and its USB port is important for the correct execution of the fall detection software instance;
- the depth frame, or frame sequence, captured by the sensor could present irregularities that require excessive processing time at the back-end. To face this issue, the back-end checks the amount of time needed to process each single frame, and if this time exceeds 1 s, it empties the ring buffer to avoid getting trapped in a long processing that would cause the buffer to be completely filled in, thus missing the acquisition of subsequent frames.

5 Conclusion

In this paper we presented the process of deploying a fall detection system, from the research activities necessary to design the algorithm, to the experimental tests performed in a lab setting, up to the final installation of a pilot in a real living environment, to monitor a 75 years old woman living alone. The installation of the system in a real home premise allowed to identify several conditions that can critically affect the system performance and reliability, and that can barely be simulated or even accounted for when experimenting only in a lab setting, with actors simulating falls.

The system designed for fall detection can actually collect useful data to implement long term behavioral analyses, thus enabling to prevent and not only to detect possibly dangerous conditions.

The impact of the system on the quality of life of the monitored subject needs to be carefully evaluated, and it is important to provide guidance and assistance to the subject by the support of trusted operators.

References

1. AAL Joint Platform: ICT for ageing well. http://www.aal-europe.eu/about/why-thisprogramme/
2. Hillcoat-Nallétamby S (2014) The meaning of independence for older people in different residential settings. J Gerontol Ser B 69(3):419–430. https://doi.org/10.1093/geronb/gbu008
3. Rashidi P, Mihailidis A (2013) A survey on ambient-assisted living tools for older adults. IEEE J Biomed Health Inf 17(3):579–590
4. World Health Organization. Falls: fact sheet. http://www.who.int/en/newsroom/fact-sheets/detail/falls. Accessed on May 3rd, 2018
5. Delahoz YS, Labrador MA (2014) Survey on fall detection and fall prevention using wearable and external sensors. Sensors 14(10):19806–19842
6. Turner S, Kisser R, Rogmans W (2015) Falls among older adults in the EU-28: key facts from the available statistics. EuroSafe, Amsterdam
7. Chaccour K, Darazi R, El Hassani AH, Andrès E (2017) From fall detection to fall prevention: a generic classification of fall-related systems. IEEE Sens J 17(3):812–822
8. Droghini D, Principi E, Squartini S, Olivetti P, PiazzaF (2018) Human fall detection by using an innovative floor acoustic sensor. In: Smart innovation, systems and technologies, pp 97–107. https://doi.org/10.1007/978-3-319-56904-8
9. Cippitelli E, Fioranelli F, Gambi E, Spinsante S (2017) Radar and RGB-depth sensors for fall detection: a review. IEEE Sens J 17(12):3585–3604
10. Gasparrini S, Cippitelli E, Spinsante S, Gambi E (2014) A depth-based fall detection system using a kinect sensor. Sensors 14(2):2756–2775
11. Kit Intel NUC NUC7i3BNH. https://www.intel.it/content/www/it/it/products/boardskits/nuc/kits/nuc7i3bnh.html

Big Data Analytics in Smart Living Environments for Elderly Monitoring

Giovanni Diraco, Alessandro Leone and Pietro Siciliano

Abstract Today, data collected in smart-living environments are constantly increasing in the dimensions of volume, velocity and variety, which characterize any big data application. In such a way, it makes sense to investigate big data analytics for elderly monitoring at home. The aim of this study is to conduct a preliminary investigation of state-of-the-art algorithms for abnormal activity detection and change prediction, suitable to deal with big data. The algorithmic approaches, under evaluation and comparison, belong to the three main categories of supervised, semi-supervised and unsupervised techniques. At this purpose, specific synthetic data are generated, including activities of daily living, home locations in which such activities take place, as well as physiological parameters. All techniques are evaluated in terms of abnormality-detection accuracy and lead-time of prediction, using the generated datasets with various kinds of perturbation. The achieved results, even though preliminary, are very encouraging, showing that unsupervised deep-learning techniques outperform traditional (machine learning) ones, with detection accuracy greater than 96% and prediction lead-time of about 15 days in advance.

Keywords Smart living · Elderly monitoring · Abnormal activity · Detection change prediction · Big data analytics · Machine learning · Deep learning

1 Introduction

The automatic detection of abnormal activity and behavior is of great interest in elderly monitoring [1] and smart living [2] related applications. The long-term health monitoring and assessment can benefit from knowledge held in long-term time series

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of daily activities/behaviors and physiological parameters [3]. In fact, today's available sensing and assisted living technologies installed in smart-living environments are able to produce a huge amount of data by days, months and even years, which should be converted into meaningful information, allowing to automatically and promptly detect changes. In such a way, it would be possible to alert caregivers and/or service providers in advance when significant changes are detected and before they reach critical levels (i.e., undetected behavioral and/or physical changes may be a high risk for subjects whose health conditions are amenable to change). Therefore, such huge data offer a unique opportunity to assist people for early detection of certain symptoms that might cause more serious disorders, as well as in preventing of chronic diseases [3].

Currently, the main challenge is to process and automatically interpret (obtaining quality information) the big data produced, at high velocity and volume, by a great variety of devices and sensors, becoming more common with the rapid advance of both wearable and ambient sensing technologies [4]. A lot of research has been done in the general area of human behavior understanding, and more specifically in the area of daily activity/behavior recognition and classification as normal or abnormal [5, 6]. However, very little work is reported in the literature regarding the evaluation of machine learning (ML) techniques suitable for data analytics in the context of elderly monitoring in smart living environments. The purpose of this paper is to conduct a preliminary study of the most representative machine/deep learning techniques, by comparing them in detecting abnormal activity and change prediction.

The rest of this paper is organized as follows. Section 2 contains related works, some background and state-of-the-art in abnormal activity and behavior detection and change prediction, with special attention paid to elderly monitoring through big data collection and analysis. Section 3 describes materials and methods that have been used, providing an overview of the system architecture and compared machine learning techniques. The findings and some discussion are presented in Sect. 4. Finally, Sect. 5 draws some conclusions and final remarks.

2 Related Works and Background

A variety of sensing techniques that are available today enable long-term continuous monitoring of activities of daily living (ADLs) and physiological parameters in the home. Both wearable and ambient sensors can be used for this purpose, also in combination (i.e., data fusion). Wearable sensors typically used in practice for motion detection are low-cost accelerometers, gyroscopes and compasses, whereas skin-contact biosensors are adopted for the detection of various physiological parameters (e.g., heart and respiration rates, blood pressure, ECG, EMG, etc.) [7]. Such wearable sensors need to be attached to wireless nodes (carried by the user), in order to process data and to communicate high-level events and/or raw data to a central base station. Although they have the advantage of being usable "on the move" and their detection performance is generally good (i.e., signal-to-noise ratio sufficiently high), nonetheless their usage is limited by battery life (both on-board processing and wireless communication are energy-demanding) [8], by the inconvenience of having to remember to wear a device and by the discomfort of the device itself.

On the other hand, ambient sensing technologies are less intrusive in terms of body obstruction, since they require the installation of sensors around the home environment. Such solutions disappear into the environment, and so are generally well-accepted by end-users. Conversely, their detection performance depends on the number and careful positioning of sensors, which may require modification or redesign of the entire environment. They can include simple switches, pressure and vibration sensors embedded into carpets and flooring. The latter kind of sensors are particularly useful for detecting abnormal activities (such as falls), since elderly people are directly in contact with the floor surface during the execution of ADLs [9]. Particularly promising, unobtrusive and privacy-preserving, ambient technologies are 3D depth vision and ultra-wideband (UWB) radars which, respectively, allow to overcome typical limitations of passive vision [10] and to perform remote detection of body movements as well as physiological parameters [11].

Generally, heterogeneous information provided by different kinds of sensors is collected by an abstraction layer which is responsible for anomaly detection and change prediction. In the previous authors' study [12], a platform able to handle heterogeneous sensors was presented for the detection of anomalies in circadian rhythm. Data coming from three different sensors were converted to, and processed as, a sequence of symbols, representing four basic body postures: standing, sitting, bending, lying down. The posture recognition included a (sensor-related) feature extraction stage [13], followed by a hierarchical classifier by which postures were represented at different level of details [14]. The basic idea presented in this paper is inspired by the previous authors' study [12] of which this study can be considered as the continuation and extension.

The algorithmic techniques for detecting abnormal activities (and predicting related changes) can be roughly categorized into three types: supervised, semi-supervised, and unsupervised. In the supervised case, the abnormality detection is treated as a binary problem, and faced by using supervised classifiers. The training phase requires both normal and abnormal activities. But, in general, the latter are not available or are simulated by volunteers or are synthetically generated. Typical supervised classifiers include support vector machine (SVM) [15] and hidden Markov model (HMM) [16]. The techniques belonging to the second category recognize abnormalities by using one-class classifiers. In this case, there is the advantage that the training phase does not need abnormal activities but only normal ones, i.e., ADLs performed by the elderly. A typical classifier belonging to this group, and adopted for abnormality detection, is the one-class SVM [17]. Finally, the last category includes unsupervised learning techniques that do not require neither normal nor abnormal activity for training. The main advantage of these techniques is their high adaptability to changing contexts and/or to the subject's characteristics and habits [18]. One disadvantage, however, is that they require a sufficient amount of observation data that, unfortunately, are not always available, especially when the system is operating for the first time.

The aspects of volume, variety and velocity (typical aspects of big data) can be effectively addressed by using deep learning (DL) algorithms [19]. In fact, the usage of massive amount of data (volume) is one of the greater advantage of DL, which can be extended and/or adapted to deal with data abstraction in various different formats (variety). Furthermore, the power of a cluster of GPU servers can be exploited for processing massive datasets coming in real-time (velocity) from sensors spread around a smart home environment. Nevertheless, the application of DL techniques for the purpose of anomaly (abnormal activity) detection is still in its infancy [20]. Convolutional Neural Network (CNN), that is the current state-of-the-art in object recognition from images [21], exhibits very high feature learning performance but it falls into the first category of supervised techniques. A more interesting DL technique for abnormal activity recognition is represented by Auto-Encoders (AEs), and in particular the Stacked Denoising AEs (SDAEs) [22], which can be subsumed in the semi-supervised techniques when only normal ADLs are used for training. However, SDAEs are basically unsupervised feature learning networks, and thus they can be also exploited as fully unsupervised techniques for anomaly detection. The main limitation of AEs is its requirement of 1D input data, making them essentially unable to capture 2D structure in images. This issue is overcome by the Convolutional AE (CAE) architecture [23], which combines the advantages of CNN and AE, besides being suitable for clustering tasks (deep clustering) [24] and, thus, making it a valuable technique for unsupervised anomaly detection.

3 Materials and Methods

In this study, both traditional ML and more advanced DL techniques are compared on both abnormal activity detection and change prediction. In particular, for each of the three categories introduced in the previous section (i.e., supervised, semi-supervised and unsupervised), one ML-based technique and one DL-based technique are selected and comparatively evaluated, as reported in Table 1. Such techniques are compared in terms of detection accuracy and prediction lead-time at the varying of both normal ADLs (N-ADLs) and abnormal ADLs (A-ADLs). Synthetic datasets are generated for evaluation purpose by referring to common ADLs and to the modality by which such activities are performed by older subjects in their home environment, as suggested by existing research [16].

Furthermore, the generated datasets include also home locations in which ADLs take place and some basic physiological parameters, namely heart-rate (HR) and respiration-rate (RR), associated with each performed action. The following six ADLs are included: eating, exercising, housekeeping, leisure, sleeping, toileting. Instead, the included home locations are bathroom, bedroom, kitchen, and living-room.

Usually, ADLs, home locations, HR and RR are sampled at different rates according to the specific variability during the entire day time. For example, since the minimum duration of the considered ADLs is of about 10 min, it does not make sense to

Table 1 Abnormal activity detection techniques considered in this study

Category	Type	Technique
Supervised	Machine learning	Support vector machine (SVM)
Supervised	Deep learning	Convolutional neural network (CNN)
Semi-supervised	Machine learning	One-class support vector machine (OC-SVM)
Semi-supervised	Deep learning	Convolutional auto-encoders (CAE)
Unsupervised	Machine learning	K-means clustering (KM)
Unsupervised	Deep learning	Deep clustering (DC)

take a sampling interval of 1 min for ADLs. Nevertheless, for uniformity reasons, a unique sampling interval is adopted for all measurements. In this study, the sampling rate of HR/RR (i.e., one sample each 5 min) is selected as reference to which the others are aligned by resampling them. Then, the generated data are prepared in a matrix form with M row and N columns, where M is the total number of observed days, N is the total number of samples per day (288 in this study). Each matrix cell holds a numeric value that indicates an ADL, or a level for HR/RR (note that HR/RR ranges are discretized in five levels as very low, low, normal, high, very high), or a location.

Therefore, for each monitored older adult, the generated historical dataset is composed of four matrices referring to ADLs, locations, HR and RR values, respectively. As an example of dataset preparation, a small portion of dataset is shown in Fig. 1. In order to evaluate the detection performance of each technique summarized in Table 1, several datasets are generated by adding random deviations from normal activities. Figure 2 reports an example of ADL dataset which covers a year of observations including a period of abnormal activities. Observing this dataset, it is clear that the abnormal period consists of three main parts. The first one, ranging from day 135th to day 172th, includes a moderate deviation from usual habits. The second period, from day 172th to 294th, is characterized by more substantial changes including also the inversion of some ADL. Finally, the third period, starting from day 294th, is very different from the initial normal period, since some activity is missing and/or inverted, although the change rate is low and the subject moves into another stability period.

The detection performance of each technique is evaluated for different A-ADL levels (i.e., percentages of abnormal activities present in a dataset) as well as different prediction lead-time, which is, the maximum number of days in advance such that the abnormality can be detected with a certain accuracy. Furthermore, in order to better

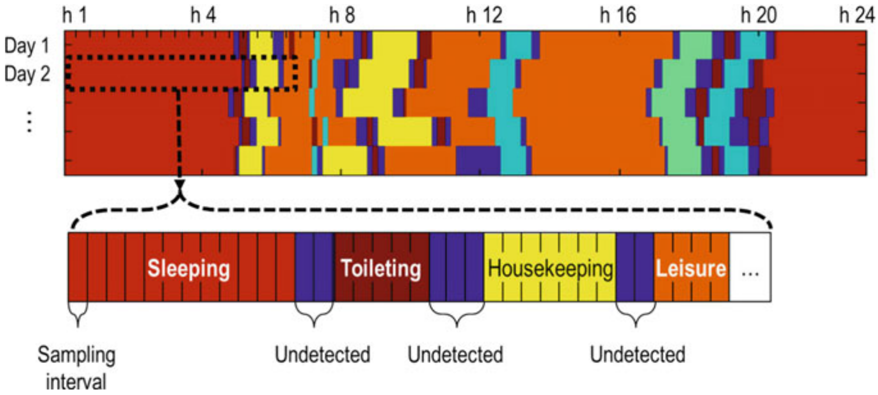

Fig. 1 Data preparation in matrix form in the case of ADLs

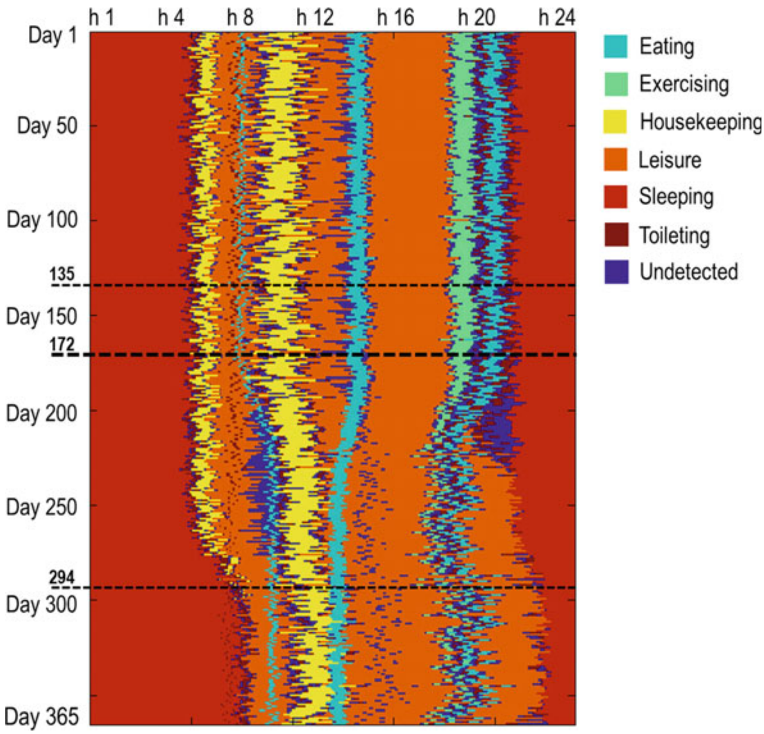

Fig. 2 A dataset of ADLs covering 1-year observations and including abnormal activities subdivided into three periods characterized by different changing rates. This data model can be treated and processed as a multi-channel image

appreciate differences among the three types of detection techniques (i.e., supervised, semi-supervised and unsupervised), beside the A-ADL also N-ADL changing is considered, that is, to take into account the potential overlapping of more ADLs in the same sampling interval as well as the occurrence of ALDs never observed before.

4 Experimental Results and Discussion

This section reports detection accuracy and lead-time of prediction related to all techniques summarized in Table 1, achieved processing the generated datasets as described in the previous sections. Detection accuracies are reported in Table 2, and the corresponding lead-times of prediction are reported in Table 3. In both cases of accuracy and lead-time, results are provided at three different levels of variation (low, medium and high) of the dataset activities. As discussed in the previous section, such variation levels regard both N-ADLs and A-ADLs. The former regard the overlapping of different activities within the same sampling interval or the occurrence of new activities. Instead, the latter take into account the amount deviations from usual activities.

From Table 2, it is evident that at a low level of activity variation, there are little differences between detection accuracies, which become more marked with the increasing of the activity variation level. In particular, the semi-supervised and

Table 2 Detection accuracy of the compared techniques

Technique	Accuracy (%)		
SVM	89	88	86
CNN	96	94	91
OC-SVM	93	91	90
CAE	99	95	94
KM	94	92	91
DC	97	96	96
Activity variations	Low	Med	High

Table 3 Lead-time of prediction of the compared techniques

Technique	Lead-time (days)		
SVM	10	7	4
CNN	14	9	5
OC-SVM	8	7	6
CAE	18	12	12
KM	7	6	4
DC	19	16	15
Activity variations	Low	Med	High

unsupervised techniques based on deep learning maintain good performance in correspondence of medium and high levels of activity variation. This is explainable by the ability of such techniques to capture spatio-temporal local features. The lead-times of prediction reported in Table 3 were obtained in correspondence of the accuracies discussed above and reported in Table 2. In other words, such times refer to the average number of days, before the second changing period highlighted in Fig. 2, at which the change can be detected with accuracy reported in Table 2. The longer the lead-times of prediction the earlier the change can be predicted. Better lead-times were achieved at low level of activity variation and with techniques CAE and DC, since they are able to learn discriminative features more effectively than the traditional ML techniques.

5 Conclusions

The contribution of this study is twofold. First, a common data model able to represent both ADLs, home locations (in which ADLs take place) and various physiological parameters (HR, RR) as a multi-channel image is presented. Second, the performance of state-of-the-art ML-based and DL-based detection techniques are evaluated by considering big datasets, synthetically generated, including both normal and abnormal activities. The preliminary results are promising and show the superiority of DL-based techniques in dealing with big data characterized by different kind of activity variations. Future and ongoing activities are focused on the evaluation of prescriptive capabilities of data analytics in order to optimize time and resources consuming in elderly monitoring tasks.

References

1. Gokalp H, Clarke M (2013) Monitoring activities of daily living of the elderly and the potential for its use in telecare and telehealth: a review. Telemed e-Health 19(12):910–923
2. Sharma R, Nah F, Sharma K, Katta T, Pang N, Yong A (2016) Smart living for elderly: design and human-computer interaction considerations. Lect Notes Comput Sci 9755:112–122
3. Parisa R, Mihailidis A (2013) A survey on ambient-assisted living tools for older adults. IEEE J Biomed Health Inform 17(3):579–590
4. Vimarlund V, Wass S (2014) Big data, smart homes and ambient assisted living. Yearb Med Inform 9(1):143–149
5. Mabrouk AB, Zagrouba E (2018) Abnormal behavior recognition for intelligent video surveillance systems: a review. Expert Syst Appl 91:480–491
6. Bakar U, Ghayvat H, Hasanm SF, Mukhopadhyay SC (2015) Activity and anomaly detection in smart home: a survey. Next Gener Sensors Syst 16:191–220
7. Taraldsen K, Chastin SFM, Riphagen II, Vereijken B, Helbostad JL (2012) Physical activity monitoring by use of accelerometer-based body-worn sensors in older adults: a systematic literature review of current knowledge and applications. Maturitas 71(1):13–19

8. Min C, Kang S, Yoo C, Cha J, Choi S, Oh Y, Song J (Sept 2015) Exploring current practices for battery use and management of smartwatches. In: Proceedings of: the 2015 ACM international symposium on wearable computers, pp 11–18
9. Droghini D, Ferretti D, Principi E, Squartini S, Piazza F (2017) A combined one-class SVM and template-matching approach for user-aided human fall detection by means of floor acoustic features. Comput Intell Neurosci
10. Hussmann S, Ringbeck T, Hagebeuker B (2008) A performance review of 3D TOF vision systems in comparison to stereo vision systems. In: Stereo vision, InTech
11. Diraco G, Leone A, Siciliano P (2017) A radar-based smart sensor for unobtrusive elderly monitoring in ambient assisted living applications. Biosensors 7(4):55
12. Caroppo A, Diraco G, Rescio G, Leone A, Siciliano P (2015) Heterogeneous sensor platform for circadian rhythm analysis. In: IEEE international workshop on advances in sensors and interfaces (ISIE), 10 August 2015, pp 187–192
13. Diraco G, Leone A, Siciliano P Geodesic-based human posture analysis by using a single 3D TOF camera. In: IEEE international symposium on industrial electronics (ISIE), 27–30 June 2011
14. Diraco G, Leone A, Siciliano P (2014) In-home hierarchical posture classification with a time-of-flight 3D sensor. Gait Posture 39(1):182–187
15. Miao Y, Song J (2014) Abnormal event detection based on SVM in video surveillance. In: IEEE workshop on advance research and technology in industry applications, pp 1379–1383
16. Forkan ARM, Khalil I, Tari Z, Foufou S, Bouras A (2015) A context-aware approach for long-term behavioural change detection and abnormality prediction in ambient assisted living. Pattern Recogn 48(3):628–641
17. Hejazi M, Singh YP (2013) One-class support vector machines approach to anomaly detection. Appl Artif Intell 27(5):351–366
18. Otte FJP, Rosales Saurer B, Stork W (2013) Unsupervised learning in ambient assisted living for pattern and anomaly detection: a survey. In: Communications in computer and information science 413 CCIS, pp 44–53
19. Sohangir S, Wang D, Pomeranets A, Khoshgoftaar TM (2018) Big data: deep learning for financial sentiment analysis. J Big Data 5(1):3
20. Ribeiro M, Lazzaretti AE, Lopes HS (2018) A study of deep convolutional auto-encoders for anomaly detection in videos. Pattern Recogn Lett 105:13–22
21. Krizhevsky A, Sutskever I, Hinton GE (2012) Imagenet classification with deep convolutional neural networks. In: Advances in neural information processing systems, pp 1097–1105
22. Krizhevsky A, Hinton GE (2011) Using very deep autoencoders for content-based image retrieval. In: ESANN, April 2011
23. Masci J, Meier U, Cireşan D, Schmidhuber J (2011) Stacked convolutional auto-encoders for hierarchical feature extraction. In: International conference on artificial neural networks, Springer, Berlin, Heidelberg, pp 52–59
24. Guo X, Liu X, Zhu E, Yin J (2017) Deep clustering with convolutional autoencoders. In: International conference on neural information processing, Springer, pp 373–382, November 2017

A Smart Inertial Pattern for the SUMMIT IoT Multi-platform

Bruno Andò, Salvatore Baglio, Ruben Crispino, Lucia L'Episcopo, Vincenzo Marletta, Marco Branciforte and Maria Celvisia Virzì

Abstract The SUMMIT project funded by the Italian MISE under the PON2020 Action, aims to the development a IoT (*Internet of Things*) platform which should be flexible and adaptive to easily embed several smart objects such as sensors, multi-sensor architectures and mobile terminals. The main idea is to lunch an open and dynamic eco-system to support the development of IoT based services both for the private and public sectors. The concept of "pattern" will lead the overall development of the SUMMIT platform which represents each element to be integrated in the SUMMIT framework by assuring security, privacy and dependability properties. Above patterns will be also *self-evolving* on the basis of their behavioral analysis to be performed during the system operation. The three main cases of study addressed by the project will be *smart energy*, *smart health* and *smart cities*. Among patterns addressed by the project the development of a smart inertial platform is considered. Such platform will find application in several contexts with a strong priority in the Smart Living framework. As an example, the architecture developed can be adopted for the sake of Activity of Daily Living monitoring (including Falls), postural instability detection, aided navigation, physical activity assessment, just to cite mostly

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addressed needs. Actually, above application contexts represent serious needs to be addressed to enable Active Ageing and Well Being. The Smart Inertial Pattern (SIP) is based on an embedded architecture equipped with sensors (accelerometer, gyroscope, compass) and communication facilities. In this paper the use of the SIP device for the implementation of a ADL classifier exploiting an event correlated approach is presented.

Keywords IoT · Activity of daily living · Assistive technology

1 Introduction

Falls are the main cause of domestic accidents, as well as the first cause of hospitalization [1–5].

Falls among weak people, like elders or people with specific pathologies, hospitalized patients and nursing home residents are usually the consequence of a combination of several risk factors. The most significant fall risk factors identified are: effects of aging on gait, balance and strength, being confused and agitated, chronic diseases, medication side effects, incontinence, falls history (having fallen before), sedatives or sleeping tablets, unsafe behaviors, environmental hazards, unsafe equipment, visual impairments [2–5]. In 5–10% of elderly patients who fall present fractures, head injuries and tears with consequent increase in the risk of hospitalization; in about 1% of patients who fall, a femoral fracture occurs with a 20–30% one-year mortality. Up to 80% of the reported accidents in hospitalized patients are falls. Approximately 2–17% of patients, depending on the hospital settings, experience a fall during their hospital stays. Fall related injuries occur in 15–50% of hospital falls and up to 10% of these patients experience a major injury (including fractures, sprains, lacerations, or contusions).

Despite prevention efforts, falls are still likely to occur, and reliable solutions are required to detect falls. Such solutions can be divided into wearable and non-wearable systems. Wearable systems generally consist of multi-sensor platforms which can detect changes in acceleration, planes of motion or impact in order detect falls. Non-wearable systems include cameras, acoustic sensors and pressure sensors that are placed in the user's normal environment and use various measurements to determine if the subject has fallen.

Different technologies have been proposed to develop systems for the assessment of human posture [6, 7], ADL and falls, such as customized devices [8–10] and smartphone-based platforms [11–16]. A review of fall detection systems is available in [17], along with most adopted paradigms for event classification. Currently, threshold algorithms and posture monitoring are used to assess and classify critical events, also exploiting analysis of body position. The latter approach suffers for misclassification due to extra movements of the user after the fall event.

In [18, 19] the authors presented a smartphone-based platform aimed to provide effective solutions for ADL detection in Ambient Assisted Living contexts. The main task of the assistive system is to acquire awareness of common ADL such as stair negotiation, sitting and falls in order to provide the frail user with a suitable degree of assistance. The proposed architecture uses advanced signal processing to detect ADL, basically considering the moving average of the magnitude of the three acceleration components and event polarized cross-correlation analysis, which makes the system robust against external influences. In particular, the system exploits two different classification algorithms. The first algorithm uses a threshold mechanism applied to the rough extracted features (maximum values of correlation between the unknown pattern and ADL signatures), while the other approach is based on a threshold mechanism applied to a new data domain obtained by a Principal Component Analysis (PCA). Moreover, an improvement of the classification methodology using also the information on the user posture after the detected ADL, by processing the embedded tri-axial accelerometer output signals, was described.

In [20] a multisensor data fusion strategy is adopted for the sake of Fall and ADL classification, which exploits a multi-sensor data-fusion approach combining data from the accelerometer and the gyroscope embedded in the user nodes.

Concerning commercial solutions providing alerts in case of anomalous events, Personal Emergency Response Systems or PERS are widely adopted [21]. These alarm systems provide a way for individuals who fall to contact an emergency center by pressing a button. Anyway, it could happen that PERS system are useless if the person is unconscious or unable to reach the button.

Due to PERS drawbacks, passive monitoring solutions have been proposed to automatically detect falls.

An example of a wearable monitoring system is Angel4 Fall Detection [22] developed by SENSE4CARE, which provides highly sensitive automatic fall detection by means of a tri-axial accelerometer and a dedicated algorithm. The device can be worn at the user belt and uses a smartphone APP to automatically carry out the communication with the emergency services in the case a fall occurs and also to provide user geolocalization (only for outdoor environment).

2 The System Developed

The SIP device is based on the STM32 Nucleo board (64-pin) which is a low-cost and easy-to-use development platform used to simply evaluate and start a development with an STM32 [23]. All the STM32 Nucleo boards include an ST-LINK/V2-1 embedded debug tool interface. This interface needs a dedicated USB driver to be installed in order to recognize the board and it is supported within different software toolchains, such as EWARM, MDK-ARM, Atollic TrueSTUDIO STM32, SW4STM32.

The expansion boards named X-Nucleo-IS01A2 has been used to include sensing features (with particular regards to the accelerometer). For this application the accelerometer LSM6DSL is used in order to acquire the acceleration from the three axes. The LSM6DSL is a system-in-package featuring a 3D digital accelerometer

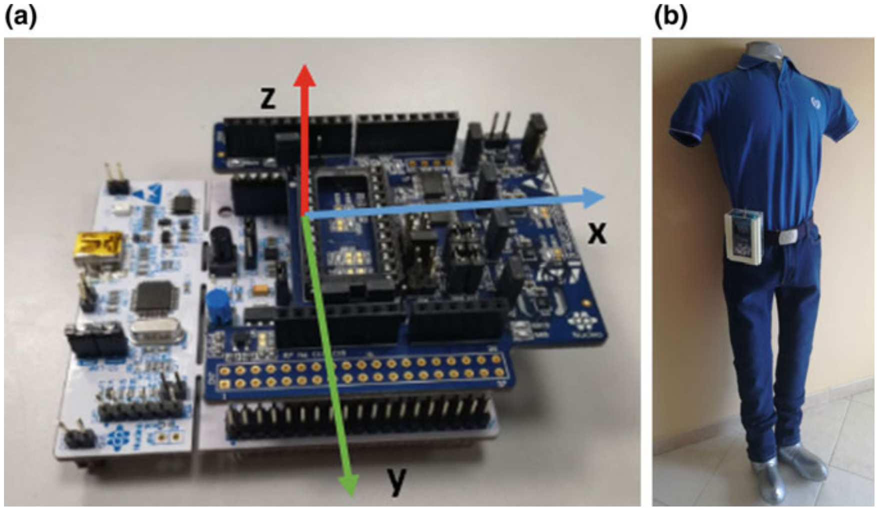

Fig. 1 **a** The developed embedded platform; **b** the mannequin used for the sake of falls emulation

and a 3D digital gyroscope performing at 0.65 mA in high-performance mode and enabling always-on low-power features for an optimal motion experience for the consumer. It has a full-scale acceleration range of ±2/±4/±8/±16 g and an angular rate range of ±125/±245/±500/±1000/±2000 dps.

The X-Nucleo board communicates with the STM32 microcontroller via the I^2C pin and the I^2C port can be eventually changed. As shown in Fig. 1a, the X-Nucleo board is placed above the Nucleo-board and stuck to it in such a way that the pins of both boards coincide.

2.1 The ADL Classification Methodology

Figure 2 shows the methodology implemented for the sake of ADL classification. The main idea is to continuously perform the correlation of 5 s of the runtime acquired acceleration magnitude with reference signatures of Activities of Daily Living (computed offline) to be classified. In particular, the following classes of events have been used to generate the signatures and consequently would be detected: backward falls (FB), forward falls (FF), left lateral falls (FFL), right lateral falls (FLR) and sitting (SI).

Steps required for signatures generation, shown in Fig. 3, are [18–20]:

1. Data acquisition for each kind of event
2. Module computation of the three acceleration axes
3. Moving average computation
4. Signals alignment

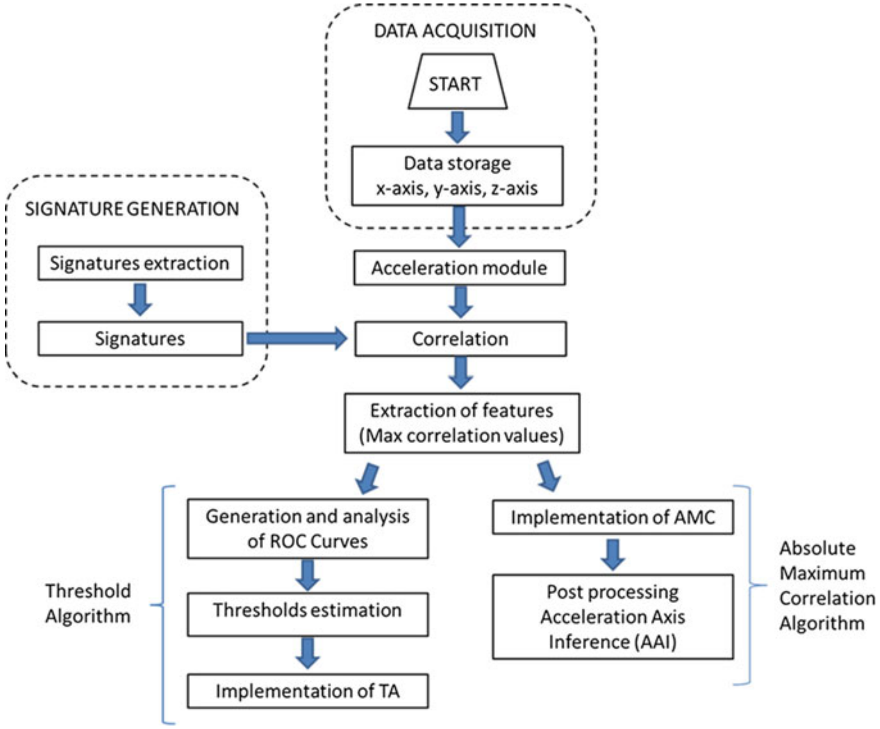

Fig. 2 Paradigms adopted for the sake of events classification

5. Outliers filtering and averaging
6. Signatures extraction.

An example of signals alignment in case of the SI event is given in Fig. 4a, while the final signature obtained by averaging repetitions is shown in Fig. 4b.

The calculation of the correlation between two signals is one of the most immediate methods of classification for the invariance to the translations and the robustness to the additive noise of the signal. This concept is used through this work to implement ADL and falls classification exploiting an event-correlated paradigm, which is based on the estimation of correlation between signatures and the moving average of the acceleration module. The degree of correlation between signals assumes values between −1 when the variables considered are inversely correlated and +1 when there is absolute correlation. A zero correlation states for an absence of correlation. The following correlation is used:

$$IC = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}. \tag{1}$$

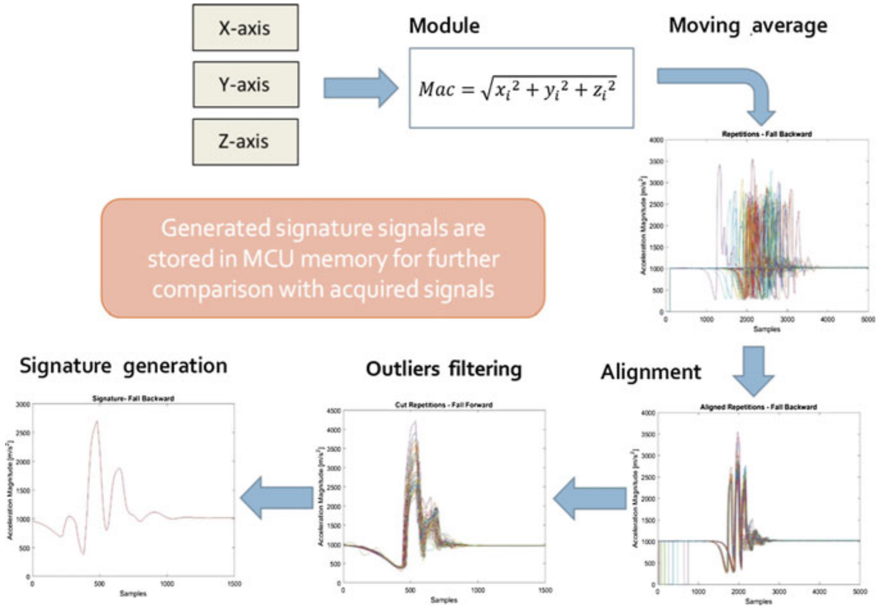

Fig. 3 The procedure adopted for signature generation

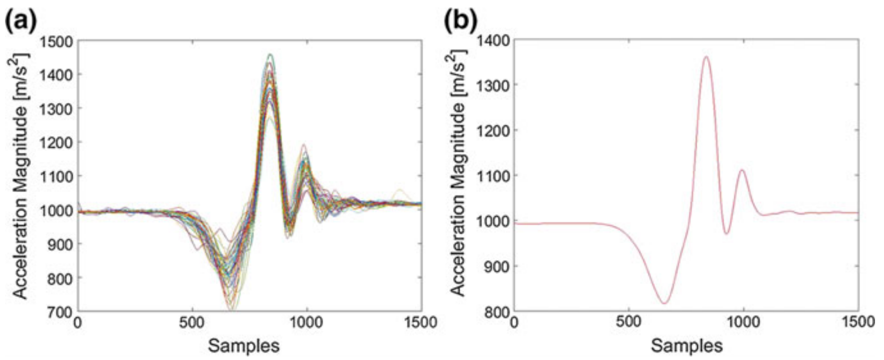

Fig. 4 Results obtained by the procedure adopted for signature generation. An example in case of Sitting Event: **a** aligned and filtered patterns; **b** the final signature

where i is the i-th sample of the acquired signal, $\bar{x}$ and $\bar{y}$ are the mean values of the vectors whose degree of correlation must be calculated. In this case, x is the signature, while y is the averaged acceleration module.

The classification algorithm has been implemented on the ST-NUCLEO board.

The acquisition process begins as soon as the device is switched on. Consequently, the acceleration module, its moving average and correlation with each of the five considered signatures are continuously calculated, for a time window of 300 ms. In case one of the five indexes exceed a pre-defined threshold, a potential event is detected. In this case the acquisition will run for another 300 ms and results of correlations are saved for successive elaboration.

To identify the class of event to which the unknown event belongs, the maximum among all estimated correlation indexes is computed. To face possible multiple classification or misclassifications a signal processing, named Acceleration Axis Inference (AAI), of the acceleration on the three is performed.

Actually, it has been observed that during the subsequent 300 ms after an event occurred, the averaged values of the three axes, have specific trends usable for improving the classification strategy.

As respect to Threshold Algorithms presented in [18–20], this solution is easy-to-be implemented by exploiting an embedded architecture, since this does not require threshold knowledge. Moreover, this approach is less sensitive to the system architecture, which strongly influences values of classification thresholds.

3 Experimental Results

An inflatable mannequin is used for pattern acquisitions both for signature estimation and the system assessment; this choice has been taken for two main reason: to avoid any risk in asking real user to perform real falls (this implies the need to alert an ethics committee) and because the main idea in developing this inertial architecture was to demonstrate the feasibility of an approach that can be pattern independent and extendable to any generic inertial pattern. As shown in Fig. 1b, the device is positioned at the waist. Fifty repetitions for each kind of fall have been acquired by emulating events using the mannequin. Moreover, 50 sitting patterns have been generated by a user wearing the device. Forty patterns have been used for the sake of signatures generation while the remaining ten patterns have been used to assess the system performances.

Results obtained in case of the Absolute Maximum Correlation algorithm are given in Table 1.

In particular, the following indexes have been used:

$$Sensitivity = \frac{TP}{(TP + FN)} \tag{2}$$

$$Specificity = \frac{TN}{TN + FP} \tag{3}$$

Table 1 Threshold Algorithm (TA) performances

Index	FB	FF	FLL	FLR	ST
Sensitivity	0.93	0.92	0.95	0.93	0.96
Specificity	0.88	0.99	0.88	0.91	0.94

Table 2 Absolute Maximum Correlation (AMC) algorithm performances

Index	FB	FF	FLL	FLR	ST
Sensitivity	1	0.98	0.95	0.94	0.98
Specificity	0.97	0.99	0.96	0.95	0.99

where, considering a generic Event Class, *E*:

TP-TRUE POSITIVE: i.e. events of type *E* correctly recognized as belonging to class *E*;
FN-FALSE NEGATIVE: i.e. events of type *E* recognized as belonging to a class different than *E*;
TN-TRUE NEGATIVE: i.e. events different from type *E* correctly recognized as belonging to a class different than *E*;
FP-FALSE POSITIVE: i.e. events different from type *E* recognized as belonging to class *E*;

For the sake of completeness results obtained in case of a Threshold Algorithm are given in Table 2 [19]. For the latter case, the ROC (Receiving Operating Curves) theory has been used to appropriately fix the optimal threshold for each class of events.

Concluding, it can be affirmed that the Absolute Maximum Correlation Algorithm performance are comparable to the TA, with the advantage to avoid the need for threshold detection, which requires extra elaboration effort and makes the methodology more sensitive to the system architecture.

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References

1. Cameron ID, Gillespie LD, Robertson MC, Murray GR, Hill KD, Cumming RG, Kerse N (2012) Interventions for preventing falls in older people in care facilities and hospitals (review). In: The Cochrane Library, Wiley & Sons, issue 12
2. Slips, trips and falls in hospital, 3rd report from the Patient Safety Observatory, NPSA (2007)
3. National Institute for Health and Clinical Excellence. Falls in older people: assessing risk and prevention (2013). http://www.nice.org.uk/guidance/cg161
4. The falls management program: a quality improvement initiative for nursing facilities, Agency for Healthcare Research and Quality, Rockville, MD, October 2014. http://www.ahrq.gov/professionals/systems/long-term-care/resources/injuries/fallspx/index.html
5. Module 3: falls prevention and management, Agency for Healthcare Research and Quality, Rockville, MD, October 2014. http://www.ahrq.gov/professionals/systems/long-term-care/resources/facilities/ptsafety/ltcmodule3.html
6. Lou E, Durdle NG, Raso VJ, Hill DL (2000) A low-power posture measurement system for the treatment of scoliosis. IEEE Trans Instrum Meas 49(1):108–113

7. Wong Wai-Yin, Wong Man-Sang (2009) Measurement of postural change in trunk movements using three sensor modules. IEEE Trans Instrum Meas 58(8):2737–2742
8. Rescio G, Leone A, Siciliano P (2013) Supervised expert system for wearable MEMS accelerometer-based fall detector. J Sens 2013(254629):11
9. Panahandeh G, Mohammadiha N, Leijon A, Handel P (2012) Chest-mounted inertial measurement unit for pedestrian motion classification using continuous hidden Markov model. In: 2012 IEEE international instrumentation and measurement technology conference (I2MTC), pp 991–995, Graz, Austria, 13–16 May
10. Kang JM, Yoo T, Kim HC (2006) A wrist-worn integrated health monitoring instrument with a tele-reporting device for telemedicine and telecare. IEEE Trans Instrum Meas 55(5):1655–1661
11. Dunkel J, Bruns R, Stipkovic S (2013) Event-based smartphone sensor processing for ambient assisted living. In: 2013 IEEE eleventh international symposium on autonomous decentralized systems (ISADS), pp 1–6, Mexico City, Mexico, 6–8 March
12. Ketabdar H, Lyra M (2010) System and methodology for using mobile phones in live remote monitoring of physical activities. In: 2010 IEEE international symposium on technology and society (ISTAS), Wollongong, Australia, 7–9 June
13. Tacconi C, Mellone S, Chiari L (2011) Smartphone-based applications for investigating falls and mobility. In: 5th international conference on pervasive computing technologies for healthcare (PervasiveHealth) and workshops, Dublin, Ireland, 23–26 May
14. Viet VQ, Lee G, Choi D (2012) Fall detection based on movement and smart phone technology. In: 2012 IEEE RIVF international conference on computing and communication technologies, research, innovation, and vision for the future (RIVF), Ho Chi Minh City, Vietnam, 27 February–1 March
15. He Y, Li Y, Bao S (2012) Fall detection by built-in tri-accelerometer of smartphone. In: 2012 IEEE-EMBS international conference on biomedical and health informatics (BHI), Hong Kong, China, 5–7 January
16. Fahim M, Fatima I, Lee S, Lee Y (2012) Daily life activity tracking application for smart homes using android smartphone. In: 2012 14th international conference on advanced communication technology (ICACT), PyeongChang, South Korea, 19–22 February
17. Igual R, Medrano C, Plaza I (2013) Challenges, issues and trends in fall detection systems. BioMed Eng (Online) 12(66). http://www.biomedical-engineering-online.com/content/12/1/66
18. Andò B, Baglio S, Lombardo CO, Marletta V, Pergolizzi EA, Pistorio A (2014) An event polarized paradigm for ADL detection in AAL context. In: Proceedings of 2014 IEEE international instrumentation and measurement technology conference (I2MTC), Montevideo, Uruguay, 12–15 May
19. Andò B, Baglio S, Lombardo CO, Marletta V (2015) An event polarized paradigm for ADL detection in AAL context. IEEE Trans Instrum Meas 64(7):1814–1825
20. Andò B, Baglio S, Lombardo CO, Marletta V (2016) A multisensor data-fusion approach for ADL and fall classification. IEEE Trans Instrum Meas 65(9):1960–1967
21. Chaudhuri S, Thompson H, Demiris G (Oct–Dec 2014) Fall detection devices and their use with older adults: a systematic review. s.l.: J Geriatr Phis Ther
22. www.sense4care.com/. SENSE4CARE
23. www.st.com. STMicroelectronics

RareBox App. Patient-Centered Monitoring System in the Self-management of Rare Diseases

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Abstract Mobile health applications (m-health app) allow connecting patients with care professionals more quickly and dynamically. Apps designed for a smartphone allow users to access in-formation and self-monitoring when and where they need it, boosting engagement and satisfaction rates. Starting from the construct of quality of life related to health and according to a biopsychosocial care perspective (ICF approach) [1], the paper presents and discusses research phases of the RareBox project: development, implementation and evaluation of self-monitoring App on quality of life of patients with rare diseases.

Keywords Rare diseases · Mobile health applications · Care needs

1 Apulia Region's Focus on Rare Diseases

The diffusion of rare disease's projects and research centers, as well as the expansion of associative and support networks, highlight the growing political and social interest in our country and in Europe about rare diseases. They represent a complex mosaic of conditions of hardly categorable conditions [2], definable based on the low prevalence in the population and characterized by clinical severity, multi-system involvement and high cost of health costs. According to an estimation by the World Health Organization (WHO), rare diseases would represent 10% of known human diseases, about 6,000 nosological entities. In Italy, rare patients are between 0.75 and 1.1% of the population, i.e. between 450,000 and 670,000 rare patients [3]. Apu-

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lia Region was the first Italian region to implement the PNMR (National Plan for Rare Diseases) whose main objective is the development of an integrated, global and medium-term strategy for action to support rare patients. A strategy centered on the caring needs of the person and his family and defined with the involvement of all the stakeholders, taking into account the European experiences and indications. Moreover, the Regional Rare Diseases Coordination, active for almost 10 years, has been re-organizing important initiatives to promote prevention, surveillance, diagnosis and therapy of rare therapies. The importance of regional governments is fundamental, because in the regions there are the nodes of assistance and social integration, as well as the economic management of prevention, action and monitoring interventions. In line with the framework outlined and in compliance with the DGR n. 158/2015 and the Agreement for the research and treatment of people with a rare disease, in 2015, the Apulia Region (southern Italy) authorized the Regional Health Agency (AReSS) to provide, for the biennium 2016/2017, five co-financed scholarships for Apulian researchers, who had carried out research in the field of Rare Diseases. One of these has been assigned to the Temporary Association of Purpose (ATS) composed by Diseased Neuropathy Patients Italian Association (CIDP Italia Onlus), People with Rheumatological and Rare Diseases National Association (APMAR Onlus) and Cerebral Cavernous Angioma National association (ANACC Onlus) with the scientific supervision of the Center on New Technologies for Disability and Inclusion, University of Salento. The funded research project is RareBox: "*design and implementation of a self-monitoring ICT based system for the person with a rare disease*".

2 RareBox Research Project

The aim of the RareBox project is to elaborate and evaluate a self-monitoring tele system for the person with a rare disease aimed at strengthening the doctor-patient relationship. The system is usable through the web and a specific App that allows patients belonging to the three associations involved to dialogue with their referring physicians, evaluating, through the technique of smiling faces, their state of health and well-being. It aims to provide the specialist doctor the patient's daily life and give voice to the personal care needs, demands not only related to the service of medical and welfare care, but to the largest and most complex of the total care of the person. The patient's history, his clinical routine, how he feels, the drugs he takes, the symptoms he feels, the tests he undergoes represent the basis of shared knowledge with clinicians and researchers who, together with life events and clinical data, affect the evolution of disease health. In this way, the person's experience, through a clinical and phenomenological report, becomes a cognitive and supportive capital for health professionals, a fundamental and decisive aspect that a good relationship of care should take into account. The research project has been developed in five specific phases, during a whole year (from February 2017 to February 2018, for four quarters).

I. Identification and analysis of the theoretical framework;
II. Mapping needs of patients and clinicians involved;
III. Elaboration of self-monitoring questionnaire;
IV. Implementation and evaluation of the RareBox App.

2.1 Phase 1. Quality of Life and Biopsychosocial Perspective: Research Tools

In the clinical-health field, the construct of *health related quality of life* has become increasingly important: a focus on the qualitative aspects related to the domains of health and disease. This indicator, commonly identified with the HRQoL acronym, shows an expression of a subjective and multidimensional construct, used as a key to health reading, which concerns the perception of well-being of the person in relation to itself, to the relationship with others and to its ability to fulfill the tasks of daily life in a satisfactory manner. What characterizes the construct of *quality of life* related to health is the attention to health outcomes, definable as outcomes capable of documenting the effects of a disease and its treatments on the life of the person [4]. The different approaches concerning the quality of life in the health field [5] believe that the quality of life is a subjective construct, as it relates the patient's point of view: it is an outcome aimed at evaluating the results of an intervention health care on the life of the person [6]. Considering the general framework of the living conditions of the person—living environment, social relationships and psychological aspects—quality of life provides more information about the genesis and development of diseases and allows, in the prognosis phase, to "use" the contextual elements for the purpose of the result, recovery, maintenance and optimization of health [7]. Assistance approach, in contrast with the illness-oriented care, becomes *patient-oriented care*, i.e. oriented towards the preferences, needs, individual values of the patient, aspects that guide and influence clinical decisions [8, 9]. It is a conceptual model that finds expression in the International *Classification of Functioning, Disability and Health*, ICF [1], conceiving the functioning of health and disability in relation to the living environments of the person and provides modalities for describing the impact of environmental factors, in terms of facilitators or barriers. The framework outlined above shows that the assessment of the quality of life essentially involves two approaches. The first, more common, makes use of the clinical assessment of the state of health and establishes the degree of physical and mental well-being, disability and work efficiency; the second is based on the subjective perception that the sick person has of his own quality of life. The research project refers more to the second approach. Scientific literature shows many scales of assessment of the quality of life related to health, many of which refers to as many theoretical models. However, none of these scales can be considered exhaustive. Many of the research tools currently used to measure the quality of life in general (WHOQoL, EQ-5D, SF-36) refer to a criterion of functional normality. The literature highlights the need to include both qualitative and quantitative aspects and to decline them according to both objective and subjective principles [10]. The interest of clinicians on the quality of life perceived depends on the observation that patients' quality of life is not directly related to the functional state. In fact, sometimes patients with the same clinical conditions can have very different perceptions of quality of life and the care taken can produce a subjective impact from patient to patient. For RareBox project different research tools were analyzed and translated to evaluate the quality of life related to health. Specifically, in relation to the reference theoretical framework, the biopsychosocial perspective, the following research tools have been considered:

- *ICF Core Set*, evaluation tools drawn from the ICF. For a specific health condition, there is a Comprehensive ICF Core Set (for a complete multidisciplinary evaluation) and a reduced ICF Core Set Brief (which includes the most important categories). In both cases, the ICF qualifiers are used for the quantization of the Core Sets.
- *World Health Organization Disability assessment schedule* (WHO-DAS II), a generic questionnaire that applies ICF principles, evaluates disability or function in six activity domains: comprehension and communication, mobility, self-care, interactions and relationships with others, domestic life or work activity, participation in society.
- *World Health Organization Quality of Life Bref* (WHOQOL-BREF) (WHO 1993), the abbreviated instrument of the WHOQOL-100, composed of 26 items with a Likert scale response modality (graduation of the agreement with the items from 1 to 5) and aims to assess the subjective perception of individual health status in relation to 4 thematic areas, which represent the construct of quality of life according to the WHO model.
- *SF-36*, self-administered questionnaire, structured in 36 items, organized into 8 scales: physics, role limitations due to physical health, role limitations due to emotional state, physical pain, general health, vitality, social activities, health mental—and in 2 synthetic indexes (Mental Composite Index and Physical Composite Index), obtained from the 8 scales.

2.2 Phase 2. Patients' and Clinicians' Needs

This phase shows the analysis of the meaning attributed by patients to living with a rare disease: perception of the self in the relationship between pathology and daily life; impact that the disease has on the quality of life compared to the biological, psychological and social dimensions of the individual; consequences that the disease has on social, family and work relationships; management of one's own time and the perception of stability, of security, of the future perspective of one's life. For this purpose, the research group elaborated and then presented a questions script to three clinicians and three patients, identified by the three associations involved in the project. Analysis of structured interviews helped to identify and elaborate the indicators that most characterize (in the short and medium term) the life and clinical situation of the patient with a rare disease. The interviews were recorded and then transcribed. A qualitative analysis was carried out on the textual corpus to identify the narrative elements identified based on the recurrence and the significance/pregnancy of the discursive production. Patient needs have been divided into four different areas: (1) symptomatology-clinical; (2) care and treatment; (3) personal-family; (4) social-work.

2.3 Phase 3. QoLSmile Monitoring Tool

In the scientific debate on the quality of life, is possible to trace two different research approaches: (1) the first, the objective one, aimed at identifying criteria for the definition of living standards, (2) the subjective one, based on indicators that measure the quality of life perceived by the individual. In this second approach, the quality of life becomes a subjective evaluation of the perceived life, which is the distance that exists in the comparison between a real life (everyday life) and the expected one (expectation). The greatest difficulty, however, is attributable to the possibility of translating into formal classification schemes and into quantitative variables the "subjective feeling", i.e. the "qualitative" dimensions concerning, for example, individual actions, emotions, psychological states, life experiences. In fact, regardless of the approaches and the disciplinary perspectives that this construct examines and although we tend to resort to psychometric methods of measurement, oriented to the myth of objectivity, the procedures prove unsatisfactory or inadequate to grasp the complexity and the qualitative nature of the Quality of Life [11]. In the RareBox project, the quality of life related to health, an abstract and not directly measurable idea has been transformed into empirically observable variables through a process of operationalization. In relation to the analysis of the interviews and the mapping of the needs identified (Phase 2), the quality of life has been declined according to indicators aimed at making this construct measurable. For the analysis, four dimensions related to the studied phenomenon have been indicated and for each one, the indicators and the variables connected to them have been identified. According to clinicians' and patients' suggestions, as well as of the survey areas present in the specific research tools, the general concept of well-being has been declined in indicators, from which the variables investigated through the *Delighted Terrible Faces Scale* (DTFS) have been obtained: a one-dimensional expressive or non-verbal scale with a face smiling faces proposed by Andrews and Whithey [12]. This kind of scale is widely used in healthcare as a tool for self-assessment of pain intensity. Also called "scale of faces", it is an intuitive and effective method to use, particularly useful when you cannot communicate your pain or emotions. For example, in the case of children, adults and the elderly who have difficulty expressing themselves. Mostly it consists of three, five or six faces, to which different degrees of perception correspond. Starting from the analysis of the interviews and research tools ICF Core Set, the World Health Organization Disability Assessment Schedule (WHO-DAS II) and the World Health

Organization Quality of Life Bref (WHOQOL-BREF) [13] research has developed a specific self-monitoring tool for the person with a rare disease. Called *SF-QAPMR "Smiling Face Self-monitoring questionnaire for the person with a rare disease",* the tool is composed by 30 items based on Delighted Terrible Faces scale. The interviewee is called to express his degree of agreement/disagreement with each statement, choosing between five response modes ranging from nothing to completely. The construction of the research tool has developed according to four specific phases: (1) formulation of the items; (2) classification of items; (3) item selection and internal consistency; (4) application of the scale. Taking up the structure of the ICF [1] and the WHOQOL-BREF, the 30 items processed refer to four specific components.

1. *Physical area/Functions and Body structures*: items refer to the physiological functions of body systems, including psychological ones. «Body» refers to the human organism in its entirety, thus including mental and psychological functions.
2. *Social relations area/Activities and Participation*: items refer to the execution of a task and an action by a person, as well as to the difficulties that an individual may encounter in carrying out activities and in his involvement in a life situation.
3. *Environmental area/Environmental factors*: items refer to the facilitating or obstructing function that the physical, social and attitudes world can have on people (attitudes, physical and social environment in which people live and lead their lives).
4. *Psychological area/Personal factors*: items refer to the personal background of the life and existence of an individual, representing those characteristics of the individual that are not part of the condition of health or health status.

2.4 Phase 4. Development and Evaluation of the RareBox App

Active participation of the patient, the compliance in the management of their care path and in the practices of prevention and promotion of their health is promoted and mediated by Health Apps. This is reiterated by the WHO (Health 2020), highlighting how web resources and new technologies represent a means that, increasingly, can help improve care, make the patient more aware of his situation, and share with others. The simple and captivating interface the frequent use of images and short news; the messages of encouragement and reminder make this technology very functional and "attractive". At the same time, the literature that deals with the binomial "new technologies and health" confirms that the App is a great resource for the user and for the clinician, as support for prevention and monitoring of diseases and promotion of styles of healthy life. Specifically, the literature on this topic has mainly focused on content analysis [14–16], on usability, acceptance and perceived utility on the part of the user [17–20] and on the quality of the user experience, mainly through qualitative studies [21–23]. In consideration of these aspects, the research activities related to the fourth phase and the last quarter were aimed at implementing the monitoring questionnaire within the App. The App was evaluated by the presidents of the three associations involved and, subsequently, proposed as the only one instrument for administering the self-monitoring questionnaire for users. For the RareBox system, App Inventor was used, a development environment for the Android operating system, popular on smartphones and tablets designed by the Massachusetts Institute of Technology. This is an open system that allows you to develop applications using a web browser connected directly to MIT servers (O.S. Windows, Mac, Linux). The system can be used by downloading the App on your smartphone (Fig. 1) or via your browser (Fig. 2).

The App is a closed "by invitation" system, aimed exclusively at the patients of the three associations involved with their personal user name. Before starting the compilation of the QoLSmile questionnaire, at the first access, the App invites the user to login and compile the items related to socio-demographic variables. The

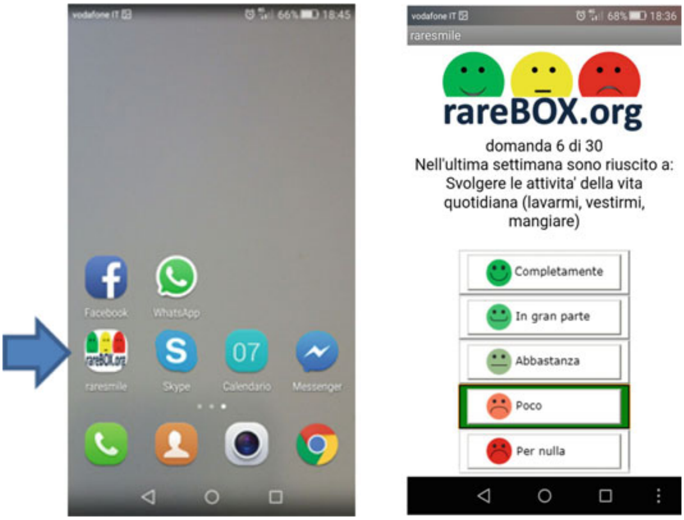


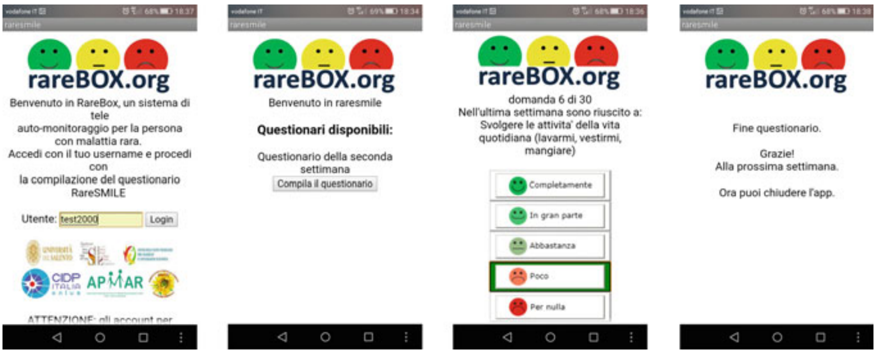
Fig. 1 RareBox App

Fig. 2 RareBox system by browser

prototype interface proposes two different type accesses: (1) new user logs in for the first time and who is presented with a brief presentation of the research and how to compile it; (2) usual user performs access and compilation on a weekly basis (Fig. 3).

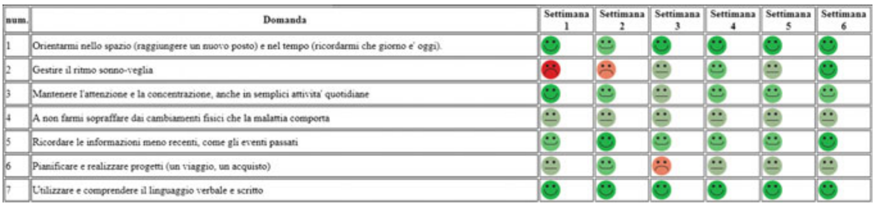
Between November and December 2017, on a weekly basis, the three associations involved invited their members to log in and fill out the questionnaire available on the App. Specifically, 16 patients participated in the study, of which eight belonging to the ANACC association, three to the APMAR one and 5 to the CIDP one. The smallness of the sample is attributable both to the specificity of the participants, patients with rare diseases, and to the nature of the administration, i.e. the control of the instrument's hold. Participants included a majority of female patients (62.5%), the presence of an employment (43.75%), a recognizable age in the 41–60 age range and, finally, a single or unmarried marital status. During the time interval of administration, about six weeks, it was possible to acquire and update the rough scores obtained by completing the questionnaire performed by each individual patient (Fig. 4).

Because of the specificity and complexity of health situations (hospitalizations, therapies, travel for treatment), not all patients have been able to strictly observe the range of administration. Nevertheless, direct comparison with patients shows that items are intelligible and relevant to the purpose. Administration through RareBox App did not give any problem, all the patients were able to finish the compilation with-



First access | Second or next access | Administration | End

Fig. 3 Prototype interface



num.	Domanda	Settimana 1	Settimana 2	Settimana 3	Settimana 4	Settimana 5	Settimana 6
1	Orientarmi nello spazio (raggiungere un nuovo posto) e nel tempo (ricordarmi che giorno e' oggi).						
2	Gestire il ritmo sonno-veglia						
3	Mantenere l'attenzione e la concentrazione, anche in semplici attivita' quotidiane						
4	A non farmi sopraffare dai cambiamenti fisici che la malattia comporta						
5	Ricordare le informazioni meno recenti, come gli eventi passati						
6	Pianificare e realizzare progetti (un viaggio, un acquisto)						
7	Utilizzare e comprendere il linguaggio verbale e scritto						

Fig. 4 E.g. scoring file

out requiring any support or help. Although detailed data analysis will be postponed to a further contribution, in a first analysis it is possible to detect areas with greater or lesser criticality. Averages analysis (Table 1) shows the most critical areas are body functions and activities and participation. Results show difficulties in balance, walking, sexual activities, existential planning, organization of domestic activities, activities necessary for work, carrying on one's own passions and hobbies. In these areas scores show that patient is slightly or fairly in agreement with what the item attests. Anyhow, other scores show positive perceptions on aspects related to speech and thinking activities, to visual and auditory perceptions, to social relationships. In addition, the results show that patients react to negative emotional states and other people's attitudes.

2.5 *Phase 5. The Evaluation of Accessibility, Usability: App Developer and User*

Use of the App with patients with rare disease is a topic of recent interest. Researches that have investigated accessibility, usability, understood as the quality of the interaction in terms of time taken to perform a task, errors committed etc. and the acceptability in terms of system suitability for the purpose in the context of use [24] are reduced. This target of users, in fact, presents different characteristics in terms of access to new technologies and in terms of health problems. The purpose of this phase is to present the evaluation plan of the developed App. Evaluation is a fundamental step in the interaction design process to make sure that the technology developed is really understandable and usable by users, but also to reduce development costs [25]. The choice of how to evaluate a technology is always complex. For this purpose, there are frameworks recognized by the Human-Computer Interaction community (for example, the Technology Acceptance Model, TAM) [26] and more or less standardized metrics (such as the various questionnaires) on usability [27–29]. Basically, an application is to be considered accessible according to the criterion that is decided to apply. Taking into consideration the accessibility of web content, the most important international standard for the evaluation of online projects is represented by the *Web Content Accessibility Guidelines* (WCAG), and the verification of compliance according to the requirements of the Stanca Law N. 4/2004 (Ministerial Decree 8, 2005, Technical Requirements accessibility for the operating environment, applications and products on the shelf), below, there is analysis of the interview proposed to the developer of the RareBox App. From the developer's point of view—semi-structured interview analysis—RareBox App shows a good level of accessibility and usability made such above all by the possibility to resort to the facilitating elements made available by the devices (Android systems, IOS Apple and Windows). In summary, analysis allows to recognize this prototype app the following elements of accessibility and usability:

Table 1 English version of the (SF-QAPMR). Smiling face self-monitoring questionnaire for the person with a rare disease

Item	ANACC	APMAR	CIDP
Orient yourself in space and time	4,83	3,67	4,53
Manage the sleep-wake rhythm	3,97	3,67	3,21
Maintenance attention and concentration	4,20	4,00	4,32
Do not be overwhelmed by the physical changes that the disease entails	3,83	3,67	3,37
Remember older information, like past events	4,51	4,33	4,58
Plan and implement projects	3,51	3,67	3,05
Use and understand verbal and written language	4,46	4,33	4,89
Perceiving the presence of light and the appearance of visual stimuli	4,83	4,33	4,95
Perceive the presence of sounds	4,66	4,33	4,95
To have a sense of balance	3,91	3,67	2,84
Having a good quality of voice and speech	3,74	3,67	4,47
Having a respiratory capacity necessary to withstand physical exertion	4,26	4,33	3,79
Manage emotions	3,43	3,67	3,11
Do not be discouraged by negative thoughts related to the disease	3,54	3,67	3,05
Maintain close or sentimental relationships	3,51	3,00	3,84
Be satisfied with my sex life	2,63	3,67	3,05
Start, maintain a conversation with one or more people	3,91	4,33	4,42
Move or manipulate objects	4,26	3,67	3,47
Walking for long distances	2,74	3,00	2,37
Perform the activities of daily life (wash, dress, eat)	4,63	4,33	3,95
Managing my home	3,83	4,33	3,05
Assist the members of my family	4,00	3,67	3,79
Keeping relationships	4,00	3,67	4,00
Performing actions of calculation, reading, writing and processing of thoughts	4,69	4,33	4,42
Perform as necessary for the job	4,03	3,00	3,32
Do not be influenced by the attitudes of others	3,83	3,67	3,79
Manage physical pains	4,31	4,33	3,58
Combine treatment/therapy with everyday life	4,26	3,67	3,68
Positively judge economic aid and support services	3,34	3,00	2,58
To dedicate oneself to my hobbies	2,71	3,67	2,53

- activation of functions provided by the interface through voice commands.
- implementation of adaptations for deaf users for access to sound features: audio signals that have an operational meaning (e.g. the beep indicating an error) and sound or voice feedback (e.g. a countdown timer, a timer) of the App are not always perceivable by users with hearing disabilities.
- presence of information, descriptions and functionalities with substitutive text labels: there is the association of a text to every element on the screen, allowing its identification by assistive technologies used by the blind (screen reader) to read the information and the descriptions of the objects. The label identifies the element, its function and its current state in such a way that the user who uses the screen reader can understand the content.
- consistency of the graphic symbols used. The App uses graphic symbols used to identify controls, status indicators or other program elements in a consistent and unambiguous way.
- development of the user's setup choices. The system does not allow you to save custom fruition elements, for example, color combinations, desktop background, contrast, screen color range, font size and type etc.
- absence of particularly unfavorable flashing elements. The user interface does not contain any text elements, objects or other flashing elements with an intermittent frequency greater than 2 Hz and less than 55 Hz.
- presence of the magnification/ zoom element to lower the visual acuity
- presence of support documentation for the App in accessible digital format.

According to "user-centered" approach to design [30, ISO 9241-21], within the project, an evaluation tool has been developed for the users. This approach, in fact, provides a cyclic process in which phases of validation with the end users are alternated with phases of development of the technology. In a UCD approach, it does not change only the moment in which the evaluation is carried out but also the sense for which it is carried out: the evaluation no longer serves merely to check that the technology serves the intended purposes of the designers but rather is intended give indications to improve the subsequent development phase. In the course of the project we were inspired by the principles of User-Centered Design, proposing to the users of the experimentation a single multidimensional grid articulated on 6 dimensions: (1) usability (2) acceptability (3) desirability (4) ethical aspects (5) accuracy (6) maturity. For this purpose, starting from some research tools produced in the field of assistive technology research (SUS Questionnaire—System Usability Scale SUS, ATD PA module C and QUEST version 2.0), the research group elaborated a user questionnaire for the evaluation Usability-accessibility of the RareBox App. The research tool consists of 20 items according to a 5-faceted Likert Delighted Terrible Faces Scale. The user is called to express his degree of agreement/disagreement with each statement, choosing between five response modes ranging from complete agreement to complete disagreement (strongly agree, agree, uncertain, disagree, strongly disagree). In consideration of the prototype App, still under development and subjected to technological evaluation by the developer, it was decided not to submit accessibility-usability questionnaire to users, postponing the administration to the presentation of the final version of the App.

3 Conclusion

Throughout the entire project we have been inspired by the principles of User-Centered Design and user needs approach. This implies a repositioning of the subjects of care, recipients of the research or intervention, to participants, owners, clients, bearers of a point of view, able to contribute to the research-intervention by assigning it a meaning and acting "with" it in a conscious way. This research project is so characterized by a new awareness: the inseparability of the continuum wellness-malaise and the centrality of the "lifestyles" in the achievement, maintenance and improvement of the state of health. The proposed monitoring questionnaire determines a shift of emphasis from negative indicators (symptoms) to positive indicators of health deeply intertwined with the concept of development and personal and social growth. Pedagogical perspective goes beyond the medical-care perspective; it points to the existential project, to taking care of the other, focusing attention not on the absence of health or on damage, but on the "power" of the relationship and the proximity that cares for the other. Taking care of the person means promoting his capacity for choice, self-regulation and, first of all, self-determination, without losing sight of the meaning of the action on the contexts of belonging and, therefore, on inclusion. At present, the analysis of the results referring to the SF-QAPMR questionnaire and to the questionnaire on the evaluation of accessibility and usability of the App are under development. In particular, for the SF-QAPMR we will evaluate not only the results in terms of the monthly evolution of the disease in the sample patients but above all the variance of the results to select the most discriminated items in order to further refine the instrument in terms of ability to assess the quality of the patient's life with a rare disease. The results of the evaluation of the accessibility of the App, however, will be used to optimize the system in its final version.

References

1. World Health Organization (2001) International classification of functioning, disability and health: ICF. World Health Organization, Geneva
2. Stolk P, Willemen MJ, Leufkens HG (2006) Rare essential: drugs for rare diseases as essential medicine. Bull World Health Organ 84(9):745–751
3. UNIAMO: MonitoRare. Secondo Rapporto sulla condizione della persona con malattia rara in Italia. Uniamo Federazione Italiana Malattie Rare Onlus, Roma (2016)
4. Lipscomb J, Gotay CC, Snyder C (2005) Outcomes assessment in cancer: measures, methods and applications. University Press Cambridge, Cambridge
5. Marciniak A, Niero M (2000) Integrating patients' views into the measurement of quality of life: examples from peri-post menopausal periods. Qual Lif Res 9:775–784
6. Niero M (2002) Qualità della vita e della salute. Strategie di analisi e strumenti per la misurazione. FrancoAngeli, Milano
7. Goldwurm GF, Baruffi M, Colombo F (2004) Qualità della vita e benessere psicologico, Aspetti comportamentali e cognitivi del vivere felice. McGraw-Hill, Milano
8. Institute of Medicine, Committee on Quality of Health Care in America (2001) Crossing the quality chasm. A new health system for the 21st century. The National Academic Press, Washington, DC

9. Grob R (2013) The heart of patient-centered care. J Health Polit Policy Law 38(2):457–465
10. Bertelli M, Brown I (2006) Quality of life for people with intellectual disabilities. Curr Opin Psychiatry. 19:508–513
11. Crispiani P, Giaconi C (2009) Qualità di vita e integrazione scolastica. Indicatori e strumenti di valutazione per le disabilità. Erickson, Trento
12. Andrews FM, Withey SB (1976) Social indicators of well-being. Americans perceptions of life quality. Plenum Press, New York
13. OMS, QOL Group (1993) Study protocol for World Health Organization project to develop a Quality of Life assessment instrument (WHOQOL). Qual Lif Res 2(2):153–159
14. Cowan LT, Van Wagenen SA, Brown BA, Hedin RJ, Seino-Stephan Y, Hall PC, et al (2013) Apps of steel: are exercise apps providing consumers with realistic expectations? A content analysis of exercise apps for presence of behavior change theory. Health Educ Behav 40(2):133–139
15. Lister C, West JH, Cannon B, Sax T, Brodegard D (2014) Just a fad? Gamification in health and fitness apps. JMIR Serious Games 2(2):e9
16. West JH, Hall PC, Hanson CL, Barnes MD, Giraud-Carrier C, Barrett J (2012) There's an app for that: content analysis of paid health and fitness apps. J Med Internet Res 14(3):e72
17. Robinson E, Higgs S, Daley AJ, Jolly K, Lycett D, Lewis A et al (2013) Development and feasibility testing of a smart phone based attentive eating intervention. BMC Public Health 13(1):639
18. Worringham C, Rojek A, Stewart I (2011) Development and feasibility of a smartphone, ECG and GPS based system for remotely monitoring exercise in cardiac rehabilitation. PLoS ONE 6(2):e14669
19. Marks DF (2002) Some observations on health and socio-economic status. In: Murray MM, Evans B, Willig C (eds) Healt psychology. Theory, research and practice. Sage press, London
20. Nes AA, van Dulmen S, Eide E, Finset A, Kristjánsdóttir OB, Steen IS, et al (2012) The development and feasibility of a web-based intervention with diaries and situational feedback via smartphone to support self-management in patients with diabetes type 2. Diabetes Res Clin Pract 97(3):385–393
21. Dennison L, Morrison L, Conway G, Yardley L (2013) Opportunities and challenges for smartphone applications in supporting health behavior change: qualitative study. J Med Internet Res 15(4):e86
22. Lyles CR, Harris LT, Le T, Flowers J, Tufano J, Britt D et al (2011) Qualitative evaluation of a mobile phone and web-based collaborative care intervention for patients with type 2 diabetes. Diabetes Technol Ther 13(5):563–569
23. Rogers WA, Walker MJ (2016) Fragility, uncertainty, and healthcare. Theor Med Bioeth 37:71–83
24. Benyon D (2012) Progettare l'interazione. Metodi e tecniche per il design di media interattivi. Pearson Italia, Milano
25. Preece J, Sharp H, Rogers Y (2015) Interaction design: beyond human-computer interaction. Wiley press, USA
26. Venkatesh V, Morris MG, Davis GB, Davis FD (2003) User acceptance of information technology: toward a unified view. MIS Q 27(3):425–478
27. Brooke J (2013) SUS: a retrospective. J. Usability Stud 8(2):29–40
28. Finstad K (2010) The usability metric for user experience. Interact Comput 22:323–327
29. Lewis JR, Utesch BR, Maher DE (2013) UMUX-LITE—when there's no time for the SUS. In: Proceedings of CHI2013
30. Norman DA, Draper SW (eds) (1986) User centred system design. Erlbaum, Hillsdale, NJ

A Cyber Secured IoT: Fostering Smart Living and Safety of Fragile Individuals in Intelligent Environments

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Abstract Due to better living conditions and progress in medicine older adults today are the main group of population in terms of growing speed. Furthermore, together with disabled people, they represent the most frail category of individuals. Indeed, they are likely to present different constellations of impairments (both at physical and cognitive level). Older adults and individuals with disabilities strongly benefit from being properly assisted or from prolonging their individual autonomy. Such interventions can be implemented levering on the IoT technologies. The present paper describes a project that aims at providing older and disabled people with smart buildings that will be equipped with IoT technologies, e.g., environmental and wearable sensors. The identification of such technologies will be based on co-design activities that will focus on their accessibility and usability. Concurrent laboratory tests will be carried out to assess the best methodologies of wireless communication between the smart devices. These ambient-assisted living tools will be installed in two real-world scenarios, i.e., a nursing home and a co-housing solution. Such tools will facilitate older and disabled people in carrying out daily activities, ensuring their safety and privacy protection. The outcomes of the project will provide pivotal information on how to improve human living in different environmental contexts.

Keywords Smart living · IoT · Fragile users

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1 Introduction

At present, individuals over 65 are the population segment growing at the highest speed in Western countries [4]. The main reason behind this occurrence is the increased life-expectancy, resulting from of both an amelioration of the living conditions and the progress achieved in the field of medicine, together with a drop in the birth rates [20]. The increase of the average lifespan is a crucial achievement, but at the same time it brings tough challenges. The normal ageing process leads to numerous declines affecting the cognitive skills and the perceptual and motor abilities [10, 6]. In addition, older adults become more likely to develop multiple diseases [4], raising healthcare costs exponentially [19]. Oftentimes, all these conditions reduce older adults' autonomy. Besides seniors, it is pivotal to consider another vulnerable part of the population, that is people with disabilities, who, to some extent, share with older adults the same needs. Indeed, in some cases, these two groups are overlapping in the measure that elderly people may present physical (i.e. motor) or mental (e.g. dementia) disabilities.

A number of different interventions can be taken to support these frail adults and to relieve national healthcare systems from the expensive cost of assistance. As a matter of fact, older adults with reduced autonomy and individuals with disabilities, benefit from remaining in their homes rather than being hospitalized or going into a nursing home/retirement home [12]. Several studies showed that, compared to nursing home, community-based interventions yield to beneficial effects for the elderly with regards to their physical functioning and their level of independence [2]. Unfortunately, it is not always viable for them to stay at their homes independently, because they may suffer from of incapacitating disease and may be alone. Therefore, in many cases these individuals need to be admitted into a nursing home in order to receive proper assistance. However, addressing the needs of individuals at their homes is associated to a reduction of the medical costs on the long term [12] and to higher psychological well-being of seniors [17]. Nevertheless, in some cases elderly people that are living alone need to access retirement houses. In this respect, social-housing projects have the potential to provide residents with adequate assistance, yet leaving them reasonably independent and recent evidence indicate that they are also well-received by senior residents [8].

In this paper we thus present the intervention we have planned for assist older and younger adults with reduced autonomy to enable them to enhance their living conditions.

2 Needs to Be Addressed

The assessment of the capacity of functioning in a community is typically based on Lawton's Instrumental Activities of Daily Living (IADL) Scale [13], which basically considers the extent to which an individual is capable to perform a number of self-care activities autonomously (e.g., toileting, bathing, shopping). Based on the score gained by the individual, one can decide whether it is safe for him/her to live independently or not. Many of the activities included in the list are effectively linked to precursory signs of mild cognitive impairment [11], but also to more general and contextual factors. For instance, older adults may tend to neglect food-related activities because they are lonely [14]. Likewise, a number of different contextual factors can be considered and addressed exploiting technology, thus prolonging individual autonomy. Because of the reduction of mass muscle and strength and the tendency of leg bones to bow and under the body weight [1], older adults may struggle to take objects that have an upper location, just like their younger counterparts on a wheelchair. Again, because of the normal changes due to the ageing process, seniors tend to get tired sooner, thus reducing their ability to stand or move for long time intervals [9], ultimately limiting their mobility.

Similarly, the life events that are more frequent during old age (i.e., retirement, grieves) together with the reduced physical activity, tend to increase the likelihood of social isolation. Targeting these conditions can result in an improvement of health, both in terms of mental well-being and quality of life, in older people [3, 18]. In addition, loneliness was found to be a risk factor connected to the likelihood to develop cardiovascular diseases (i.e. hypertension, heart disease and stroke). Social and/or family support are pivotal to counteract the negative effects associate to loneliness and social isolation [18]. In addition, the unobtrusive monitoring of the activities of individuals with reduced autonomy, either elderly or not, can effectively reduce the likelihood of minor or major accidents (e.g., falls) and eventually promptly signal an emergency.

In summary, regardless of the specific individual characteristics (i.e. elderly or disable people), there is a need to find innovative solutions to provide users with more comfortable and safe environments. Priority must be given to the promotion of a healthy and active style of lifestyle and to guarantee a degree of independence (different according to the specific cases).

3 Buildings, Sensors, and Internet of Things

The concept of smart building refers to a regular construction that is equipped with various types of sensors and actuators. The sensors could be divided in two main categories: environmental, that is integrated into the rooms, and wearable/mobile, that is attached to the user's body. Examples of the former are motion (e.g. individuals' movement), presence, and pressure sensors (on the floor or on a chair), magnetic switches (e.g. door opening/closing), cameras (general activity). In consideration of the wearable and mobile sensors, we list accelerometers, glucometers, global positioning system (GPS), electrodes for monitoring physiological (e.g., electrocardiography, ECG; galvanic skin response; GSR) and cognitive activity (e.g. electroencephalography, EEG). Smart buildings are designed with the objective to provide a greater comfort to inhabitants and for monitoring their physical and psychological/cognitive health. Data from all these sensors is acquired and processed (in real-time) in order to implement a series of automated actions that aim at supporting residents in several different cases. These actions are triggered by means of the actuators.

In consideration of facilitating users' daily activities data collected through a GPS sensor, presence sensors, cameras could be utilized to enable automatic door opening and closing or turning lights on and off. In terms of residents' safety, abrupt changes in the signals acquired through the wearable sensors (e.g. ECG) may trigger an alarm signal to inform a health care professional, a caregiver (a family member) or a doctor (inside a hospital or a retirement home) about an individual in need of an urgent medical attention [5]. Furthermore, the environmental and wearable sensors may be utilized in order to detect falls of elderly people through smart cameras [7] and so providing immediate assistance.

Thus, these digital smart buildings are substantially changing the human-environments interaction as they are capable of sensing and adapting in an unobtrusive way to the humans' needs (Sandri 2011). Recently, the concept of ambient intelligence has been popularized to describe these adaptive environments, while the term ambient-assisted living (AAL), [16] applies to smart devices that means to assist elderly people (i.e. in terms of well-being and general health). In the information and communication technology (ICT) research field another key concept has to be considered, namely the Internet of Things (IoT). The term refers to the modification of everyday physical objects (e.g. light bulb) with the embedding of electronic components that are capable of communicating with one another and/or with the humans. These smart objects are featured with a physical embodiment, they are able to receive and reply to digital messages, they have the capability of basic computing, they may possess sensors for monitoring physical facts (e.g. temperature variations) and trigger actions through specific actuators. In the context of IoT an aspect that is pivotal is the security related to the confidentiality and privacy regarding the collected users' data [15]. Confidentiality and security have to be ensured to the relevant stakeholders. In consideration of the former, it is fundamental to guarantee the access to the data not only to users themselves, but also to authorized persons (e.g. physicians, researchers). With regard to the latter, especially when IoT is applied to the healthcare domain, it is crucial to enact proper mechanisms to ensure it. Indeed, the acquired personal data may be particular sensitive.

4 Smart Buildings Solutions for Elderly and Disabled People

The current project "Sistema Domotico IoT Integrato ad elevata Sicurezza Informatica per Smart Building" (POR FESR 2014-2020, Asse 3, Azione 1.1.4) involves both academic and industrial parties in the frame of Regional policy related to R&D projects. The project is funded by Regione Veneto and it includes different

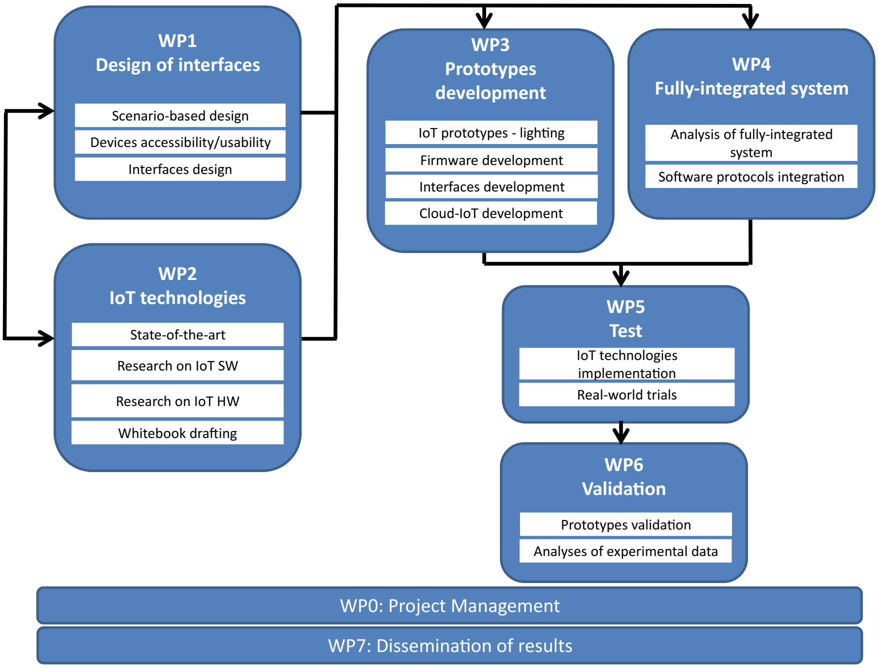

Fig. 1 Project graphical depiction

universities, each contributing with knowledge in various domains (e.g. cognitive ergonomics, computer science, etc.), and 22 industrial partners operating in several sector (e.g. lighting, automation, etc.). The total duration of the project will be 36 months (i.e. from 07/11/2017 to 06/11/2020). A graphical representation of the work packages and related activities is depicted in Fig. 1.

The project aims at examining the alleged benefits related to the introduction of ambient-assisted living tools [16] in living spaces shared by fragile people. One of the main limitations of current home automation systems is the difficulty in achieving a full interoperability among the different IoT components and services. Indeed, to fully exploiting the effectiveness of IoT, the smart objects have to be connected at the same time both to one another (in terms of finding/being found, accessing/being accessed, managing/being managed) and to the Internet. In other words, the objective is to overcome the physical and functional gap between the devices in the smart environment through the definition of standard protocols enabling a better communication and data exchange among the different smart tools and buildings. By doing this we foreseen to overcome current issues related to the lack of shared protocols of communication among the different smarts tools, for instance the lighting system and the automatically operated service door. The project will target two different contexts with specific features: nursing home and social-housing/co-housing. At the nursing home the older residents may have various levels of autonomy and cognitive functioning. In the social-housing situation the residents will be people with disabilities (e.g. severe motor disability). In both situational contexts, user interfaces and control units will be designed to properly respond to the specific needs of the inhabitants. For instance, in the co-housing scenario, the height of the control and display devices will be automatically adjusted to the current user's physical characteristics. This adaptation will facilitate the individuals in both unfolding the daily activities and easily accessing the information about the smart environment.

The project will operate at two levels. Firstly, the *desiderata* and the different impairments (residents) of the stakeholders (i.e. residents, operators, management) will be considered in order to identify a set of suitable automated and to design the software. For this purpose, co-design activity will be carried out as well as laboratory tests concerning the accessibility and usability of the smart devices. Furthermore, the technical feasibility of the selected smart devices will be tested in the laboratory and later they will be installed in the target buildings where they will be evaluated by end-users (i.e. system accessibility, usability, security, users' experience, acceptance, satisfaction, and safety). An additional test will involve residents' and operators' performance in carrying out their activities in order to assess the efficiency (i.e. speed in carrying out these tasks) and the accuracy of the interaction with the smart environment (i.e. reduction in errors made).

In the second scenario, namely the co-housing, the project will pursue a further goal targeting an increased independence of disabled people, yet ensuring professional assistance when/if required (e.g. healthcare professionals or other caregivers).

The adaptive "actions" that will be implemented in these smart environments will be based on the residents' needs as well as their daily habits. In relation of the former an example may be triggering an alarm signal to the nearest operator when a person' fall is detected, while concerning the latter, a light that will automatically turn on/off the moment a person is starting/finishing to read a book. Considering the social-housing scenario, the level of customization of such smart environment may be further enhanced on the basis of the individual preferences (e.g. the level and type of lighting, kind of access to the various rooms).

The project will address both end-users and various stakeholders, comprising residents of the nursing home (i.e., older people with and without disabilities), professional caregivers and members of the managerial staff (i.e., nursing home scenario), and young adults with motor disabilities (i.e., co-housing scenario).

The second operational level, will constitute a real/the technological challenge. Indeed, the project will aim at overcoming the actual limitations, highlighted in the domain of IoT, which are tied to the wireless protocols in anticipation of the massive development that is expected in the immediate future. All the smart devices will communicate through a shared protocol in order to ensure efficiency and efficacy of the exchange of information and in real-time resulting in an increased quality of the human living. Furthermore, the aspect of data security too frequently neglected because of the high computational costs, will be seriously considered. More specifically, in order to protect the data, the project will develop cost-effective communication protocols based on cryptography. In so doing, for the speed of data transmission and the battery life of wireless devices will be preserved.

An additional consideration will be given to the privacy protection of individuals. The smart sensors that will be installed will let to distinguish different activities occurring in the smart buildings. Thus, allowing operators interventions in case of emergency. However, the detection process will be based on physical characteristics and events protecting the actual identity of the residents. For instance if the system would detect that users have fallen on the basis of variations in the positions of their body shape. Moreover, it will be possible to monitor the passage of users through specific gates in order to locate and count the amount of people within the building.

5 Conclusions

In summary, several relevant aspects of the human living will be considered: accessibility, giving the elderly and disabled people the opportunity to access to goods and services; care, helping to alert the operators health professionals in order to provide critical emergency assistance; safety, detecting individuals' falls and controlling their access, monitoring gas leaks, fires and other dangerous situations; health and well-being, increasing both at physical and psychological level.

The project will contribute to both increase the scientific knowledge in the field of smart buildings tailored on the needs and characteristics of frail individuals, and to open significant market opportunities. The outcomes of the project may be extended to different scenarios such as the industrial setting in which older and disabled people work and may benefit from the enhanced safety provided by the introduction of these smart technologies. Finally, the expected socio-economic impact of the project will be: a decrease in the costs related to health care (i.e. fewer accidents) as well as an improvement in the general quality of living, especially in regard of the co-housing situation, insofar as mood disorders, depression, and decline in cognitive functions may be better contained when people lived at their own home [2].

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References

1. Amarya S, Singh K, Sabharwal M (2015) Changes during aging and their association with malnutrition. J Clin Gerontol Geriatr 6(3):78–84
2. Beswick AD, Rees K, Dieppe P et al (2008) Complex interventions to improve physical function and maintain independent living in elderly people: a systematic review and meta-analysis. Lancet 371(9614):725–735
3. Cattan M, White M, Bond J et al (2005) Preventing social isolation and loneliness among older people: a systematic review of health promotion interventions. Ageing Soc 25(1):41–67
4. Chatterji S, Byles J, Cutler D et al (2015) Health, functioning, and disability in older adults—present status and future implications. Lancet 385(9967):563–575

5. Eklund JM, Sprinkle J, Sastry S et al (Jan 2006). Information technology for assisted living at home: building a wireless infrastructure for assisted living. In: Proceedings of the EEE-EMBS 27th annual international conference of the IEEE engineering in medicine and biology society. IEEE, pp 3931–3934
6. Fisk AD, Czaja SJ, Rogers WA et al (2004) Designing for older adults: principles and creative human factors approaches. CRC press, p 12–28
7. Fleck S, Straßer W (2008) Smart camera based monitoring system and its application to assisted living. Proc IEEE 96(10):1698–1714
8. Fox S, Kenny L, Day MR et al (2017) Exploring the housing needs of older people in standard and sheltered social housing. Gerontol Geriatr Med 3:2333721417702349
9. Giacalone D, Wendin K, Kremer S et al (2016) Health and quality of life in an aging population–food and beyond. Food Qual Prefer 47:166–170
10. Hawthorn, D (2000) Possible implications of aging for interface designers. Interact Comput 12(5): 507–528.
11. Jekel K, Damian M, Wattmo C et al (2015) Mild cognitive impairment and deficits in instrumental activities of daily living: a systematic review. Alzheimers Res Ther 7(1):17
12. Kaye HS, LaPlante MP, Harrington C (2009) Do noninstitutional long-term care services reduce Medicaid spending? Health Aff 28(1):262–272
13. Lawton MP, Brody EM (1969) Assessment of older people: self-maintaining and instrumental activities of daily living. Gerontologist 9:179–186
14. MacIntosh C, Morley JE, Chapman IM (2000) The anorexia of aging. Nutrition 16(10):983–995
15. Miorandi D, Sicari S, De Pellegrini F et al (2012) Internet of things: vision, applications and research challenges. Ad Hoc Netw 10(7):1497–1516
16. Rashidi P, Mihailidis A (2013) A survey on ambient-assisted living tools for older adults. IEEE J Biomedical Health Inform 17(3):579–590
17. Seitz D, Purandare N, Conn D (2010) Prevalence of psychiatric disorders among older adults in long-term care homes: a systematic review. Int Psychogeriatr 22(7):1025–1039
18. Tomaka J, Thompson S, Palacios R (2006) The relation of social isolation, loneliness, and social support to disease outcomes among the elderly. J Aging Health 18(3):359–384
19. Vergados D, Alevizos A, Mariolis A et al (July 2008) Intelligent services for assisting independent living of elderly people at home. In: Proceedings of the 1st international conference on pervasive technologies related to assistive environments. ACM, p 79
20. Zweifel P, Felder S, Meiers M (1999) Ageing of population and health care expenditure: a red herring? Health Econ 8(6):485–496

Fabrication of Flexible ALN Thin Film-Based Piezoelectric Pressure Sensor for Integration Into an Implantable Artificial Pancreas

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Abstract This works reports about the fabrication and the characterization of AlN-based flexible piezoelectric pressure sensor, to be integrated into an implantable artificial pancreas. The artificial organ comprises an intestine wall-interfaced refilling module, able to dock an ingestible insulin capsule. A linearly actuated needle punches the capsule to transfer the insulin to an implanted reservoir. The pressure sensor, located at the connection of the needle with the linear actuator, is designed to sense the occurred capsule punching. Polycrystalline AlN thin film was successfully sputtered at room temperature on Kapton substrate with a preferential orientation along c-axis, as peremptorily required for the intrinsic piezoelectric response of the nitride layer. The characterization, aimed to verify the sensor capability to convert the local stress

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into electrical charge, confirms the linear proportionality of the generated charges with the applied force within the range of the interest values (0.3–3.3 N) and at very low frequency (lower than 5 Hz) for the specific application of the ingestible capsule punching and insulin transfer.

Keywords Flexible pressure sensor · Piezoelectric thin films · Artificial organ

1 Introduction

In the health domain, elements such as smart devices, biosensors, artificial organs and smart pharmaceuticals, represent key targets for care provisions. Among them, artificial organs, which are engineered devices, implanted or integrated into a human, replace a natural organ by duplicating specific functions, and help the patients with a particular disease to return to a normal life as soon as possible. One of the most diffused disease is Type 1 diabetes mellitus (T1DM) which destroys the pancreatic β-cells with the consequent body incapability to produce insulin, leading to chronically high glucose concentrations in the blood. It requires regular blood sugar monitoring and treatment with insulin. An artificial pancreas (AP) mimics the glucose regulating function of a healthy pancreas by using a closed-loop controller.

In this work, a flexible piezoelectric pressure sensor (PPS) is fabricated for integration into an implantable AP. The AP prototype comprises a refilling module, interfaced with intestine wall, able to dock an ingestible insulin capsule [1]. A linearly actuated needle punches the capsule to transfer insulin to an implanted reservoir. The PPS is located at the connection of the needle with the linear actuator (Fig. 1), to assure the occurred capsule punching by measuring the dynamic force profile. The most studied piezoelectric materials are PZT and ZnO [2, 3], but, recently, AlN is inspiring the scientific interest for its challenging physical properties [4]. Our piezoelectric device is a flexible AlN-based sensor operating in d_{31}-mode, where the active sensing material, consisting of an AlN thin film (500 nm-thick) is sandwiched between two Ti electrodes (150 nm-thick). All the materials have been deposited by sputtering at room temperature on Kapton substrate.

2 Results and Discussion

Figure 2 depicts the XRD spectrum of AlN thin film deposited on Ti bottom electrode, both sputtered on kapton substrate, confirming the preferential orientation of the nitride film along c-axis to guarantee the piezoelectric behavior. In the inset, a representative SEM image of a Ti/AlN bilayer sample deposited on kapton substrate is shown. The flexibility of the structure is well remarked.

Figure 3a shows the fabricated piezoelectric pressure sensor on kapton substrate. The prototype device was fabricated with a 4-step photolithographic process in order

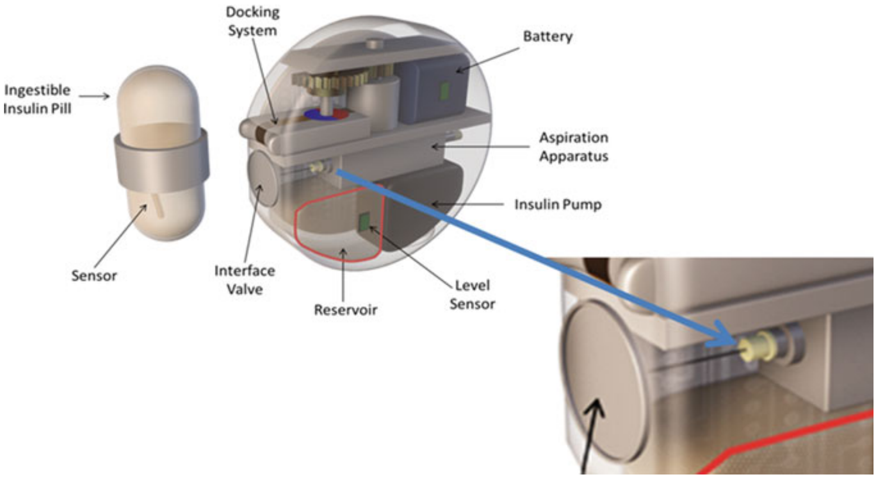

Fig. 1 Schematic of all parts constituting such artificial pancreas; the blue arrow indicates the piezoelectric pressure sensor's housing in the AP, that is the mounting socket of the needle with the linear actuator

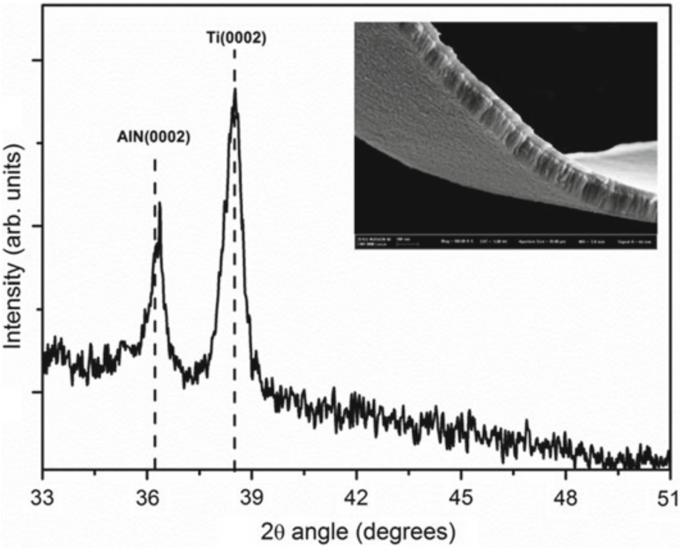

Fig. 2 XRD spectrum of the bilayer Ti(150 nm)/AlN(500 nm) sputtered on kapton substrate. In the inset, SEM image of a representative Ti/AlN bilayer sputtered on kapton substrate (AlN film is 250 nm-thick); the flexibility of the sample is particularly evidenced

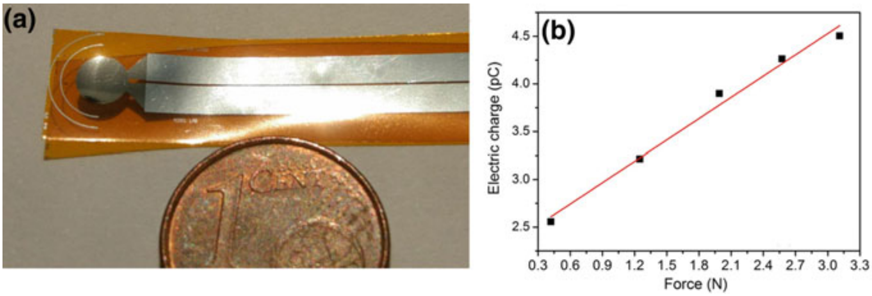

Fig. 3 **a** Image of the fabricated piezoelectric pressure sensor; **b** charge generation as a function of the force applied to the piezoelectric pressure sensor

to obtain the circular sensing area with 40 mm long Al contact for amplifier front-end connection. Figure 3b represents the sensor device charge generation vs the applied force onto sensitive circular area; the linear fit (red line) confirms the linearity of the generated charge with the applied force at about 2 Hz of frequency. The pressure sensor is very sensitive, exhibiting an appreciable output signal at a such low mechanical stimuli and working frequency. The generated charge normalized to the active area is comparable to the state-of-the-art devices fabricated on silicon substrate.

3 Conclusions

Flexible pressure sensor, based on sputtered AlN thin film, operating in d_{31}-mode, has been fabricated and characterized with the aim to be integrated into an implantable artificial pancreas. The measurements proved the reliability of such fabricated sensors, indicating that the designed circular pressure sensor measures dynamic force up to 3.3 N at a frequency of few Hz, according to the experimental conditions required by the specific application of the ingestible capsule punching and insulin transfer. This study provides a concept of device design with an easy fabrication method for wearable and implantable electronic applications.

References

1. Iacovacci V, Ricotti L, Menciassi A, Dario P (2016) The bioartificial pancreas (BAP): biological, chemical and engineering challenges. Biochem Pharmacol 100:12–27. https://doi.org/10.1016/j.bcp.2015.08.107
2. Khan A, Abas Z, Kim HS, Oh K (2016) Piezoelectric thin films: an integrated review of transducers and energy harvesting. Smart Mater Struct 25:053002–053016. https://doi.org/10.1088/0964-1726/25/5/053002

3. Francioso L, Malucelli G, Fioravanti A, De Pascali C, Signore MA, Carotta MC, Bonanno A, Duraccio D (2018) UV-cured composite films containing ZnO nanostructures: effect of filler shape on piezoelectric response. Lect Notes Electr Eng 457:323–330. https://doi.org/10.1007/978-3-319-66802-4_40
4. Signore MA, Taurino A, Catalano M, Kim M, Che Z, Quaranta F, Siciliano P (2017) Growth assessment of (002)-oriented AlN thin films on Ti bottom electrode deposited on silicon and kapton substrates. Mater Des 119:151–158. https://doi.org/10.1016/j.matdes.2017.01.035. ISSN 0264-1275

Facial Expression Recognition in Ageing Adults: A Comparative Study

Andrea Caroppo, Alessandro Leone and Pietro Siciliano

Abstract Facial Expression Recognition is one of the most active areas of research in computer vision. However, existing approaches lack generalizability and almost all studies ignore the effects of facial attributes, such as age, on expression recognition even though research indicates that facial expression manifestation varies with ages. Recently, a lot of progress has been made in this topic and great improvements in classification task were achieved with the emergence of Deep Learning methods. Such approaches allow to avoid classical hand designed feature extraction methods that generally rely on manual operations with labelled data. In the present work a deep learning approach that utilizes Convolutional Neural Networks (CNNs) to automatically extract features from facial images is evaluated on a benchmark dataset (FACES), the only one present in literature that contains also labelled facial expressions performed by ageing adults. As baselines, with the aim of making a comparison, two traditional machine learning approaches using handcrafted features are evaluated on the same dataset. Our experiments show that the CNN-based approach is very effective in expression recognition performed by ageing adults, significantly improving the baseline approaches, at least with a 8% margin.

Keywords Facial expression recognition · Deep learning · Machine learning

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1 Introduction

The constant increase of the life expectancy and the consequent aging phenomenon will inevitably produce in the next 20 years deep social changes that lead to the need of innovative services for elderly people, focused to maintain independence, autonomy and, in general, improve the wellbeing and the quality of life of ageing adults [17]. It is obvious how in this context many potential applications, such as robotics, communications, security, medical and assistive technology, would benefit from the ability of automatically recognize facial expression [5, 15, 20].

Facial expression recognition (FER) is related to systems that aim to automatically analyze the facial movements and facial features changes of visual information to recognize a facial expression. A classical automatic facial expression system usually employs three main stages: face acquisition, facial feature extraction and classification. For static images, there are two types of facial feature extraction methods: geometric feature-based methods and appearance-based methods. Geometric features are able to depict the shape and locations of facial components such as mouth, nose, eyes and brows. The main purpose of geometric feature-based methods is to use the geometric relationships between facial feature points to extract facial features.

Extracting geometric features usually requests an accurate feature point detection technique but a limitation of these techniques lies in ignoring the changes in skin texture such as wrinkles and furrows that are usually accentuated by the age of the subject. On the other hand appearance-based methods aim to use the whole-face or specific regions in a face image to reflect the underlying information in a face image.

It is important to emphasize how geometric and appearance feature-based methodologies require a process of feature definition and extraction very daunting. Moreover, recent studies have pointed out that classical approaches used for the classification of facial expression are not performing well when used in real contexts where face pose and lighting conditions are broadly different from the ideal ones used to capture the face images within the benchmark datasets.

Among the factor that make FER very difficult, one of the most discriminating is the age [7, 19]. In particular, expressions of older individuals appeared harder to decode, owing to age-related structural changes in the face which supports the notion that the wrinkles and folds in older faces actually resemble emotions. Consequently, state of the art approaches based on handcrafted features extraction (both geometric and appearance based) may be inadequate for the classification of FER performed by aging adults. It seems therefore very important to analyze approaches that can make the recognition of facial expressions of the ageing adults more efficient, considering that, as highlighted above, they could be broadly different from facial expressions performed by young or middle-aged.

Recently, a viable alternative to the traditional feature design approaches is represented by deep learning algorithms which straightforwardly leads to automated feature learning [10]. These approaches became computationally feasible thanks to the availability of powerful GPU processors, allowing high-performance numerical computation in graphics cards. It comes as no surprise that Convolutional Neural

Networks (CNNs), for example, have worked very well for FER, as evidenced by their use in a number of state-of-the-art algorithms for this task, as well as winning related competitions [6, 8, 11]. The problem with CNNs is that this kind of neural network has a very high number of parameters and moreover achieves better accuracy with big data.

Because of that, it is prone to over-fitting if the training is performed on a small sized dataset. Another not negligible problem is that there are no publicly available datasets with sufficient data for FER with deep architectures. Therefore, to tackle the problem, this work proposes, in the pre-processing step, standard methods for data generation in synthetic way (techniques indicated in the literature as "data augmentation"). Three different methodologies are then applied to the set of generated data: the first methodology is based on a deep architecture while the other two methodologies are based on manual features extraction approaches.

The structure of the paper is as follows. Section 2 reports some details about the implemented pipeline for FER in ageing adults, emphasizing theoretical details for the pre-processing steps. Moreover, the same section describes the implemented CNN architecture and both traditional machine learning approaches used for comparison. Section 3 presents the results obtained, while discussion and conclusion are summarized in Sect. 4.

2 Methods

Figure 1 shows the structure of our FER system. First, the implemented pipeline performs a pre-processing task on the input images (data augmentation, face detection, cropping and down sampling, normalization). Once the images are pre-processed they can be either used to train and test the implemented deep network or to extract handcrafted features (both geometric and appearance-based).

Here are some details about the blocks that perform the pre-processing algorithmic procedure, whereas the next sub-sections illustrates the theoretical details both the deep learning methodology and the methodologies based on handcrafted features.

It is well known that one of the main problems of deep learning methods is that they need a lot of data in the training phase to perform this task properly. In the present work the problem is accentuated from having very few datasets containing images of facial expressions performed by ageing subjects. So before training the CNN model, we need to augment the data (produce new images from the original ones) with a series of transformations for generate various small changes in appearances and poses. The number of available images has been increased with three data augmentation strategies. The first strategy is to use flip augmentation, mirroring images about the *y-axis* producing two samples from each image. The second strategy is to change the lighting condition of the images. In this work lighting condition is varied by adding Gaussian noise in the available face images. The last strategy consists in rotating the images of a specific angle. Consequently each facial image has been rotated through 7 angles randomly generated in the range [$-30°$; $30°$] with respect to the

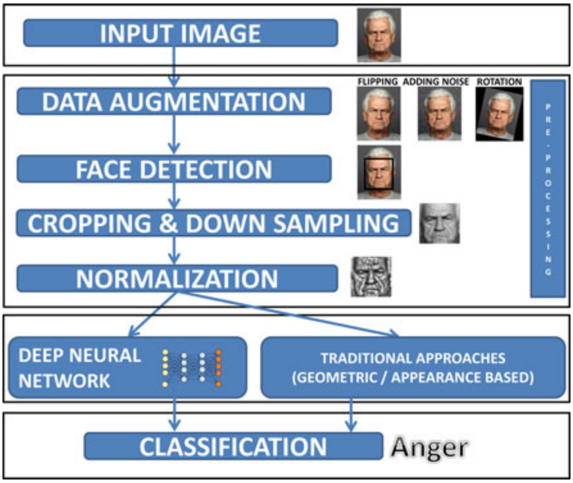

Fig. 1 Pipeline of the proposed system. First a pre-processing task on the input images was performed. The obtained normalized face image is used to train and test the deep neural network architecture. Moreover, both geometrical and appearance-based features are extracted from normalized image. Finally, each image is classified associating it with a label of most probably facial expression

y-axis. Summarizing, starting from each image present in the dataset, and through the combination of the three previously described data augmentation techniques, 32 facial images have been generated.

The next step consists in the automatic detection of the facial region. Here the facial region is automatically identified by means of the Viola-Jones face detector [18]. Once the face has been detected by the Viola-Jones algorithm, a simple routine was written in order to crop the face image. This is achieved by detecting the coordinates of the top-left corner, the height and width of the face enclosing rectangle, removing in this way all background information and image patches that are not related to the expression. Since the facial region could be of different sizes after cropping, in order to remove the variation in face size and keep the facial parts in the same pixel space, the algorithmic pipeline provides a down-sampling step that generates face images with a fixed dimension using a linear interpolation (set 32×32 pixels in the present work). Next, the obtained cropped and down-sampled RGB face image is converted into grayscale by eliminating the hue and saturation information while retaining the luminance. Finally, since the image brightness and contrast could vary even in images that represent the same facial expression performed by the same subject, an intensity normalization procedure was applied in order to reduce these issues. Generally histogram equalization is applied to enhance the contrast of the image by transforming the image intensity values since images which have been contrast enhanced are easier to recognize and classify. However, the noise can also be amplified by the histogram equalization when enhancing the contrast of the image through a transformation of its intensity value since a number of pixels fall inside the same gray level range. Therefore, instead of applying the histogram equalization, in this work the method introduced in [21] called “contrast limited adaptive histogram equalization” (CLAHE) was used. This algorithm is an improvement of the histogram equalization algorithm and essentially consists in the division of the original image into contextual regions, where histogram equalization was made on each of these sub regions. These sub regions are called tiles. The neighboring tiles are combing by using a bilinear interpolation to eliminate artificially induced boundaries.

2.1 CNN Architecture

A typical implementation of CNN for FER encloses three learning stages in just one framework. The learning stages are: (1) feature learning, (2) feature selection and (3) classifier construction. Moreover, two main phases are provided: training and test. During training, the network acquires grayscale facial images (the normalized image output of pre-processing step), together with the respective expression labels, and learns a set of weights. Generally the order of presentation of the facial images can influence the classification performance. Consequently to avoid this problem a group of images was selected and separated for a validation procedure, useful to choose the final best set of weights out of a set of trainings performed with samples presented in different orders. After, in the test step, the architecture receives a grayscale image of a face and outputs the predicted expression by using the final network weights learned during training. The CNN designed and implemented in the present work is inspired at the classical LeNet-5 architecture [9], a pioneering work by Yann LeCun used mainly for character recognition (Fig. 2).

It consists of two convolutional layers each of which followed by a sub-sampling layer. The resolution of the input grayscale image is 32 × 32, the outputs are numerical value which correspond with the confidence of each expression. The maximum confidence value is selected as the expression detected in the image. The first convolution layer applies a convolution kernel of 5 × 5 and outputs 32 images of 28 × 28 pixels. It aims to extract elementary visual features, like oriented edges, end-point, corners and shapes in general. In FER problem, the features detected are mainly the shapes, corners and edges of eyes, eyebrow and lips. Once the features are detected, its exact location is not so important, just its relative position compared to the other features. For example, the absolute position of the eyebrows is not important, but their distances from the eyes are, because a big distance may indicate, for instance,

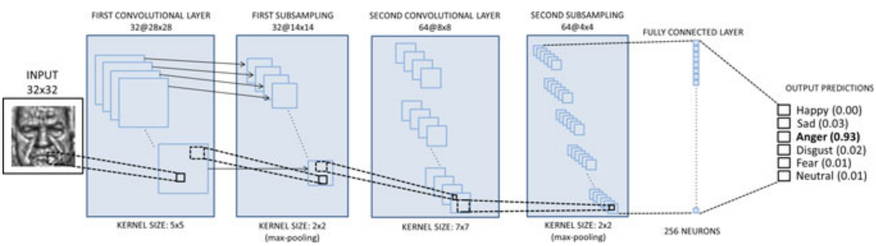

Fig. 2 Architecture of the proposed Convolutional Neutral Network. It comprises of five layers: 2 convolutional layers, 2 sub-sampling layers and one fully connected layer

the surprise expression. This precise position is not only irrelevant but it can also pose a problem, because it can naturally vary for different subjects in the same expression. The first convolution layer is followed by a sub-sampling layer that uses max-pooling (with kernel size 2×2) to reduce the image to half of its size. This operation aims to reduce the precision with which the position of the features extracted by the previous layer are encoded in the new map.

Subsequently, a new convolution layer performs 64 convolutions with a 7×7 kernel to map of the previous layer and is followed by another sub-sampling, again with a 2×2 kernel. The aforementioned two layers (second convolutional layer and second sub-sampling layer) aim to do the same operations that the first ones, but handling features in a lower level, recognizing contextual elements (face elements) instead of simple shapes, edges and corners. The concatenation of sets of convolution and sub-sampling layers achieves a high degree of invariance to geometric transformation of the input.

The last hidden layer (a fully connected layer) receives the set of features learned and outputs the confidence level of the given features in each one of the considered expressions. The implemented network uses the stochastic gradient descent method to calculate the synaptic weights between the neurons [2]. The loss is calculated using a logistic function of the soft-max output (known as *SoftmaxWithLoss*), while the activation function of the neurons is a ReLu (Rectified Linear unit) [14].

2.2 Handcrafted Features Approaches for FER in Ageing Adults

In contrast to deep learning approaches, FER approaches based on handcrafted features do not provide a feature learning stage but a manual feature extraction process. The commonality of various types of conventional approaches is detecting the face region and extracting geometric features or appearance-based features. Even in this category of approaches, the behaviour and relative performance of algorithms is poorly analysed by scientific literature with images of expressions performed by ageing adults. Consequently, in this work, two of the best performing handcrafted features extraction methodologies have been implemented and applied.

Generally, geometric features methods are focused on the extraction from the shape or salient point locations of specific facial components (e.g. eyes, mouth, nose, eyebrows, etc.). From an evaluation of the recent research activity, Active Shape Model (ASM) [3] turns out to be a performing method for FER. In the present work the face of an ageing subject was processed with a facial landmarks extractor exploiting the Staked Active Shape Model (STASM) approach. STASM uses Active Shape Model for locating 77 facial landmarks with a simplified form of Scale-invariant feature transform (SIFT) descriptors [12] and it operates with Multivariate Adaptive Regression Splines (MARS) for descriptor matching [13]. After, using the obtained landmarks, a set of 32 features, useful to recognize facial expressions, has been defined. The 32 geometric features extracted are divided into the following three categories: linear features (18), elliptical features (4) and polygonal features (10). The last step provides a classification module that uses a Support Vector Machine (SVM) for the analysis of the obtained features vector in order to get a prediction in terms of facial expression.

Regarding the use of appearance-based features, local binary pattern (LBP) [16] is an effective texture description operator, which can be used to measure and extract the adjacent texture information in an image. The LBP feature extraction method used in the present work contains three crucial steps. At first, the face image is divided into several non-overlapping blocks (set to 8 × 8 after experimenting with different block sizes). Then, LBP histograms are calculated for each block. Finally, the block LBP histograms are concatenated into a single vector. The resulting vector encodes both the appearance and the spatial relations of facial regions. In this spatially enhanced histogram, we effectively have a description of the face image on three different levels of locality: the labels for the histogram contain information about the patterns on a pixel-level, the labels are summed over a small region to produce information on a regional level and the regional histograms are concatenated to build a global description of the face image. Finally, also in this case, a SVM classifier is used for the recognition of facial expression.

3 Results

To validate our methodologies a series of experiments were conducted using the age-expression dataset FACES [4], which includes 58 young, 56 middle-aged and 57 older Caucasian women and men. The faces are frontal with fixed illumination mounted in front and above of the faces. The ages of the subjects range from 19 to 80. The age distribution is not uniform and in total there are 37 different ages. Each model in the FACES dataset is represented by two sets of six facial expressions (Anger, Disgust, Fear, Happy, Sad and Neutral) totaling 171 * 2 * 6 = 2052 frontal images. Table 1 presents the total number of persons in the final FACES dataset, broken down by age group and gender, whereas in Fig. 3 some examples of expressions performed by aging adults are represented (one for each class of facial expression):

For the performance evaluation of the methodologies all the images of FACES were considered and pre-processed. Consequently, applying the data augmentation

Table 1 Total number of images contained in FACES dataset broken down by age group and gender

Gender	Age (years)			
	(19–31)	(39–55)	(69–80)	Total (19–80)
Male	29	27	29	85
Female	29	29	28	86
Total	58	56	57	171

Fig. 3 Some examples of expressions performed by aging adults from the FACES database

techniques previously described (see Sect. 2), in total 65,664 facial images were used (equally distributed among the facial expression classes), a sufficient number for using a deep learning technique.

For CNN methodology the training, validation and testing phase were performed on Intel i7 3.5 GHz workstation with 16 GB DDR3 and equipped with GPU NVidia Titan X using the Python library for machine learning Tensorflow, developed for implementing, training, testing and deploying deep learning models [1].

As described in Sect. 2.1, for each performed experiment the facial images were separated in three main sets: training set, validation set and test set. Moreover, since gradient descent method was used for training [2], and considering that it is influenced by the order of presentation of the images, the accuracy obtained was an average value of the values calculated in 15 different experiments, in each of which the images were randomly ordered. To be less affected by this accuracy variation, a training methodology that uses a validation set to choose the best network weights was implemented.

The final accuracy obtained by CNN for each age group of FACES dataset is reported in Table 2. It is computed using the network weights of the best run out of

Table 2 FER accuracy on FACES dataset evaluated for different age group with deep learning and traditional machine learning approaches

Age group	CNN (%)	ASM + SVM (%)	LBP + SVM (%)
Young	92.43	86.42	87.22
Middle-aged	92.16	86.81	87.47
Older	93.86	84.98	85.61
Average value	**92.81**	**86.07**	**86.77**

Table 3 Confusion matrix of six basic expression on FACES dataset (performed by older adults) using CNN

		Estimated (%)					
		Anger	Disgust	Fear	Happy	Sad	Neutral
Actual (%)	Anger	**96.8**	0	0	0	2.2	1.0
	Disgust	3.1	**93.8**	0	0.7	1.8	0.6
	Fear	0	0	**95.2**	1.5	3.3	0
	Happy	0.7	2.8	1.1	**94.3**	0	1.1
	Sad	0.6	0	4.1	0	**90.2**	5.1
	Neutral	2.5	2.0	2.6	0	0	**92.9**

15 runs, having a validation set for accuracy measurement. The same table shows the accuracy values obtained using traditional machine learning techniques described in Sect. 2.2 (ASM + SVM and LBP + SVM).

The result reported in the previous table confirm that CNN approach is superior to traditional approaches based on handcrafted features and this is true for any age group in which the dataset is partitioned. Analyzing in more detail the results obtained, it is clear that CNN obtains a better improvement in the case of recognition of facial expressions performed by ageing adults (about 8.2% considering CNN vs. LBP). Moreover, the hypotheses concerning the difficulties of traditional algorithms in extracting features from an ageing face was confirmed from the fact that ASM and LBP get a greater accuracy with faces of young and middle-aged.

In a multi-class recognition problem, as the FER one, the use of an average performance value among all the classes could be not exhaustive since there is no possibility to inspect what is the separation level, in terms of correct classifications, among classes (in our case, different facial expressions). To overcome this limitation the confusion matrix is then reported in Table 3 (only the facial images of older adults were considered). The numerical results obtained in terms of recognition rate of each class of facial expression makes possible a more detailed analysis of the misclassification and the interpretation of their possible causes. With the application of the CNN to facial images of older adults, anger and fear are the facial expression better recognized, whereas sad and neutral are the facial expression confused the most. Finally, sad is the facial expression with the lowest accuracy.

4 Discussion and Conclusion

The present work examined the ability of a deep learning method to classify facial expression of ageing adults with respect traditional machine learning approaches. Since the majority of the works in the literature that address this topic uses datasets that contain face images with a small span of lifetime, it was considered interesting to evaluate the recognition of facial expressions performed by the elderly.

Recent studies have demonstrated that human aging has significant impact on computational FER. In fact, by comparing the expression recognition accuracy across different age groups, it was found that the same classification scheme for the recognition of facial expressions cannot be used. Consequently, it was necessary first to evaluate how classical approaches perform on the faces of the elderly, and then consider more general approaches able to automatically learn what features are the most appropriate for expression classification of aging adults. It is worth pointing out that hand designed feature extraction methods generally rely on manual operations with labelled data, with the limitation that they are supervised. In addition, the hand designed features are able to capture low-level information of facial images, except for high-level representation of facial images. However, deep learning, as a recently emerged machine learning theory, has shown how hierarchies of features can be directly learned from original data in an unsupervised manner.

As the literature suggests that CNNs are the state of the art for FER, but only when a very large number of training images are available, it was considered advisable to implement data augmentation techniques on the images contained in FACES dataset, the only one present in literature with labelled facial expressions performed by a young, middle-aged and older subjects.

As hypothesized, the results obtained showed that a deep architecture allows to have higher recognition rates, and the improvement in recognition performance was more evident in trying to classify expressions of elderly subjects. The numerical result obtained finds correspondence in the social evaluations made in some scientific studies in which it is pointed out that the elderly subjects tend to be less expressive and consequently on these faces differentiating the type of expression is a more difficult task.

Future works will deal with two main aspects. First of all the simplified CNN architecture implemented in the present work will be compared with others CNNs architectures structured with multiple hidden layers which, as demonstrated by recent publications, get high recognition rates on datasets containing facial images of subjects of different ages (ex. AlexNet, VGG, ResNet, GoogleNet, etc.). On the other hand, a more wide analysis of how a non-frontal view of the face can affect the facial expression detection rate using a deep learning architecture will be done, as it may be necessary to monitor the mood of the elderly by using for example a camera installed in the “smart” home for other purposes (e.g. activity recognition or fall detection), and the position of these cameras almost never allows to have a frontal face image of the monitored subject.

References

1. Abadi M, Barham P, Chen J, Chen Z, Davis A, Dean J, Kudlur M et al (2016) Tensor-flow: a system for large-scale machine learning. In: Proceedings of the 12th USENIX symposium on operating systems design and implementation (OSDI), Savannah, Georgia, USA
2. Bottou L (2010) Large-scale machine learning with stochastic gradient descent. In: Proceedings of COMPSTAT'2010, pp 177–186. Physica Verlag HD
3. Cootes TF, Taylor CJ, Cooper DH, Graham J (1995) Active shape models-their training and application. Comput Vis Image Underst 61(1):38–59
4. Ebner NC, Riediger M, Lindenberger U (2010) FACES—a database of facial expressions in young, middle-aged, and older women and men: development and validation. Behav Res Methods 42(1):351–362
5. Fasel B, Luettin J (2003) Automatic facial expression analysis: a survey. Pattern Recogn 36(1):259–275
6. Goodfellow IJ, Erhan D, Carrier PL, Courville A, Mirza M, Hamner B, Zhou Y et al (2013) Challenges in representation learning: a report on three machine learning contests. In: International conference on neural information processing, pp 117–124. Springer, Berlin, Heidelberg
7. Guo G, Guo R, Li X (2013) Facial expression recognition influenced by human aging. IEEE Trans Affect Comput 4(3):291–298
8. Kahou SE, Pal C, Bouthillier X, Froumenty P, Gülçehre Ç, Memisevic R, Mirza M et al (2013) Combining modality specific deep neural networks for emotion recognition in video. In: Proceedings of the 15th ACM on international conference on multimodal interaction, pp 543–550. ACM
9. LeCun Y, Bengio Y, Hinton G (2015) Deep learning. Nature 521(7553):436–444
10. LeCun Y, Bottou L, Bengio Y, Haffner P (1998) Gradient-based learning applied to document recognition. Proc IEEE 86(11):2278–2324
11. Liu M, Wang R, Li S, Shan S, Huang Z, Chen, X (2014) Combining multiple kernel methods on riemannian manifold for emotion recognition in the wild. In: Proceedings of the 16th international conference on multimodal interaction, pp 494–501. ACM
12. Lowe DG (1999) Object recognition from local scale-invariant features. In: The proceedings of the seventh IEEE international conference on computer vision, 1999, vol 2, pp 1150–1157. IEEE
13. Milborrow S, Nicolls F (2014) Active shape models with SIFT descriptors and MARS. In: Proceedings of the 9th international conference on computer vision theory and applications, Lisbon, Portugal, 5–8 Jan 2014
14. Nair V, Hinton GE (2010) Rectified linear units improve restricted boltzmann machines. In: Proceedings of the 27th international conference on machine learning (ICML-10), pp 807–814
15. Pantic M, Rothkrantz LJM (2000) Automatic analysis of facial expressions: the state of the art. IEEE Trans Pattern Anal Mach Intell 22(12):1424–1445
16. Shan C, Gong S, McOwan PW (2009) Facial expression recognition based on local binary patterns: a comprehensive study. Image Vis Comput 27(6):803–816
17. United Nations Programme on Ageing, The Ageing of the World's Population, Dec 2013. http://www.un.org/en/development/desa/population/publications/pdf/ageing/WorldPopulationAgeing2013.pdf. Accessed April 2018
18. Viola P, Jones MJ (2004) Robust real-time face detection. Int J Comput Vis 57(2):137–154
19. Wang S, Wu S, Gao Z, Ji Q (2016) Facial expression recognition through modeling age-related spatial patterns. Multimed Tools Appl 75(7):3937–3954
20. Zeng Z, Pantic M, Roisman GI, Huang TS (2009) A survey of affect recognition methods: audio, visual, and spontaneous expressions. IEEE Trans Pattern Anal Mach Intell 31(1):39–58
21. Zuiderveld K (1994) Contrast limited adaptive histogram equalization. Graph Gems 474–485

Physiological Wireless Sensor Network for the Detection of Human Moods to Enhance Human-Robot Interaction

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Abstract Although it is already possible to issue utility services that use robots, these are still not perceived by society as capable of actually delivering them. One of the main motivations is the lack of a human-like behaviour in the interaction with the user. This is displayed both at physical and cognitive level. This work investigates the optimal sensor configuration in the recognition of three different moods, as it surely represents a crucial element in the enhancement of the human-robot interaction. Mainly focusing towards a future application in the field of assistive robotics, electrocardiogram, electrodermal activity and electroencephalographic signal were used as main informative channels, acquired through a wireless wearable sensor network. An experimental methodology was built to induce three different emotional states by means of social interaction. Collected data were classified with six supervised machine learning approaches, namely decision tree, induction rules and lazy, probabilistic and function-based classifiers. The results of this work revealed that the optimal configuration of sensors which maximizes the trade-off between accuracy and obtrusiveness is the one surveying cardiac and skin activities. This sensor configuration reached an accuracy of 87.07% in the best case.

Keywords Mood detection · Physiological sensors · MIP · Social interaction

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1 Introduction

In a not remote future scenario, mobile robotic platforms will share environments with humans in most of their daily time, such as houses, offices and public spaces. The interactions between robots and humans would be led not only by the simple presence of humans in the environment, but also and especially by the current activity done by humans. Hence, it is crucial for a service robot acting in a social unstructured environment to be sensitive to emotions and properly react to them [1]. Additionally, robots should be able to engage a human-like interaction with users to efficiently cooperate with human beings.

It is demonstrated that several aspects influence the interaction between people, including emotions which can affect the decision-making process [2]. In this sense, emotions can be used to improve human-robot interaction [3], to efficiently handle relationships with humans or other autonomous physical agents by means of social behaviours and rules. Particularly, it is important, for an assistive robot, to monitor feelings of the user, not only for interactional purposes but also to assess his/her cognitive development, aspect usually ignored in the elderly care, especially in the case of Mild Cognitive Impairment (MCI) [4]. For this purpose, being aware of the emotional state of the user through his/her physiological activity could be extremely useful. Nonetheless, by issuing such sensing modality to this purpose, the robot will be continuously exposed to indicators of the physiological health of the user, enhancing this role of elderly monitoring.

2 Related Work

Most affective computing applications primarily use vision sensors [1], since the detection of facial expressions is the most natural and intuitive way to perceive emotions of people. However, it recently has become evident that the typical use of vision in social robotics is not feasible in real-life applications because of the occlusion of the camera, adequate room lighting and privacy issues [5]. It is also known that physiological systems are regulated by the autonomous nervous system, strictly related to emotions [6]. So, physiology surely constitutes a reliable informative channel to emotion recognition [1].

Besides privacy issues and problems of good conditions to acquire good-quality images, the user could sometimes hide the external expression of emotion, invalidating the recognition process. Moreover, if, in the context of an assistive robotics application, the camera is mounted on the robot, this last will engage the user prior to having clues about his/her emotional state, making this application pointless.

On the other side, physiology could partially solve these limitations. In fact, as people cannot consciously handle their own physiological activity, unless through proper training, emotional awareness of the robot could not be deceived. This is very helpful, mainly considering emotional monitoring in elderly care. Furthermore, sensors would continuously stream data to the robot, enabling it to be aware of the emotional state of users before starting an interaction with him/her. Moreover, there are fewer problems related to needed conditions to have a good acquisition of this informative channel [7, 8].

Several works exploited physiological signals such as electrodermal activity (EDA), the electrocardiogram (ECG), and the electroencephalography (EEG) (Table 1). For instance, Nardelli et al. [9] and evoked the emotions in the subjects by means of the International Affective Digitalized Sounds (IADS) dataset and recorded the ECG signal, achieving a recognition accuracy of 84.26%. Instead, Henriques et al. [10] used an actor and a robot to provoke emotions in the subjects.

Khezri et al. [11] performed a detailed analysis by examining multiple parameters. Specifically, they recorded EEG, electrooculography (EOG), electromyography (EMG), blood volume pressure (BVP), galvanic skin response (GSR), and heart rate variability.

(HRV) from subjects simultaneously, while building an emotion recognition process based on a weighted linear fusion model.

As stated from literature [1], but also depicted in Table 1, subjects are elicited with different mood induction procedures (MIP). In most of these cases, subjects were asked to sit in front of a computer and watch films or static images or listen

Table 1 Comparison of related works (DT = Decision Tree, SVM = Support Vector Machine, HMM = Hidden Markov Model, MLP = Multilayer Perception, KNN = k-nearest neighbour, lazy = lazy learners, Bayesian = Bayesian learners)

References	Physiological source	Machine learning	Activity to evoke moods
Nardelli et al. [9]	ECG	Quadratic discriminant classifier	27 subjects were stimulated with sounds from the IADS dataset
Henriques et al. [10]	EDA	HMM, iBk	30 participants (two groups). Group one: emotion elicited by an actor's performance; Group two: elicited by NAO robot
Khezri et al. [11]	EEG, ECG, EDA, electrooculography, blood volume pressure, electromyography	SVM, k-nearest neighbour	The emotions in 50 subjects were elicited through videos
Our work	EDA, ECG, EEG	DT, SVM, MLP, KNN, Bayesian, lazy	20 participants. Three moods were elicited during a social interaction

to music [9, 11]. Even if these are effective MIPs, they do not address challenges in social robotics fields. Indeed, in these experiments, the dyadic interaction [12] is not considered.

3 Aim of the Work

This work aims to develop and test a physiological wearable system able to recognize three different moods, inside a purposely built MIP by means of social interaction: relaxed, positive and negative. Particularly, in this work, the authors investigated the optimal sensor configuration able to distinguish the three different moods with a good trade-off between the accuracy of the performance and the obtrusiveness of the system.

The proposed system is composed of three different physiological sensors able to monitor the EDA, the ECG and the EEG signals. Additionally, an RGD-B camera will be used to record all the experiment to support the analysis of the collected data and discuss the results, as common practice in emotional experiments [13]. Five supervised machine learning classifiers families, namely decision tree, induction rules, lazy, probabilistic learners and function-based classifiers were used to test and to compare the different sensor configurations.

4 Material and Method

The first part of this section describes the system and the data acquisition, whereas the second part is related to the data analysis.

4.1 Instruments

Three commercial wearable sensors were selected to measure physiological response to the emotional stimuli. The reasonable trade-off between accuracy in measurements and unobtrusiveness led to the selection of Zephyr™ BioHarness3™ (Zephyr™, Maryland, USA), Shimmer™ GSR Module (Shimmer™, Ireland) and The MindWave™ EEG headset (Neurosky®, California USA) (See Fig. 1).

Zephyr BioHarness is a Bluetooth chest belt capable of monitoring cardiac activity by recording the ECG signal and calculating parameters such as Heart Rate and R-R Intervals [14]. The ECG signal is sampled at 250 Hz. Inter-Beat-Interval data provided by the device were used for data analysis and features extraction (Fig. 1a).

The Shimmer GSR Module is a small-size, lightweight wearable sensor that streams one channel data related to EDA at sampling rate of 51.2 Hz [15]. The Shimmer module is composed of two special finger electrodes and the main unit

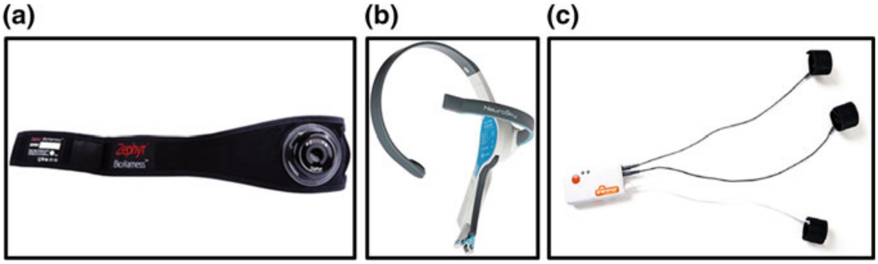

Fig. 1 **a** BioHarness. **b** MindWave headset. **c** Shimmer GSR module

that streams data related to the galvanic skin response using a Bluetooth connection (Fig. 1b).

The MindWave headset is a Bluetooth device able to capture single frontal lobe channel EEG raw data at a sample rate of 512 Hz [16]. In addition, the headset provided the indexes of attention and meditation of the user, related to the frequency power spectrum of the acquired signal, with a sample rate of 1 Hz (Fig. 1c).

A Kinect™ v1.80 camera (Microsoft®, Washington, USA), 30 Hz transmission of 640×480 images, was included in the system to record the experimentation thus to support the data analysis.

The overall set of sensors was handled through an interface implemented in Microsoft Visual Studio™ 2017 (Microsoft®, Washington, USA). It managed the connection of devices, the data acquisition, synchronization and storage. Furthermore, the experimenter could use this interface to take timed notes of events occurring during the experimentation.

4.2 Experimental Protocol

The protocol purposely designed to grow a positive or negative mood in the user through social interaction with the experimenters involved the oral administration of a questionnaire (Fig. 3). Before starting the 15 min phase dedicated to the MIP

Fig. 2 Process of the experimental methodology

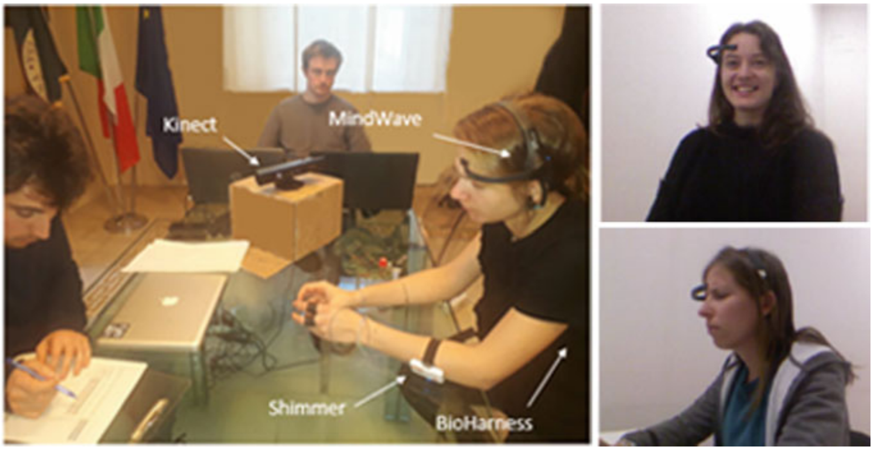

Fig. 3 Experimental set-up

(elicited phase), the subject, unaware of the real purpose of the test [17], was dressed in wearable sensors and accommodated on a chair inside a room with no specific visual and sound input. After that, the user remained for 10 min in the absence of stimuli, initially to record a baseline (baseline phase) of the physiological parameters and subsequently to achieve a state of relaxation (relax phase), closing his eyes and avoiding interactions with objects and people (Fig. 2).

After that, the interaction between the experimenters and the subject came into play to stimulate a specific mood. It was impossible to sequentially administer the positive and negative condition to the same subject, because the mood achieved during the first type of social interaction could have influenced the subject's mood during the second one. Only one between positive and negative conditions was administered to each subject, maintaining a balance in terms of percentage between the two cases.

In the positive condition, one of the experimenters, who was a psychologist (the other one, an engineer, was mainly charged to monitor the sensor interface, providing complementary interaction during each session), was immediately very affable with the subject, who had to answer orally to 55 questions selecting one of the 4 possible answers, among which just one was correct. The questions selected for this condition had been prepared to result funny and strange to make laugh without making the subject feel ignorant if he did not know the correct answer. Each answer was followed by implicit signs of appreciation, like nodding. However, there were 5 interventions experimenters planned at a fixed moment of the protocol to reinforce the administered condition. Indeed, these 5 moments were intended to gradually increase the complacency and gratification of the user.

The negative condition was dual to the positive one. In this case, instructions were provided unkindly by the second experimenter, which entered during the first recordings without introducing himself. The 55 questions had a level of difficulty that causes discomfort and shame in subjects, when not capable of answering them.

During the task execution, both experimenters performed a mean attitude towards the subject, through signs of contempt and 5 negative scheduled reinforcements, delivered with modality which was dual to the positive condition.

At the end of positive or negative induction phase, the Self-Assessment Mannikin (SAM) questionnaire was proposed to the subject [18]. It is a picture-oriented questionnaire, containing nine images for each of the three affective dimensions (pleasure, arousal and dominance). Filling the SAM, the participant described how and what they felt during the test in a quantitative manner.

Given the importance of the subject's unawareness on the real purpose of the test induction, the real aim of the experiment was revealed to the subject at the end of the protocol, after having assessed the persistence of unawareness through a post-experimental interview. Then, the experimenters asked the subject if they identified a moment coinciding or close to one of the 5 reinforcements after which the felt emotion mostly suited the selected SAM's scores. This information was used in the subsequent analysis (see Sect. 4.4.2). Finally, the subject filled the Beck Depression Inventory and the Maudsley Obsessive Compulsive Questionnaire to assess the presence of depression and obsessive-compulsive behaviour in subjects. In fact, these are two mental diseases that alter significantly the self-perception of emotions and their presence would represent an exclusion criterion. In the negative condition, the experimenters apologized for the pretended rude attitude.

4.3 Participants

Twenty-one voluntary healthy young subjects (9 male, 12 female) with a mean age of 24.0 years (standard deviation: 3.7, range: 20–35) participated on purpose in this study. Among tested subjects, two were occasional smokers, and the remaining were no smokers. Participants completed the experimental session at the Scuola Superiore Sant'Anna (Pisa, Italy). Written informed consent was obtained from all the participants prior entry into the study.

Unfortunately, one subject was discarded during the post-processing analysis. The HRV signal was not usable probably because the BioHarness was not worn properly in this case. All the subjects were not depressed nor affected by obsessive-compulsive behaviour.

4.4 Data Analysis

The physiological signals obtained during the experimental protocol from the three sensors for each subject were segmented to subsequently obtain three different datasets, one for each of the three phases (baseline, relax, elicited). The dataset was analysed using Matlab 2016 (MathWorks, Massachusetts USA).

The features extraction strategy discussed below was applied to signals samples belonging to 180 s-long windows. In fact, emotion recognition is not a real-time application in common sense, as user's emotional state, by its nature, is not expected to change with a high-frequency. Moreover, the selected window allows analysing sufficiently long physiological signal ranges to be able to extract also the main frequency characteristics. Indeed, the selected time is one of the most used ranges in physiological data analysis for emotion recognition [6, 19]. A 50 s-long overlapping of adjacent windows was implemented to correctly handle the transitions.

4.4.1 Physiological Signals Analysis

The BioHarness device provided HRV data that specify the temporal distance between one heartbeat and the following one. Ectopic rhythm, which is an irregular heart rhythm due to a premature heartbeat, was identified and corrected. A R-to-R sample was considered an ectopic interval if its difference from the previous sample was¸ in absolute value, greater than 20% [20]. By correcting ectopic rhythm, replacing with the average of the two antecedent and two following ones, a Normal-to-Normal (NN) interval sequence, appropriate for HRV analysis, was obtained [21]. From NN signal, 6 time-domain features were extracted for each time window (Table 2).

Then, after a signal smooth detrending, the NN interval sequence was resampled at 4 Hz, as suggested by Mali et al. [22], to properly estimate Power Spectral Density (PSD), through a parametric autoregressive (AR) model of the order 16 with coefficients determined through the Burg method. A total of 10 frequency-domain features were extracted, high frequency (HF), low frequency (LF) and very low frequency (VLF) bandwidths (Table 2).

The Shimmer sensor provided output galvanic resistance that was converted into galvanic skin conductance (SC). The SC is characterised by startles, of 1–5 s of duration [23] and by a tonic component, related to other uncorrelated sweating activities taking place over a period longer than the one characterising the local peak events. The SC signal frequency content is entirely located within 0–1 Hz [7]. Therefore, the Shimmer sampling frequency was set to 51.2 Hz. The signal was filtered through a 4th-order Butterworth low-pass filter, with a cut-off frequency of 2 Hz. Then, the tonic component was extracted through average process by means of a 5 s-long moving window. By subtracting tonic level from the filtered conductance signal, phasic response was obtained. Finally, an ad hoc algorithm for detection of informative startles was implemented. 16 features were extracted from GSR signal (Table 2).

The MindWave EEG headset mobile device provided a one channel raw EEG signal and information about the PSD in different frequency ranges. Regarding parameters named "Attention" and "Meditation", they are calculated by the device itself starting from the PSD values. They both range from 0 to 100 (see Table 2).

Table 2 Features from HRV, GSR and EEG signals in time (t) and frequency (f) domain

Feature name	Signal	Description
RR mean	HRV(t)	Mean of R-to-R inter-beat intervals belonging to the same time window
SDNN	HRV(t)	Standard deviation of normal RR intervals (also said as NN intervals)
HR mean	HRV(t)	Mean of heart rate
SD mean	HRV(t)	Heart rate standard deviation
RMSSD	HRV(t)	Square root of mean of squared differences between adjacent NN intervals
pNN50	HRV(t)	Percentage of differences between adjacent NN intervals >of 50 ms
VLF peak	HRV(f)	Frequency peak of heart activity VLF (0–0.04 Hz)
VLF power	HRV(f)	PSD area in VLF
%VLF	HRV(f)	Percentage ratio between PSD area in VLF and total one
LF peak	HRV(f)	Frequency peak of LF (0.04–0.15 Hz)
LF power	HRV(f)	PSD area in LF
%LF	HRV(f)	Percentage ratio between PSD area in LF and total one
HF peak	HRV(f)	Frequency peak of HF (0.15–0.40 Hz)
HF power	HRV(f)	PSD area in HF
%HF	HRV(f)	Percentage ratio between PSD area in HF and total one
LF/HF	HRV(f)	Ratio between LF and HF powers
# Startle	GSR(t)	Number of detected startles
Amplitude mean	GSR(t)	Mean value of startles peak amplitude (μS)
Amplitude std	GSR(t)	Standard deviation of startles peak amplitude (μS)
Sum rise time	GSR(t)	Sum of all detected startles rise time duration within the phasic signal portion analysed (s)
Sum fall time	GSR(t)	Sum of all detected startles fall time duration within the phasic signal portion analysed (s)
Rise rate mean	GSR(t)	Mean value of a startle rise time (s)
Rise rate std	GSR(t)	Standard deviation of startle rise time (s)
Decay rate mean	GSR(t)	Mean of a startle fall time (s)
Decay rate std	GSR(t)	Standard deviation of a startle fall time (s)
Phasic value mean	GSR(t)	Mean value of the phasic signal (μS)
Phasic value std	GSR(t)	Standard deviation of the phasic signal (μS)
Startle time mean	GSR(t)	Mean value of a startle duration (s)

(continued)

Table 2 (continued)

Feature name	Signal	Description
Startle time std	GSR(t)	Standard deviation of a startle duration (s)
Startle RMS mean	GSR(t)	Mean value of the root mean square of the curve identifying a startle (μS)
Startle RMS std	GSR(t)	Standard deviation of the root mean square of the curve identifying a startle (μS)
Startle RMS overall	GSR(t)	Value of the root mean square of the whole phasic signal portion analysed (μS)
Alpha1	EEG(f)	EEG signal power in frequency range 8–9 Hz
Alpha2	EEG(f)	EEG signal power in frequency range 10–12 Hz
Beta1	EEG(f)	EEG signal power in frequency range 13–17 Hz
Beta2	EEG(f)	EEG signal power in frequency range 18–30 Hz
Delta	EEG(f)	EEG signal power in frequency range 1–3 Hz
Gamma1	EEG(f)	EEG signal power in frequency range 31–40 Hz
Gamma2	EEG(f)	EEG signal power in frequency range 41–50 Hz
Theta	EEG(f)	EEG signal power in frequency range 4–7 Hz
Attention	EEG(f)	NeuroSky index for user's level of mental "focus" or "concentration"
Meditation	EEG(f)	NeuroSky index for user's level of mental "calmness" and "relaxation"

4.4.2 Feature Selection

Collected features were then normalized. The main motivation behind this procedure was the reduction of inter-subject variability of physiological activity [21, 23]. It was performed in each subject, calculating parameters by using its specific data coming from baseline acquisition. For these reasons, the features related to relaxed and elicited phases were scaled as a relative percentage variation from their correspondent mean baseline value.

Labels ("Relax", "Positive" and "Negative") were attributed to each feature windows to perform the feature selection process. Moreover, it was important to understand which instances could be used as a carrier of reliable information about elicited (positive and negative) states of the subject. The minimal condition for this to be true was that the subject effectively felt the emotional state, better said the mood [24]. Therefore, for the elicited phase, only features vectors coming from time windows during which subjects declared to have felt the emotional state reported in the SAM were withheld and used for further analysis. Indeed, at the end of the protocol, the experimenter asked the subject about the moment when he/she began to feel a positive or negative mood during the protocol, using the 5 fixed reinforcements as references (see Sect. 4.2).

The normal distribution of the computed features was disproved, using the Shapiro-Wilk test of normality. Consequently, the non-parametric Spearman (RHO) correlation coefficient between each feature was calculated. Those couples of features with correlation coefficient below 0.85 (absolute values) and $p < 0.05$ were carefully assessed to decide which ones to exclude for each case [25, 26].

As this work aimed at considering trade-offs between performance and feasibility of a solution in a daily-life application, the correlation analysis was performed, considering each possible combination of sensors used, in couples or singularly. This analysis generated 7 different sets of features to train the upcoming supervised learning processes. They namely were called: BMS (in which Bioharness, Shimmer and Mindwave were considered all together), BM, BS, MS, B, M and S.

4.4.3 Supervised Classification

From this point on, the 7 datasets were analysed in WEKA™ 3.8.2 (University of Waikato, Hamilton, New Zealand) environment. Five different families of algorithms were explored in their performance with each case considered: Decision Tree (C4.5 with default parameters) [27], Rules Induction (RIPPER with 10 folds) [28], Lazy Learners (iBk, with $k = 4$) [29], Probabilistic Learners (Bayesian classifier with default parameters [30]), and function-based classifiers, represented by a SVM (with training data standardization and polynomial kernel) [31] and Multilayer Perceptron (MLP) (7 neurons in the only hidden layer, learning rate of 0.9 and momentum of 0.1) [32].

Each classification process was tested through a Leave-One-Out cross-validation. and its overall accuracy, F measure and ROC area were calculated.

5 Results

The average, standard deviation, max value and min value of pleasure, arousal and dominance scores (integer values ranged from −4 to 4) were calculated for the three emotional components, separately for each condition:

- Positives' pleasure: 2.900, 0.876, 4, 2;
- Positives' arousal: 2.100, 0.994, 4, 1;
- Positives' dominance: 0, 1.764, 2, −2;
- Negatives' pleasure: −1.200, 1.549, 2, −4;
- Negatives' arousal: 1.000, 1.564, 2, −3;
- Negatives' dominance: −0.900, 1.792, 2, −3

Starting from a set of 42 features the results of the correlation analysis led to a subset of 29 features, 12 from HRV (SDNN, HR mean, SDHR, RMSSD, pNN50, LF peak, HF peak, VLF power, LF power, %VLF, %LF, %HF), 9 from GSR (# startle, Amplitude std, Rise rate mean, Rise rate std, Decay rate mean, Decay rate std, Phasic value mean, Startle time std, Startle RMS std) and 8 from EEG (Alpha1, Alpha2, Beta2, Gamma1, Gamma2, Delta, Attention and Meditation). Since the analysis has showed significant correlation exclusively between parameters deriving from the same signal, to the performed analysis with different sensors combination it was enough to combine in a subset the uncorrelated features extracted from the selected sensors.

The results of the classification algorithms are summarized in Fig. 4. Concerning the classification performances, the function-based algorithms obtained the best results. Indeed, SVM provided the highest metric scores, while the MLP maintained the highest average performances. This suggests that the related family of learning algorithms could be suitable for multi-class problems in the recognition of human moods. On the other side, the Bayesian classifier is the algorithm with the worst performance in recognizing these three moods independently from the combination explored. The other algorithms showed oscillating results, even considering different evaluation metrics of the same case.

The complete configuration of sensors (BMS) obtained the best results in every evaluation metrics. Particularly, as concerns the accuracy, it reached the highest value (89.67%) with SVM. It is worth to underline that, for BMS case, SVM outperformed all other classifiers in each evaluation metric.

As concern the results of the combination of couples of sensors (BM, BS, MS), the BS and BM configurations reached better performance with respect to the MS configuration. Particularly, BM and BS performances were comparable one to each other, while the MS case performed slightly worse, except for the ROC area, in which all three cases scored approximately in the same range (Fig. 4). Mainly, regarding the BS configuration, the accuracy reached the highest value for the SVM (87.07%). The performances of SVM and MLP were very similarly in BMS and BS cases, 89.67% and 87.07% respectively. Table 3 reports the accuracy of the classifiers in recognizing the three moods with the BS configuration. The negative mood was the worst classified, whereas the relax and the positive mood were well classified. Particularly, the recognition of the positive mood reached the best accuracy with the SVM, whereas the recognition of the relaxed status reached his highest performance with the Rules classifier.

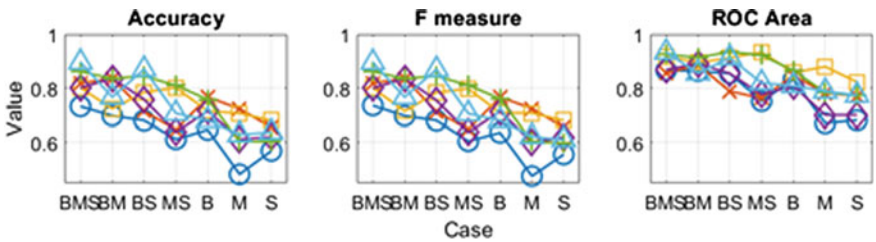

Fig. 4 Accuracy values for each classifies and combination of sensors. In the figures ○ = Bayes, x = Tree, □ = Lazy, ◊ = Rules, + = MLP and Δ = SVM

Table 3 Accuracy (%) of BS configuration in recognizing the three moods

Accuracy	Relax	Positive	Negative
Bayes	77.50	65.20	60.00
Tree	80.00	71.70	60.00
Lazy	85.00	76.10	73.30
Rules	87.50	80.40	53.30
MLP	82.50	89.10	80.00
SVM	80.00	91.30	90.00

Regarding cases with the use of only one sensor (B, S, M), the B case was the most performing one considering all the evaluation metrics, which were always greater than the best ones of M and S cases, for each metric considered. The DT algorithm applied to B features showed the higher accuracy level of single sensor configurations (76.72%).

6 Discussion and Conclusion

The aim of this work was to assess the optimal sensors' configuration to recognize three different moods evoked during a social interaction.

The results obtained from SAM regarding the pleasure average rate (2.90 for positive and −1.20 for negative condition) show that our proposed protocol can evoke in the subject the desired moods. The performances obtained by the classifiers in the case of using only the features extracted from the HRV show that cardiac activity might represent a good standalone informative channel in recognizing mood in real-life applications (76.72% accuracy with DT). However, the present work highlighted that the exploitation of cardiac and skin activities (BS configuration) should be pursued for the final application of recognizing moods of the user inside social environments. According to the results, BS is the configuration which should be selected as the best one to optimize the trade-off between accuracy and obtrusiveness of sensors. Indeed, the accuracy of 87.07% obtained with the SVM applied on HRV and GSR features are significantly higher than the best single sensor case discussed above but does not present significant disadvantages respect to use of the whole system (89.67%).

This leads to think that in the final application the use of only one device able to acquire both HRV and GSR signals would be feasible and performing at the same time. In fact, it is important to state that the ECG waves would not be needed to obtain HRV signal. For instance, photoplethysmography (PPG) would come in handy for measuring the HRV [33, 34]. PPG is a measurement methodology that is applied at the level of fingers. Therefore, as GSR is measured on the fingers, thinking about a device that acquires both the sensing modalities from the same site is a plausible and affordable hypothesis [35].

The obtained results in terms of accuracy are in line with the state of the art (see Sect. 2). But in this case, the result is quite remarkable for the conditions in which it was obtained. In fact, such outcome was achieved monitoring a social interaction, without the usual ideal conditions of emotional experiments. According to the experimental protocol, people could freely move, with no requirement to stay still during the experimental phases, thus introducing noise sources. The positive outcome of this work opens the path to further developments in the way of using physiological activity to monitor affection of people in social environments, which can constitute useful information for a social robotics application, as well.

This work can undergo further developments in each of its aspects. First, other sensing modalities could be integrated to the explored other informative channels and compared with the vision sensor. Secondly, the so-built MIP through social interactions could become increasingly more complex and develop itself in different versions capable of eliciting a higher number of emotional states and covering a wider variety of social contexts in which emotions take place. Third, unsupervised learning methods could be assessed, to overcome the constraints of having instances that must be labelled in advance, main concept behind supervised classifiers. At this point, the behavioural architecture of an intelligent machine, or robot, able to efficiently use the achieved result, should be implemented. The intelligent machine should be finally validated in an experimental framework that will incorporate its presence inside it.

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References

1. Cavallo F, Semeraro F, Fiorini L, Magyar G, Sinčák P, Dario P (2018) Emotion modelling for social robotics applications: a review. J Bionic Eng 15
2. Isen AM (2000) Some perspectives on positive affect and self-regulation 11:184–187
3. Picard RW, Vyzas E, Healey J (2001) Toward machine emotional intelligence: analysis of affective\physiological state. IEEE Trans Pattern Anal Mach Intell 23:1175–1191
4. Bruno B, Mastrogiovanni F, Sgorbissa A (2013) Functional requirements and design issues for a socially assistive robot for elderly people with mild cognitive impairments. In: 22nd IEEE international symposium on robot and human interactive communication, pp 768–773
5. Koelstra S, Patras I (2013) Fusion of facial expressions and EEG for implicit affective tagging. Image Vis Comput
6. Betti S et al (2017) Evaluation of an integrated system of wearable physiological sensors for stress monitoring in working environments by using biological markers. IEEE Trans Biomed Eng
7. Schumm J, Bächlin M, Setz C, Arnrich B, Roggen D, Tröster G (2008) Effect of movements on the electrodermal response after a startle event. In: Proceedings of 2nd international conference on pervasive computing technologies for healthcare, PervasiveHealth, 2008, pp 315–318
8. Chen M, Ma Y, Song J, Lai C-F, Hu B (2016) Smart clothing: connecting human with clouds and big data for sustainable health monitoring. Mob Netw Appl 21:825–845

9. Nardelli M, Valenza G, Greco A, Lanata A, Scilingo EP (2014) Arousal recognition system based on heartbeat dynamics during auditory elicitation
10. Henriques R, Paiva A, Antunes C (2013) Accessing emotion patterns from affective interactions using electrodermal activity. In: 2013 humaine association conference on affective computing and intelligent interaction, pp 43–48. IEEE
11. Khezri M, Firoozabadi M, Sharafat AR (2015) Reliable emotion recognition system based on dynamic adaptive fusion of forehead biopotentials and physiological signals. Comput Methods Programs Biomed
12. Roberts NA, Tsai JL, Coan JA (2007) Emotion elicitation using dyadic interaction tasks. Handbook of emotion elicitation and assessment, pp 106–123
13. Koelstra S, Uhl C, Soleymani M, Lee J-S, Yazdani A, Ebrahimi T, Pun T, Nijholt A, Patras I (2012) DEAP: a database for emotion analysis using physiological signals. IEEE Trans Affect Comput 3:18–31
14. Kim J-H, Roberge R, Powell JB, Shafer AB, Williams WJ (2013) Measurement accuracy of heart rate and respiratory rate during graded exercise and sustained exercise in the heat using the Zephyr BioHarness ^{TM}. Int J Sports Med 34:497–501
15. Burns A, Greene BR, McGrath MJ, O'Shea TJ, Kuris B, Ayer SM, Stroiescu F, Cionca V (2010) SHIMMER^{TM}—a wireless sensor platform for noninvasive biomedical research. IEEE Sens J 10:1527–1534
16. Salabun W (2014) Processing and spectral analysis of the raw EEG signal from the MindWave. Prz Elektrotechniczny 169–173
17. Harmon-Jones E, Amodio DM, Zinner LR (2007) Social psychological methods of emotion elicitation. Handbook of emotion elicitation and assessment, pp 91–105
18. Bradley M, Lang PJ (1994) Measuring emotion: the self-assessment manikin and the semantic differential. J Behav Ther Exp Psychiatry 25:49–59
19. Kreibig S (2010) Autonomic nervous system activity in emotion: a review. Biol Psychol 3:394–421
20. Lippman N, Stein KM, Lerman BB (1994) Comparison of methods for removal of ectopy in measurement of heart rate variability. Am J Physiol 267:H411–H418
21. Acharya UR, Joseph KP, Kannathal N, Lim CM, Suri JS (2006) Heart rate variability: a review. Med Biol Eng Comput 44:1031–1051
22. Mali B, Zulj S, Magjarevic R, Miklavcic D, Jarm T (2014) Matlab-based tool for ECG and HRV analysis. Biomed Signal Process Control 10:108–116
23. Boucsein W (2012) Electrodermal activity. Springer Science + Business Media, LLC
24. Lochner K, Eid M (2016) Successful emotions: how emotions drive cognitive performance. Successful emotions: how emotions drive cognitive performance, pp 43–67
25. Wang H-M, Huang S-C (2012) SDNN/RMSSD as a surrogate for LF/HF: a revised investigation. Model Simul Eng 2012:1–8
26. Kao F-C, Wang SR, Chang Y-J (2015) Brainwaves Analysis of Positive and Negative Emotions. WSEAS Trans. Inf. Sci. Appl. 12:200–208
27. Webb GI (1999) Decision tree grafting from the all-tests-but-one partition. IJCAI Int J Conf Artif Intell 2:702–707
28. Cohen WW (1995) Fast effective rule induction. In: Machine learning: proceedings of twelth international conference
29. Aha DW, Kibler D, Albert MK (1991) Instance-based learning algorithms. Mach Learn 6:37–66
30. John GH, Langley P (1995) Estimating continuous distributions in Bayesian classifiers. In: Eleventh conference on uncertainty in artificial intelligence, pp 338–345
31. Keerthi SS, Shevade SK, Bhattacharyya C, Murthy KRK (2001) Improvements to Platt's SMO algorithm for SVM classifier design. Neural Comput 13:637–649
32. White BW, Rosenblatt F (1963) Principles of neurodynamics: perceptrons and the theory of brain mechanisms. Am J Psychol 76:705
33. Tamura T, Maeda Y, Sekine M, Yoshida M (2014) Wearable photoplethysmographic sensors—-past and present. Electronics 3:282–302

34. Lee J, Matsumura K, Yamakoshi KI, Rolfe P, Tanaka S, Yamakoshi T (2013) Comparison between red, green and blue light reflection photoplethysmography for heart rate monitoring during motion. In: Annual international conference of the IEEE engineering in medicine and biology society EMBS, pp 1724–1727
35. Esposito D, Cavallo F (2015) Preliminary design issues for inertial rings in ambient assisted living applications. In: 2015 IEEE international instrumentation and measurement technology conference (I2MTC) proceedings, pp 250–255. IEEE

An Embedded Localization System for the SUMMIT IoT Multi-platform

Ruben Crispino, Bruno Andò, Salvatore Baglio and Vincenzo Marletta

Abstract The SUMMIT project, funded by the Italian MISE under the PON2020 Action, has the goal to develop a flexible and adaptive IoT framework able to accelerate the development of Smart Solutions. The main idea is to launch an open and dynamic eco-system to support the development of IoT based services both for the private and public sectors. The concept of "pattern", that will lead the overall development of the SUMMIT framework, represents the innovation of the SUMMIT project (it offers ready-made solutions to known implementation problems) which represents each element to be integrated by assuring dependability properties. The three main cases of study addressed by the project will be *smart manufacturing*, *smart health* and *smart building*. Among patterns addressed by the project the development of a localization system is considered. Such system will find application in several contexts and in particular in the scenarios addressed by this project. As an example, the architecture developed can be adopted for the sake of frail people monitoring. In this paper a localization system, that implements an improved trilateration algorithm, is presented.

Keywords IoT · Localization · Assistive technology

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1 Introduction

The indoor localization problem, where common satellite-based solution cannot be used (GPS, Galileo and GLONASS), has led the research and the industrial community into the experimentation of always more efficient solutions able to guarantee a good trade-off between accuracy, precision and cost.

Analyzing the literature, it is possible to notice that all existing solutions do not converge with each other but show a distinction mainly based on the application; the application, in turns, fix the requirement such as the necessary accuracy, resolution and transducer. Typical applications involve: (a) positioning, (b) navigation, (c) Location-Based-Services.

The above solutions require the use of different technologies whether used in a single way or combined by using data fusion algorithms. Among the system described in literature we find dead reckoning systems, system based on interaction between different wireless communication [1–5], computer vision systems, RFID based system [6] just to cite few of them.

Dead Reckoning by using sensors such as accelerometers, magnetometers and gyroscopes can provide an estimation of the current user position starting from the initial one (known). Despite the system based on dead reckoning can theoretically be used to compute the user position with high accuracy they suffer of big drift errors. For this reason, all applications that make use of this system needs to perform a regular recalibration to compensate the cumulative drift error [2, 7–10].

The systems based on interaction between different wireless communication, typically WLAN and Bluetooth (both the standard and the Low Energy version), are the most used solution due to the large diffusion of mobile device that has on-board wireless communication. Among the main measuring paradigms, it's possible to find: (a) RSS (Received Signal Strength), (b) AoA (Angle of Arrival) [1], (c) ToA (Time of Arrival) [1]. Typical accuracies are greater than 1 m [11–13]; although they can be neglectable in applications concerning the LBS, applications that requires a continuous user-environment interaction with the purpose to assist frail people requires much more restricting specifications (<1 m).

Regarding the system based on computer vision algorithms, thanks to the recent progress that has led to the vast distribution of high-performance cameras even on-board of low-cost smartphones, many solution and algorithms, based on machine learning, have been developed for the sake of tag recognition [14–17] and, using ad hoc made maps, for the estimation of the user position. This type of application suffers from poor resolution and the inability to perform a continuous space-time monitoring of the user position. Using this technology in assistive scenario could prevent the possibility to offer real-time information regarding the presence of obstacle or services. In general, assistive systems require specific attention and solution [18–20].

Ultrasound-based localization systems, in the contrary, offers a good trade-off between cost and accuracy. They are normally made-up of two elements: (1) transmitting node, node from where the ultrasound signal start, and (2) the receiving node, that represents the target to localize. In [21] Lindo et al. introduces two novel multiband waveform synthesis applied to ultrasound-based indoor positioning systems and they compare their performance with current coding schemes used in such systems. They find, in the horizontal position estimation, and error below 35 cm. The approach proposed in [22] make us of a system with almost ultrasound signals (17 kHz) that has an error of about 2 cm in noisy environments.

2 Architecture of the Localization System

The main idea behind the realization of this system is that of a Wireless Sensor Network (WSN). This type of network is a distributed architecture made-up of electronic devices able to implements connection is such a way to implement a standard and/or ad hoc network topology (ring, bus, etc.). In particular the WSN can be adopted in many applications where a high flexibility, in terms of collected data, processing methodology and communication, is a must and where robustness against influencing quantities must be guaranteed. The communication level has been realized using the XBee Pro S1 module that implements the standard IEEE 802.15.4 with a carrier frequency of 2.4 GHz.

In Fig. 1 is shown a representation of the realized WSN; three elements can be noted: (1) the user node, (2) the environmental node and (3) the gateway. The user node represents the moving target, i.e. the frail people one wants to monitor and localize. It includes the analog circuit for the ultrasound transducer conditioning and control. The environmental node has a key role in the architecture; the basic principle behind the localization system is the use of an improved trilateration algorithm and it requires the computation of the target-environmental node distance. So, these nodes, having known coordinates in the space, allows the computation of this distance. In addition, they include a filtering algorithm, called Anti-Bouncing-Filter (ABF), to improve the robustness against outlier and influencing quantities. The gateway is the core of all the system. It handles the timing, the implementation of the calibration model and the execution of the trilateration algorithm. The novelty of this system resides on the gateway embedded architecture: everything is handled, even the communication with cloud services, by a single small-size board.

The three elements are reported in Fig. 2.

2.1 *The Measuring Protocol*

The measuring protocol, described in Fig. 3, is structured as follow:

a. The gateway sent 1 ack to the user and environmental nodes; when the signal is received each environmental node start its own counter;
b. The same ack received from the user node is translated into a generation of an ultrasonic burst;

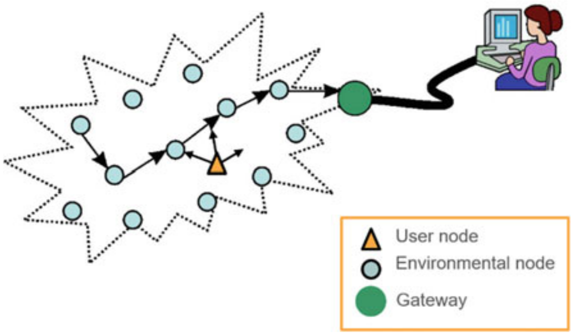

Fig. 1 WSN scheme

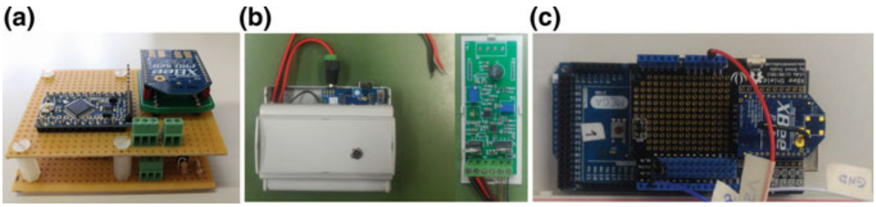

Fig. 2 **a** The developed user node, **b** the developed environmental node and **c** the developed gateway

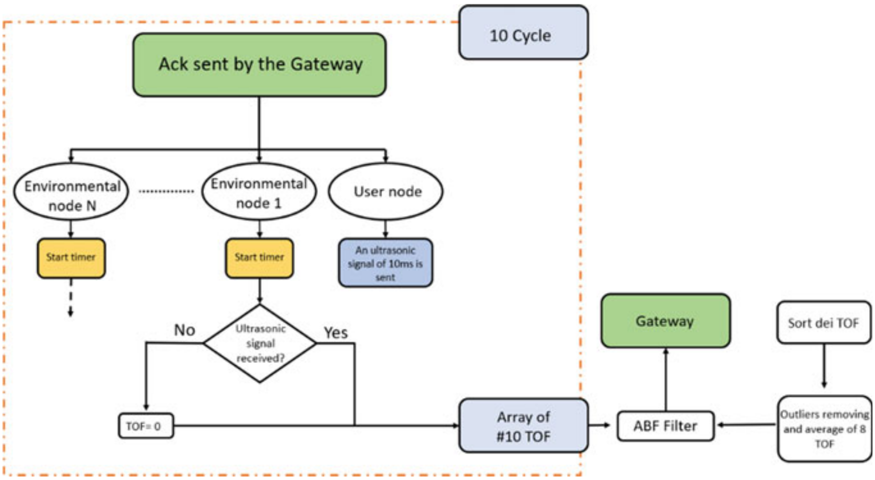

Fig. 3 Measuring protocol scheme

c. Each environmental node, once received the ultrasonic signal, stops the counter; the elapsed time is a measure of the time of flight (TOF) between the target and the environmental node;
d. This process is repeated 10 times in order to remove possible outliers;
e. Once 10 TOF are collected they are filtered and averaged (ABF);
f. The TOF are finally sent to the gateway that has the duty to apply the calibration diagram for each environmental node and to apply the MTA algorithm.

3 Preliminary Results

Each environmental node has been subjected to a static metrological characterization process in order to pick up the fundamental parameters useful for the correct coordinate estimation. In particular the calibration diagram, and the related uncertainty, has been computed.

The static characterization has been carried out for the following distances: 50, 100, 200, 500, 550, 600 cm. Each measure has been repeated 10 times. In Fig. 4 are reported the transduction and calibration diagram for one of the five environmental nodes along with the uncertainty associated with the model.

The results show that an uncertainty in the order of few centimeters is achievable in the single TOF measurements and hence this can guarantee an accurate and precise estimation of the user coordinate once the whole system will be characterized dynamically.

For debugging purpose, a LabView GUI, providing a visual feedback of the user position in the space, has been developed; some shots of the video produced are reported in Fig. 5.

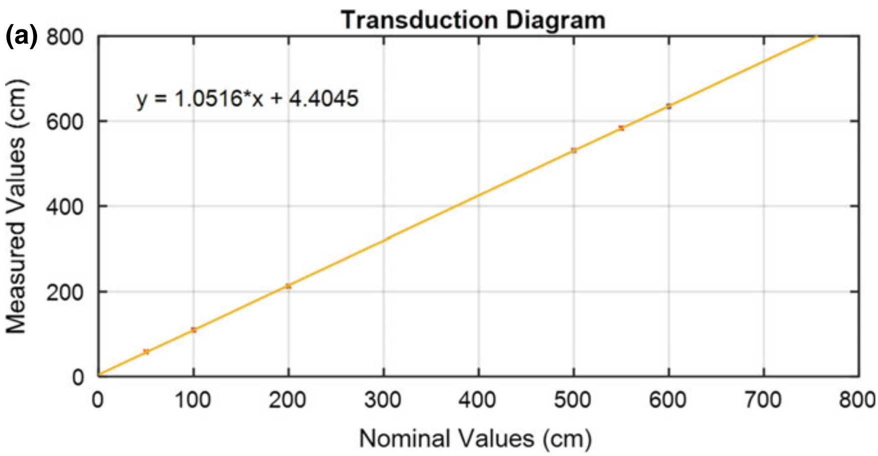

Fig. 4 **a** Transduction diagram and **b** calibration diagram along with its 3σ uncertainty band (dotted lines in the plot)

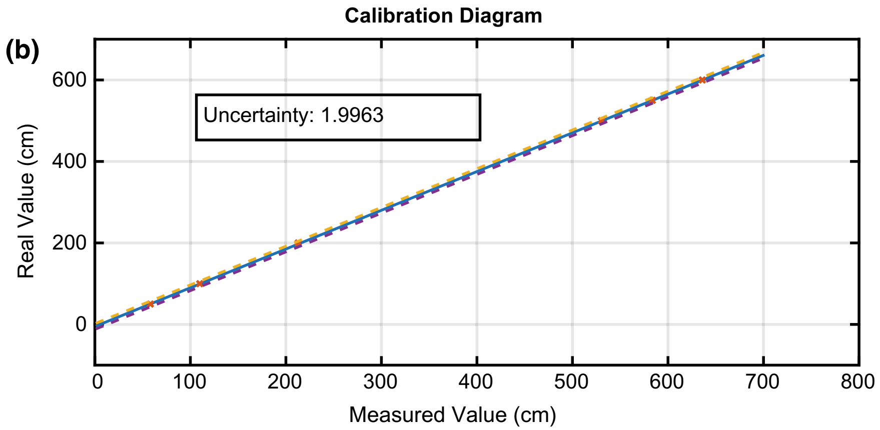

Fig. 4 (continued)

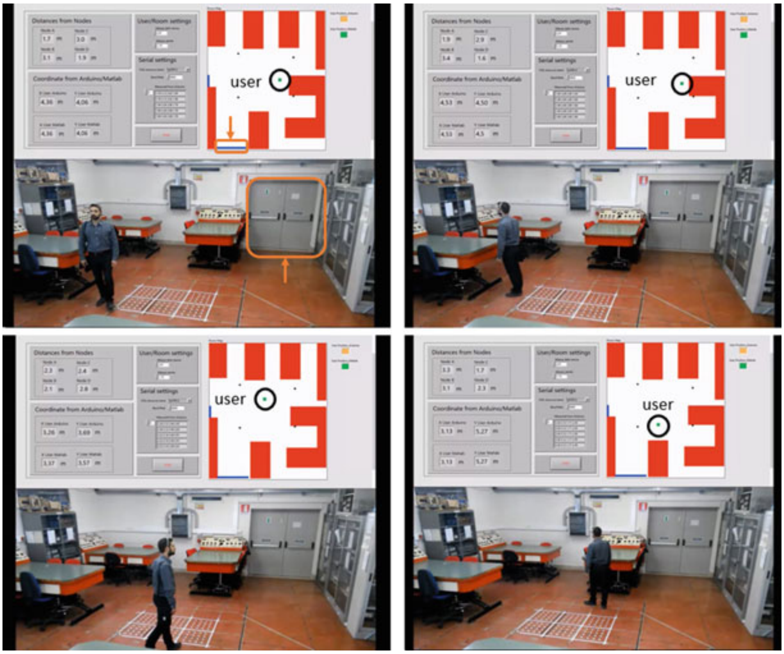

Fig. 5 Snapshot of the video showing how the system behave in real a scenario

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References

1. Yassin A, Nasser Y, Awad M, Al-Dubai A, Liu R, Yuen C, Aboutanios E (2017) Recent advances in indoor localization: a survey on theoretical approaches and applications. IEEE Commun Surv Tutor 19(2):1327–1346
2. Buchman A, Lung C Dec (2013) Received signal strength based room level accuracy indoor localisation method. In: 2013 4th International conference on cognitive infocommunications (CogInfoCom). IEEE, pp 103–108
3. Fuchs C, Aschenbruck N, Martini P, Wieneke M (2011) Indoor tracking for mission critical scenarios: a survey. Pervasive Mob Comput 7:1–15
4. Prieto J, De Paz JF, Villarrubia G, De la Prieta F, Corchado JM (2015) Self-organizing architecture for information fusion in distributed sensor networks. Int J Distrib Sens Netw
5. Han D, Jung SH, Lee M, Yoon G (2014) Building a practical Wi-Fi-based indoor navigation system. IEEE Pervasive Comput 13(2):72–79
6. Ni LM, Liu Y, Lau YC, Patil AP (2004) LANDMARC: Indoor location sensing using active RFID. Wirel Netw 10:701–710
7. Liu Y, Dashti M, Zhang J (2013) Indoor localization on mobile phone platforms using embedded inertial sensors. In: 2013 10th workshop on positioning navigation and communication (WPNC). IEEE, pp 1–5
8. Li F, Zhao C, Ding G, Gong J, Liu C, Zhao F (2012) A reliable and accurate indoor localization method using phone inertial sensors. In: 2012 Proceedings of the ACM conference on ubiquitous computing, UbiComp'12, New York, NY, USA. ACM, pp 421–430
9. Beauregard S, Haas H (2006) Pedestrian dead reckoning: a basis for personal positioning. In: Proceedings of the 3rd workshop on positioning, navigation and communication, pp 27–35
10. Bajo J, De Paz JF, Villarrubia G, Corchado JM (2015) Self-organizing architecture for information fusion in distributed sensor networks. Int J Distrib Sens Netw, 2015
11. Zhou M, Tang Y, Nie W, Xie L, Yang X, Grass MA Graph-based Semi-supervised manifold alignment for indoor WLAN Localization. IEEE Sens J 17(21):7086–7095. https://doi.org/10.1109/JSEn.2017.2752844
12. Alikhani N, Amirinanloo S, Moghtadaiee V, Ghorashi SA (2017) Fast fingerprinting based indoor localization by Wi-Fi signals. In: 2017 7th International conference on computer and knowledge engineering (ICCKE), Mashhad, pp 241–246. https://doi.org/10.1109/iccke.2017.8167884
13. Fet N, Handte M, Marrón PJ (2017) Autonomous signal source displacement detection and recalibration of fingerprinting-based indoor localization systems. In: 2017 International conference on indoor positioning and indoor navigation (IPIN), Sapporo, pp 1–8
14. Jovicic A, Li J, Richardson T (2013) Visible light communication: opportunities, challenges and the path to market. Commun Mag IEEE 51(12):26–32
15. Danakis C, Afgani M.Z, Povey G, Underwood I, Haas H (2012) Using a CMOS camera sensor for visible light communication. In: 2012 Workshops Proceedings of the Global Communications Conference, GLOBECOM , 3–7 Dec 2012, Anaheim, California, USA, pp 1244–1248
16. Chandgadkar A, Knottenbelt W (2013) An indoor navigation system for smartphones
17. Arias Bellot S et al (2011) Visual tag recognition for indoor positioning
18. Andò B (2008) A smart multisensor approach to assist blind people in specific urban navigation tasks. IEEE Trans Neural Syst Rehab Eng 16(6):592–594
19. Andò B, Graziani S (2009) Multisensor strategies to assist blind people: a clear-path indicator. IEEE Trans Instrum Meas 58(8):2488–2494
20. Andò B, Baglio S, Lombardo CO, Marletta V (2014) An advanced tracking solution fully based on native sensing features of smartphone. In: 2014 Proceedings sensors applications symposium, SAS. IEEE, pp 141–144. https://doi.org/10.1109/sas.2014.6798934
21. Lindo A, García E, Urena J, del Carmen Pérez M, Hernandez A (2015) Multiband waveform design for an ultrasonic indoor positioning system. IEEE Sens J 15(12):7190–7199

22. Murata S, Yara C, Kaneta K, Ioroi S, Tanaka H September (2014) Accurate indoor positioning system using near-ultrasonic sound from a smartphone. In: Proceedings of the 8th International conference on next generation mobile applications, services and technologies (NGMAST'14), Oxford, UK, pp 13–18

Part III
Experiments, Evaluation and Lessons Learnt

Understanding the Interest Toward Smart Home Technology: The Role of Utilitaristic Perspective

Vera Stara, Massimo Zancanaro, Mirko Di Rosa, Lorena Rossi and Stefania Pinnelli

Abstract Every day, innovative devices support healthcare for the escalating needs of the population ageing but the poor adoption hinder their spread older adults. The present study aims to investigate the factors that may influence perceptions and expectations of 306 Italian older adults (M = 74, SD = 7.43) towards smart home and wellbeing technology. A questionnaire was verbally administered in face-to-face sessions by trained interviewers in order to collect data. Overall, the results return a positive picture of participants' perception of the technology though attitude towards technology is definitely driven by utilitaristic means: usefulness, easiness, safety and privacy are considered important while aesthetics, size and weight are not. Around half of our respondents have a positive interest in technology and almost all of them believe that technology may eventually improve their life. According to these findings, the paper discusses some challenges for the whole research sector that appears still fragmentary and lacking of a strong body of evidence. Moreover, the promotion of trust and empowerment actions through instructional programs is highlighted.

Keywords Smart home technology · Active ageing · Utilitaristic perspective

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1 Introduction

Advancements in Information and Communication Technologies (ICTs) have enabled the creation of artifacts to cope with the escalating needs of the population ageing. This unprecedented demographic change and the expected increase of health demand is going to lead for a rising demand for innovative services aimed to support this increasing worldwide phenomenon [28].

In particular, there is a growing interest in the so-called "smart home" and "home health monitoring" technologies: unobtrusive interactive technologies deployed in the homes that aimed at assisting older adults in their own independent life while ensuring safety and a sense of control [1]. Every day, these devices support healthcare for purpose including disease prevention, monitor both physical and cognitive status and treatment, fitness and wellbeing as well as medication dispensation [7].

Indeed, a wide range of devices are already available on the market, such as, passive and active sensors, monitoring systems, environmental control systems and electronics aids to daily living. However, they often have relative poor acceptability and, consequently, low adoption [12] among older adults, a wide target group that differs by age, sex, degree of impairment, lifestyle and existential needs, income, education, religion, culture as well as technology experience [10, 11, 20, 25, 27, 29, 35, 40].

Nevertheless, this low adoption, several studies suggest that older adults are a growing group of users [36] when technologies meet their needs and expectations [6, 11, 19, 39]. This approach is not recent by the fact that since 2005, according to McCreadie and Tinker, the interactions between a 'felt need' for assistance, the recognition of 'product quality'—the efficiency, reliability, simplicity and safety of the technology, and its availability and cost, are the basic components of a complex model of acceptability for assistive technology to older people. Similarly, Melenhorst et al. in [19] suggested that the lack of perceived advantages, or benefits, might explain older adults' reluctance to use digital technologies. According to [6], the perspective of older adults towards new technologies might be assumed to be that of the "perpetual beginners" for which efficiency, reliability, simplicity and safety as well as the advantages and benefits need to be often restated and assured. Most recently, biophysical and psychosocial factors have being seen as overlooked factors to take into account to understand how older adults interact successfully with technological devices and systems [5]. An integrated approach to identifying enablers and barriers to older adults' adoption of technology is proposed by Lee and Coughlin [15] that classify common themes and concepts in the field of gerontology, information technology, behavioural sciences, human factors, consumer studies and design. Factors such as usability, affordability, accessibility, emotion, confidence, independence, compatibility, reliability, social, technical support, and cost represent the complex and multiple aspects of a comprehensive understanding of older adults as users and consumers of technology next to other factors such as the perception of the real advantage and system trusts, which the user has towards technology for health [14]. Several studies report older adults' perceptions and expectations towards features of smart home care technologies [17, 23, 24]. These findings suggest that older users are open to the idea of living in smart environment if this technological advancement would guarantee to stay in their own homes and improve their quality of life [13] but at the same time, if the technology does not conflict with the changing emotional perspective that older adults have toward their homes [16].

The aim of this paper is to contribute to the understanding of older adults' perceptions and expectations on technology by investigating the factors that may influence the acceptance of technologies in terms of interest and willingness to pay for technological tools to keep an active aging. Specifically, these two dimensions are particularly significant in predicting the possibilities for timeless continuity in the users' use of technical aids in autonomy and to orient the areas of development and investment of specialized companies.

2 Method

This study was part of a user requirement analysis for the design of the "Active Ageing@home" project (acronym AA@H), financed by the Ministry of Education, aggregating public/private partnership set up by a network of companies, National Centres of Research and the Universities of Ancona, Trento and Lecce. The AA@H project aims to develop services for older people in order to improve their quality of life, to promote an independent life and maintain processes of self-determination, through the use of ICT solutions such as smart-sensors, smart-actuators and smart-devices integrated into a context-aware scalable platform, aimed at assist and monitor users in their own life environment. Specifically, this paper sought to explore the attitudes of users to some possibly features of the platform (in particular, video monitoring devices and sensors) that can be installed at home. The research group aimed to explore their opinions on perceived usefulness and to guide the development of research and the technology implementation goals. In order to assess perceptions and expectations of Italian older adults towards smart home and wellbeing technology, data was collected on three Italian regions: Trentino Alto Adige region, in the North; Marche region, in the central area and Puglia region in the South. The three Regions may be considered representative of the socio-economic differences throughout the Country.

2.1 Participants

From November 2014 to April 2015 a sample of older adults was contacted via both personal acquaintances and social services in each Region. Inclusion criteria were: male and female over 65 years old, in good or moderate health status, living alone or with their relatives but without the assistance of a professional of familiar caregiver. People were identified by a non-probabilistic snow ball sampling.

Each participant was initially informed (in a simplified way) about the nature and the purpose of the study and asked to sign a release form for the use of data in anonymized and aggregate form.

Then a questionnaire was verbally administered in a face-to-face session by a trained interviewer who filled the response on a paper version of the questionnaire (using a paper version was preferred in order to maintain a personal connection with the respondent). The interviewers were instructed to provide further explanations to the questions if needed. This aspect might have introduced some biases, since the interviewers were different from each region, but it was deemed necessary in order to keep a friendly social context during the interview and to avoid misinformed responses [4].

The total sample has been of 306 questionnaire: 100 from Marche Region, 104 from Puglia Region and 102 from Trentino Region.

2.2 Survey Protocol and Data Collection

The questionnaire consists of 20 items on 4 areas:

(1) Socio-demographic information. This area included age, gender, educational level and other information that might be useful to control the sample and as confounding variables in the interpretation of the data.
(2) Users' needs. This area included items from the framework of the International Classification of Functioning, Disability and Health (ICF) of the World Health Organization to analyze the needs of the community aged over 65. In line with the ICF's suggestions, we decided to guide respondents in their selection of priority needs by framing questions around functions or activities deemed most important for older people in maintaining their independence. Respondents were asked to rate and rank the list associated with each need.
(3) Experience with technology. This dimension assess the respondent's familiarity and experience with different technology. It was generated based on standard CREATE materials and the Technology Experience Questionnaire [8].
(4) Technology demand and costs. This area investigated the drivers for the demand of technology on the users' side and what are the costs considered reasonable.

The items were structured as rating scale (either 4 or 5-point). Table 1 summarizes the dimensions and the items used.

2.3 Data Analysis

At first, characteristics of the participants such as age, gender, education, living arrangement and social status were analyzed (results not shown in table). Distribution of perceived needs were analyzed by means of proportions for each function/activity

Table 1 Design of the questionnaire

Dimension	Variable	No. of items	Type of answer
User's need	• Physical and psychological well being • Mobility • Personal and environmental safety • Sociality	4	5-point scale
Attitude toward technology	• Interest on technology • Perceived quality of life from technology • Attributes of technology	3	4-point scale
Demand and cost	• Role of recommendations • Factors affecting purchase decision • Willingness to buy • Income spent towards technological support	4	5-point scale and multiple choise

in a 5-points scale ranging from "not important at all" to "really important". The same analysis was performed also for interest in technology (4-points scale), if technology improved user's life (yes/no), willingness to pay (6-points scale) and reasons to by technology (5-points scale).

In a second step, user's need were grouped into four main variables and evaluated through measure of central tendency (mean, median, sd) in order to rank them by importance.

Third, needs were compared with interest towards technology through Kruskal-Wallis equality of population rank test. Finally, in order to evaluate the impact of user need on interest toward technology and willingness to pay, two separate logistic regression were performed. Both models were adjusted for Age, gender and education.

All analyses were carried out using SPSS version 17.0 (SPSS Inc., Chicago, IL, USA) and STATA version 11.2 Statistical Software Package for Windows (StataCorp, College Station, TX, USA).

3 Results

3.1 Descriptive Statistics

The respondents was 39% males (n = 118) and 61% females (n = 188) with a mean age of 74 years (median = 74; sd = 7.43). The majority (60.5%) were living with a partner. Several of them (56.5%) lived together with their children. Still, 26.1% of respondents lived alone. The level of education was relatively low with an average of 8.90 years of education (sd = 4.51). Specifically, 1.3% did not have any degree, 44.1% had a primary school degree only, 18.09% had a middle school degree, 24.4 had a college degree and 11.51% had a university degree. The overall majority (93%) was retired from work.

Among the technology used by our respondents, a large majority (88%) owned the mobile phone but among them 14.1% declared they are not using it at all and other 29.7% said they were using it not much. Only 16.9% had a smartphone but 86.93% of them were not using it. We had similar figures for the tablet (10.1% had one but 90.52% had never used) and the computer (35.52% had one but 71.6% did not use it). The media which is most used is TV: 98.7% of respondents had one and 59.15 declared to watch it "always", only 2.9% declared not to watch it.

For what concerns the needs, as explained above, we explored them with 4 scales: Physical and Psychological Well Being, Mobility, Personal and environmental security, and Sociality. Their distributions are shown in Table 2.

It is worth noting that all the items are quite skewed on the higher scores and, apparently, none of them is linearly distributed. All the scales have a reasonably high internal coherence: *Physical and Psychological Well Being* alpha = 0.8399, *Mobility* alpha = 0.8752, *Personal and environmental security* alpha = 0.7315 and sociality alpha = 0.8215. In the analysis below, the scale are considered as individual variables with value as the average of the values of the items. Table 3 reports the distributions.

For what concern the experience with technology, Fig. 1 reports the distribution (in percentage) of the value attributed to usefulness (89.6% regards it as important or very important), easiness (92.1% regards it as important or very important), aesthetics (30.08% regards it as important or very important), size (54.08% regards it as important or very important), weight (65.4% regards it as important or very important), security (92.4% regards it as important or very important) and privacy (87.2% regards it as important or very important).

Table 4 reports the distributions (in percentage) of the interest toward the use of technology and the perceived impact of technology on life. The two variables are not normally distributed.

Finally, for what concerns the dimension of demand, we considered the willingness to pay that is, how much they would consider to spend for buying technological artefact. As a control, we also asked our respondents how much they had recently spent on technology. Table 5 reports the distributions (in percentage). We also investigated the reasons to buy technology, Table 6 reports the distribution (in percentage).

Table 2 Variables about user's needs

Variable	Functions or activities	Really not important	Not important	Rather important	Important	Really important
Physical and psychological well being	Health status	2.0	2.6	5.2	9.8	80.4
	Lifestyle	3.3	3.0	8.2	21.0	64.6
	Vital signs monitoring	3.3	5.4	9.0	14.7	67.6
	Cognitive decline slowing	5.9	3.0	6.3	18.2	66.7
	Loneliness and depression reduction	11.9	4.8	8.5	12.6	62.2
Mobility	Indoor mobility	8.2	3.0	8.2	18.1	62.5
	Outdoor mobility	8.6	4.0	8.9	19.2	59.3
	Deambulation	9.4	3.3	8.4	16.7	62.2
	Monitoring/prevention falls	10.7	5.0	5.7	23.4	55.2
Personal and environmental security						
	Home safety	8.0	4.3	8.0	15.6	64.2
	Alarm and family contact	9.3	2.7	9.7	15.3	63.0
	Automatic home control	27.3	11.8	14.5	14.5	32.0
Sociality	Relation with friends and relatives	4.6	2.7	11.9	17.9	62.9
	Relation with new friends	9.6	14.2	19.5	16.8	39.9
	Social inclusion	10.0	10.0	22.3	14.6	43.2

Table 3 Distribution of perceived needs (mean, median, standard deviation)

	Mean	Median	SD
Psycho-physical wellbeing	4.4	4.6	0.9
Mobility	4.2	4.5	1.1
Ambient and personal safety	3.8	4.0	1.1
Sociality	3.9	4.0	1.1

Table 4 Distribution of the interest toward the use of technology and the perceived impact of technology on life (in percentage)

	Not at all	Slightly	Moderately	A lot
Interest in technology	17.9	27.5	33.4	21.2
	No	Yes		
Technology improved your life	10.0	90.0		

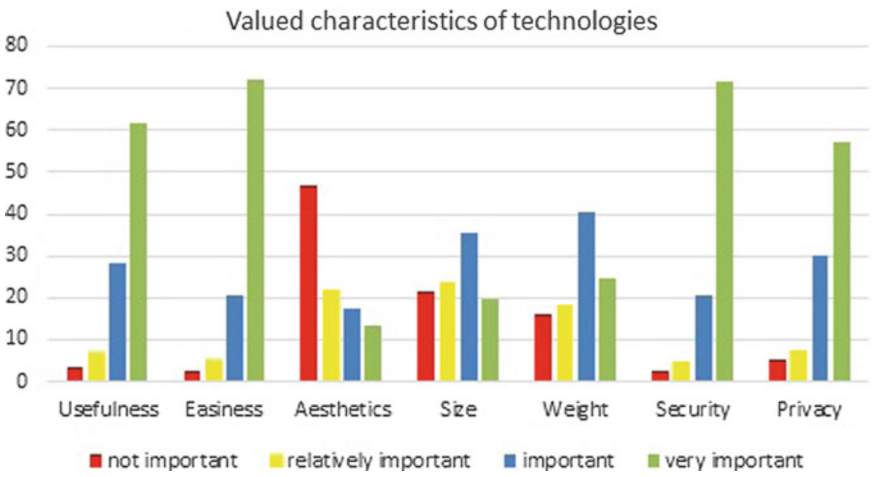

Fig. 1 Importance attributed to different characteristics of technologies (in percentage)

Table 5 Distribution of the willingness to pay and how was recently spent on technology (in percentage)

	None	Less than €100	From €200 to €500	From €500 to €1000	From €1000 to €2000	Over €3000
How much would spend in technology	19.7	9.6	24.1	20.1	14.5	12.1
How much recently spent	59.5	19.4	11.8	4.3	3.2	1.8

3.2 *Inferential Statistics*

There were no statistical difference for what concerns the 4 variables related to the needs with respect to gender, level of instruction and region (Kruskal-Wallis with level of significance 0.05). We were interested in modelling the interest on technology and the willingness to pay. For the sake of simplicity, we dichotomized all the relevant variables.

For the variables related to the needs, we considered the level "high" for the values important and really important and a level of low for the others. Table 7 reports the distribution of the dichotomized variables.

Similarly, we dichotomized the variable of interest toward technology considering the value of "not al all" and "slightly" as a low interest and the others as high interest.

There is a statistically significative difference between the low and the high interest on technology for mobility, safety and sociality (but not on well being). In all cases, a low interest corresponds a lower perception of the need (Table 8).

Table 6 Distribution of the reasons to buy technology (in percentage)

Classes	Really not important	Not important	Rather important	Important	Really important
Health status	2.0	2.4	4.4	9.4	81.8
Easiness of use	1.4	2.4	4.7	16.5	75.1
Cost	4.7	3.7	13.0	18.3	60.5
Comfort level with technology	5.4	7.1	10.9	29.9	46.6
Perceived value	7.6	6.5	16.2	33.5	36.3
Public subsidy	4.4	3.7	5.1	10.4	76.4
Aesthetics of device	33.0	17.9	13.1	19.5	16.5
Availability	7.0	7.0	15.4	27.8	42.8
Physician's recommendation	6.1	2.4	9.2	23.7	58.6
Support by caregivers	7.7	3.5	12.3	19.0	57.5

In order to investigate the relationship between interest and willingness to pay, we ran two logistic regressions to model these variables with respect to the needs. In the model, we also consider gender, age and education as possible correlate (for the sake of simplicity, the latter was dichotomized with none and primary versus the others).

Table 7 Distribution of the dichotomized variables for the needs (values and percentages)

	Wellbeing	Mobility	Safety	Sociality
High	63 (20.6)	80 (26.1)	123 (40.2)	127 (41.5)
Low	243 (79.4)	226 (73.9)	183 (59.8)	179 (58.5)

Table 8 Distribution of the needs with respect to low and high interest (Kruskall-Wallis)

	Wellbeing	Mobility	Safety	Sociality
Low interest	21.5	15.9	11.0	11.0
High interest	22.2	17.3	12.0	12.2
p-value	0.083	0.024	0.003	0.001

Table 9 Logistic regression on interest to technology (dichotomized)

	Odds ratio	Std. err.	P > z
Wellbeing (high vs. low)	0.52	0.23	0.134
Mobility (high vs. low)	1.13	0.43	0.740
Safety (high vs. low)	2.78	0.92	0.002
Sociality (high vs. low)	1.41	0.42	0.252
Education (high vs. low)	2.96	0.91	0.000
Gender (female vs. male)	0.34	0.10	0.000
Age	1.00	0.02	0.914

n = 265; R2 = 0.1447

Table 10 Ordered logistic regression on willingness to pay

	Odds ratio	Std. err.	P > z
Wellbeing (high vs. low)	0.79	0.27	0.493
Mobility (high vs. low)	0.92	0.29	0.799
Safety (high vs. low)	2.00	0.56	0.014
Sociality (high vs. low)	0.68	0.17	0.130
Education (high vs. low)	3.05	0.83	0.000
Gender (female vs. male)	0.59	0.15	0.038
Age	1.01	0.02	0.577
cutoffs			
Less than 100€	−1.55	1.25	
From 200€ to 500€	−0.96	1.24	
From 500€ to 1000€	0.19	1.24	
From 1000€ to 2000€	1.21	1.24	
More than 3000€	2.28	1.25	

n = 265; R2 = 0.1447

Table 9 reports the results of the logistic regression for interest on technology and Table 10 the results of the logistic regression for the willingness to pay. In both cases, the only variables for the needs that contributes to explain the respective target is safety and in both cases the level of education and gender are significative. As it can be noted from the odds ratios, an increase in the need of safety brings an increase in interest as well as in the willingness to pay. Similarly, people with higher education are more interest and willing to pay more and male are more interest and more willing to pay than female. The other needs as well as age do not have influence in our model.

4 Discussion and Implications

Overall, our results provides a positive perspective of older adults' perceptions of the technology. The senior respondents in this study seem to consider psycho-physiological needs the most important ones to be satisfied by technology. In particular, health and lifestyle monitoring are the most desirable functions that could be provided. Mobility needs come after. Safety and socialization follows (with the exception of the relationships with family both in terms of contacting the family in case of alarms and improving the relationships with the relatives). Expanding the social networks is seen as a less desirable need to be addressed by technology. The consolidated idea of interpersonal relationships is, for the sample examined, a direct, face-to-face interaction that can not be replaced by technological devices except in the case of sending alarm situations and therefore not related to the affective sphere Emotions of relationships but of functional ones. These results might support recent studies on social media [21, 26], discussing how older adults did not expect any benefit or relevance from technology in everyday living.

Indeed, around half of our respondents have a positive interest in technology and almost all of them believe that technology may eventually improve their life. Yet, their attitude toward technology is definitely driven by utilitaristic means: usefulness, easiness, safety and privacy are considered important while aesthetics, size and weight are not. The utilitaristic prominence is also confirmed by the characteristics deemed as important when considering purchases: again, the relation with their own health status is the most important characteristic together with the recommendation from their physician. Also in this case, easiness of use is considered important while aesthetics is not. Furthermore, cost is a concern and the possibility of receiving public subsidy is considered important. Again, the latter confirm the strong utilitaristic perspective and it is also consistent with several studies ([2, 15, 33]). This aspect is understood in the general perspective of the elderly person, for whom, often and unfortunately, the only priority in maintaining a good quality of life is the health care system.

The analysis conducted in this study shows that technologies providing some potential usefulness and ease to use are well accepted and this results seems to suggest that older adults who participated in the study are aware of the benefits of technology. In accordance to other studies, the results of that study suggest that older adults' relationship with technology is much more complex and the stereotype that older adults would be afraid and unwilling to use technology is wrong [33]. Yet, we found that the sense of safety is a strong mediator for interest and willingness to buy. The models show that among the 4 needs, the only one that directly influence both the interest to technology and the willingness to buy is the need for safety (together with gender and level of education but not directly the age). Indeed, the sense of safety is an important dimension for healthy ageing, quality of life and aging well, but little is still known about how to promote it [3, 9, 22, 24, 34, 38].

It is well understood that the majority of elderly people prefer to stay and live independently in their own homes having control of the domestic environment (safety), with the hope to remain autonomous as long as possible (independence), in a good functional status (health and wellness), being part of everyday life in their family, neighbour and community (social inclusion), free of moving to reach things or to train the body (mobility). Consequently, people over 65 tend to accept technologies that are perceived as functional to these needs and are less likely to accept those with unclear evidence of personal benefit ([2, 15, 31, 32, 33], 37).

If the sense of security is a key determinant for the acceptance and the willingness to buy technologies, new challenges will emerge not only for smart home care technologies market but also for the whole research sector on aging and technology. Indeed, this field is still far from defining a unique identity despite its early work since 1980 [28], due to a lack of researches that involve multidisciplinary team. Thus, the first challenge is to act synergically to establish an agreed proof of concepts among the diverse scientific approaches in order to overcome the fragmentary research effort that seems to affect the interest on aging and technology. It could be the greatest opportunity to better understand how and why community dwelling older adults approach technology.

The second challenge is to drive technology to satisfy the fundamental need of older adults. Unfortunately, despite the recognition of the impact of users needs on adoption of technology by older adults, many existing technologies are poorly matched to the real need faced by the majority of person aged 65 and older. The evaluation of the degree to which a technology matches users 'needs and the capacity of technologies to address and characterize individual wants still remain an open issue in the field [33]. Much more effort need to be spent on this side to build a strong body of evidence in the literature as well as to find methodological standards for evaluating how technology can really enhance the quality of life of older people.

A related challenge is the promotion of trust and empowerment toward technologies especially in those users experiencing cultural resistances and concerns toward technology enabled care. This target population is usually less exposed to the use of new technologies considering that they have left both the educational system and the workplace before the widespread introduction of ICT [8]. This lack of experience and knowledge determines a consequently lack of motivation and reasons to reject ICT devices. Moreover, age-related decline (i.e. vision decline, hearing loss, motor skill diminishment), and cognitive effects (i.e. trouble remembering names, trouble remembering the flow of a conversation, an increased tendency to misplace things), make new technologies difficult to use [30].

Strategies based on spreading awareness and knowledge about technology's benefit and utility could be keys enablers to build or increase users' trust and empowerment in smart home technologies. The promotion of trust and empowerment actions are strictly related to instructional program and support. Since modern devices and systems are often perceived as complex, difficult to control and error-inducing, the introduction of innovative services requires training to develop, adapt and guide users' digital skills. Clear instructional materials and technical support could act as facilitators for those users who experience unfamiliar features, options and information in technology. As a consequence, older adults could enhance their responsibility and awareness over health and wellbeing, their motivation in using new devices as well as in treatment compliance. Furthermore, this empowerment could lead to a more participative role in monitoring their own health status.

The principal strength of the present study is to have enrolled a relatively large sample of older adults in three different Italian regions that may be considered representative of the socio-economic differences in Italy. Nevertheless, there might be some weaknesses in the study. We only interviewed participants in city areas with a dense network of public transportation, numerous community and senior centers, as well as easily accessible technological stores. The experiences of our participants may be substantially different from those individuals living in rural areas. Furthermore, the study analyzed the positions of older persons that had to adapt to a technological context at an advanced age of their life. Their point of view, therefore, is that of digital immigrants who have limited technological confidence. Probably when attentive generations of fifty years will enter the silver age, the process of adaptation and delegation with regard to technological aids will be changed and, consequently, the expectations and demands will be different.

Still, we believe that the results reported may shed an interesting light on the ongoing research on design of technological artefacts for older people.

5 Conclusion

In this study, we present a survey study that highlights a several useful details to inform the development and implementation technological artefacts for older people. Our evidences suggest a central role of an utilitaristic perspective on technology and the role of safety to increase the interest and the willingness to buy. It also highlights some issues, such as the relevance of gender and level of education in accepting the technology: that implies that it is important to increase the education among older adults, in particular women and less educated people, about the benefit they might get from technology. Furthermore, we discuss some challenges for the whole research sector that seems to not have achieve yet a unique identity. First, there is the strong need to overcome the fragmentation of different scientific approaches through the establishment of an agreed proof of concepts among all disciplines interested on aging and technology. Secondly, the study on how technology can really enhance the quality of life of older people deserves much more efforts to reach the required body of evidence and the related methodological standards. Finally, the promotion of trust and empowerment toward technologies among older adults experiencing cultural resistances and concerns toward innovative devices is an action to be strictly planned when tackling the barriers to the uptake of technology enabled care.

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References

1. Adair B, Miller K, Ozanne E, Hansen R, Pearce AJ, Santamaria N, Said CM (2013) Smart-home technologies to assist older people to live well at home. J Aging Sci
2. Arning K, Ziefle M (2007) Understanding age differences in PDA acceptance and performance. Comput Hum Behav 23(6):2904–2927
3. Boström M, Bravell M, Lundgren D, Björklund A (2013) Promoting sense of security in old-age care. Health 5:56–63. https://doi.org/10.4236/health.2013.56a2009
4. Bowling A (2005) Mode of questionnaire administration can have serious effects on data quality. J Public Health 27(3):281–291. https://doi.org/10.1093/pubmed/fdi031
5. Chen K, Chan AH (2011) A review of technology acceptance by older adults. Gerontechnology 10(1):1–12
6. Conci M, Pianesi F, Zancanaro M (2009, August) Useful, social and enjoyable: mobile phone adoption by older people. In: IFIP conference on human-computer interaction. Springer, Berlin, Heidelberg, pp 63–76
7. Costa F (2014) Big data in biomedicine. In: Drug discovery today, vol 19, Issue 4, pp 433–440. ISSN 1359-6446, https://doi.org/10.1016/j.drudis.2013.10.012
8. Czaja SJ, Charness N, Fisk AD, Hertzog C, Nair SN, Rogers WA, Sharit J (2006) Factors predicting the use of technology: findings from the center for research and education on aging and technology enhancement (CREATE). Psychol Aging 21(2):333
9. Demiris G, Rantz MJ, Aud MA, Marek KD, Tyrer HW, Skubic M, Hussam AA (2004) Older adults' attitudes towards and perceptions of 'smart home' technologies: a pilot study. Med Inform Internet Med 29(2):87–94
10. Farage MA, Miller KW, Ajayi F, Hutchins D (2012) Design principles to accommodate older adults. Glob J Health Sci 4(2):2
11. Fisk AD, Rogers WA, Charness N, Czaja SJ, Sharit J (2009) Designing for older adults: principles and creative human factors approaches. CRC press
12. Hill R, Betts LR, Gardner SE (2015) Older adults' experiences and perceptions of digital technology: (Dis) empowerment, wellbeing, and inclusion. Comput Hum Behav 48:415–423
13. Jacelon CS, Hanson A (2013) Older adults' participation in the development of smart environments: an integrated review of the literature. Geriatr Nurs 34(2):116–121
14. Jimison H, Gorman P, Woods S, Nygren P, Walker M, Norris S, Hersh W (2008) Barriers and drivers of health information technology use for the elderly, chronically Ill, and underserved. Evidence Report/Technology Assessment No 175. AHRQ Publication No 09-E004. Agency for Healthcare Research and Quality, Rockville, MD, Nov 2008
15. Lee C, Coughlin JF (2015) Perspective: older adults' adoption of technology: an integrated approach to identifying determinants and barriers. J Prod Innov Manag 32(5):747–759
16. Leonardi C, Mennecozzi C, Not E, Pianesi F, Zancanaro M, Gennai F, Cristoforetti A (2009, April) Knocking on elders' door: investigating the functional and emotional geography of their domestic space. In: Proceedings of the SIGCHI conference on human factors in computing systems. ACM, pp 1703–1712
17. Liu L, Stroulia E, Nikolaidis I, Miguel-Cruz A, Rios Rincon A (2016) Smart homes and home health monitoring technologies for older adults: a systematic review. Int J Med Inform 91:44–59
18. McCreadie C, Tinker A (2005) The acceptability of assistive technology to older people. Ageing Soc 25(01):91–110
19. Melenhorst AS, Rogers WA, Caylor EC (2001, October) The use of communication technologies by older adults: exploring the benefits from the user's perspective. In: Proceedings of the human factors and ergonomics society annual meeting, vol 45, no 3. SAGE Publications, pp 221–225
20. Mitzner TL, Boron JB, Fausset CB, Adams AE, Charness N, Czaja SJ, Sharit J (2010) Older adults talk technology: technology usage and attitudes. Comput Hum Behav 26(6):1710–1721
21. Morton TA, Wilson N, Haslam C, Birney M, Kingston R, McCloskey LG (2016) Activating and guiding the engagement of seniors with online social networking experimental findings from the ages 2.0 project. J Aging Health. https://doi.org/10.1177/0898264316664440

22. Nijhof N, van Gemert-Pijnen LJ, Woolrych R, Sixsmith A (2013) An evaluation of preventive sensor technology for dementia care. J Telemed Telecare 19(2):95–100
23. Peek ST, Luijkx KG, Rijnaard MD, Nieboer ME, van der Voort CS, Aarts S, Wouters EJ (2015) Older adults' reasons for using technology while aging in place. Gerontology 62(2):226–237
24. Pol MC, van Nes F, van Hartingsveldt M, Buurman BM, de Rooij SE, Kröse BJA (2014) P315: older people's perspectives regarding the use of sensor monitoring in their home. Eur Geriatr Med 5:S180–S181
25. Porter CE, Donthu N (2006) Using the technology acceptance model to explain how attitudes determine Internet usage: the role of perceived access barriers and demographics. J Bus Res 59(9):999–1007
26. Quinn K (2016) 10 Older adults and social media. Digital media usage across the life course, p 132
27. Sarker S, Wells JD (2003) Understanding mobile handheld device use and adoption. Commun ACM 46(12):35–40
28. Schulz R, Wahl HW, Matthews JT, Dabbs ADV, Beach SR, Czaja SJ (2014) Advancing the aging and technology agenda in gerontology. Gerontology gnu071
29. Seeman TE, Lusignolo TM, Albert M, Berkman L (2001) Social relationships, social support, and patterns of cognitive aging in healthy, high-functioning older adults: MacArthur studies of successful aging. Health Psychol 20(4):243
30. Selwyn N, Gorard S, Furlong J, Madden L (2003) Older adults' use of information and communications technology in everyday life. Ageing Soc 23(05):561–582
31. Spinsante S, Stara V, Felici E, Montanini L, Raffaeli L, Rossi L, Gambi E (2016) The human factor in the design of successful ambient assisted living technologies. Ambient assisted living and enhanced living environments. Princ Technol Control 61
32. Stara V, Harte R, Di Rosa M, Rossi L, ÓLaighin G (2016) Toward a connected health system for older adults: lessons learned. In: Advances in physical ergonomics and human factors. Springer, Cham, pp 849–857
33. Thielke S, Harniss M, Thompson H, Patel S, Demiris G, Johnson K (2012) Maslow's hierarchy of human needs and the adoption of health-related technologies for older adults. Ageing Int 37(4):470–488
34. Van Hoof J, Kort HSM, Rutten PGS, Duijnstee MSH (2011) Ageing-in-place with the use of ambient intelligence technology: perspectives of older users. Int J Med Inform 80(5):310–331
35. Venkatesh V, Davis FD (1996) A model of the antecedents of perceived ease of use: development and test. Decis Sci 27(3):451–481
36. Vroman KG, Arthanat S, Lysack C (2015) "Who over 65 is online?" Older adults' dispositions toward information communication technology. Comput Hum Behav 43:156–166
37. Walsh K, Callan A (2011) Perceptions, preferences, and acceptance of information and communication technologies in older-adult community care settings in Ireland: a case-study and ranked-care program analysis. Ageing Int 36(1):102–122
38. Wild K, Boise L, Lundell J, Foucek A (2008) Unobtrusive in-home monitoring of cognitive and physical health: reactions and perceptions of older adults. J Appl Gerontol 27(2):181–200
39. Wilkowska W, Ziefle M (2009, November) Which factors form older adults' acceptance of mobile information and communication technologies?. In: Symposium of the austrian HCI and usability engineering group. Springer, Berlin, Heidelberg, pp 81–101
40. Yusif S, Soar J, Hafeez-Baig A (2016) Older people, assistive technologies, and the barriers to adoption: a systematic review. Int J Med Inform 94:112–116

Health360: An Open, Modular Platform for Multimodal Data Collection and AAL Monitoring

Raffaele Conte, Alessandro Tonacci, Francesco Sansone, Andrea Grande and Anna Paola Pala

Abstract Health and care features a strong need for computerised tools providing support in daily life activities, especially among elderly people. Platforms capable of safely collecting several data can represent a useful add-on to the home-care of elderly people, paving the way for a patient empowerment, improving their quality of life without needing for recurrent medical examinations at clinics. Here, we present an open, modular platform capable of collecting multimodal (anamnestic, clinical, etc.) data, gathered through different approaches, including questionnaires, medical examinations, and wearable sensors, usable by the caregiver to remotely check the health status of a patient, without needing for frequent recalls at clinics. The extensive use of this platform will allow the patient performing an automated self-monitoring, eventually with the help of a caregiver directly at home, enabling remote data sharing with General Practitioners, reducing the needs for clinics admittance, without sacrificing the quality of care.

Keywords AAL · Aging · Empowerment · Medical record · Wearable sensors

1 Introduction

Italy has one of the longest life expectancies in Europe (83.9 years for men, 87.2 for women), but the quality of life significantly decreases among over 75s.

Around 50% of over 65s presents at least one serious chronic disease and nearly one-quarter of elderly people displays serious motor limitations, with a deep impact on their life quality and independence [17].

A good part of the national healthcare expenditure, whose overall amount is estimated to be around 112 billion Euros in 2016 [18], is related to the care provision to elderly, mostly non-self-sufficient, people.

Therefore, a strong need for new paradigms of assistance is present, to optimise benefits to the end-users reducing, at the same time, the related costs.

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Patient-centred care is defined as a socio-psychological treatment approach recognising the individuality of the patient in relation to the attitudes and care practices surrounding them [20].

The concept of patient-centred care is progressively shifting the health care systems towards an increased exploration of the so-called *patient empowerment* [30], estimated to ease the patient control through self-management and shared decision-making, and to promote fair, collaborative approaches to healthcare as well as to improve cost-benefit ratios of care delivery [21].

Despite the still unclear definition of the complex concept of patient empowerment, for which debates are still proliferating worldwide (see, for example [30]), patient's self-management appears to be among the most used means to reach such an empowerment, with the use of technology significantly influencing this process.

More specifically, patient portals have become pivotal in patient empowerment, merging information gathered by Medical Doctors at clinics, General Practitioners at ambulatory and directly by the patient at home, taking advantage of personal health devices, including wearable sensors for physiological signal acquisition [2] and mobile Apps [8].

However, few platforms are capable of providing a support in daily life activities of a patient, as well as performing a multimodal (anamnestic, clinical, psychophysiological, etc.) data integration within a single platform [27, 33].

In addition, despite the important evolution of the ICT market in this field [1], mainly fostered by the quick success of solutions for storage and elaboration based on Web technologies and Cloud computing [7] and of mobile devices, recent studies suggest a scarce spread of computerised tools in health and care. This fact is evident even for applications dealing with the clinical management of patients in Hospitals and Scientific Institutes for Research, Hospitalization and Health Care [24]. Therefore, the need for granting the continuing care appears to be strong, possibly through the sharing of the patient's data, even when collected in different locations (hospitals, ambulatories, and directly at home), widespread within the national and European territory.

2 Computerized Systems for Health and Care Data Collection

In the field of health and care, computerised systems include:

- Booking Information Desk (CUP)/Admission-Discharge-Transfer (ADT): such systems are widely computerised and common in both public and private structures;
- Medical records (within a ward): when existing, they are closed, proprietary systems, often provided by biomedical industries or specialised software factories [3]. They are usually quite difficult to be used in small-medium enterprises, due to their complex installation and customisation.

- Radiology Information Systems (RIS)/Picture Archiving and Communication Systems (PACS): normally, they are standard systems, widely employed in both private and public structures. Usually, they can be integrated, often requiring a time-consuming human effort and a significant economic effort (private PACS, resistance by system managers at departmental level) [5];
- Diagnostic instrumentation: in most cases, the manufacturers adhere to the common industrial standard protocols (DICOM, XML, etc.). Generally, they are easy to be integrated [15];
- Laboratory Information Systems (LIS): they are generally digitised. However, data export could require an important, time-consuming human effort and a significant economic investment, as happens with the RIS/PACS [26].

To date, the existing solutions in this field are extremely versatile concerning their configuration, but often exhibit scarcely customisable architectures, which are poorly expandable and scalable a posteriori, rarely allowing the integration with third-parties, including tools and apps.

2.1 Filling in the Gaps: Health360

Differently from several other integrated systems, Health360 can be considered as an interoperable tool allowing external sources to keep their own hardware and software characteristics, to manage their own databases and to exchange only shared information through modules and plug-ins. Its strong points include the capability of overtaking the limitations of existing tools, in terms of limited flexibility and configurability, or excessive personalisation, when not necessary, which could lead to a reduced intuitiveness and practicality: in few words, complexity. Health360 is, therefore, a tool that can integrate existing platforms and is particularly suitable for those applications not satisfactorily covered by traditional, commercial Electronic Medical Record systems, including the management of research projects, specific laboratories or devices fostering the so-called *patient empowerment*, including wearable sensors and related Apps.

Indeed, the system aims at acting as a central hub of several activities dealing with the analysis and the management of several data including, as stated above, anamnestic, instrumental and clinical data, results of questionnaires, physiological signals acquired by wearable systems. Actually, the platform, ready to be used, hosts personal data, vital statistics, including information on risk factors, instrumental exams (including ECG trace and echocardiographic images), data from wearable sensors, results from blood tests, as well as a module for neuromotor assessment, featuring physiotherapy tests and EMG traces. All those data can be retrieved by selected end-users, including clinicians and, in particular cases, by the patients themselves.

2.1.1 System Architecture

Overall, the Health360 system is built following the API-first principles [22], with the API (Application Program Interface) based on ReST (Representational State Transfer) [13] paradigm, whose main advantages include a modular, web-compatible, flexible structure, able to operate also with mixed infrastructures and architectures, including local servers combined with web platforms or, in some cases, cloud [11, 13]. A two-level architecture was designed in order to achieve a good level of scalability and modularity, in compliance with the purpose of the platform. This architecture is composed of a web-accessible User Interface (UI), implemented by a front-end, which performs data aggregation, and a distributed, modular back-end (Fig. 1), where each single module manages a subset of data with an own specific DataBase, whose model can be relational or non-relational (NoSQL) depending on the type of data to be stored. Whenever is possible, NoSQL DB are preferred (as in Core Backend) due to their features in terms of flexibility. Indeed, the NoSQL family includes several DataBase Management Systems that treat data in a non-relational way (key-value, wide column, graph, document, etc.). They usually simplify scalability (thanks to sharding that, in turn, means performance, high availability and speed in write/read operations) and distribution on more servers.

This solution was chosen as it is thought to be more suitable to be used within a web environment, securing a significant operative flexibility [25], placing Health360 as a Software provided as a Service (SaaS) built on a cloud environment [6].

Going into depth with the architectural choices performed, the SILEX framework was employed to develop the whole system, in PHP language. The development of the software was performed using the architectural pattern MVC (Model-View-Controller).

2.1.2 The Health360 Back-End

The back-end is composed by a core module, which is intended to manage the basic information of each subject (they could be a patient of a health centre, a guest of an old-age home as well as an athlete of a sport team). Such information include basic vital statistics, anamnestic data and risk factors, as well as all the connections between patient and the relevant healthcare organisations, among which Emergency Room admissions, visits, hospitalisations, day hospital, day surgery. In addition, the back-end module is in charge of managing some further data related to the medical examinations of the subject.

The schema-less structure of the NoSQL, *document-oriented*, MongoDB database allows to structure the data (semantics and syntax) with high flexibility, defining them on a configuration file, using the YAML syntax [4]. Thus, Health360 can be adapted to different contexts only modifying the attributes managed in a fast and simple way.

Moreover, the modular structure of the Health360 and its back-end, allows to structure further modules, possibly stored on different servers, which can be integrated upon the needs of the end-user. Such modules could store further data sources,

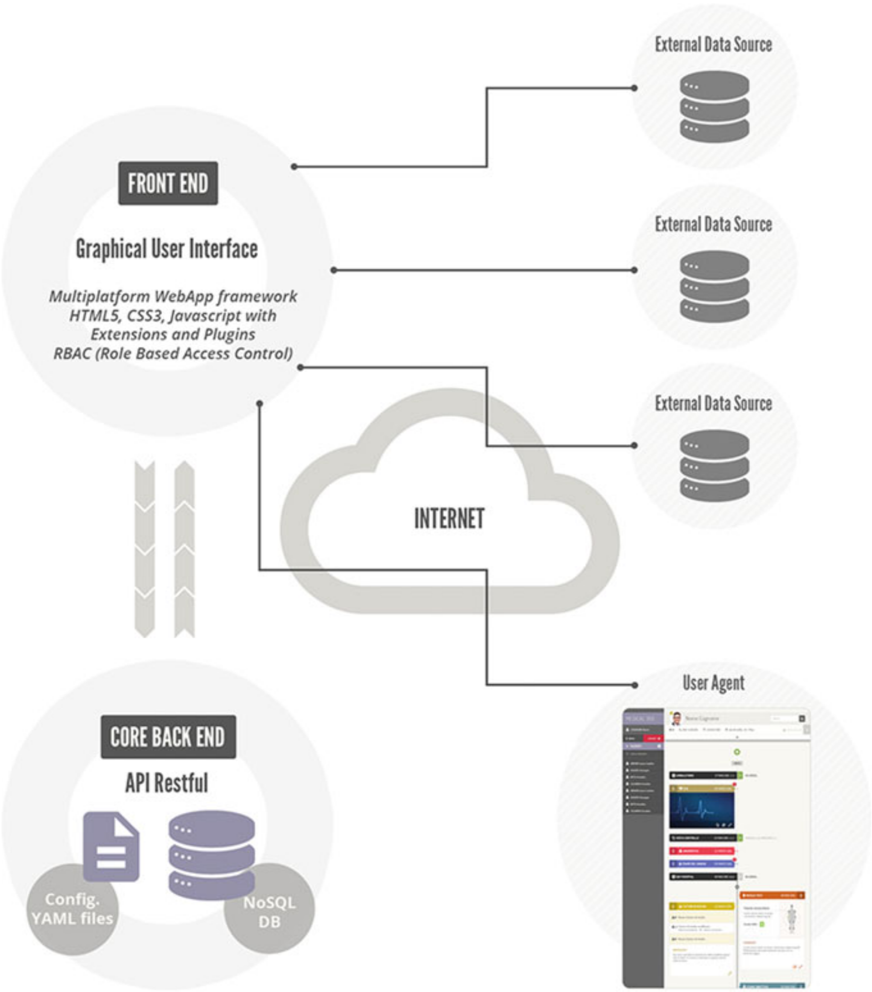

Fig. 1 The Health360 system architecture

including RIS-PACS, screening archives, systems for medical record management, digitised systems for laboratory medicine. Therefore, the classical *join* operation, typical of the relational databases, is here raised at the application level and performed by the front-end module.

2.1.3 The Health360 Front-End

Differently from the back-end, the front-end, developed as a Web Application, aims at retrieving the information derived from the modules of the back-end described

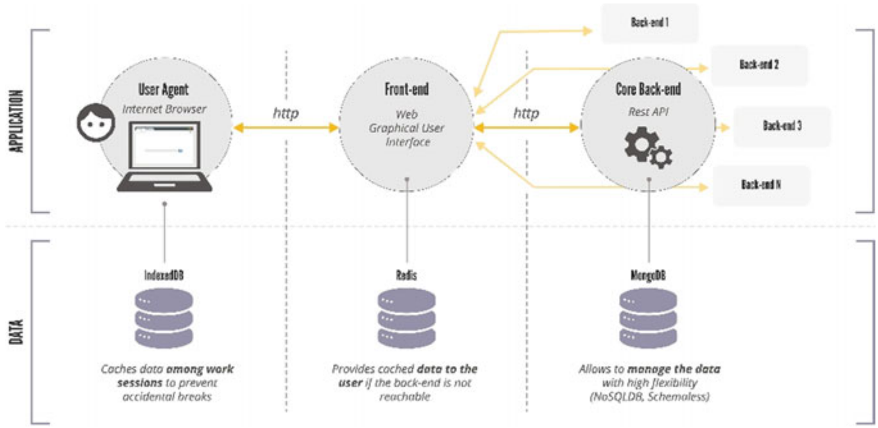

Fig. 2 User Agent, Front-end and Back-end application and data level

above, aggregating them in real-time and presenting them to the user by way of a responsive Graphical User Interface. The communication between front-end and back-end is allowed by the use of the RESTful API, with the CRUD (creation, reading, up-date, delete) operations [14] mapped in the corresponding http methods (POST, GET, PUT and DELETE), applied to the resources managed by the back-end modules and reachable with URLs (uniform resource locator).

This type of architecture is highly based on the presence of good network connectivity but, to overcome network downtimes, two solutions are implemented: a cache DB on the frontend and a cache DB on the User Agent (the web browser).

The aim of the first cache database, built with Redis (an associative, highly fast, NoSQL database) [28], is to provide data to the user also when the data module is not reachable. The information, cached from previous accesses to the module, are returned to the user's requests, in case of loss of connectivity towards the modules back-end, as non-authoritative data (borrowing the concept from the Domain Name Service protocol) [29].

To prevent accidental breaks (unwanted page reloads, browser crashes) a User Agent's level cache is implemented, using Indexed Database API 2.0 (also known as IndexedDB). Although IndexedDB is born with the aim of managing significant amounts of structured data, including files/blobs, enabling high performance searches, it also implements persistency among different sessions, on the same app. A loss of connectivity or a software crash could result unpleasant during, for example, the execution of a clinical test with the measures sent to the front-end at the end of the test (Fig. 2). In this way, an accidentally stopped test can be recovered accessing the same patient. The platform notifies to the user the presence of an incomplete test; in this way, the user can recover or definitely delete it.

Like the back-end, the front-end is also organised with modules, and eventually, with plug-ins. The built-in module is the Patient module (although, as said, the platform can treat subjects in a more general meaning). The data, in the patient module, are organised in two main classes: states and events. A state displays data that are permanently related to the subject (i.e. personal and anamnestic data), while the events display data related to the subject in a specific moment (i.e. the execution of a clinical or instrumental test, a modification on their personal data or the acquisition of a measurement from a remote, personal device) by way of a timeline (see Fig. 3 for an example of the Health360 user interface). Preliminary feedbacks from clinicians (both cardiologists and neurologists) are promising, highlighting the ease of use of the platform from their point of view.

3 Applications of Health360 to Elderly People: AAL and Beyond

As mentioned, the main advantage of the Health360 platform lies in its modularity, flexibility and high customisability upon the needs of the end-users. The AAL approach is somewhat strictly linked to patient engagement and empowerment [9, 31], and acquires importance with the use of personal health devices, such as wearables [2] and mobile Apps [8].

A possible, hypothetic scenario for this application is linked with the monitoring of elderly patients at home through wearable sensors (Fig. 4).

The solution's end-user will be equipped by a network of unobtrusive physiological sensors linked by Bluetooth/Wi-Fi to a customised Mobile App. The data collected by the Mobile App are then sent to Health360 for storage at the back-end level. Once data are stored, they can be accessed by the caregiver, General Practitioner or Specialist for consultation, in order to properly check the health condition of the patient. The consultation of such data by the caregiver will be simplified thanks to some basic principles followed by the computer interface designers which will include, at front-end level, some visual markers (such as different colours: red, yellow, green, depending on the value of some relevant data) helping in data interpretation and triggering eventual alarms in case abnormal values are produced.

Following the principles above mentioned, the patient can be continuously monitored at home and during their daily activities, without the need for frequent visits at the ambulatory or at clinics. This may improve their quality of life, minimising the annoyance caused by visits and clinic admittance, saving time and money and reducing, at a time, the economic burden required to the regional or national health system.

Another possible scenario relies on the application of Health360 to the monitoring of the activity of residents of assisted living facilities (ALF) (see, for example [16]). In such communities, elderly people are often free to leave the structure during the day, in order to improve their quality of life by not forcing them necessarily within the structure. In this framework, mobile Apps can be useful to detect their position and eventually to send messages to the management of the ALF when the person is not coming back late in the evening or when they go too far from the facility avoiding, in this way, serious issues for the subject's integrity eventually arising.

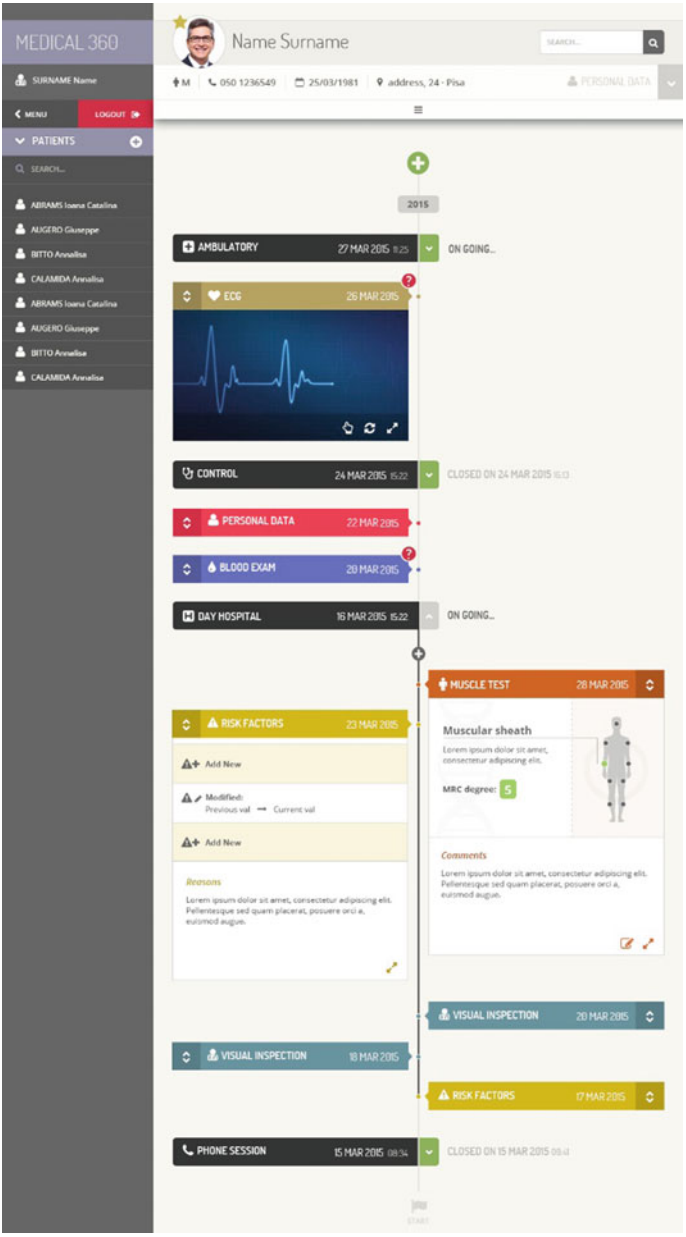

Fig. 3 The Health360 user interface

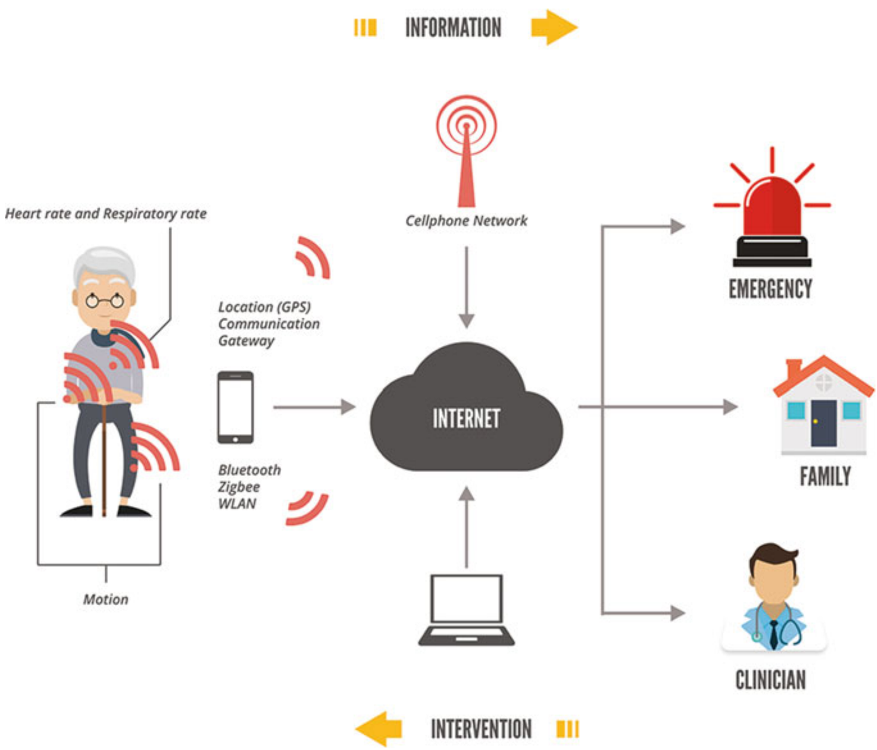

Fig. 4 Scenario for Health360 applied to AAL

Both those potential scenarios will implement the so-called "patient empowerment", which changes the patient's perspective, from an old concept of "passive recipients of healthcare" to a modern, broader idea of "self-determining agents with some control over their own health and healthcare". The use of ICT-based, simple self-monitoring tools (wearable physiological sensors, user-friendly interfaces and web-based tools, etc.) would help patients in successfully accomplish such aims improving, at a time, their quality of life.

3.1 Biomedical Wearable Sensors

Several biomedical wearable sensors could be useful for this purpose. Among the most widely used wearable sensors are accelerometers [10], thanks to their spread in nearly all the mobile devices currently on the market. Such sensors are extremely useful for a variety of purposes, including the estimation of physical activity, gait parameters (stance and swing phase), speed and walking distance. All those parameters can be used to empower the elderly by monitoring their well-being through

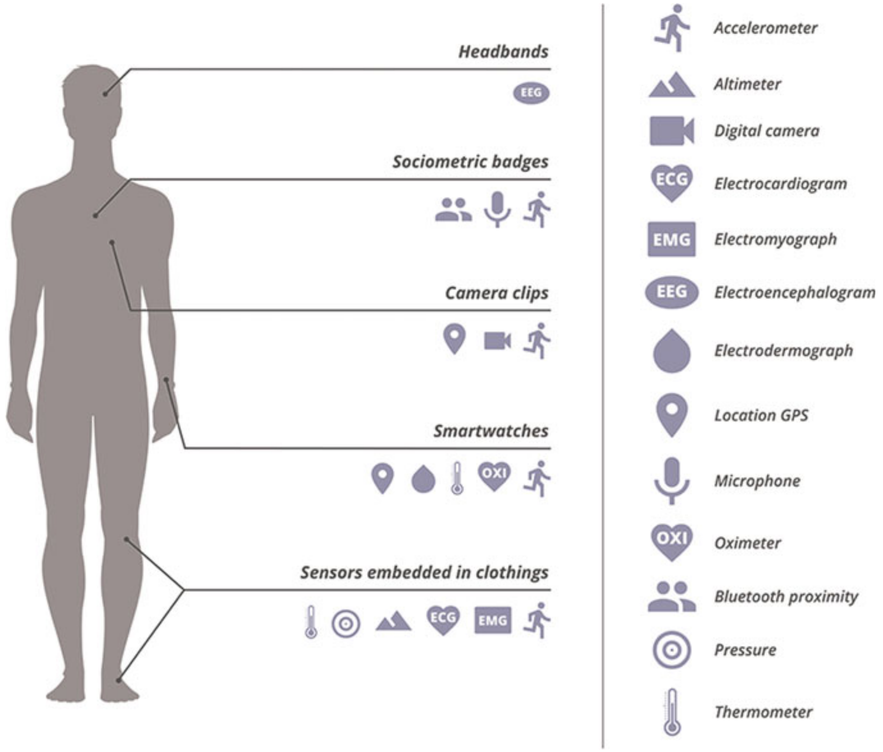

Fig. 5 Wearable sensors for health and well-being

their physical activity, or estimating their gait parameters to early discover eventual neuromuscular diseases.

According to [10], wearables for monitoring electrocardiogram (ECG) are also extremely diffuse. In most cases, such devices are just able to estimate basic ECG parameters, such as the Heart Rate (HR), giving immediate feedback to the end-user, for example within a Mobile App. However, more complex devices have been developed, able to estimate the overall ECG signal at 1-lead or 3-leads, therefore enabling the end-user to check for significant features other than HR, including the Heart Rate Variability (HRV), important for tracking a person's well-being [19].

A number of other wearables are able to estimate important parameters linked to the well-being of elderly subjects, including headbands for electroencephalography (EEG), microphones for voice analysis, temperature and skin conductance sensors, oximeters, pressure and electromyography (EMG) sensors (Fig. 5).

4 Conclusion

Health360, the system here described, is able to collect multimodal data and can find its field of application in various domains, among which AAL can be one of the widest, given the continuous increase of life expectancy in Western countries. Preliminary feedbacks from clinicians (both cardiologists and neurologists) are promising, highlighting the ease of use of the platform from their point of view. The use of Health360, together with the employment of wearable sensors and other smart solutions, will enable the patient to benefit from an effective empowerment, which, when applied at large, could reduce the economic and social burden of ageing to the national healthcare providers and to the caregivers. One of the main advantages of Health360 applied to AAL relies on the architectural design of this solution, conceived for interoperability, therefore allowing the end-user to employ a wide variety of personal self-monitoring devices without sacrificing the good outcome of the measurement, nor the transmission to the data collection platform. Being Health360, based on ReST, JSON and other state-of-art protocols and technologies, it could be seamless enhanced to integrate the Fast Healthcare Interoperability Resources (FHIR) standard [12], designed for the web, whose resources are based on simple XML or JSON structures, with RESTful protocol. Created by the Health Level Seven (HL7) International organisation for health-care standards, FHIR has the goal of facilitating the interoperation between legacy health care systems and of allowing third-party application developers to provide medical applications that can be easily integrated into existing systems. Furthermore, a proxy App will be developed in future to exchange data from the Health360 tool and Apple HealthKit [32] or Google Fit [23] and similar frameworks, for the collection of healthcare-related data from sensors integrated into smartphones and mobile devices.

References

1. Alderete MV (2017) Examining the ICT access effect on socioeconomic development: the moderating role of ICT use and skills. Inform Technol Devel 1:1–17
2. Alharbi M, Straiton N, Gallagher R (2017) Harnessing the potential of wearable activity trackers for heart failure self-care. Curr Heart Fail Rep 14(1):23–29
3. Aminpour F, Sadoughi F, Ahamdi M (2014) Utilization of open source electronic health record around the world: a systematic review. J Res Med Sci 19(1):57–64
4. Ben Kiki O (2005) YAML Ain't Markup Language (YAML) Version 1.2. http://www.yaml.org/spec/1.2/spec.html
5. Creighton C (1999) A literature review on communication between picture archiving and communication systems and radiology information systems and/or hospital information systems. J Digit Imaging 12(3):138–143
6. Cusumano M (2010) Cloud computing and SaaS as new computing platforms. Commun ACM 53(4):27–29
7. Dahlberg T, Kivijärvi H, Saarinen T (2017) Longitudinal study on the expectations of cloud computing benefits and an integrative multilevel model for understanding cloud computing performance. In: Proceedings of the 50th Hawaii international conference on system sciences, https://doi.org/10.24251/hicss.2017.514

8. Davis SW, Oakley-Girvan I (2017) Achieving value in mobile health applications for cancer survivors. J Cancer Surviv 11(4):498–504
9. Demiris G, Thompson H (2011) Smart homes and ambient assisted living applications: from data to knowledge-empowering or overwhelming older adults? Contribution of the IMIA smart homes and ambient assisted living working group. Yearb Med Inform 6:51–57
10. de Arriba-Pérez F, Caeiro-Rodríguez M, Santos-Gago JM (2016) Collection and Processing of data from wrist wearable devices in heterogeneous and multiple-user scenarios. Sensors (Basel) 16(9):E1538
11. Douzis K, Sotiriadis S, Petrakis EGM et al (2018) Modular and generic IoT management on the cloud. Fut Gener Comput Syst 78:369–378
12. FHIR (2014) http://www.hl7.org/implement/standards/fhir/
13. Fielding RT, Taylor RN (2002) Principled design of the modern web architecture. ACM Trans Intern Technol 2:115–150
14. González-Aparicio MT, Younas M, Tuya J et al (2016) A new model for testing CRUD operations in a NoSQL database. In: 30th IEEE international conference on advanced information networking and applications (AINA), pp 79–86
15. Haak D, Page CE, Reinartz S et al (2015) DICOM for clinical research: PACS-integrated electronic data capture in multi-center trials. J Digit Imaging 28(5):558–566
16. Hawes C, Phillips CD, Rose M et al (2003) A national survey of assisted living facilities. Gerontologist 43(6):875–882
17. ISTAT: Anziani: le condizioni di salute in Italia e nell'Unione europea (2017). Indagine europea sulla salute (EHIS) 2015. https://www.istat.it/it/files/2017/09/Condizioni_Salute_anziani_anno_2015.pdf?title=Condizioni+di+salute+degli+anziani+-+26%2Fset%2F2017+-+Condizioni_Salute_anziani_anno_2015.pdf
18. Italian Ministry of Economy and Finances: 2017 Monitoring Report of Healthcare Expenditure (2017). https://welforum.it/wp-content/uploads/2017/09/Rapporto-spesa-sanitaria.pdf
19. Kemp AH, Quintana DS (2013) The relationship between mental and physical health: Insights from the study of heart rate variability. Int J Psychophysiol 89:296–304
20. Kim SK, Park M (2017) Effectiveness of person-centered care on people with dementia: a systematic review and meta-analysis. Clin Interv Aging 12:381–397
21. McAllister M, Dunn G, Payne K et al (2012) Patient empowerment: the need to consider it as a measurable patient-reported outcome for chronic conditions. BMC Health Serv Res 12:157
22. Medrano R (2012) Welcome to the API economy. Forbes Online: CIO Network, https://www.forbes.com/sites/ciocentral/2012/08/29/welcome-to-the-api-economy/#190c99a83a21
23. Mishra SM (2015) Wearable android: android wear and google fit app development. Wiley, Hoboken, NJ
24. National Academy of Engineering (US) and Institute of Medicine (US) Committee on Engineering and the Health Care System (2005) Building a better delivery system: a new engineering/health care partnership. In: Reid PP, Compton WD, Grossman JH, Fanjiang G (eds) National Academies Press (US), Washington, DC
25. Padhy RP, Patra MR, Satapathy SC (2011) RDBMS to NoSQL: reviewing some next-generation non-relational database's internat. J Adv Eng. Sci. Technol. 11(1):15–30
26. Radisic Biljak V, Ozvald I, Radeljak A et al (2012) Validation of a laboratory and hospital information system in a medical laboratory accredited according to ISO 15189. Biochem Med 22(1):86–91
27. Raptopoulos A, Tsoutsouras V, Soudris D (2015) Advancing integrated and personalized healthcare services, the AEGLE approach. In: 13th IEEE international conference on embedded and ubiquitous computing (EUC) pp. 154–157
28. Redis (2011) http://redis.io/
29. RFC 1034 IETF—Domain Names—Concepts and Facilities (1987). https://tools.ietf.org/html/rfc1034
30. Risling T, Martinez J, Young J et al (2017) Evaluating patient empowerment in association with eHealth technology: scoping review. J Med Internet Res 19(9):e329

31. Triberti S, Barello S (2016) The quest for engaging Am I: Patient engagement and experience design tools to promote effective assisted living. J Biomed Inform 63:150–156
32. Welch C (2014) Apple HealthKit announced: a hub for all your iOS fitness tracking needs. http://www.theverge.com/2014/6/2/5772074/apple-healthkit-ios-8-announcement
33. Woznowski P, Fafoutis X, Song T et al (2015) A multi-modal sensor infrastructure for healthcare in a residential environment. In: IEEE international conference on communication workshop (ICCW), pp 271–277

Assessment of Parkinson's Disease At-home Using a Natural Interface Based System

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Abstract A system for the management of the automatic assessment of Parkinson's Disease (PD) at-home is presented. The system is based on a non-contact and natural human computer interface which is suitable for motor impaired users, as are PD patients. The interface, built around optical RGB-Depth devices, allows for both gesture-based interaction with the system and tracking of hands and body movements during the performance of standard upper and lower limb tasks, as specified by the Unified Parkinson's Disease Rating Scale (UPDRS). The accurate tracking and characterization of the movements allows for an automatic and objective assessment of the UPDRS tasks, making feasible the monitoring of motor fluctuations at-home and on daily basis, which are important features in the management of the disease progression. The assessment of the different tasks is performed by machine learning

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techniques. Selected kinematic parameters characterizing the movements are input to trained classifiers to rate the motor performance. Results on monitoring experiments at-home and on the system accuracy as compared to clinical evaluations are presented and discussed.

Keywords Parkinson's disease · Movement disorders · UPDRS · Automated assessment · Natural human computer interface · RGB-Depth · At-home monitoring · Hand tracking · Body tracking

1 Introduction

Parkinson's Disease (PD) is a neurodegenerative disease characterized by a progressive motor impairment [1], whose severity is subjectively assessed by clinicians during the performance of standard motor tasks defined by some PD rating scales, such as the motor examination section of the Unified Parkinson's Disease Rating Scale (UPDRS) [2].

Objective and automatic assessment of the tasks at-home can improve the reliability of the assessment, generally influenced by inter-rater disagreements [3], and can reduce both the patient discomfort and the costs for the health care system. The symptomatic treatment of PD by drugs is crucial to reduce impairment in daily activities, so improving the quality of life. Moreover, a weekly adjustment of the therapy would be desirable to reduce fluctuations in motor impairment and to avoid or delay the long-term side effects of the pharmacological treatment [4]. Proposed solutions for the automatic assessment of PD motor tasks make use of the established correlation existing between kinematic characteristics of the movements and the severity of the impairment [4, 5], mainly by technologies based on optical devices and wearable sensors [6, 7]. Approaches based on wearable sensors do not suffer of occlusion problems respect to the optical ones, but they require the involvement of the patient for the initial setup and, possibly, for the calibration phase. Specifically for hand-worn systems, they are uncomfortable for impaired people and their invasiveness can affect functional performance [8, 9]. On the contrary, optical approaches based on recent RGB-Depth devices [10] are less invasive and allow for accurate measurements, so they have been proposed for tracking the body [11] and hand [12–14] movements in the framework of PD assessment.

In this context, we present a low-cost system for the automatic and at-home assessment of the upper limb tasks of the UPDRS, namely Finger Tapping (FT), Opening-Closing (OC) of the hand and Pronation-Supination (PS) of the hand; and some of the lower limb tasks of the UPDRS, in particular Sit-to-Stand (S2S) and Leg Agility (LA). The system implements a non-invasive gesture-based human computer interface (HCI), which allows people with motor impairments both to interact with the graphical interface of the system through simple gestures such as opening and closing of the hand or pointing with fingers on interactive objects, and the tracking of hands and body movements, for the assessment of the motor performance during the performance of standard UPDRS tasks.

In particular, the developed algorithm for the hand tracking has proved to be more robust and accurate for fast movements respect to other solutions based on proprietary algorithms provided by commercial devices [15], making the assessment more reliable. In addition, the algorithm for the hand tracking does not depend on any particular device or proprietary Software Development Kit (SDK), but requires only the RGB and depth information availability at a proper frame rate. Results on experiments performed to validate the system are presented: the accuracies obtained in the automatic assessment of the considered UPDRS tasks, as compared to the clinician standard assessment, demonstrate the feasibility of the system in the at-home monitoring of PD.

2 Patient Movement Analysis

The hardware and software components of the system are described in the following sections. The human computer interaction occurs in two operative modalities: a *near mode*, in which the accurate tracking of hand and fingers is employed both for the self-management of the task performance and for the automatic assessment of upper limb tasks; a *far mode*, in which a coarse hand gestures tracking is employed just for the self-management of lower limb tasks performance.

2.1 System Setup

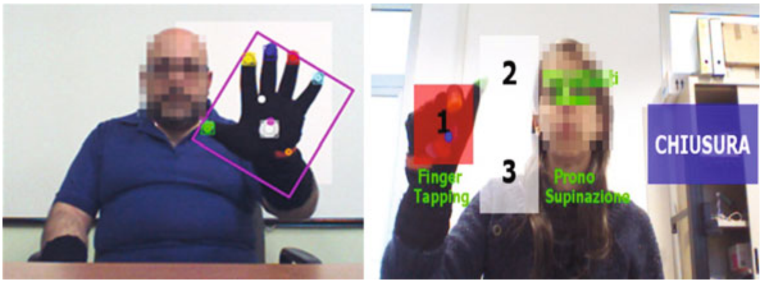
The near mode setup (Fig. 1a) is based on lightweight colored gloves and a low-cost short-range RGB-Depth device (Intel RealSense SR300©). The far mode setup (Fig. 1b) is based on long-range RGB-Depth device (Microsoft Kinect v.2©). Both configurations share the same monitor, positioned in front of the user, on which the visual feedback of the human computer interface is provided. The RGB-Depth devices are connected via USB ports to a mini-PC (Intel NUCi7©) running the software component of the system under the Microsoft Windows 10 environment. For the near mode configuration, a user equipment that consists of black lightweight gloves with colour markers imprinted on them is used. Each marker corresponds to a specific part of hand to be tracked for specific system actions (i.e. colour calibration, selection of the task to be executed).

(a) near mode (b) far mode

Fig. 1 System setup for the two operative modes. For the near mode, coloured gloves are also used to interact with the system. Visual feedback is showed on the monitor for both modes

2.2 Human Computer Interface and Tracking of the Movement

The hand gesture-based human computer interface is implemented in two ways, depending on tasks. In *near mode* operation, the short-range device acquires the RGB and depth streams to be processed. The custom software performs the real-time hand and finger tracking by fusion of both colour (RGB) and depth information from the streams [10, 12]. Some preliminary operations, such as global image brightness adjustment, colour calibration for marker detection and hand segmentation, are performed during the initial setup phase. The 3D position of the hand centroid is estimated from the depth stream, and it is used to coarsely segment the hand from the background. Specific colour thresholds, selected during the initial setup phase according to the environment lighting conditions, are used to detect and track all the color blobs of the markers in the 2D image (Fig. 2a). Every color marker area is then re-projected on the corresponding 3D point cluster, and the 3D cluster centroids are then evaluated to estimate the 3D position of the fingers and the hand in real time. This information is used both for the movement analysis and to implement the gesture-based human computer interface for the management of the system (Fig. 2b). In *far mode* operation the skeleton tracking capabilities provided by the SDK of Microsoft Kinect v.2 are used both for the analysis of body movements and for the coarse tracking of the bare-hand position, as shown in Fig. 1b. In this case, some simple gestures such as raising the hand and shaking it, or positioning the hand on interactive objects, are used for the interaction with the system.



(a) Hand/fingers tracking (b) Menu Selection

Fig. 2 Tracking algorithm in action: for movement analysis of hand/fingers and for human computer interaction (for example to select activities by moving and closing the hand on drawn squares)

2.3 Clinical Assessment and Data Acquisition

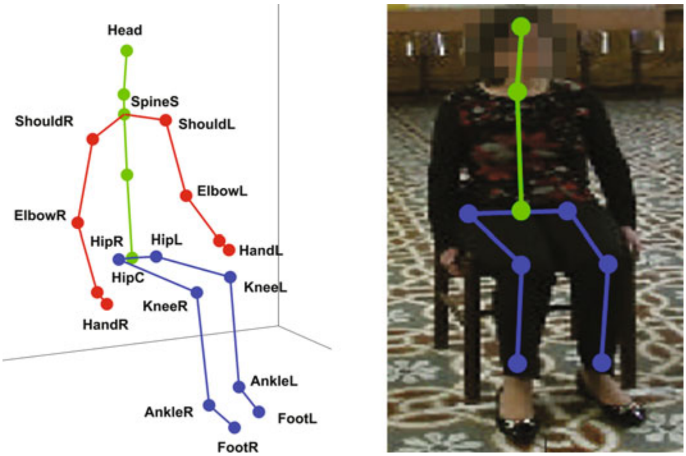
Two cohorts of forty PD patients and fifteen Healthy Control (HC) subjects respectively were recruited according the UK Parkinson's Disease Society Brain Bank Clinical Diagnostic [16] standards. They met the following criteria: Hoehn and Yahr score (average 2.2, min 1, max 4); age 43–81 years; disease duration 2–29 years. Patients were excluded if they had previous neurosurgical procedures, tremor severity > 1 or cognitive impairment (Mini–Mental State Examination Score < 27/30). The HC subjects met these criteria: age 45–78 years, not affected by neurological, or motor and cognitive disorders.

All subjects provided their informed consent prior to their participation. The PD cohort was assessed by one neurologist with experience in movement disorders: all the patients were evaluated for the FT, OC and PS upper limb tasks, and one half also for the S2S and LA lower limb tasks. At the same time, the motor performance of the PD patients were tracked by the system and the related kinematic parameters were automatically extracted. The HC subjects performed the same tasks, in the same environmental conditions and with the same system setup of PD patients.

2.4 Movement Characterization by Kinematic Features

The automatic assessment of the UPDRS tasks makes use of some kinematic parameters automatically estimated from the movements of several body parts: fingertips and palm for the upper limbs; femur, knee, tibia and spine for the lower limbs.

While for the upper limbs the 3D trajectories of fingers and hand are directly tracked by the algorithm we developed, as described in Sect. 2.2, for lower limbs we use the 3D joint coordinates of hip, knee and ankle provided by the Microsoft Kinect SDK [10] in the form of a skeletal model of the body. In particular, we focus our attention on SpineS, HipC, HipR/L, KneeR/L and AnkleR/L joints (Fig. 3a) which are



(a) SDK skeleton (b) Skeleton on PD patient's body

Fig. 3 Positions of SDK joints **a** in the 3D skeleton representation; **b** superimposed on the RGB image

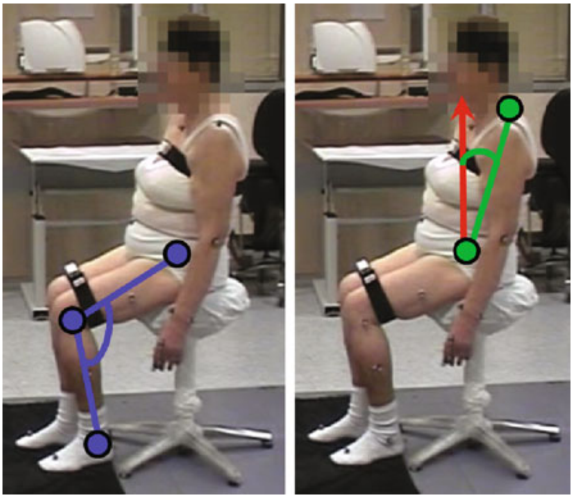
used to estimate the angles between specific body segments of PD patients (Fig. 3b). These angles are useful for the assessment of the lower limbs tasks as indicated by the UPDRS guidelines. Specifically, we use the angle between the spine segment (i.e. SpineS—HipC) and the vertical direction for the S2S task (Fig. 4b), and the angle between femur and tibia segments (represented by the segments HipR/L-KneeR/L and KneeR/L-AnkleR/L respectively) for the LA task (Fig. 4a). The vector **p** of selected parameters we have considered is related to typical motor features implicitly taken into account by neurologists to score the patient performance: amplitude, speed, rhythm variation and typical anomalies as hesitations, freezing or partial movements.

3 Experimental Results

3.1 Discriminant Parameters for Upper and Lower Limb UPDRS Tasks

The most discriminative parameters have been identified for every UPDRS tasks, as shown in Tables 1 and 2. Principal Component Analysis (PCA) was applied to the initial set of kinematic parameters of every task to filter out those ones contributing for less than 5% to the total information and to reduce the intrinsic redundancy among them. Then, the remaining parameters were correlated (using the Spearman's correlation coefficient ρ) to the neurologist UPDRS scores of the motor performances for all the subjects of the PD cohort, keeping only those parameters showing a good

Fig. 4 Body segments and joints involved in the estimate of the limb angles during lower limb tasks



(a) Leg Agility (b) Sit To Stand

correlation at significance level $p < 0.01$: the list of the selected kinematic parameters is shown in Table 1 for the upper limbs tasks and in Table 2 for the lower limbs tasks. The feature selection procedure allows us to reduce the initial set of parameters significantly for each task: from 20 to 12 parameters for FT; from 20 to 10 for OC; from 20 to 8 for PS; from 10 to 6 for LA; from 8 to 3 for S2S. It should be noted that, for the activities of the upper limb, the initial set of parameters was essentially the same, only with a different physical meaning of some parameters, due to the similarities in the measures and the standard assessment of upper limb tasks; but the importance of each parameter is strictly related to the specific activity, so their weight in discriminating the impairment severity is not the same for all the tasks.

As expected, on the average, the HC subjects performed better respect to PD subjects for all the tasks. Hence, the average parameters $\mathbf{p_i}_{\,HC}$ of the HC subjects were used to normalize the $\mathbf{p}_{i\ PD}$ ones, giving the normalized PD parameters $\mathbf{p_i}_{\,PD\,norm}$ of Eq. 1:

$$\mathbf{p_i}_{PD\,norm} = \mathbf{p_i}_{PD} / \mathbf{p_i}_{HC} \quad (1)$$

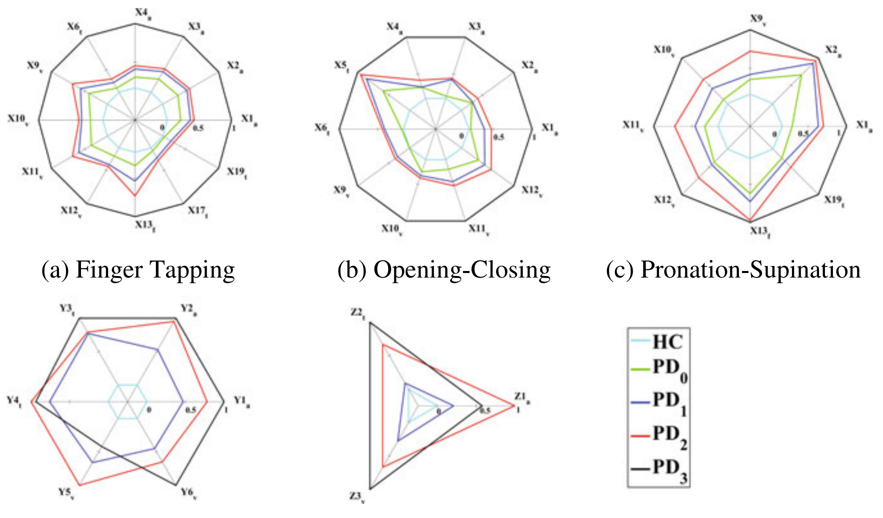
As a consequence, most of these parameters result able to discriminate the different UPDRS severity classes for each specific task, highlighting the increasing level of severity of the motor impairment with the corresponding increasing of the values of the components of **p**. This is also visually confirmed by the radar graphs in Fig. 5 for all the considered tasks: the increasing severity of motor performances is highlighted by the expansion of the corresponding radar graph that represents the mean values of the selected parameters **p** both for the HC subjects and the UPDRS severity classes of the subjects in the PD cohort.

Table 1 Kinematic parameters for upper limb tasks

Task	Name	Meaning	Unit	ρ value
FT	$X1_a$, $X2_a$	Max opening (mean and CV)	(mm), (–)	−0.43, 0.35
	$X3_a$, $X4_a$	Max amplitude (mean and CV)	(mm), (–)	−0.41, 0.39
	$X6_t$	Total duration (CV)	(–)	0.42
	$X17_t$, $X19_t$	Opening and closing duration (CV)	(–), (–)	0.45, 0.47
	$X9_v$, $X10_v$	Max opening velocity (mean and CV)	(mm/s), (–)	−0.58, 0.39
	$X11_v$, $X12_v$	Max closing velocity (mean and CV)	(mm/s), (–)	−0.55, 0.43
	$X13_f$	Main frequency of voluntary movement	(Hz)	−0.48
OC	$X1_a$, $X2_a$	Max opening (mean and CV)	(mm), (–)	−0.54, 0.34
	$X3_a$, $X4_a$	Max amplitude (mean and CV)	(mm), (–)	−0.55, 0.31
	$X5_t$, $X6_t$	Total duration (mean and CV)	(s), (–)	0.25, 0.58
	$X9_v$, $X10_v$	Max opening velocity (mean and CV)	(mm/s), (–)	−0.63, 0.47
	$X11_v$, $X12_v$	Max closing velocity (mean and CV)	(mm/s), (–)	−0.54, 0.53
PS	$X1_a$, $X2_a$	Max opening (mean and CV)	(degree), (–)	−0.36, 0.25
	$X9_v$, $X10_v$	Max supination velocity (mean and CV)	(degree/s), (–)	−0.42, 0.35
	$X11_v$, $X12_v$	Max pronation velocity (mean and CV)	(degree/s), (–)	−0.46, 0.44
	$X13_f$	Main frequency of voluntary movement	(Hz)	−0.47
	$X19_t$	Pronation phase duration (CV)	(–)	0.33

Table 2 Kinematic parameters for lower limb tasks

Task	Name	Meaning	Unit	ρ value
LA	$Y1_a$, $Y2_a$	Max knee angle (mean and CV)	(degree), (–)	−0.58, 0.45
	$Y3_t$, $Y4_t$	Duration (mean and CV)	(s), (–)	0.24, 0.25
	$Y5_v$	Rate	(hits/s)	0.13
	$Y6_v$	Mean speed	(degree/s)	−0.66
S2S	$Z1_a$	Max bending angle	(degree)	0.43
	$Z2_t$	Total duration of standing movement	(s)	0.73
	$Z3_v$	Mean speed of standing movement	(degree/s)	−0.52



(a) Finger Tapping (b) Opening-Closing (c) Pronation-Supination

(d) Leg Agility (e) Sit To Stand (f) List of classes

Fig. 5 Radar graphs of HC and PD severity classes versus mean parameter values for upper and lower limbs UPDRS tasks. PD classes range from UPDRS 0 (no impairment) to UPDRS 3 (moderate impairment)

3.2 *Automatic Assessment by Machine Learning*

The results shown in Fig. 5 concerning the discriminant power of the selected kinematic parameters respect to different PD classes make them suitable for the automatic assessment of the UPDRS tasks.

In order to achieve this goal, five data sets consisting of "vector of parameters **p**–neurologist UPDRS score" pairs from the PD cohort were used to train five different supervised classifiers, one for each UPDRS task. In particular, the LIBSVM library package [17] was used to implement five Support Vector Machine (SVM) classifiers with polynomial kernel: each classifier was trained by the corresponding set of pairs to create a predictive model and to learn how to automatically evaluate new instances of parameters, this for every specific task, and in agreement with the standard neurological assessment of the motor performance expressed by UPDRS score. The classification accuracy in assigning correctly the UPDRS scores to new sets of parameters was tested by using the *leave-one-out* cross validation method, and the resulting confusion matrices were used to characterize the classification performance of each classifier. The classification errors, considered as the absolute difference between the observed and predicted UPDRS severity score, were few in number and limited to one UPDRS score. The classification accuracies, obtained from the confusion matrices, were 80% for FT; 72% for OC; 74% for PS; 54% for LA; and 52% S2S respectively.

Assuming the automatic assessments by the system as neurological scores of a second clinician rater, the results for upper limbs can be considered satisfactory as compared to standard inter-rater agreement [3].

The slightly worse performances of the lower limb classifiers are probably due to the small number of training samples and the scarcely discriminant power of some parameters (e.g. $Y3_t$, $Y4_t$ and $Y5_v$ for LA; $Z1_a$ for S2S). They show low values of correlation with the standard UPDRS scores and they generate partial overlapping among the radar graphs of different severity classes. This suggests not only to increase the training data set with new samples, but also to identify other more discriminant parameters for the lower limb tasks.

4 Conclusions

This work presents a system for the automatic and objective assessment of PD patients performing standard UPDRS tasks, which suitable for the at-home monitoring of the motor performance. The system is non-invasive and low-cost: it is based on a gestural human computer interface that allows, at the same time, both the self-management of the system and the motor performance evaluation according to the UPDRS guidelines. The assessment is performed by supervised classifiers, which are trained on the selected kinematic parameters estimated from the patient's movements. The automated assessments of the task performances are in good agreement with the clinical ones.

The results obtained and presented in this paper show that classification accuracies are satisfactory for upper limb tasks, making the system suitable for self-administrated assessment of UPDRS tasks at-home. Instead, further work has to be done both to improve the accuracy in the assessment of the lower limb tasks, and also to estimate the effect of different datasets coming from different raters on the classification accuracy of each classifier. In addition, the system usability has to be verified in real home environments, with people suffering of motor impairments and, in general, with poor skill in the use of technologies.

In conclusion, the proposed solution represents a first step toward a more comprehensive, objective and automated assessment of the motor status in PD. The approach is suitable for the at-home monitoring of the disease, with consequent benefits for the patients and increased cost-efficiency for the health care system. Besides, the approach can also be extended to other neurological, pathological and non-pathological conditions characterized by an impairment in motor functionality.

References

1. Pal G, Goetz CG (2013) Assessing bradykinesia in Parkinsonian disorders. Front Neurol 4(54):1–5. eCollection

2. UPDRS (2003) Movement disorder society task force on rating scales for Parkinson's disease: the unified Parkinson's disease rating scale (UPDRS): status and recommendations. Mov Disord 18(7):738–750
3. Richards M, Marder K, Cote L, Mayeux R (1994) Interrater reliability of the unified Parkinson's disease rating scale motor examination. Mov Disord 9(1):89–91
4. Taylor Tavares AL, Jefferis GS, Koop M, Hill BC, Hastie T, Heit G, Bronte-Stewart HM (2005) Quantitative measurements of alternating finger tapping in Parkinson's disease correlate with UPDRS motor disability and reveal the improvement in fine motor control from medication and deep brain stimulation. Mov Disord 20(10):1286–1298
5. Heldman DA, Giuffrida JP, Chen R, Payne M, Mazzella F et al (2011) The modified bradykinesia rating scale for Parkinson's disease: reliability and comparison with kinematic measures. Mov Disord 26(10):1859–1863
6. Espay AJ, Bonato P, Nahab FB, Maetzler W, Dean JM et al (2016) Technology in Parkinson's disease: challenges and opportunities. Mov Disord 31(9):1272–1282
7. Patel S, Lorincz K, Hughes R, Huggins N, Growdon J, Standaert D et al (2009) Monitoring motor fluctuations in patients with Parkinson's disease using wearable sensors. IEEE Trans Inf Technol Biomed 13(6):864–873
8. Espay AJ, Giuffrida JP, Chen R, Payne M, Mazzella F, Dunn E, Vaughan JE, Duker AP, Sahay A, Kim SJ, Revilla FJ, Heldman DA (2011) Differential response of speed, amplitude and rhythm to dopaminergic medications in Parkinson's disease. Mov Disord 26(14):2504–2508
9. Mera TO, Heldman DA, Espay AJ, Payne M, Giuffrida JP (2012) Feasibility of home-based automated Parkinson's disease motor assessment. J Neurosci Methods 203(1):152–156
10. Han J, Shao L, Xu D, Shotton J (2013) Enhanced computer vision with Microsoft Kinect sensor: a review. IEEE Trans Cybern 43(5):1318–1334
11. Galna B, Barry G, Jackson D, Mhiripiri D, Olivier P, Rochester L (2014) Accuracy of the Microsoft Kinect sensor for measuring movement in people with Parkinson's disease. Gait & Posture 39(4):1062–1068
12. Ferraris C, Nerino R, Chimienti A, Pettiti G, Pianu D, Albani G, Azzaro C, Contin L, Cimolin V, Mauro A (2014) Remote monitoring and rehabilitation for patients with neurological diseases. In: 10th international conference on body area networks, London, Sep 29–Oct 1
13. Bank PJM, Marinus J, Meskers CJP, De Groot JH, Van Hilten JJ (2017) Optical hand tracking: a novel technique for the assessment of bradykinesia in Parkinson's disease. Mov Disord Clinical Practice 4(6):875–883
14. Dror B, Yanai E, Frid A, Peleg N, Goldenthal N, Schlesinger I, Hel-Or H, Raz S (2014) Automatic assessment of Parkinson's disease from natural hands movements using 3D depth sensor. In: IEEE 28th convention of Electrical & Electronics Engineers in Israel (IEEEI)
15. Ferraris C, Pianu D, Chimienti A, Pettiti G, Cimolin V, Cau N, Nerino R (2015) Evaluation of finger tapping test accuracy using the LeapMotion and the Intel RealSense sensors. In: EMBC 2015, 37th annual international conference of the IEEE Engineering in Medicine and Biology Society
16. Hughes AJ, Daniel SE, Kilford L, Lees AJ (1992) UK Parkinson's disease society brain bank clinical diagnostic criteria. J Neurol Neurosurg Psychiatry 55:181–184
17. Chang CC, Lin CJ (2011) LIBSVM: a library for support vector machines. ACM Trans Intell Syst Technol (TIST) 2(3)

Seniors' Acceptance of Virtual Humanoid Agents

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Abstract This paper reports on a study conducted as part of the EU EMPATHIC project, whose goal is to develop an empathic virtual coach capable of enhancing seniors' well-being, focusing on user requirements and expectations with respect to participants' age and technology experiences (i.e. participants' familiarity with technological devices such as smartphones, laptops, and tablets). The data shows that seniors' favorite technological device is the smartphone, and this device was also the one that scored the highest in terms of easiness to use. We found statistically significant differences on the preferences expressed by seniors toward the gender of the agents. Seniors (independently from their gender) prefer to interact with female humanoid agents on both the pragmatic and hedonic dimensions of an interactive system and are more in favor to commit themselves in a long-lasting interaction with them. In addition, we found statistically significant effects of the seniors' technology savviness on the hedonic qualities of the proposed interactive systems. Seniors with technological experience felt less motivated and judged the proposed agents less captivating, exciting, and appealing.

Keywords Assistive technologies · Virtual agents · Aging well · Agent's appearance · User's requirements and expectations

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1 Introduction

Aging engenders several health disorders among which are poor vision, memory loss, fine motor skill impairments and cognitive decline. These impairments provoke social isolation making elders less inclined to preserve their relationship with friends and relatives. In turn, social isolation affects mental well-being and leads to psychological and depressive disorders [1]. Statistics have shown that in Europe approx. 1.2 million senior citizens are suffering from Parkinson's disease (www.parkinsons.org.uk/content/about-parkinsons), 15% of adults aged 60+ years from a mental disorder (www.who.int/mediacentre/factsheets/fs381/en/), and one-in-six people from anxiety and depression with limited access to therapeutic interventions [2]. In addition, it is estimated that 47.5 million people worldwide are living with dementia and that this number is likely to increase in the years to come (http://www.who.int/mediacentre/factsheets/fs381/en/). Consequently, considerable burdens are placed on national health care institutions in terms of medical, social, and care costs associated to the assistance of such people [3]. Complex autonomous computer interfaces in the form of embodied conversational agents have been proposed as a solution to these problems (see [4] for communication disorders; [5] for ageing, and Prescott et al. [6] for companionship) because they can provide an automated on-demand health assistance reducing the abovementioned costs, and lighten human caregivers' workload. Such virtual agents, depending on the user's needs would serve as guides, assistants, information presenters, companions, or simply as a reminder for taking medications. Furthermore, it has been shown that a virtual agent can positively influence elderly people's wellbeing acting on psychological aspects like motivation, self-determination, mood, self-efficacy, and copying capabilities [7]. Nevertheless, the current developers' efforts in implementing such systems are unsuitable to the users' demand because of a lack of attention to their requirements and expectations, as well as, a lack in understanding how the interaction with such complex autonomous ICT (Information Communication Technologies) interfaces affects/enhances human reactions/actions, social perception and meaning-making practices in long-term relationships.

One aspect to focus on with respect to human-agent interaction is the level of user acceptance. This concept was introduced by Davis [8] in an attempt to explain what leads people to the acceptance of technological devices. To this end, acceptance was defined as:

A process affected by two main factors:

1. *Perceived Usefulness, defined as the degree to which an individual believes that using a particular* [technological device] *would enhance his/her performances*
2. *Perceived Ease of Use, defined as the degree to which an individual believes that using a particular* [device] *would be free of effort* [8]

[… and therefore, simplify the understandings and fulfilments of habitual or unfamiliar tasks]. For aged people, the acceptance of new technologies is an adaptive negotiation between the improvements (quality of life, usefulness, enactment) provided by the offered resource and the struggles required (in terms of the costs, cognitive loads, and environmental changes) to allocate such in their personal environment [9]. In summary, the elders' acceptance of a new technology is entwined to their ability to control it, its easiness to use, as well as, its practical advantages. Beside these practical considerations, the concept of the agent's appearance is a strong factor in favoring elders' acceptance of assistive technologies. The user's preference toward the agent's physical and social features—such as face, voice, hair, age, gender, eyes, dressing mode, attractiveness, personality—plays a role. As an example, a recent study conducted with 45 healthy elders, aged 65+ showed that they are able (without being informed) to sense agents' personalities and prefer joyful and practical personalities on both the pragmatic and hedonic dimensions (see Sect. 2.3 for a description of the pragmatic and hedonic dimensions of an interactive system) of the interactive system [10]. To our knowledge, there are no systematic investigations devoted to assess the role of these agents' features taking particularly into account seniors' preferences. Gong and Nass [11] showed that the pairing of a human face with a humanoid voice or a humanoid face with a human voice led to distrustful user reactions toward the agents. Sträfling et al. [12] showed that students' learning motivations did not change no matter whether they are interacting with a humanoid or animal shaped virtual tutor, or a speech only based interactive system. Ring et al. [13] showed that humanoid agents with cartoon like or toon shaded semblances are considered more friendly and likable than more realistic humanoid agents. Gender and race, as well as, agent's attractiveness have also been found to impact on users' willingness to interact and consequently influence agents' purpose effectiveness [14]. It has been shown that ICT interfaces with a human face improve employers' productivity [15] and agents with human-like faces trigger in users more positive reactions than agents with animal or iconic faces, independently from the agent's gender [16]. However, it must be mentioned that participants in these studies, were either students or age was not a variable accounted for. Seniors have been involved in a very limited number of studies. When elders are involved, it has been shown that they clearly enjoy interacting with a speaking synthetic voice produced by a static female agent (note: these were 65+ aged seniors in good health, [17], and that such seniors are less enthusiastic than impaired people in recognizing the agent's usefulness [18]. To our knowledge, the only comparison among user's age, definitely systematized affording a categorization of specific agent features that may engage senior and young users differently was provided by Straßmann and Krämer [19]. This study was "*a qualitative interview study with five seniors and six students*" [19] and showed that senior users prefer embodied human like agents over machine or animal like ones. Building upon this pilot study, the present study aims to provide a systematic investigation to assess the role of humanoid agent's appearance and as such potentially increase their acceptance among elders. In particular, the present study aims to:

- Assess elders' preferences in initiating conversations with a humanoid agent characterized by a given voice, age, eyes, face, gender, clothing style, winsomeness, and non-emotional facial expressions.

- Summon elders' responses arising from the agents' non-verbal behavior according to the pragmatic and hedonic dimensions of an interactive system firstly introduced by Hassenzahl through the *AttrakDiff* questionnaire [20], and further enriched in this study by new items developed by the authors (more details in Sect. 2.3).
- Measure elders' interest in favor of a lasting interaction with such humanoid virtual agents endowed of specific human like features.

The final aim is to test whether elders would accept a hypothetical interaction with artificial humanoid agents and, consequently, whether these agents may function as a tool for entertainment, assistance, and company.

2 Materials and Methods

Two experiments were conducted in order to appraise the results of the present research. The first experiment was devoted to assessing physical and social agents' features among a non-senior largely age range population of subjects. This experiment was a search for consensus to substantiate the selection made by the experts. It was attempting to identify agreements (in a differently aged papulation) toward agents' characteristics such as eyes, face, voice, hair, perceived age, clothes, formal dressing, winsomeness, juvenility, look, and adjutant abilities in order to estimate substantial changes or accords in seniors' preferences. The second experiment was devoted to evaluating elders' preferences of the same agents on the hedonic and pragmatic dimensions of the interactive system.

2.1 Stimuli

In order to conduct these experiments four virtual agents were defined. The virtual agents were selected from the website BOTLIBRE (www.botlibre.com) that allows users to freely create a customer service virtual agent according to their preferences and goals, providing a wide set of agents with different visual semblances. The selection of the agents was made by three experts on the basis of preferences dictated by the agents' professional and non-emotional appearance. The selected four virtual agents two males and two females, as illustrated in Fig. 1, named Michael (Fig. 1a), Eddie (Fig. 1b), Julie3 (Fig. 1c) and Victoria2 (Fig. 1d) respectively, received 100% of agreements among the experts.

The agents were depicted half torso, with definite clothing. To contextualize the agent in the local culture (the experiments were conducted in Campania a south region of Italy) they were renamed Michele, Edoardo, Giulia and Clara respectively. Each agent was provided with a different synthetic voice, producing the following Italian sentence "Hi, my name is Clara/Edoardo/Giulia/Michele. If you want, I would like to assist in your daily activity!". The synthetic voice was created through the website

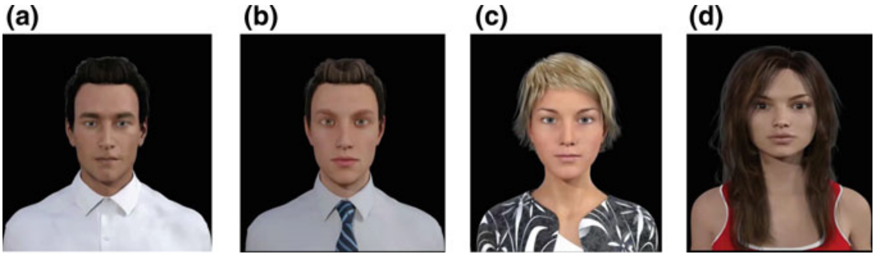

Fig. 1 The four selected agents: **a** Michael (renamed Michele); **b** Eddie (renamed Edoardo); **c** Julie3 (renamed Giulia); **d** Victoria2 (renamed Clara)

Natural Reader (www.naturalreaders.com) that allows converting text to speech. The voices (recorded using the free software Audacity) were embedded into each agent's video-clip which had an average duration of about 6 s.

2.2 Participants

The first experiment involved 20 participants (13 females) aged between 27 and 64 years (mean age = 40 years, SD = ±11) recruited in Salerno, a city of the Campania region, in the south of Italy. They were all in good health, with no hearing and eyesight problems (appropriately corrected with glasses in some cases) and their task was to assess physical and social features of the selected virtual agents, e.g. eyes, face, voice, hair, perceived age, clothes, formal dressing, winsomeness, juvenility, look, and adjutant abilities, on the basis of an ad hoc questionnaire created by the authors.

The second experiment involved 46 seniors (24 females), all aged 65+ years (mean age = 71.58, SD = ±6.31) recruited in Caserta a city of the Campania region, in the south of Italy. Also, in this case, participants were in good health, with no hearing and eyesight problems (appropriately corrected with glasses in some cases), and their task was to assess their preferences toward the four selected virtual agents on the pragmatic and hedonic dimensions of the interactive system (see Sect. 2.3 for more details), their willingness to initiate a lasting interaction with them, and theirs preferred technological device to do so. Participants in both experiments accepted to join on a voluntary basis, and signed an informed consent formulated in accord with the privacy and data protection procedures established by the current Italian and European laws. The ethical committee of the Department of Psychology at the Università degli Studi della Campania, "Luigi Vanvitelli", authorized this research with the protocol number 25/2017.

2.3 Tools and Procedures

For the first experiment, stimuli and questionnaire were administered in the relaxation rooms of gyms and associations. Participants were asked to watch each agent's video clip and immediately after to complete a questionnaire composed of 16 items. The first part of the questionnaire consisted of 11 items and was devoted to collecting participants' opinions about the pleasantness of agents' physical and social features such as their eyes, face, voice, hair, perceived age, clothes, formal dressing, winsomeness, juvenility, look, and adjutant abilities attributed to the agents; all rated on a 5-point Likert scale ranging from 1 = not at all, to 5 = very much (as an example consider the question: "Did you like the agent's eyes?"). The second part of the questionnaire was devoted to assessing the type of professions participants would endorse to the agents, among welfare, housework, protection and security, and front office jobs. Also, in this case participants' answers were rated on a 5-point Likert scale ranging from 1 = I think the agent is unsuitable for this task, to 5 = I think the agent is very suitable for this task.

The second experiment was devoted to assess seniors' preferences toward each of the proposed agents. The administration of stimuli was carried out either in participants' private dwellings, or day-care facilities for older people. To accomplish this goal, an ad hoc questionnaire was developed by the authors, structured in the following clusters:

(1) Cluster 1 was devoted to collecting participants' socio-demographic information, and their degree of familiarity and understanding toward smartphones, tablets, and laptops;
(2) Cluster 2 collected participants' willingness to be involved in a long-lasting interaction with each of the proposed agents. This section was clustered in four sub-clusters, each consisting of 10 items, investigating the practicality, pleasure, feelings, and attractiveness experienced by participants while watching the agents' video-clips. The items proposed in each sub-cluster were inspired by Hassenzahl's theoretical model underpinning the qualities an interactive system should possess in order to receive a high acceptance from the user [21]. According to this model, a user's perception of interactive systems varies along two dimensions:

    (a) The system's pragmatic qualities (PQ), which focus on the usefulness, usability, and accomplishment of the tasks of the proposed system. A system receiving high scores in the PQ dimension is intended to be perceived by the user as well structured, clear, controllable, efficient, and practical.
    (b) The system's hedonic qualities (HQ), which focus on motivations, i.e. the reason why a user should own and use such an interactive system, (hedonic quality stimulation (HQS), identification, i.e. how captivating, as well as, of good taste the system appears, (hedonic quality identification (HQI), A system receiving high scores in the HQS and HQI sub-clusters is meant to be original, creative, captivating as well as presentable, professional,

of good taste, and bringing users close to each other. These pragmatic and hedonic dimensions affect the subjective perception of the system's attractiveness (ATT) and give rise to behaviors as increased use, or dissent, as well as, emotions as happiness, engagement, or frustration. Please note, HQS will be substituted in the following with HQF (where F stands for feelings).

Cluster 2 of the proposed questionnaire is therefore organized in 4 sub-clusters, devoted to measure respectively the pragmatic quality (PQ), the hedonic identification (HQI), the hedonic feeling (HQF), and the attractiveness (ATT) of the four agents. The complete questionnaire had two more clusters respectively devoted to assessing the type of professions seniors would endorse to the agents, among which were welfare, housework, protection and security, and front office jobs, and agents' age preferences. These two last clusters were developed by the authors after the data collection had started and thus they were not administered. Future works will, however, include such data.

Each questionnaire item required a response given on a 5-point Likert scale with 1 = strongly agree, 2 = agree, 3 = I don't know, 4 = disagree, and 5 = strongly disagree. Since both the second and third section of the questionnaire contained positive and negative items evaluated on a 5-point Likert scale, scores from negative items were corrected in a reverse way. This implies that low scores summon to positive evaluations, whereas high scores to negative ones. For this second experiment, participants were first asked to provide answers to the items of cluster 1, then they were asked to watch each agent's video-clip and immediately after to complete the items from cluster 2. Finally, items from cluster 3 were administered after they had seen all the four agents.

3 Results

This section summarizes the results of both the first and second experiments. First how naïve users assessed the physical features of the proposed agents is investigated. We will see the role played by physical and social features, as well as, adjutant abilities and professions attributed to the agents. Then, we will see how the agents have been evaluated on the pragmatic, hedonic, and attractiveness dimensions by senior users and try to correlate these preferences to the physical and social qualities of the proposed agents in order to provide explanations to the motivations and preferences offered by seniors. The scores obtained from both questionnaires were analyzed through a repeated measure ANOVA analysis, where participants' gender was considered as between factor, and agents' physical and social features as within factors. In the second experiment, participants' technology savviness was also accounted for as a between factor. Main differences among group means were assessed through Bonferroni's post hoc tests.

3.1 Results on Agents' Physical and Social Features, and Careers (Experiment 1)

The physical and social agents' features under assessment were eyes, face, voice, hair, perceived age, clothes, formal dressing, winsomeness, juvenility, look, and adjutant abilities. Participants were asked to rate how much they "enjoyed/endorsed" each of these agent's features on a 5-point Likert scale ranging from 1 = not at all, to 5 = very much.

It was found that agents' eyes scored significantly different, ($F(3, 54) = 6.215$, $p < 0.01$). Bonferroni post hoc tests showed that Clara's eyes (mean = 2.89) scored significantly lower ($p < 0.01$) than Giulia's (mean = 4.02) and Michele's eyes (mean = 3.94).

Agents' faces were significantly different ($F(3, 54) = 3.875$ $p < 0.05$). In particular, differences ($p < 0.05$) concerned Clara's (mean = 3.33) and Michele's faces (mean = 4.15), where Clara's face was rated the least enjoyable.

Also voice ($F(3, 54) = 6.143$ $p < 0.01$), showed significant differences. These differences ($p < 0.01$) were between Clara (mean = 2.26) and Giulia (mean = 3.85), with a clear preference for Giulia's voice.

The attributed age was found to be significantly different ($F(3, 54) = 13.279$, $p < 0.01$) among the agents. Clara was perceived as the younger, receiving an attributed mean age of 24.6 years, which differed significantly from Giulia (mean age = 29.4), Edoardo (mean age = 29.8) and Michele (mean age = 30.7).

Furthermore, agents' clothes differed significantly ($F(3, 54) = 6.539$, $p < 0.01$) because Clara's clothes (mean = 2.725) were significantly less appreciated when compared with Edoardo's (mean = 3.874, $p < 0.01$) and Michele's clothes (mean = 3.714, $p < 0.05$).

Winsomeness was found to be significantly different ($F(3, 54) = 6.077$, $p < 0.05$): the main differences emerged between Clara (mean = 2.60) which was considered less winsome than Giulia (mean = 3.65) and Michele (3.69).

Significant differences were found among the agents regarding them being formally dressed, ($F(3, 54) = 4.182$, $p < 0.05$). Clara was considered the least (mean = 1.48) and Edoardo (mean = 2.75) the most formally dressed ($p < 0.05$).

Participants endorsed significantly different adjutant abilities ($F(3, 54) = 6.899$, $p < 0.05$) to the agents. Clara was considered the least able to act as an assistive agent (mean = 2.66) compared to Giulia (mean = 3.80), Edoardo (mean = 3.77) and Michele (mean = 3.82).

Finally, significant differences were found between agents' hair ($F(3, 54) = 3.878$, $p < 0.05$), look ($F(3, 54) = 4{,}728$, $p < 0.01$), and juvenility ($F(3, 54) = 3.636$, $p < 0.05$). However, Bonferroni post hoc tests did not reveal any significance concerning those variables.

As for the data concerning the second part of the questionnaire, focusing on selecting which of the agents was judged more suitable to explicate either welfare, housework, protection and security, or front office jobs, it was found that Giulia (mean = 3.05) was considered the most suitable to perform a housework occupation compared to Edoardo (mean = 1.81) and Michele (mean = 2.07), justifying the significant differences detected by the ANOVA ($F(3, 54) = 4.973$, $p < 0.01$). Michele (mean = 3.78) was considered the most appropriate for protection and security ($F(3, 54) = 6.324$, $p < 0.01$), compared to Giulia (mean = 3.11) and Clara (mean = 2.67). Front desk occupations ($F(3, 54) = 4.893$, $p < 0.01$), were considered more appropriate for Michele (mean = 3.96) compared to Clara (mean = 3). Despite significant ANOVA differences with respect to welfare occupations ($F(3, 54) = 3.190$, $p < 0.05$), Bonferroni post hoc tests did not show a significant difference among agents, even though Giulia received higher mean scores (3.30).

3.2 Results on Seniors' Preferences on the Pragmatic, and Hedonic, Dimensions of the Proposed Interactive Systems (Experiment 2)

This second experiment involved senior participants aged 65+ years being in good health. An ad hoc questionnaire was developed with the aim to assess seniors' preferences toward the most used technological device (note: possible choices included smartphones, tablets, and laptops) and to evaluate their preferences concerning agents' pragmatic, hedonic, and attractiveness dimensions, following the definitions reported in Sect. 2.3.

3.2.1 Descriptive Statistics

Analyzing the frequency of use of the proposed technological devices, it was shown that smartphones were regularly used by 56.5% of the target population, frequently but not always used by 32.6%, and never used by 10.9%. Tablets were regularly used by 4.3% of the users, frequently but not always used by 4.3%, and never used by 91.4% of the users. Laptops were regularly used by 8.7% of the target population, frequently but not always used by 30.4%, and 60.9% of the respondents had never used them. For sake of clarity this data are depicted in Fig. 2 (left).

Participants were also asked to evaluate their perceived easiness of using each technological device. In this context, smartphones were considered the easiest to use by 76.1% of the respondents, followed by laptops (34.8%) and tablets (13%), as depicted in Fig. 2 (right).

3.2.2 Virtual Agents' Assessment

A repeated measure ANOVA analysis was conducted on the scores obtained from each questionnaire cluster and sub-cluster, considering the gender of the target population and their degree of experience with technology as between factors. The degree

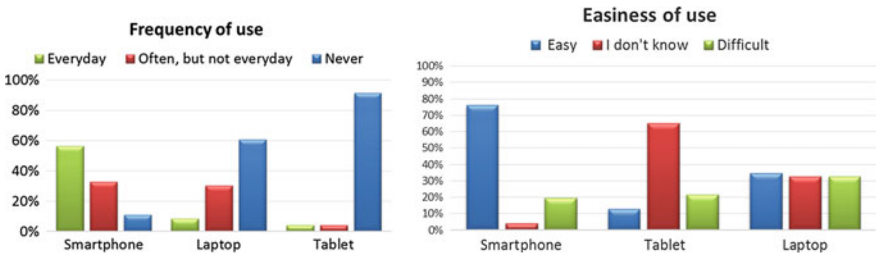

Fig. 2 Descriptive statistics: (left) Target population's frequency of use for smartphones, tablets, and laptops; (right): Easiness of use for smartphones, tablets, and laptops

of experience with technology was determined separating the participant sample into two groups: participants who used a technological device often or every day were considered at "high level of expertise", while participants who used a technological device rarely or never were considered at "low level of expertise". The scores obtained by each agent on each questionnaire cluster, i.e. on the acceptance to interact with agents (cluster1), on the pragmatic (PQ), hedonic quality identity (HQI), hedonic quality feelings (HQF), and attractiveness (ATT) dimensions were considered as within factors. The significance was set at $\alpha = 0.05$. The scores obtained from the questionnaire's negative items were reversed so that lower scores indicate strong preferences and higher scores low preferences toward the agent dimensions defined by the questionnaire clusters.

Willingness to Interact with the Agents

Significant differences were found among agents ($F(3, 126) = 16.323$, $p \ll 0.001$) on the seniors' willingness to interact with them. Bonferroni post hoc tests revealed that these differences were due to significant differences in the scores obtained by Giulia (mean score = 1.40) with respect to Clara (mean score = 1.85, $p < 0.05$), Edoardo (mean score = 2.40, $p \ll 0.001$) and Michele (mean score = 2.58, $p \ll 0.001$), as well as, significant different scores obtained by Clara compared to Edoardo ($p < 0.05$) and Michele ($p < 0.05$). No significant differences were found between Edoardo and Michele.

An interaction was found between the participants' gender and their willingness to interact with the virtual agents ($F(3, 126) = 4.323$, $p < 0.05$). Bonferroni post hoc tests revealed this was because male and female participants differed significantly in their willingness to interact with Michele ($p < 0.05$), being females less available (mean score = 3.08) than male participants (mean score = 2.09) to interact with them.

Pragmatic Qualities (PQ)

The pragmatic qualities seniors attributed to the agents differed significantly ($F(3,126) = 24.530$, $p \ll 0.001$). Bonferroni post hoc tests attributed these differences to significant differences in the scores obtained by Giulia (mean score = 18.84) in comparison to Edoardo (mean score = 32.52, $p \ll 0.001$), and Michele (mean score = 33.36, $p \ll 0.001$), as well as, significant different scores obtained by Clara (mean score = 22.23) with respect to Edoardo ($p < 0.05$) and Michele ($p \ll 0.001$). No significant differences were found between Giulia and Clara and between Edoardo and Michele.

Hedonic Qualities—Identity—(HQI)

Agents' HQI scores were significantly different ($F(3, 126) = 22.5$, $p \ll 0.001$). Bonferroni post hoc tests revealed that these differences were caused by significant differences in the scores obtained by Giulia (mean score = 19.97) compared to Edoardo (mean score = 34.62, $p \ll= 0.001$) and Michele (mean score = 33.67, $p \ll 0.001$), as well as, Clara (mean score = 24.38) compared to Edoardo ($p < 0.05$) and Michele ($p < 0.05$). No significant differences were found between Giulia and Clara and between Edoardo and Michele. An interaction emerged between participants' gender and their degree of experience with technology ($F(1, 42) = 4.687$, $p < 0.05$). Bonferroni post hoc tests revealed that female participants with high technological experience (mean = 30.35) attributed to the agents higher HQI scores ($p < 0.05$) (and therefore were less prone to identify themselves with the agents) than female participants with low technological experience (mean score = 26.66).

Hedonic Qualities—Feelings—(HQF)

Agents' HQF scores differed significantly ($F(3, 126) = 20.99$, $p \ll 0.001$). Bonferroni post hoc tests revealed that these differences were due to significantly different scores obtained by Giulia (mean score = 19.41) with respect to Edoardo (mean score = 33.00, $p \ll= 0.001$) and Michele (mean score = 32.31, $p \ll 0.001$), as well as, the score obtained by Clara (mean score = 23.60) with respect to Edoardo ($p < 0.05$), and Michele ($p < 0.05$). No significant differences were found between Giulia and Clara or between Edoardo and Michele.

Participants' experience with technology ($F(1, 42) = 7.368$, $p < 0.05$) also played a significant role in the assessment of the HQFs features attributed by seniors to the agents. Bonferroni post hoc tests revealed significant differences between seniors highly technological experienced with respect to low experienced ones ($p < 0.05$), the first group scored the agents (mean = 28.47) less exciting, appealing, and captivating than the second one (mean score = 25.69).

Attractiveness (ATT)

Attractiveness was also found to be significantly different ($F(3, 126) = 25.127$, $p \ll 0.001$) among the agents. Bonferroni post hoc tests revealed that these differences were caused by better scores obtained by Giulia (mean score = 19.14) in comparison with Edoardo (mean score = 33.91, $p \ll 0.001$) and Michele (mean score = 32.62, $p \ll 0.001$), as well as, by Clara (mean score = 22.49) in comparison with Edoardo ($p \ll 0.001$) and Michele ($p \ll 0.001$). No significant differences were found between Giulia and Clara or between Edoardo and Michele.

Participants' experience with technology was also significantly different ($F(1, 42) = 4.288$, $p < 0.05$). Bonferroni post hoc tests revealed that participants with high technological experience (mean = 28.15) scored the agents less attractive than those with low technological experience (mean score = 25.93). In addition, a significant interaction was found between participants' gender and their level of experience with technology ($F(1, 42) = 4.192$, $p < 0.05$), because (Bonferroni post hoc tests) female participants with high technological experience find the agents less attractive (mean = 29.31) than female participants with low technological experience (mean score = 24.89, $p < 0.05$).

4 Discussions and Conclusion

The data of the first experiment showed that specific human like features such as eyes, face, voice, perceived age, clothes, formal dressing, adjutant abilities, and winsomeness affect user's preferences toward agents, while hair, juvenility, and look do not seem to play any role on user's acceptance. Users also expressed preferences on the type of job the proposed agents are most suitable at, suggesting that they attributed to agent's specific competences and capabilities. From these data, it has been learned that young looking agents (such as Clara) are evaluated as ingenuous, and inexperienced and therefore may not serve to specific purposes or occupy specific positions. However, this first experiment served just as a means to assess agents' physical and social features over a large age range of the target population.

The second experiment was instead devoted to assessing elders' preferences, involvement, and engagements with such agents. The interesting results were that no matter how inappropriate, young, and inexperienced, Clara was considered by the non-elder population of the first experiment, seniors clearly expressed their willingness to interact with her rather than with the two male agents. This was true on both the pragmatic (seniors considered Clara better designed, more unmistakable, controllable, user-friendly, and efficient than her male counterparts) and hedonic (seniors judged Clara more captivating, exciting, engaging than her male counterparts) dimensions.

Our data underlined a strong preference of seniors toward female humanoid agents, independently from their gender and their technology savviness. Between the two proposed female agents, seniors' preferences toward Giulia scored statistically significantly higher than those attributed to Clara. It can be hypothesized that Giulia is preferred to Clara because Clara may have been perceived younger, more ingenuous, and less professional as from the results of the first experiment. Giulia is always rated significantly better than Clara, Michele and Edoardo. This is true for the pragmatic qualities (PQ), i.e. for facets inherently concerning the practicality, expertise and usefulness of the agent; and the hedonic qualities (HQI and HQF), i.e. for features regarding the individual identity of the agent as well as the feelings that can emerge during a potential interaction with the agent. Lastly, the female agents seem more engaging than male ones on the attractiveness (ATT) dimension.

The above reported data suggests as conclusion of this study, that seniors' willingness to be assisted by a virtual agent is strongly affected by the gender of the proposed agent. Starting from this data we tried to figure out why our seniors behaved like that. Seniors are more willing to interact and be assisted by female agents. We might argue that this maybe the results of social and cultural wisdoms with respect to the individual perception of others and the role females occupy in society, intended here as the social experience, culture, and environment in which an individual grows. These elements provide the first cognitive and learning understandings about others and therefore, about the social role of men and women and their social differentiation in the community. Gender is the way in which historically and socially in a given community, a (mutable) meaning is attributed to the physical and biological differences between human beings. These differences are converted in artefacts of human activities by the cultural environment, establishing a form of labour division, initiated by the prehistoric gathering-hunter division, and exemplified by modern complex societies, through cultural distinctions among masculine and feminine professions [22]. Therefore, because of their specific cultural heritage and the role of women in the specific society of the target population, it is expected that seniors may prefer a female assistive virtual adjutant. Change in the cultural heritage and social rules may however alter such preferences.

The proposed work attempts to assess elders' preferences in initiating conversations with humanoid agents and provide measures of their interest in favor of a long-lasting interaction, as well as, their degree of acceptance, and their willingness to exploit these agents as tools for entertainment, assistance, and company. To this aims it provides original data suggesting a seniors' preference toward female agents, and a disenchantment of the most technologically experienced ones on the agents' hedonic and attractiveness qualities. Seniors' savviness of technological devices is an impediment to feel captivated, engaged, and rise behaviors of increased use, or dissent, as well as, positive or negative emotions. The research also offers to the international scientific community an original assessment tool (the questionnaire developed by the authors) that deliver a systematic way for conducting such investigations, in order to identify further differences caused by social, cultural, and environmental factors. This is the way this research was envisaged, since it was conducted as part of an EU funded project, underlining the limitations associated to the present results. Currently, the preferences identified in this study refer to the South Italian population located in the Campania region. We do not yet know whether these results may be different for the Northern Italian senior population, neither do we know about potential differences found in other EU countries. The research undertaken by the Empathic project (https://www.cordis.europa.eu/project/rcn/212371_en.html) is intended to answer some of these questions, and consequently offer insights that can support the foundation of reliable predictions on seniors' acceptance of virtual humanoid interfaces for assistive uses.

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References

1. Theng Y-L, Paye A (2011) Interactive digital social activity space for the elderly and positive ageing. Designing with and for the elderly: an interactive digital social activity space addressing elderly loneliness and IADIS, Society and Human Beings
2. Munoz RF, Cuijpers P, Smit F, Barrera AZ, Leykin Y (2010) Prevention of major depression. Annu Rev Clin Psychol 6:181–212
3. McDaid D, Curran C, Knapp M (2005) Promoting mental well-being in the workplace: a European policy perspective. Int Rev Psychiatry 17(5):365–373
4. Hawley MS, Cunningham SP, Green PD, Enderby P, Palmer R, Sehgal S, O'Neill P (2013) A voice-input voice-output communication aid for people with severe speech impairment. IEEE Trans Neural Syst Rehabil Eng 21(1):23–31
5. Parker SG, Hawley MS (2013) Telecare for an ageing population? Age Ageing 42(4):424–425
6. Prescott TJ, Epton T, Evers V, McKee K, Hawley M, Webb T, Benyon D, Conran S, Strand R, Buning M, Verschure P, Dario P, Group T (2012) Robot companions for citizens: roadmapping the potential for future robots in empowering older people. In: Bridging research in ageing and ICT development final conference, Springer-Verlag, Prague
7. Gallego-Perez J, Lohse M, Evers V (2013) Robots to motivate elderly people: present and future challenges. In: Proceedings of IEEE international workshop on robot and human interactive communication, pp 685–690
8. Davis FD (1989) Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Q 13(3):319–340
9. Giuliani MV, Scopelliti M, Fornara F (2005) Elderly people at home: technological help in everyday activities. In: Robot and human interactive communication. ROMAN 2005 IEEE international workshop, Nashville, TN, USA, 13–15 August
10. Esposito A, Schlögl S, Amorese T, Esposito AM, Torres MI, Masucci F, Cordasco G (2018) Seniors' sensing of agent's personality from facial expressions. In: Proceedings of ICCHP, 2018
11. Gong L, Nass C (2007) When a talking-face computer agent is half-human and half-humanoid: human identity and consistency preference. Hum Commun Res 33(2):163–193
12. Sträfling N, Fleischer I, Polzer C, Leutner D, Krämer NC (2010) Teaching learning strategies with a pedagogical agent: the effects of a virtual tutor and its appearance on learning and motivation. J Media Psychol: Theor, Methods, Appl 22(2):73–83
13. Ring L, Utami D, Bickmore T (2014) The right agent for the job? The effects of agent visual appearance on task domain. In: Proceedings of international conference on intelligent virtual agents (IVA 2014). LNCS, 8637. Springer International Publishing, pp 374–384
14. Guadagno RE, Blascovich J, Bailenson JN, Mccall C (2007) Virtual humans and persuasion: the effects of agency and behavioral realism. Media Psychol 10(1):1–22
15. Kong H (2013) Face interface will empower employee. IJACT 5(15):193–199
16. Oh SY, Bailenson J, Krämer N, Li B (2016) Let the avatar brighten your smile: effects of enhancing facial expressions in virtual environments. PLoS ONE 11(9):e0161794. https://doi.org/10.1371/journal.pone.0161794
17. Cordasco G, Esposito M, Masucci F, Riviello MT, Esposito A, Chollet G, Schlögl S, Milhorat P, Pelosi G (2014) Assessing voice user interfaces: the vAssist system prototype. In: Proceedings of 5th IEEE international conference on cognitive infocommunications, pp 91–96
18. Yaghoubzadeh R, Kramer M, Pitsch K, Kopp S (2013) Virtual agents as daily assistants for elderly or cognitively impaired people. In: Proceedings of international workshop on intelligent virtual agents (IVA 2013). LNCS, 8108. Springer International Publishing, pp 79–91
19. Straßmann C, Krämer NC (2017) A categorization of virtual agent appearances and a qualitative study on age-related user preferences. In: Proceedings of international conference on intelligent virtual agents (IVA 2017). LNCS, 10498. Springer International Publishing, pp 413–422
20. Hassenzahl M (2014) AttrakDiff(tm). Internet resource http://www.attrakdiff.de
21. Hassenzahl M (2004) The interplay of beauty, goodness, and usability in interactive products. Hum-Comput Interact 19:319–349

22. Signorelli A (2011) Antropologia culturale, 2nd edn. McGraw-Hill, Milano, pp 209–213
23. Cereghetti DM, Kleanthous S, Christophorou C, Tsiourti C, Wings C, Christodoulou E (2015) Virtual partners for seniors: analysis of the users' preferences and expectations on personality and appearance. In: CEUR workshop proceedings, vol 1528, pp 7–10

Human and Animal Welfare Assessment During Animal Assisted Interventions (AAI): A Pilot Project in Progress

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Abstract The use of technology and technological tools has always been to support the improvement of the people life quality. The present project intended to value the animal and human comfort and welfare during the Animal Assisted Interventions (AAI). The approach used in this project is in according to the biopsychosocial model, using both the International Classification of Functioning, Disability and Health (ICF) and behavioral aspects and hormonal levels evaluation in the animals in order to obtain important data to standardize an no invasive method of welfare assessment during therapy, rehabilitation, and pedagogical education activities.

Keywords Life quality · Human and animal welfare · Animal Assisted Interventions

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1 Introduction

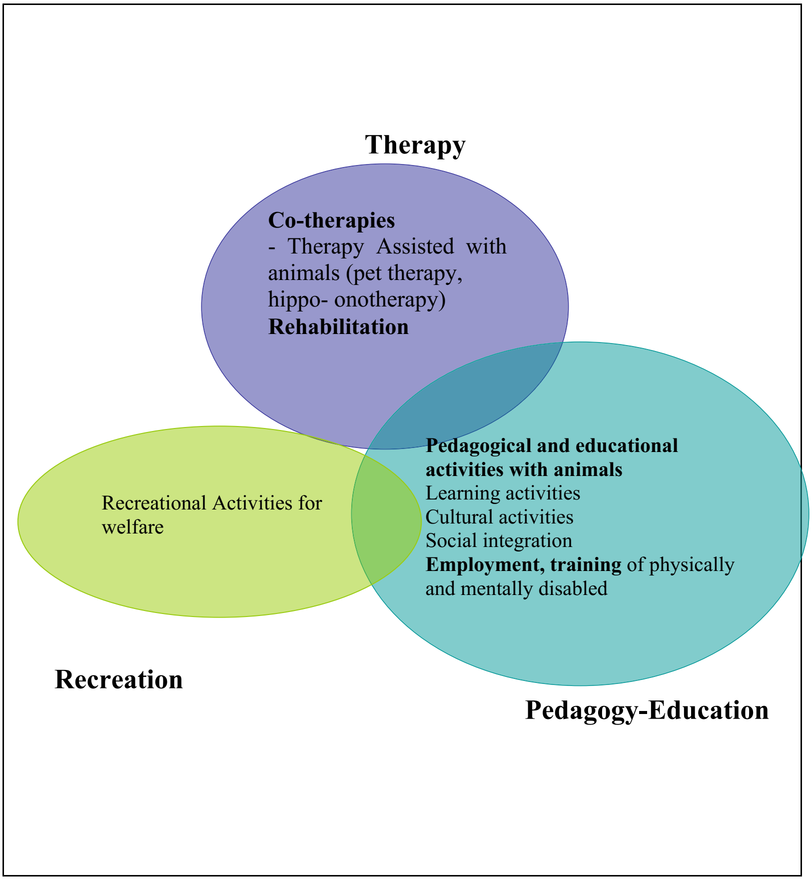
A new rural paradigm stands out as the interrelationship between agriculture, landscape protection and social services (e.g. Social Agriculture, Teaching Farms, Social Farms, Animal Assisted Interventions and so on) [1]. Multifunctionality Agriculture, in fact, has received a lot of attention over the last decade from scholars and policymakers. Models based on forms of solidarity or trust could be a crucial driver for fostering the competitiveness of rural areas. Evaluation tools are needed for analyzing the current system and for improving the social approach.

This research involves a multidisciplinary team with behavioural sciences in human and animals and educational skills to evaluate all the aspects of the development of an assistive enabling environment, the welfare of the human and the animals employed. The experimentation of these criteria shows the effects of physical environment on functional performance and gives evidence based knowledge to a supportive environment that is able to control sensorial stimulation and to improve individual abilities, especially during the childhood, as a life-project in terms of wellbeing, autonomy and quality of life.

The focus is on the spirit of responsibility and the importance of evoking choices by House [2] and on the crucial role of the education function and on functions of networking several stakeholders. Management of multifunctional land models is by several components which structure development deriving from the new rural paradigm [3]; in this respect, the need to define indicators concerning the economic and social/health dimensions of agriculture and rural development stands out. Several studies provide indicators [4–8] based on local data such as a practical method to monitor progress towards aims and new models. However, since there are many conflicting frameworks proposed to develop indicators, it is unclear how best to collect these data [8]. Here we select from existing literature and propose possible indicators with a special look at the health and social dimension and not only. There is no unique way of defining or measuring the "attractiveness" of rural areas, but important aspects include the level of income, the possibilities for employment and new opportunities for income in these areas, the physical infrastructure, the social capital, the quality of the environment, and so on. Far from being exhaustive. The following Table 1 provides an overview of the main aspects in this work and specifically the AAI intervention areas (therapeutic, rehabilitative, educational-pedagogical and wellness); further steps will be needed to define the methods and criteria for assessing the effects of the AAI on human well-being. As is evident, indicators and methods for estimating the features and potential to generate welfare of the rural areas and the green care. These evaluation tools can be very interesting in the light of the ongoing transformations within the agricultural sector (from productivity towards multifunctional practices) and within the health and social service sector (from highly institutionalized to community care) [9].

The aim of this proposal project is to provide an analysis of the educational and social opportunities deriving from multifunctional agriculture and AAI. Furthermore, we define indicators focusing on the social/education dimension and to identify a non-

Table 1 AAI functions, our processing



invasive standardized and objective method to evaluate and judge both the attitudinal characteristics that the welfare state [10, 11] in animals (e.g. donkey and horse) in order to maximize the possibilities for their use in AAI.

2 Pilot Project in Progress

The use of technology and technological tools has always been to support the improvement of the people life quality. Growcare is proposed as a useful tool to ensure a complete and reliable management of complementary therapies such as AAI and interventions of *Orto di Aiuto* (*OdA*) [12].

Growcare is an advanced technological programm as therapies and educational support.

Considering that the project MISS Masseria of educational Social—Sanity Inclusion has evaluated, thanks to the ICT support also the human comfort during the AAI; considered that the pilot study performed to the Department of Veterinary Science has valued the animal comfort this pilot project intends to integrate and to implement the data of two research to the purpose of study of correlation human and animal welfare during the AAI.

2.1 Proposal Project Methodology

2.1.1 Approach to Human

The implementation of the platform in the cloud "MISS", aims to give a service that facilitates the staff employed in the AAI and OdA as well as customers/patients, to monitor the patient. The person/user who takes advantage of the AAI and OdA, within the platform, is identified with the folder. Each patient has, from the moment of registration (before acceptance), a personal folder in which is enclosed all its clinical and demographic information. You can manage change master folders, generate a report of the entire activity on each folder directly from the home page. The platform consists of two areas. The first, dedicated to activities, is the area interventions: AAI and OdA, the second is related to the monitoring of the user/patient. The first is the inclusion of activities associated to the program established in the previous phase, called the intervention program. Here the operator has access to the program established by the clinician of reference and following his directions, once carried out the task, it writes the results collected inside the mask for insertion. The inclusion of the program there are: activities of AAI (Fig. 1). For each operation, you should provide the following information: • date; • type; • the number of session; • animal/plant; • meetings; • Tools.

At each stage, you can add, through the analysis and testing, documentation of information. This useful to collect the documents accumulated during treatments and the activities carried out on the farm.

The material and all patient behaviour are attached to each folder. They are available at any time, simply download the material, if you have the privilege to access the area, and view the documentation previously loaded.

To create an entity analysis and testing you must locate the clinical phase, the test date and any additional notes (Figs. 2 and 3) [13].

The type of activities related to the use of agricultural resources (e.g. care of plants, therapeutic gardens), environmental resources (e.g. the simple vision of a landscape), animal relationship (e.g. AAI, hippotherapy) of therapeutic-rehabilitative programs with people with different problems, undoubtedly presents a challenge for the definition of practices conducted on the strictly scientific level and for the evaluation of information aimed at the formulation of judgments on actions and structured activities, for the realization of rehabilitative pathways and psycho-educational individualized.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António Campinos

Fig. 1 Sesamo Software spa—Grow Care—a pilot projet in progress

During the project MISS, the team defined the methods to be adopted in the farm and the procedures to update the data in the platform and monitor the progress of the treatments. For the validation of the routes, ad hoc tests were structured [14].

Adult patients underwent the following tests and evaluations: Mini-International Neuropsychiatric Interview—MINI [15], Psychiatric Rating Scale—BPRS [16] Short Intelligence Test—TIB, Activities of Daily Living—ADL, Short Form 36 Health Survey Questionnaire SF-36 [17].

Minor patients underwent the following tests and evaluations: Colored Progressive Matrices—CPM [18], Psychoeducational Profile—Third Edition—PEP III [19] (Fig. 4).

All participants underwent clinical and neuropsychological evaluation on entry into the farm before treatment exposure (T0), during—3rd month (T1) and at the end of treatment—VIth month (T2), and monitored through a specially designed test.

According to the biopsychosocial model, the ICF (International Classification of Functioning, Disability and Health) was inserted to measure the well-being of the person. In 2001 the World Health Organization [20] to describe the health and the disability of the population has adopted the classification ICF and subsequently the ICF-CY (Children and Young) that keeps in mind of the relationships among mind, body, environments, contexts and culture, setting as plant the quality of the life of the people affect from a pathology, underlining that the knowledge is necessary of the functional state of a person as an unified and shared language that you

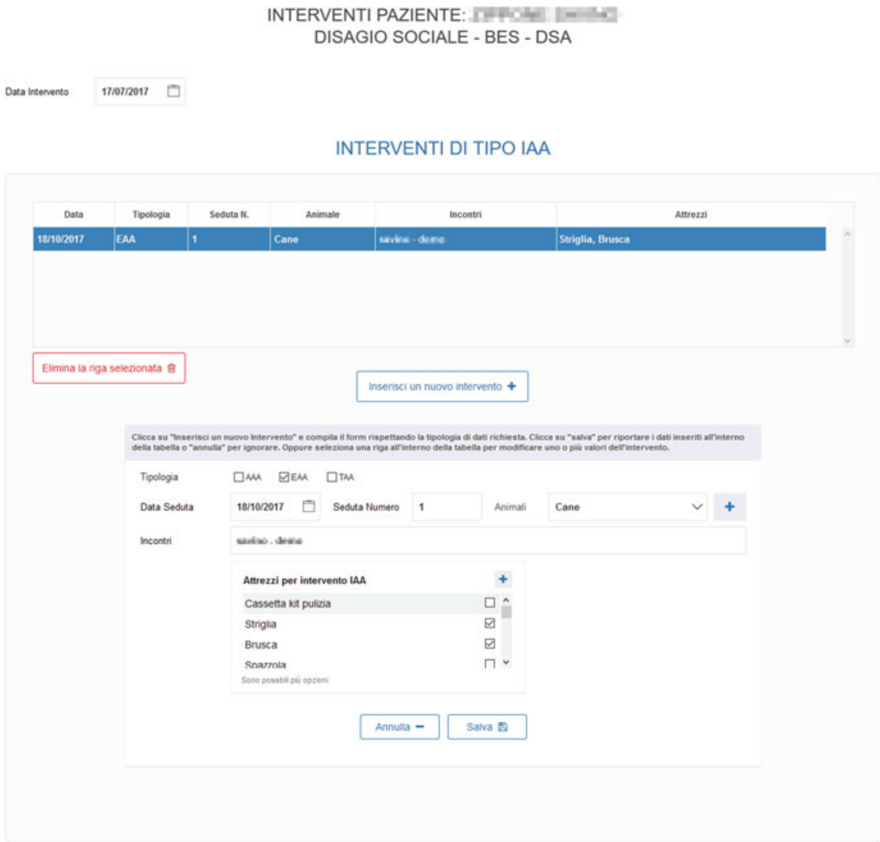
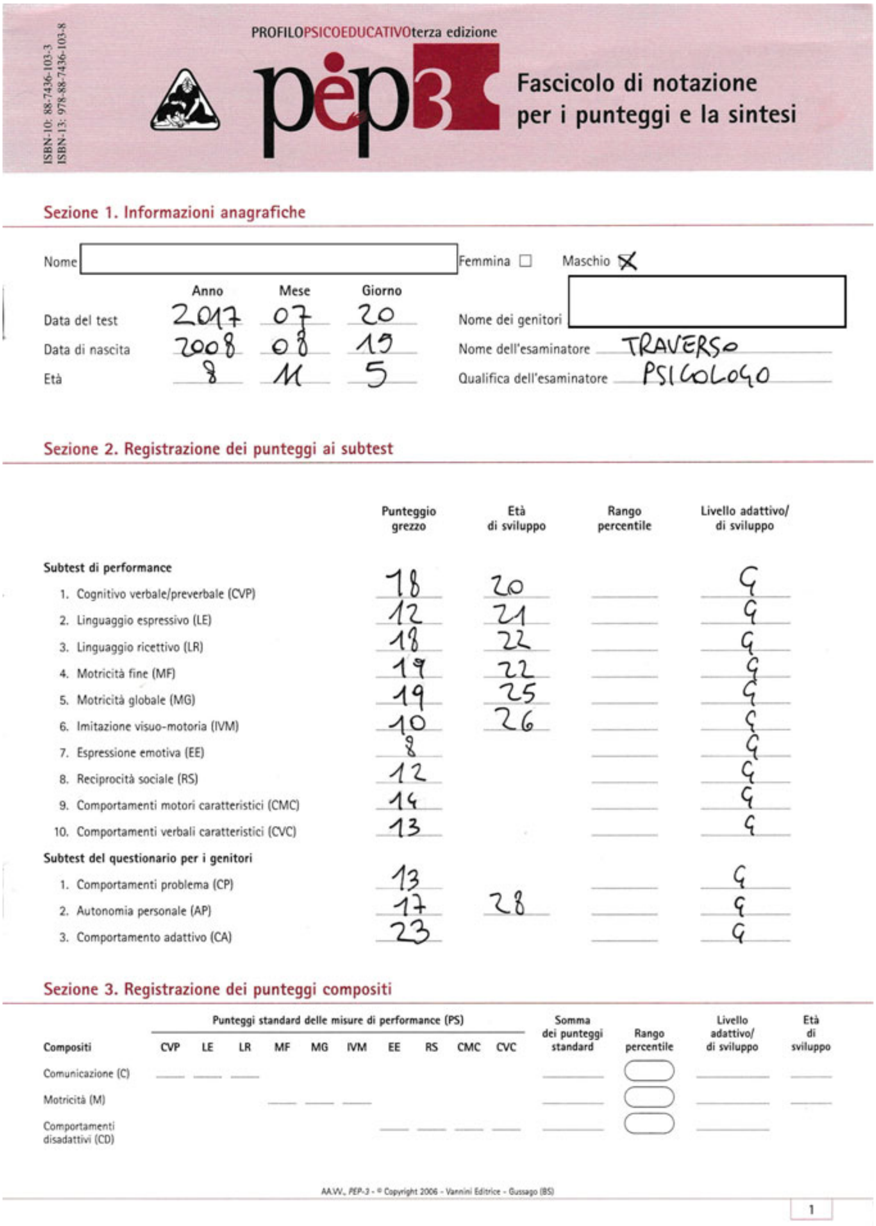


Fig. 2 Sesamo Software—Cluster Tecnologico MISS, 2018

Fig. 3 Sesamo Software spa—Cluster Tecnologico MISS, 2018



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Fascicolo di notazione per i punteggi e la sintesi

Sezione 1. Informazioni anagrafiche

Nome | Femmina ☐ | Maschio ☒

	Anno	Mese	Giorno
Data del test	2017	07	20
Data di nascita	2008	08	15
Età	8	11	5

Nome dei genitori

Nome dell'esaminatore TRAVERSO

Qualifica dell'esaminatore PSICOLOGO

Sezione 2. Registrazione dei punteggi ai subtest

	Punteggio grezzo	Età di sviluppo	Rango percentile	Livello adattivo/di sviluppo
Subtest di performance				
1. Cognitivo verbale/preverbale (CVP)	18	20		G
2. Linguaggio espressivo (LE)	12	21		G
3. Linguaggio ricettivo (LR)	18	22		G
4. Motricità fine (MF)	19	22		G
5. Motricità globale (MG)	19	25		G
6. Imitazione visuo-motoria (IVM)	10	26		G
7. Espressione emotiva (EE)	8			G
8. Reciprocità sociale (RS)	12			G
9. Comportamenti motori caratteristici (CMC)	14			G
10. Comportamenti verbali caratteristici (CVC)	13			G
Subtest del questionario per i genitori				
1. Comportamenti problema (CP)	13			G
2. Autonomia personale (AP)	17	28		G
3. Comportamento adattivo (CA)	23			G

Sezione 3. Registrazione dei punteggi compositi

Compositi	CVP	LE	LR	MF	MG	IVM	EE	RS	CMC	CVC	Somma dei punteggi standard	Rango percentile	Livello adattivo/di sviluppo	Età di sviluppo
	Punteggi standard delle misure di performance (PS)													
Comunicazione (C)														
Motricità (M)														
Comportamenti disadattivi (CD)														

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Fig. 4 Patient 01. Diagnosis: Autism spectrum disorders. Age at T0 6 years—Cluster Tecnologico MISS, 2018 frame those that are the consequences of the conditions of health so that can be improved. The ICF doesn't classify illnesses, disorders or troubles, that are proper of the classification ICD (International Classification of Diseases) (2000) rather, it tries to individualize what can happen in association with a condition of health, understood the personal and environmental resources. Among the conditions of health that can bring to intervention with the daily activities there are congenital anomalies or genetic predispositions as those correlated to the onset of the trouble of the ghost of the autism but with the ICF it also looks him at the abilities or potentiality on which to make lever for the construction of a quality of best life, despite the diagnosis. Just for this, the job of the operators of help that you/they aim to the comfort of the consumer must be a job of team, that must be multidisciplinary, global, tense to sustain the improvement of the quality of the life of the person.

2.1.2 Approach to Animal

The careful assessment and selection of animal in according to their specific characteristics are necessary to develop a protocol assuring the animal welfare and allowing them to become co-therapists. In order to do this, the multidisciplinary team is required according to the Italian Guidelines in AAI [21, 22]. The use of the animal as a co-therapist in the AAI [23–25] requires to study behavioral aspects related to each species, for which the scientific data and issue are inconsistent or even absent. In order to understand the animal's response to stimuli and the ability to live together with other animals and humans, it is also essential to know the ethogram and learn to assess the subject temperament [26].

Specific studies on different species (dog, donkey and horse) were made to fix an objective standardized protocol by monitoring the animal welfare during IAA (Fig. 5). The collection of the samples to be analysed has been performed according to a standardized protocol for schedule (to the morning) and for collection (not invasive to guarantee the welfare without restraint) with the purpose to reduce the hormonal variations to its secretion and the external interferences not related to the specific stimuli to be analysed. The behavior of subjects without experience and learning in the field of assisted activities was observed during the administration of external stimuli, repeated during two experimental sessions. The response to each stimulus was evaluated and a score was assigned: *approach*—score from 1 to 5 based on the time elapsed between the administration and response (5 approaching less than 10″ and 1 over 60″) with a value of 0 for the missed approach; *exploration*, *removal*, *block*, *attack* and *escape*—indicating the occurrence or not (1/0). The results were expressed as the frequency percentage. The correlation between the activity and welfare of animals was determined by quantifying, with an immunoassay kit validated for different species (chosen for family affinity and gender), the fecal cortisol metabolites concentration (FCMC) the day before and the 2 days following the administration of each stimulus. Statistical analyzes were performed using GraphPad Prism 4 software (GraphPad Inc). The Kolmogorov-Smirnov test, the Friedman non-parametric test for repeated measurements with post-test (Dunn's

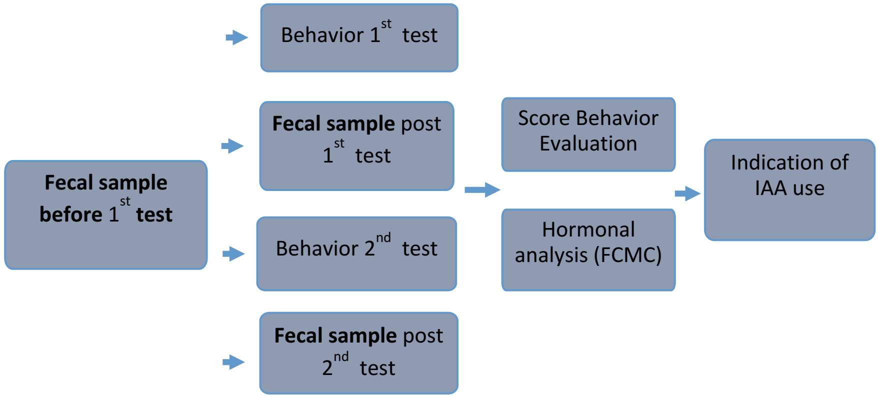

Fig. 5 Standardized protocol by monitoring the animal welfare during IAA

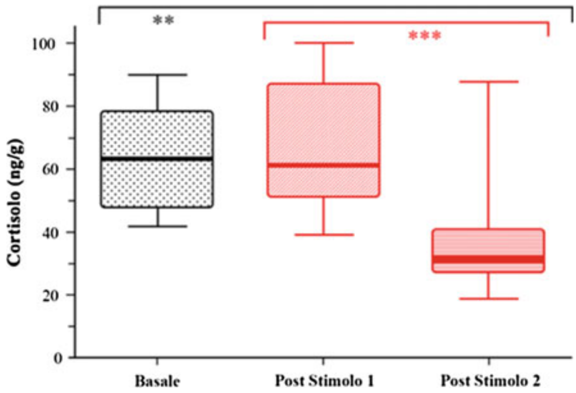

Fig. 6 The correlation between the activity and welfare of animals (FCMC) is indicated as Cortisol (ng/ml) and Basal, Post Stim 1 and Post Stim 2

Multiple Comparison Test), the t-student test for paired data and the Pearson test and Spearman were used ($p < 0.05$). The behavioral and FCMC analysis showed statistically significant differences between the results obtained by the subjects during the first and the second exposure to the stimuli (Fig. 6). Analyzing the results obtained with the second evaluation the attitudes of the subjects and their possible employment as AAI co-therapists were recognized (Table 2). In particular, the positive behavioral ratings obtained during the first exposure to the stimuli are associated with higher FCMC, while for the second exposure to stimuli discrete ratings are associated with low FCMC variations. These differences indicate initial curiosity, accompanied by increased discomfort with unfamiliar stimuli and replaced by habituation and less discomfort when the same stimuli become known.

Table 2 Possible employment of monitored subjects as AAI co-therapists

Use yes	FCMC score evaluation < 60%
	Behavioral evaluation ≥ **Good**
Use no	FCMC score evaluation > 60%
	Behavioral evaluation ≤ **Good**
Partial use	FCMC score evaluation > 60% Behavioral evaluation ≥ **Good**
	Or FCMC score evaluation < 60% Behavioral evaluation ≤ **Good**

3 Conclusion

The aim of this work has been to provide an insight into the role of Social Agriculture. Far from being exhaustive, our analysis utilized a multidisciplinary approach in order to capture the essence of Green Care. The present paper puts the focus on the importance of green care activities and on indicators concerning the social/health dimension of agriculture and rural development. As a general requirement, indicators have to be policy-relevant [3, 6] and can guide policy-makers in their decisions; furthermore, indicators should help to identify the policy fields where action is needed. Scholars [27] argue that an improvement of knowledge and awareness about care farming is considered the key to promoting a shared recognition of care farming amongst agricultural and health care agents, and as well as following up institutionalization of care farming arrangements in policy frameworks. We have provided an extension to the multi-level dimension of agriculture, as asked for in EU policies and in previous studies [28–35]. In line with these studies, we argue that a new rural paradigm stands out and, furthermore, we highlight that this paradigm strengthens solidarity, trust, proximity, emotional states, psychological well-being such as NCOs. To conceptualize and formalize we have defined the Multifunctional Agricultural House starting from the House of functions by [2] by taking into account the educational and relational dimension of the agricultural system.

Moreover, we have used insights from existing policy reports and scientific studies in order to define indicators focusing on the educational/social dimension and behavioral and welfare assessment.

For the behavioral evaluation and the welfare assessment of the subjects to be employed in the AAI the results showed statistically significant differences between the subjects during the first and the second exposure to the stimuli.

Analyzing the results obtained with the second evaluation the attitudes of the subjects and their possible employment as AAI co-therapists were recognized.

In particular, the positive behavioral ratings obtained during the first exposure to the stimuli are associated with higher glucocorticoid levels, while for the second exposure to stimuli discrete ratings are related with low hormonal levels variations.

These differences indicate initial curiosity, accompanied with increased discomfort with unfamiliar stimuli and replaced by habituation and less discomfort when the same stimuli become known.

Our study showed that he experience of educational, therapeutic and rehabilitation interventions in the farm (AAI in the particular case) and a comparison between traditional rehabilitation workers and complementary rehabilitation interventions. However, it is possible to report that the follow-up in both adult and minor patients is an improvement in the global, in the quality of life, in the implementation of consequent objectives.

We, therefore, underline the importance to analyze further details of the methodology for constructing indicators. In future studies, we will test our hypothesis by investigating initiatives in care farming and evaluating them by means of the indicators elaborated. Much more remains to be done.

References

1. Finuola R, Pascale A (2008) L'agricoltura sociale nelle politiche pubbliche. Roma, INEA
2. Fleskens L, Duarte F, Eicher I (2009) A conceptual framework for the assessment of multiple functions of agro-ecosystems: a case study of Tras-os-Montes olive groves. J Rural Stud 25
3. OECD a (2006) The new rural paradigm: policies and governance. OECD Publications, Paris
4. OECD b (2000) Environmental indicators for agriculture: methods and results—the stocktaking report contextual indicators, Paris
5. OECD c (2000) Environmental indicators for agriculture: methods and results—the stocktaking report contextual indicators: farm financial resources, Paris
6. EU Commission (2001) A framework for indicators for the economic and social dimensions of sustainable agriculture and rural development, Agriculture Directorate-General, 05 Feb 2001
7. Riley J (2001) Multidisciplinary indicators of impact and change: key issues for identification and summary. Agric Ecosyst Environ 87
8. Reed MS, Fraser EDG, Dougill AJ (2006) An adaptive learning process for developing and applying sustainability indicators with local communities. Ecol Econ 59
9. De Krom MPMM, Dessein J (2013) Multifunctionality and care farming: contested discourses and practices in Flanders. NJAS—Wagening J Life Sci 64–65
10. Cozzi G, Brscic M, Gottardo F (2006) Il benessere degli animali da reddito: quale e come valutarlo 40:45–46
11. Möstl E, Palme R (2002) Hormones as indicators of stress. Domest Anim Endocrinol 23:67–74
12. di Matteo A., Traverso T., Interventi di aiuto e giochi clinici in agricoltura sociale nel territorio del Gal Daunofantino. Andrea Pacilli, Manfredonia. ISBN: 978-88-96256-76-3 (2015)
13. Cluster MISS Masseria di Inclusione Sociale Sanitaria-educativa, progetto finanziato dalla Regione Puglia, a valere su "Aiuti a sostegno dei Cluster Tecnologici Regionali per l'Innovazione" (2018)
14. Andrich R, Porqueddu B (1990) Educazione all'autonomia: esperienze, strumenti, proposte metodologiche - Europa Medicophysica, 26, 3 Minerva, Torino
15. Folstein MF, Folstein SE, McHugh PR (1975) "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 12(3):189–198, PMID 1202204. https://doi.org/10.1016/0022-3956(75)90026-6
16. Overall JE, Gorham DR (1962) The brief psychiatric rating scale. Psychol Rep 10:799–812
17. Apolone G, Mosconi P, Ware Jr J (1997) Questionario sullo stato di salute SF-36, Guerini e Associati

18. Belacchi C, Scalisi TG, Cannoni E, Cornoldi C (2016) Colored Progressive Matrices—CPM standardizzazione italiana. Giunti O.S., Firenze
19. Schopler E, Lansing MD, Reichler RJ, Marcus LL (2006) Psychoeducational profile, 3d edn, PEP III. Vannini Editrice, Gussago, BS
20. WHO (2002) International classification of functioning, disability and health (trad. it. O.M.S.—Organizzazione Mondiale della Sanità, ICF, Erikson, Trento)
21. Linee guida nazionali per gli Interventi Assistiti con gli Animali (2016)
22. di Matteo A, Traverso T (2016) Cura e benessere con l'agricoltura. Andrea Pacilli, Manfredonia. ISBN 9788896256923
23. Grandgeorge M, Hausberger M (2011) Human–animal relationships: from daily life to animal-assisted therapies. Annuario Istituto Superiore di Sanità 47(4):397–408
24. Cantiello PR (2009) a cura di. L'asino che cura, Carocci Faber
25. De Rose P, Cannas E, Cantiello PR (2011) Donkey-assisted rehabilitation for children: a pilot study. Annuario Istituto Superiore di Sanità 47(4):391–396
26. Amendola S, Macchi E, Rasola M, Carluccio A, Marsilio F, Contri A, Pio Sfirro M, Ponzio P (2012) Monitoraggio del comportamento e del benessere di asine in Attività e Terapie Assistite con gli Animali (TAA/AAA) simulate. Ippologia 23(2):9–16
27. Di Iacovo F, O'Connor D (2009) Supporting policies for social farming in Europe: progressing multifunctionality in responsive rural are as. Regione Toscana Ltd, Florence, Italy, Arsia
28. Andersen PS, Vejre H, Dalgaard T, Brandt J (2013) An indicator-based method for quantifying farm multifunctionality. Ecol Indic 25
29. Barbieri C, Valdivia C (2010) Recreation and agroforestry: examining new dimensions of multifunctionality in family farms. J Rural Stud 26
30. Bernard C, Dobremez L, Pluvinage J, Dufour A, Havet A, Mauz I, Tchakérian E (2006) Multifunctionality at the local level: farms and issues of agribusiness and designations of origin [La multifonctionnalité àl'épreuve du local: Les exploitations agricoles face aux enjeux des filières et des territoires]. Cahiers Agricultures 15
31. Grouiez P (2011) Farm strategies and the multifunctionality of Russian agriculture [Les stratégies des exploitations agricoles et la multifonctionnalité de l'agriculture russe], Revue d'Etudes Comparatives Est-Ouest 42
32. Ohe Y (2011) Evaluating internalization of multifunctionality by farm diversification: evidence from educational dairy farms in Japan. J Environ Manag 92
33. van der Ploeg JD, Laurent C, Blondeau F, Bonnafous P (2009) Farm diversity, classification schemes and multifunctionality. J Environ Manag 90
34. Wilson GA (2008) From 'weak' to 'strong' multifunctionality: conceptualising farm-level multifunctional transitional pathways. J Rural Stud 24
35. Kizos T (2010) Multifunctionality of farm households in Greece. Norsk Geografisk Tidsskrift 64

"Casa Amica", Project for the Construction of a Social-Assistance Structure and a Social-Healthcare Unit C.R.I., to Be Used for the Reception of Elderly People with Disabilities

Giuseppe Losco, Andrea Lupacchini and Luca Bradini

Abstract Following the earthquake of 24 August 2016 and subsequent replies that have affected several municipalities in the regions of Abruzzo, Lazio, Marche and Umbria, resulting in a serious situation of danger and damage to structures and infrastructure falling within the territory, the City of Camerino and the Croce Rossa Italiana, National Committee, have signed a memorandum of understanding (of 28/04/2017) and a preliminary design document for the construction of a structure for hospitality and social-health facilities called "Casa Amica" to temporarily host the elderly with disabilities residing in the structure damaged by the earthquake. The aim of the intervention is to restore as soon as possible the functionality of the main activities serving the community by applying the most recent theories known in research, development and innovation related to the sector of technologies and services for active aging and healthy. Hence the idea of a structure that in the first instance serves to deal with the emergence of a social-sanitary type of accommodation and subsequently, to return to ordinary conditions, to meet the collective needs of the citizenship, to strengthen social and welfare activities, promote training and information activities, as well as recreational and creative activities for people of all ages. The SAAD, School of Architecture and Design "Eduardo Vittoria", with headquarters in Ascoli Piceno,

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University of Camerino UNICAM, which for years has been involved in scientific research in the context of Smart City-House-Object, has Preliminary project of this innovative structure, trying to apply and experiment with all the design principles oriented to the Environment Assisted Living, Active and Healthy Aging and Smart Living culture.

Keywords Smart living · Design · Social healthcare

1 Description of Architectural Interventions

The project aims to accommodate the elderly guests of the structure damaged by the earthquake of 24 August 2016, offering health care services and functional recovery, encouraging socialization through the creation of accessible recreational and recreational spaces and simultaneously meet the collective needs of the citizenship (Fig. 1).

Particular importance has been given to the planimetric distribution and to the volumetric articulation of the designed building, so as to be in itself strongly orientating. Formally it consists of a central body and two side wings connected by a central path.

As a whole it presents itself as an articulated functional fabric, spread over a single level in which there are, next to the rooms, areas dedicated to social relations, links between the various areas to facilitate the mobility of those present and spaces

Fig. 1 Exterior view of the building

Fig. 2 Plan and main elevation

reserved for occupational activities and of laboratory to actively engage guests if their experiences and attitudes are achieved (Fig. 2).

1.1 Preservability, Flexibility and Usability

The internal connection path that runs along the entire building offers a global permeability from a functional and perceptive point of view. The two lateral bodies, destined to the residences and the central one, are connected by it as a skeletal-lymphatic system which houses the plant system in the covering part.

It is equipped with more access to the outside, this facilitates the mobility of patients/residents, not confining them, but giving them the opportunity to reach the outdoor spaces equipped with laboratory and/or rehabilitation activities. At the same time it promotes further security for escape routes and emergency assistance when needed.

Two small patios, located in each of the two residential wings, interrupt this path prospectively, reinforcing the contact with the outside, favoring the entrance of natural light and improving the emotional quality of the environment by bringing the green inside the building.

The course also allows users the possibility of reaching the health center directly from within, to carry out routine examinations and checks.

A circular path equipped around the structure guarantees a direct relationship with the outside, and favors the expansion of recreational activities also for the entire community.

1.2 Spaces for Individual and Collective Well-Being

Located in a central position with respect to the entire structure, we find the main volume.

Architecturally distinguishable by morphology and dimensions, easily identifiable from the outside, it is the fulcrum of socio-recreational activities it forms the functional core of services, takes on the characteristics of a reference space and is the functional access node, marking with a shelter strongly jutting out the entrance to the structure.

Formed by coating layers that alternate in the materials, they envelop the entire underlying space and characterize its central role.

Here we find in fact the reception with waiting room, the administrative offices, the medical staff of C.R.I. with its own waiting room, the changing rooms for the staff, the support kitchen for the canteen service, a small bar, the accessible toilet facilities and the large multi-purpose space.

The garrison (45.00 m^2) is a single space, separable with movable walls in two separate rooms for visits, is equipped with an independent toilet and a small room with bed for the night service attendant and waiting room outside, where the independent entrance is located.

The changing rooms for the staff and the kitchen have been placed near one of the side entrances to allow the employees to reach the structure without having to go through the main entrance or through hygienic zones reserved for guests.

The bar is located in a central position with respect to the entrance and the multipurpose hall and is directly connected to the kitchen.

The multifunctional space opens on the opposite side to the entrance of the structure, occupies a total area of about 130.00 m^2 and generally houses the gym (about 38.00 m^2), the living room (about 42.00 m^2) and a central space with tables for canteen activities and recreational partner (about 50.00 m^2).

The multi-purpose functionality of the space is guaranteed by the possibility of modulating it through the movable, rototranslating and packing walls according to the needs of the structure or events hosted from time to time.

This space has large windows that allow seasonal continuity with the outside, is further expanded at events and for the performance of the activities to which it is intended when the external temperatures allow it.

This increases the flexibility and multi-purpose for which it was designed in addition to improving the level and uniformity of lighting and natural ventilation (Fig. 3).

1.3 Functional Identifiability, Rationality of Use

Like the central body strongly characterized by its dimensions and the diversified covering, so the two side wings destined to the residence are articulated in decomposed volumes, diversified in the forms, the colors and the materials; here form and function are inextricably linked to each other.

Fig. 3 Render of external areas

Modularity may also allow for assistance differentiation, with a view to guaranteeing the possibility of switching from one type of care to another in relation to the changing health and welfare needs offered by the structure.

The form is not only linked to the optimization of lighting and energy comfort, because together with the formal and chromatic diversification and the use of different coating materials it helps to improve the spatial orientation, giving users the possibility to associate form and color to the own residence: the volume is identified as the house, the alternation of shapes and colors reminds the skyline of a hypothetical village in which to find the residents, a domestic, familiar and a sense of domestic belonging.

This aspect turns out to be fundamental for therapeutic purposes and solves a problem that is often found by healthcare workers in serial buildings and characterized by too geometric, orthogonal, repetitive, regular spatial lines merged into unique rather anonymous volumes.

Each block of the bedrooms is connected to the next by prefabricated monoblocks containing the toilets, all meeting the accessibility requirements set by the regulatory standards, which can also be used by people in wheelchairs.

In fact, the structure provides for the presence of self-sufficient people and not, so within the residential volumes has been placed both in the right wing and in the left also a bathroom assisted (as per legislative provisions).

The residential volumes of the left wing internally house 2 or 4 double rooms (each with its own bathroom), an assisted bathroom, a small dining area with kitchenette and storage areas.

The volumes of the right wing house 2 double rooms, 2 single rooms, 1 single room and 1 double room, also here there is a bathroom for each room with direct access, a bathroom assisted, a small dining area with kitchenette, linen deposit dirty,

Fig. 4 Functional area

the clean linen store, with space reserved for the staff and the burning room, located in a peripheral position with access also from the outside.

The single rooms have been deliberately placed in a separate block, since they can be destined to patients with more serious and non self-sufficient pathologies, who need a minimum of separation and privacy (for example night and daytime noises linked to certain pathologies), for improving their conditions and those of other guests (Fig. 4).

The double rooms have an area of about 18.20 m^2, while the individual rooms of 14.80 m^2.

The double rooms have not been designed as common spaces, but with reserved micro spaces: each patient, besides his bed with a bedside table, has a wardrobe and a desk; a curtain positioned between the two beds helps to divide the space, giving each occupant more privacy, and the ability to carve out their own protected space during the day.

All the rooms are equipped with small "bioclimatic greenhouses", which can be closed with packed glass windows, inside which various activities can be carried out, exploiting the heating due to direct solar irradiation (Fig. 5).

1.4 The Elimination of Architectural Barriers

The elimination of architectural barriers is not only physical, but also perceptive and emotional, so the project emphasizes the use of color functions not only with regard to the outer shell, but also with reference to the interiors and furnishings e.g. the recognizability of places and routes.

The color then becomes the identification code of the zones, differentiating them by their dangerousness, use and frequentation.

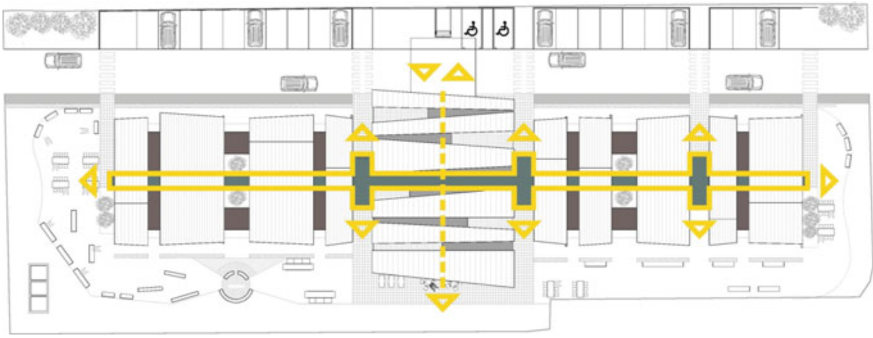

Fig. 5 Distribution path

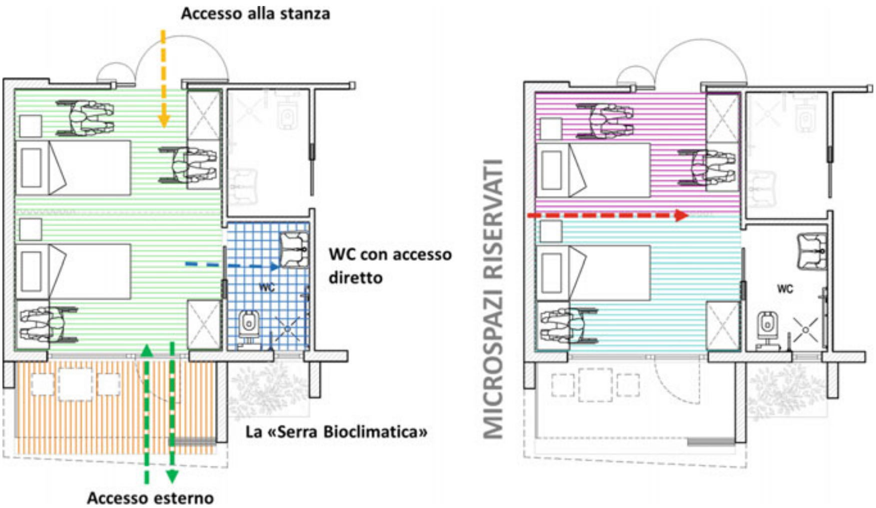

Fig. 6 Double rooms

In environments dedicated to care it is important to favor simplicity, using homogeneous colors, optimizing the lighting thanks to a remarkably high refractive index.

A correct chromatic intervention in environments in which older people live in a state of particular psycho-physical fragility has an additional therapeutic power, can favor and accelerate the recovery of health (Fig. 6).

1.5 Architectural Objectives

The entire project is aimed at the user comfort of the user, emotional communication, recognizability as a social point at the service of the community put to the test by the seismic event, to environmental integration.

The structure designed for nuclei or basic modules, is able to adapt to the different needs determined by the different and/or changed composition of the guests and also ensure a good flexibility in internal organization and management methods.

At the same time it creates opportunities for spontaneous socialization within the nucleus, in the relations between nuclei and in relationships with users.

1.6 Accessibility to the Area

Located in an already urbanized area, integrated with the existing context, the area has been given double access to the intervention lot. This is guaranteed by an internal two-way road, with a small parking lot for the users of the structure, a parking lot for ambulances and for the disabled, the latter covered by a shelter that marks the entrance to the structure itself and the night access to health care.

1.7 Integration with the Context and Reduction of Environmental Impact and Noise and Air Pollution

The structural fragmentation of the building also allows for greater integration with outdoor spaces and greenery: a green not only linked to rehabilitative requirements, but also to technological ones for environmental mitigation and the isolation of structures.

Small niches of green are inserted near the blocks that house the toilets; the hedges create a natural screen in front of the rooms, guaranteeing privacy to the occupants.

Natural space can become a fundamental element that materially allows "being together" and that for this reason takes on relational qualities. It is also shown that green is able to produce cognitive, psychological, social and physical benefits.

The ancients spoke of vis medicatrix naturae and Aristotle reads: "The doctor cares, nature heals."

Green as a design element and environmental integration, reduces the impact of the building, but becomes an active protagonist of the project. If, on the one hand, the simple "vision" of a natural space is able to offer a contribution to healing, on the other it is possible to amplify its effects allowing the patient to interact with the garden by also acting through increased physical activity; in fact, the equipped part covers the 3 sides of the structure.

The outer space is presented as the project of a real Therapeutic Gardens, to be used as part of an occupational therapy treatment program, of physical therapy.

Rehabilitation gymnasiums, sensory paths with "raised flowerbeds" have been provided, in which to insert interesting plants from the olfactory and tactile point of view, which give different sensations, or thought of as containers of different materials such as grass, rock, gravel and sand to emphasize diversity of sensations.

The plants are of considerable importance so, accessible tables for the ortho-therapy allow to recover self-esteem and dignity, stimulating creativity.

Trees shade meeting places, resting points, areas for outdoor recreation. The seats placed in sheltered places surrounded by vegetation can be a place that invites rest and meditation.

Green helps to partially mask the anthropic element, inserting it, in the environmental context, reduces the temperature peaks in the surrounding environments, bringing advantages even on a small scale. The green is also a useful tool in reducing noise pollution by reducing the transmission of sound within the structure, reducing even the reflection outside.

The prefabrication of the elements allows a personalized design respecting the landscape, the nature of the terrain, the orientation and distribution of functions, the application of the bioclimatic principles, the integration between exterior and interior, all aimed at adaptation and exaltation of the characteristics of the sites and their climate.

The entire building is designed as a prefabricated modular system.

The complete prefabrication of all the technological elements allows to have a completely dry and clean building site because the only required processing is the assembly and tightening of macro components, without need of scaffolding or impacting machinery, nor of fixed logistic structures, but using light installation systems, such as the same mobile cranes used to transport the construction elements.

This contributes to producing a very low pollution, a minimum energy consumption with significant direct benefits for the surrounding environment (Fig. 7).

1.8 Use of Innovative Technologies and Use of Durable Materials

Dry prefabricated construction systems have considerable advantages:

- Speed of realization
- Ability to make certain predictions about times and costs
- Construction fantasy
- Low environmental impact
- Freedom of choice of construction materials depending on the desired performance
- Reversibility: possibility of decommissioning the building with possible reuse, recycling or disposal of materials
- Flexibility.

Fig. 7 Spaces for the community

For the construction of the volumes intended for residential spaces, the project envisages a two-dimensional prefabrication system with a galvanized light steel bearing structure and sandwich panels with "wall modules" that allow to maintain complete compositional and expressive freedom at an architectural level.

The "wall modules" are designed so as to be completely assembled with plugs, finishes and systems, before the assembly phase on site; this allows to eliminate from the construction process in situ, the need to find a specialized workforce and at the same time to drastically reduce production and assembly time, all in favor of a reduction in costs strictly related to the use of hand of handicraft work.

The building is schematised as a global box system, since both the wall elements and the slabs behave like cutting walls able to guarantee the seismic safety required by the law.

Then arranging the extreme surfaces of each component with particular shapes it is possible to allow an easy insertion with the corresponding counter-shaped elements of the adjacent elements; to house and facilitate the preparation for fixing components; delimit the housing sites for the passage of the plant connections. Each block is connected to the next by a prefabricated block of toilets completely built and assembled outside the building.

The project involves the use of materials from renewable sources, certified with quality and/or environmentally friendly brands, not treated with toxic, harmful or polluting substances, which do not cause problems for the weight of the structure allowing for minimal intervention on the ground with a system of a few timely, well spaced and small supports. This not only allows a greater speed of realization of the work, but also a better way to manage the construction site and an enormous saving of all the materials traditionally used as well as the energy required for the work of months.

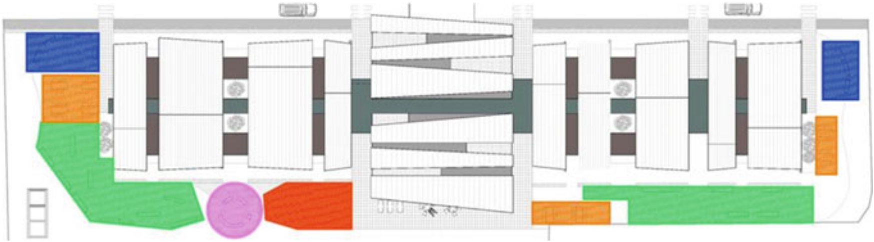

Fig. 8 Therapeutic green

1.9 Use of Light

The small prefabricated volumes are covered with appropriately shaped sheets to ensure the optimization of natural light input according to the orientation of the lot and the hours of the day in the various seasons.

The rooms are equipped with large windows that can also allow a contact with external spaces from a supine position. In this way the light distribution will be uniform, to guarantee visual comfort and reduce the consumption of electricity (Fig. 8).

The small “bioclimatic greenhouses”, amplify the usable space of the single rooms, are able to capture the heat in winter and favor summer ventilation, to act with small scale solar energy recovery systems thus improving efficiency energy consumption and consumption in the building.

According to numerous published studies, the lack of light constitutes a serious threat to health.

The feeling of wellbeing and warmth, induced by exposure to sunlight, is the result of a complex interaction that involves all the physiological systems.

The practice of exploiting natural sunlight for therapeutic purposes has a very ancient origin: in all cultures the sun represents energy, heat and life.

Designing with natural light has important implications for energy saving: the costs for artificial lighting represent up to 20% of total consumption.

For this purpose large windows also characterize the central volume both in multipurpose spaces and in the entrance area for offices and medical facilities.

The light permeates the whole building, even through the small patios inserted in the connecting path, becoming also a fundamental design element (Figs. 9 and 10).

Fig. 9 Insertion in the context of the building

Fig. 10 External area

References

1. Lombardo F (2017) Residenze per Anziani. Dario (ed) Flaccovio editore
2. Fumagalli M, Arrigoni F (2015) Gli operatori sanitari e la demenza: case manegement e programmi di intervento. (ed) Maggioli Editore, collana Sociale e Sanità
3. De Masi G, Plastino V, Vitale R (2001) Progettare la Qualità nelle R.S.A. Strumenti di valutazione e verifica della qualità nelle residenze per anziani. (ed) Franco Angeli, collana Politiche e Servizi Sociali
4. Iacomoni A (2009) Architetture per Anziani. (ed) Alinea
5. Lanzetti C, Marchetti A (1998) L'animazione nelle case di riposo. Metodi e tecniche per un intervento psicosociologico integrato. (ed) Franco Angeli

6. Livon E, Valcovic E (2003) Le Residenze Collettive per Anziani. (ed) EUT
7. Modesti B (1996) Vivere in casa di riposo. Le residenze degli anziani. Storia, evoluzione, nuovi orientamenti. (ed) Edizioni Lavoro
8. Curcio S, Nesi A (1999) Residenze sanitarie per gli anziani. Strumenti per il controllo del processo edilizio e del progetto tecnologico. (ed) Edizioni Kappa
9. De Felice F, Furlanetto L (2002) I servizi residenziali per anziani non autosufficienti. Il controllo della qualità. (ed) Edizioni Goliardiche, collana Psicologia di Comunità
10. FrattariA, Dalprà M, Chiogna M (2015) La casa intelligente per l'utenza debole. (ed) Maggioli Editore
11. Vigorelli P (2016) Aria nuova nelle case per Anziani. Progetti capacitanti. (ed) Franco Angeli
12. Fazzi L (2014) Il lavoro con gli anziani in casa di riposo. (ed) Maggioli Editore

Architecture for Cooperative Interacting Robotic Systems Towards Assisted Living: A Preliminary Study

L. Ciuccarelli, A. Freddi, S. Iarlori, S. Longhi, A. Monteriù, D. Ortenzi and D. Proietti Pagnotta

Abstract The present study aims at providing a robotic architecture system composed by a semi-autonomous mobile robot and a manipulator robot. The user, on a smart wheelchair, is able to move in an indoor environment, by selecting, through a user-interface, the room where he/she wants to move and the object he/she would like to get. In case an object is selected, the user is automatically driven in front of a robotic workstation, where the desired object is picked and placed by a robotic arm in front of the user. The system has been tested on a simulator, and preliminary experimental results show the feasibility of the proposed architecture.

Keywords Cooperation · Human-Robot Interaction · Ambient Assisted Living

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1 Introduction

Human-Robot Interaction (HRI) is a field of study dedicated to design robotic systems to be used by or with people. The interaction requires communication between robots and humans and can be realized in several forms influenced by whether the human and the robot are in close proximity to each other or not.

The communication and the interaction can be separated into two categories:

- remote interaction during which the human and the robot are not co-located and are, spatially or even temporally, separated;
- proximate interactions during which the humans and the robots are co-located (for example, service robots may be in the same room as humans).

Within these categories, it is useful to distinguish between applications that require mobility, physical manipulation, or social interaction. Remote interaction with mobile robots is referred to teleoperation, while with a physical manipulator is defined as telemanipulation. Proximate interaction with mobile robots may fall within the robot assistant domain and may include a physical interaction. Social interaction may be either remote or proximate (cognitive and/or physical interaction). In the last years, HRI field is in constant growth due to the attention given to this topic and the great progresses realized about close-proximity activities [1–3].

For the assistive robots, the goal is to create close and effective interactions with an user, to give assistance and achieve measurable progress in convalescence, rehabilitation and learning. In a near future, service robotic platforms will be machines that cooperate with human-beings to assist people in daily activities at home, providing for an easier and healthier life [4, 5]. In this context, assistive robots, in particular for older adults, can be categorized into two main subgroups:

- physically assistive rehabilitation robots that provide functional and physical assistance, as shared transportation of loads or passing objects [6];
- socially assistive robots (or social robots) that aim to improve the quality of life and can have measurable social interactions with people [7].

Despite physical and/or social purpose, an assistive robot has to interact with the user in some ways [8].

In the literature, different applications of HRI have been realized, aiming at providing various kind of support. An approach for performing a Human-Robot Cooperation (HRC) task, by integrating a Brain Computer Interface (BCI) with a robotic manipulator, has been proposed in [9]: it consists in selecting an object via an assistive interface and moving it by means of a robotic arm. Also for activities of daily living as dressing, assistive robots can provide their contribution as in [10], where a compliant robotic arm has been employed. In detail, the Baxter robot was used to dress one arm of a jacket, by tracking the joints location and calculating their trajectory. In different situations, robots can promote engagements through group interaction as in [11]. In this case, the proposed framework applies haptic robots as mediators that allow multiple users with the same conditions to interact with each other, supporting a human-human group interaction. Another kind of approach, proposed in

[12], shows a human-robot interaction in human populated environments. The paper reports the use of a robotic wheelchair as an example of robots that offer services to the passengers of driving them safely. Other works present integrate mobile robots and robotic manipulators systems as in [13], where an electrical wheelchair with an embedded robotic arm assists a user to realize a task as picking up a cup of water. The user selects the control task through Electroencephalography (EEG) signals, acquired by a BCI system and a graphic interface. With the same scope, in [14] the authors equipped a wheelchair with a robotic arm and a graphical interface to select an object to take it on a shelf. In the literature, there are also projects addressing the development of assistive robotics, e.g., the ACCRA (Agile Co-Creation for Roots and Aging) project, which aims to promote the independent living by means of personal mobility applications to support daily life management [4].

The present work aims at providing an assistive robotic architecture which integrates a mobile-based and a robot manipulator. The user, on a semi-autonomous smart wheelchair can move in an indoor environment and can select, by a robotic manipulator, a desired object, among those available in a dataset. The object is recognized by the robotic manipulator and, once the user is driven in front of the manipulator, the pick and place algorithm is realized to pose the object in a point that the user arm can reach. To realize all the presented tasks related to the wheelchair movement, a localization and an autonomous navigation algorithm have been implemented. For the object pick and place task, both an image classification and a specific kinematic controller have been realized. All the algorithms are implemented in the Robotic Operating System (ROS) framework. A preliminary study of this work was presented in [15]. The system has been first tested on a simulator, namely Gazebo, where all the algorithms and the navigation parameters have been tried, and finally tested in the real environment of the university laboratory.

The design steps to realize the whole system are described as follows:

- user selects the object he/she needs from a user-friendly interface;
- smart wheelchair starts the autonomous navigation until it arrives in front of robotic workstation (i.e., a table equipped with a robotic manipulator);
- robot arm, through the pick and place algorithm, provides the selected object in a point easily reachable by the user arm;
- user can move to a different position on the room map by selecting it on the navigation interface.

The paper is organized as follows. The proposed main architecture is presented in Sect. 2 with the hardware and software related to the wheelchair and the robot manipulator tasks. A brief introduction of the implemented algorithms and the developed ROS nodes are presented in Sect. 3. The trials on the simulator and the experimental tests are shown in Sect. 4, while conclusions and future works are addressed in Sect. 5.

2 Details of the Interacting Architecture

In the context of AAL and assistive robotics, this work is addressed to disabled people who are forced to use a wheelchair and can need a robotic manipulator to get distant objects. In detail, the aim of this study is to develop an interacting robotic system that allows the user to move to a chosen room at home and to get a desired object by means of a robotic arm. The selection, both of the room and the object, is performanced via a user-friendly interface.

The study has been conducted in two different steps: firstly developing and testing the proposed architecture in a simulation scenario, and then in the real environment. The creation of the virtual environment that reproduces the proposed architecture can be summarized as follows:

- smart wheelchair model has been created in the Gazebo simulator;
- robotic manipulator has also been reproduced in the virtual system;
- autonomous navigation of the wheelchair has been implemented;
- user interface has been realized in order to select the object;
- interaction task between the smart wheelchair and the robotic manipulator has been designed for the correct pick and place of the selected object.

The tasks of the two main robotic modules of the proposed architecture can be summarized as represented in Fig. 1 and described as follows:

- *Wheelchair task*: the smart wheelchair, equipped with an autonomous navigation system, allows the user to move within a room. The wheelchair recognizes its position in the environment (*localization phase*), then the user can select, on the developed interface, the room that he/she wants to reach and the desired object. The user is conducted in front of the robotic workstation, during the *navigation phase*, in this case the path planning is realized employing the measurements of the encoder sensors, of the IMU and the Quick Response (QR) code to improve the position estimation as used in [16];
- *Robot manipulator task*: once the user is in front of the robotic workstation, the pick and place phase starts, the developed algorithm recognizes the selected object from a previously created database, localizes its position and the relative coordinates, and chooses which is the robot arm that will be employed in the task. Then, the robot arm places the object on a fixed goal point easily reachable by the user hand, and returns in its state position (untuck position).

2.1 Software: ROS and Gazebo

The software architecture is composed by ROS and the Gazebo simulator, chosen for their easy interfacing and possibility of integration, that represent a good tool to test the developed algorithms.

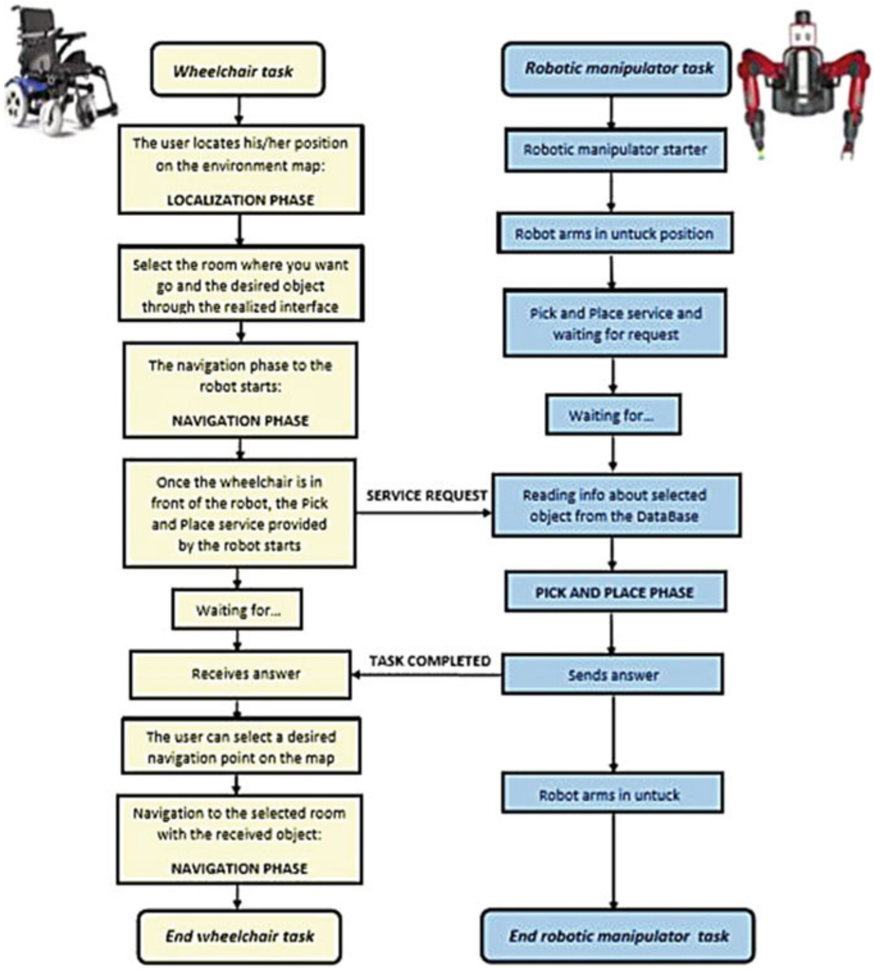

Fig. 1 Scheme of the human-robot interaction realized in the proposed architecture

ROS is a robotic middleware (i.e., collection of software frameworks for robot software development) and, although it is not an operating system, it provides services designed for heterogeneous computer cluster such as hardware abstraction, low-level device control, implementation of commonly used functionality, message-passing between processes and package management. Running sets of ROS-based processes are represented in a graph architecture where processing takes place in nodes that may receive and send messages, and control multiple sensors and actuators [17]. All the implemented algorithms are managed by ROS structure nodes.

While ROS serves as the interface for the robot, Gazebo is a 3D simulator by which is possible to create a 3D scenario on the computer with robots, obstacles and many other objects; it also uses a physical engine for illumination, gravity, inertia, etc.

Gazebo was designed to evaluate algorithms, for many applications; in fact, it is essential to test the developed robot applications, like error handling, battery life, localization, navigation and grasping.

2.2 Hardware: Wheelchair and Robotic Manipulator

The two robotic modules of the proposed architecture, the smart wheelchair and the robotic manipulator are described in details in the following.

2.2.1 Quickie Salsa R2 Electric Wheelchair

The mobile-based robot, developed and used for this study, is the Quickie Salsa R2 smart wheelchair, produced by Sunsrise Medical (see Fig. 2a). The mechanic system is constituted by two rear driving wheels and two forward caster wheels; these last are not actuated wheels, but they are able to rotate around a vertical axis. The mobile system is equipped with a battery of 60/70 Ah that feeds all the on-board electronics. The driving wheels are independently actuated by two brushless motors. The maximum velocity of the wheelchair is about 6–10 km/h, controlled by standard modules and provided by the developer. The internal control module (OMNI) is linked to two basically control interfaces (a joystick and a LCD-control monitor) provided of two serial 9 pins communication port as in Fig. 2b.

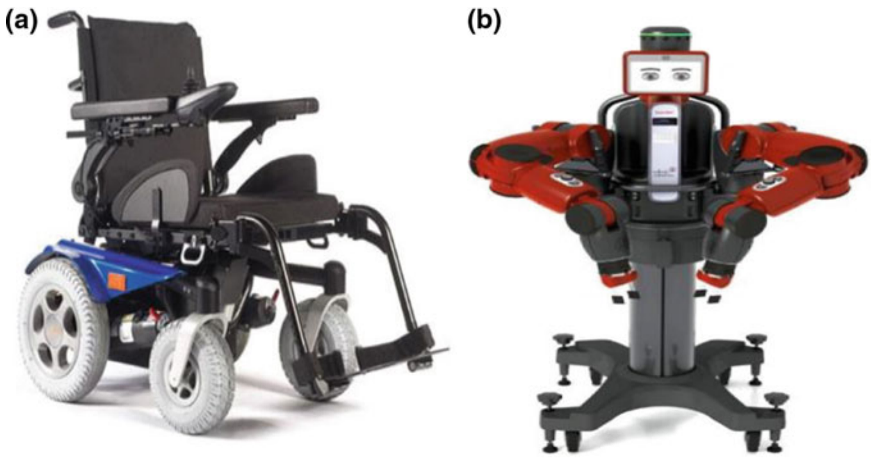

Fig. 2 **a** Smart wheelchair Quickie Salsa R2; **b** the Baxter Research Robot

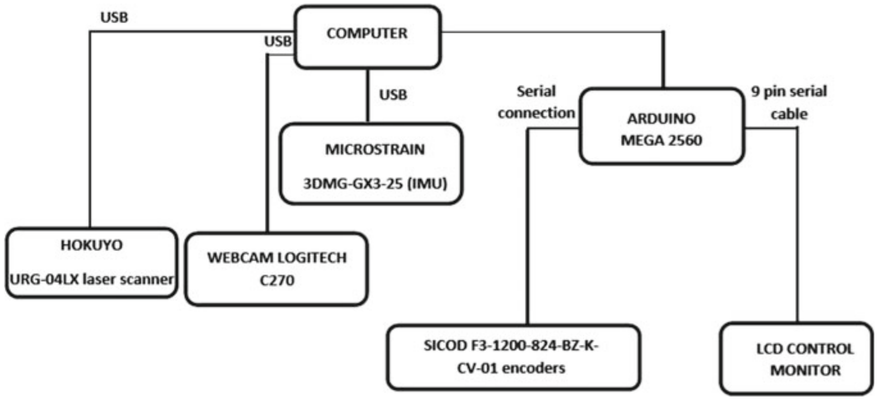

Fig. 3 Schematic hardware system architecture

The smart wheelchair illustrated in Fig. 2 is equipped with:

- an Arduino MEGA 2560 microcontroller;
- a Microstrain 3DM-GX3-25 inertial measurement unit;
- two Sicod F3-1200-824-BZ-K-CV-01 encoders;
- an Hokuyo URG-04LX laser scanner;
- a Webcam Logitech C270.

The developed smart sensor system equips the Sunrise wheelchair granting its localization and its navigation capabilities [18].

The Arduino board realizes the gateway between computer and the internal wheelchair control. It realizes a one-direction communication to the wheelchair, converting control signals from the computer into electrical signals conveyable by the 9-pins serial port. The Arduino board also realizes the encoders driver interface, sending converted signals to the computer with a frequency of 20 Hz. External encoders are used to obtain a system exportable to other vehicles. The IMU and the laser scanner are connected with the computer by USB 2.0 cables. The sensors are mounted to the wheelchair chassis, in positions studied to avoid impacts and to have stability, without hindering the final user. The cabling system is easy to realize, and the customization related to the particular vehicle is limited to an open-technology-base board characterization by a smart programming paradigm. The hardware system and its connections are represented in the scheme described in Fig. 3.

2.2.2 Anthropomorphic Baxter Robot

The Baxter robot and its two robotic arms, illustrated in Fig. 2b, have been chosen to realize the interaction with the user for the pick and place phase. The Baxter robot communicates directly with the controller via a ROS node created to manage the pick and place. The controller provides joint angle trajectories for Baxter's 7 degree-of-freedom arm left in order to take the object selected by the user.

3 Developed Algorithms

The three main developed algorithms are introduced in this section. Two of them are related to the smart wheelchair localization and navigation, while the last regards the pick and place with the Baxter arm.

3.1 Localization and Navigation Algorithms for the Mobile Robotic System

For the autonomous localization and navigation of the smart wheelchair, a map is created, scanning the environment with the Hokuyo laser scanner. This process is known as Simultaneous Localization and Mapping (SLAM), which has been validated in [18]. IMU and encoder data are fed to an Unscented Kalman Filter (UKF), based on the wheelchair kinematic model, which provides position and heading estimation with reduced uncertainty, as shown in [18]. Moreover, exteroceptive measurement aids, such as QR codes [16], can be used to reset the odometric uncertainty. Finally, a Monte Carlo algorithm is used to map the calculated position and improve the localization.

The navigation or pianification algorithm associates the scan map to a grid (*cost map*), where to each cell is assigned a number that identifies the occupation of that cell: the higher is the number, the bigger is the probability to find an obstacle. The trajectories depend on the characteristics of the environment and on the physical characteristics of the robot (i.e., smart wheelchair), such as the velocity and acceleration limits (i.e., for the considered wheelchair, it is impossible to reach a velocity greater than 0.6 m/s). The methods used to define the paths are: the *Trajectory Roll-out* (*TR*) and the *Dynamic Window Approach* (*DWA*). Both the approaches follow this procedure:

- acquire the longitudinal, lateral and angular speed samples dx, dy, $d\theta$;
- realize a simulation of duration Δt with each sample of velocity;
- observe the obtained trajectory;
- evaluate all the possible trajectories with a score considering the global path, the proximity to obstacles and to the goal;
- select the trajectory with major score and send the velocity control to the mobile base;
- repeat the algorithm until the achievement of the goal.

TR and *DWA* differ in the way to sample the velocity. While the *Trajectory Rollout* obtains the samples from all the achievable velocities in the whole time of simulation, the *Dynamic Window Approach* does it, considering an interval equivalent to the control loop.

3.2 Pick and Place Algorithm via Baxter Robot

In order to complete the motor task of taking the desired object, the movement of the Baxter arm for picking the object and placing it to a different position, was studied and controlled applying the Inverse-Kinematics (IK) Pick and Place. This method combines a simulated IK service to obtain the joint angles solutions for a given Cartesian orientation endpoint, and for a controlled position movement together with grasping and releasing services. The position of the object on the desk is calculated as the center of the designed rectangular that inscribes the desired object, recognized among all those presented in the Database by a classifier. The Visual Servoing was used to convert the image pixel to workspace Baxter coordinates. This has been realized by knowing the pose of the Baxter arm, its height from the table where the object is located, the camera calibration factor and using the following formula

$$B = (Ip - Cp) \times cc \times d + Bp + Go \tag{1}$$

where B is the Baxter point in x or y direction, Ip is the image pixel, Cp is the centre image pixel: height/2 (x direction) or width/2 (y direction), cc is the camera calibration factor (= 0.0029), d is the distance from the table (= 0.30 m), Bp is the Baxter point in pixels coordination and Go is the gripper offset. It is important to note, that the calculation in x-direction is for the front/back movement of the Baxter arm, while the calculation in y-direction is for the left/right movement of the Baxter arm. The setup of the Baxter Robot Pick and Place experiment, with an old and new position related to the box, can be seen in Fig. 4.

3.3 Implementation Details

To complete the information related to the implementation realized in the ROS framework, the different nodes associated with the algorithms have been reported in the following.

To acquire the information from the sensors and to communicate with Arduino, these ROS nodes have to be launched:

- *serial_node.py* is contained in the package */rosserial_python*, that allows the serial communication between Arduino and the pc with ROS;

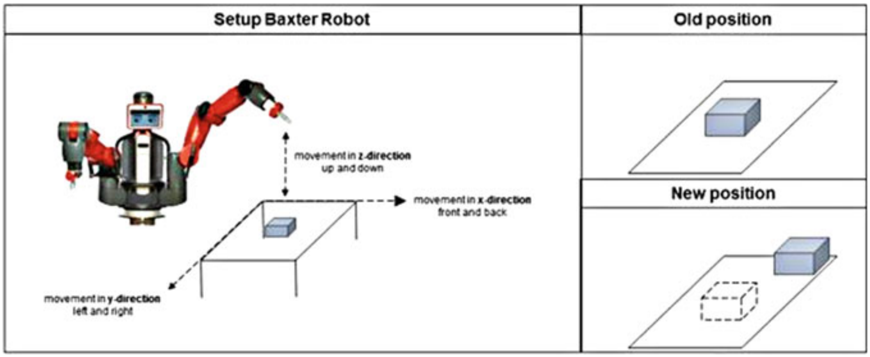

Fig. 4 Description of the pick and place service realized by Baxter Robot with an example of the old and new position of the box

- *imu_node* is included in the package */microstrain_3dmgx2_imu* to read data provided by IMU sensor;
- *hokuyo_node* is included in the package that has the same name to manage the laser scanner.

Moreover, the following nodes are required:

- *Interface_node* allows to define some predefined navigation goals;
- *Automatic_node* changes the linear and angular velocity values in output in simple digital commands to give to the mobile system;
- *Comando_node* limits the effect of the misalignment of the anterior caster wheels;
- *Arduino_node* allows the communication among pc, encoder and OMNI. It acquires the information provided by the encoder and gives the command for the wheelchair;
- *robot_setup_tf* defines the transformation from *hokuyo_node*;
- *localization* algorithm allows the localization;
- *map_saver* allows to save the realized scanned map of the room and is related to the */gmapping* package.

About the Baxter tasks, the most important developed nodes are:

- *pickPlaceBaxter* realizes the pianification activity and the robot arms actuation;
- *classyfy_sendPos* realizes the object classification and recognition.

4 Simulation and Experimental Trials

This section describes how the proposed architecture has been implemented and qualitatively tested in a simulated scenario first (Sect. 4.1) and in a real environment later (see Sect. 4.2).

4.1 Simulation Trial

In the Gazebo simulator, a model of the room has been developed to reproduce the test environment. It presents 9 QR codes on the ceiling and a desk in front of the Baxter, where the objects are placed. The QR codes have been placed to be used by the odometric algorithm to improve the position estimation. The 3D model of the wheelchair is characterized by two rear driving and two forward caster wheels, two cylindrical supports that connect the front wheels to the wheelchair frame, and by all the structure to support the user. In addition, also the RGB camera (i.e., the Logitech webcam) for the QR code reading, the IMU for acquiring the yaw of the vehicle, and the Hokuyo laser scanner for scanning the map, have been integrated in the simulation. In the simulation phase, it is also important to have the reference systems of the user, as shown in Fig. 5, because with the opportune Cartesian transformation, it is possible to know the position and orientation with respect to another frame. A 3D model that represents the user has been added, to have the orientation triad of both the user hands. Also the model of the Baxter robot has been inserted in the room with fixed position. The obtained rotations are expressed with the roll-pitch-yaw notation and the angular values are reported in radiant.

As already described in Sect. 3, a UKF has been used for localization purposes. In the simulation scenario, a set of QR codes has been integrated as well to improve the filter output. To read the QR code information, the stack *vision_visp* of ROS has been used, based on the library of the open source Visual Servoing Platform together with a node that realizes the algorithm of computer vision for the automatic reading of QR codes. This is based on an algorithm of tracking, based on the gradient method, to compare a defined template and the image acquired by the vision sensor. The QR

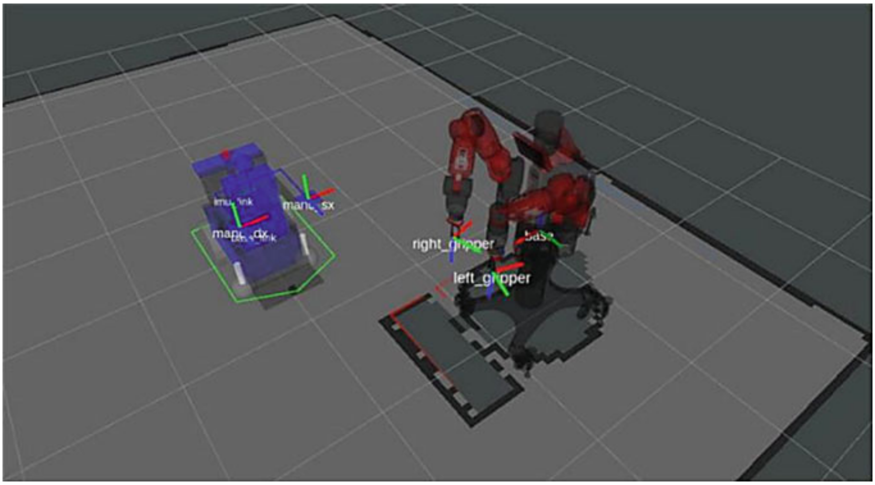

Fig. 5 Reference systems related to the user hands and the robot arms

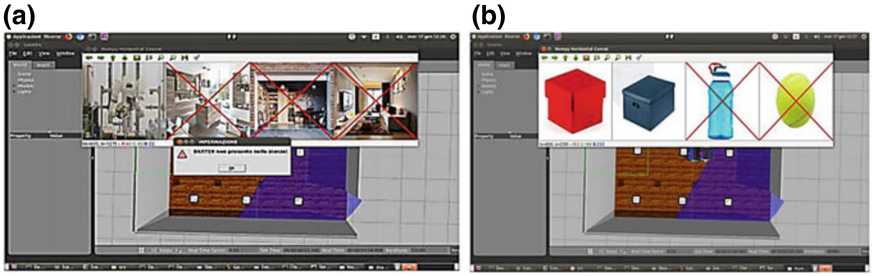

Fig. 6 In **a** user interface for the choice of the room, and in **b** user interface for the choice of the object

codes, used to identify the absolute position in the room, present the information in this structure: $X\#Y\#Z\#room$ where the coordinates and the name of the room are split by an asterisk.

For the choice of the desired object, a graphical user interface has been realized (see Fig. 6). The selection can be done by a double click of the mouse on the icon of the desired object image. Once the interface is on, different rooms are presented: the available rooms are related to the presence of a robot workstation in it. If no robotic station is available in a certain room, it is shown in the interface with a red cross on it, meaning that it can not be selected for objects to get, and a message invites the user to choose a different room. If the choice is valid, all the objects presented in the room are visualized, those not available have a red cross on the image. All the objects are included in a database, and the implemented algorithm of object recognition uses the OpenCV libraries.

If the selection is correctly realized, the wheelchair begins its navigation to a fixed point in front of the Baxter and the robot starts the pick and place task. As illustrative example, two selectable objects were built, a red and a blue box, positioned upon the desk. The blue box is next to the left arm of the robot, while the red box is next to the right one. If the user chooses the red box, this is positioned in a point that should correspond to the user left hand position, while if he/she chooses the blue box, the right hand will be involved as illustrated in Fig. 7a.

Once the user has obtained the desired object, he/she can navigate through any point in the room by setting up the goal from the Rviz screen by the command *goal_position* (see Fig. 7b).

4.2 Experimental Trial

In this work, in addition to the implementation of the proposed architecture on the Gazebo simulator, it was also implemented and tested in a real scenario, insidethe

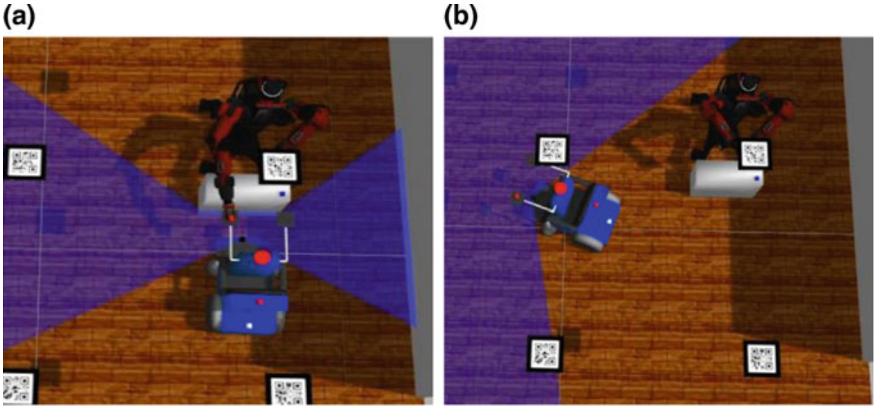

Fig. 7 In **a** the robot arm poses the object in a point easily reachable by the user hand, and in **b** the user can move on a different position chosen on the map

University Robotics and Automation laboratory. A student, on the wheelchair, chooses through the designed interface, the room (i.e., in this case it was tested just in the laboratory) and one object. At the same time, the map of the environment is created and obtained by the Hokuyo laser scanner, allowing a path planning for the wheelchair to reach the point in front of the desk, where the objects are placed.

The successive phase, that regards the object classification and the pick and place by the Baxter robot arm, starts as shown in Figs. 8 and 9. To complete the task, the object is then moved on a point in the robot workspace that the user, in this case the student, can easily reach with his hand (see Fig. 10).

Fig. 8 The user is in front of the Baxter robot arm

Fig. 9 Pick and place realized by the baxter robot

Fig. 10 The object is moved on the user hand

5 Conclusions and Future Works

The work, presented in this paper, proposed the development of an architecture for interacting robotic systems towards assisted living. In details, the following three main aspects were faced:

- development of the simulator for the smart wheelchair and the robot arm in order to test the implemented algorithms;
- development of a simple interface for the human-robot interaction;
- definition of interaction between mobile robot and manipulator robot.

There are some possible improvements to realize:

- placing position of the object could directly be the hand of the user, identified by a camera sensor like a Microsoft kinect. The disadvantage of the kinect in the context of a person, forced on a wheelchair, is related to the calibration phase. For this step, the person would be indeed asked to stay standing in the well known Psi Pose, characterized to have the arms pointing upwards.
- integration for the localization/navigation of the wheelchair into a mini-PC to install on board, with an easier user interface (i.e., tablet and/or smartphone).

- use of a RGB-D sensor, able to see the whole room and to recognize the gesture of a person sit on the wheelchair (i.e., avoiding the problem of the user calibration in the Psi Pose like for the kinect). In this way, it could be possible to select the object by a gesture.

Another aspect for future works is the improvement of the developed database which could add some information for the Baxter, related to the objects available for pick and place.

References

1. Feil-Seifer D, J Matarić M (2005) Defining socially assistive robotics, pp 465–468
2. Bekele E, Wade J, Bian D, Fan J, Swanson A, Warren Z, Sarkar N (2016) Multimodal adaptive social interaction in virtual environment (MASI-VR) for children with autism spectrum disorders (ASD), pp 121–130
3. Clodic A, Pacherie E, Alami R, Chatila R (2017) Key elements for human-robot joint action. Springer International Publishing, Cham, pp 159–177
4. Fiorini L, D'Onofrio G, Limosani R, Sancarlo D, Greco A, Giuliani F, Kung A, Dario P, Cavallo F (2017) ACCRA project: agile co-creation for robots and aging
5. Cavallo F, Aquilano M, Bonaccorsi M, Limosani R, Manzi A, Carrozza MC, Dario P (2013) On the design, development and experimentation of the ASTRO assistive robot integrated in smart environments. In: 2013 IEEE international conference on robotics and automation, May 2013, pp 4310–4315
6. Sciutti A, Sandini G (2017) Interacting with robots to investigate the bases of social interaction. IEEE Trans. Neural Syst Rehabil Eng 25(12):2295–2304
7. Lee HR, Tan H, Sabanovic S (2016) That robot is not for me: addressing stereotypes of aging in assistive robot design. In: 25th IEEE international symposium on robot and human interactive communication, pp 312–317
8. Romer G, Stuyt H, Peters A (2005) Cost-savings and economic benefits due to the assistive robotic manipulator (ARM). In: 9th International conference on rehabilitation robotics, pp 201–204
9. Foresi G, Freddi A, Iarlori S, Monteriù A, Ortenzi D, Pagnotta DP (2017) Human-robot cooperation via brain computer interface. In: 7th International conference on consumer electronics-Berlin (ICCE-Berlin). IEEE, pp 1–2
10. Chance G, Camilleri A, Winstone B, Caleb-Solly P, Dogramadzi S (2016) An assistive robot to support dressing—strategies for planning and error handling. In: 6th IEEE International conference on biomedical robotics and biomechatronics (BioRob), pp 774–780
11. Le HH, Loomes MJ, Loureiro RC (2016) Group interaction through a multi-modal haptic framework. In: 12th International conference on intelligent environments (IE), pp 62–67
12. Morales Y, Miyashita T, Hagita N (2017) Social robotic wheelchair centered on passenger and pedestrian comfort. Robot Auton Syst 87:355–362
13. Achic F, Montero J, Penaloza C, Cuellar F (2016) Hybrid BCI system to operate an electric wheelchair and a robotic arm for navigation and manipulation tasks. In: IEEE Workshop on advanced robotics and its social impacts. IEEE, pp 249–254
14. Tsui K, Yanco H, Kontak D, Beliveau L (2008) Development and evaluation of a flexible interface for a wheelchair mounted robotic arm. In: Proceedings of the 3rd ACM/IEEE international conference on Human robot interaction. ACM, pp 105–112
15. Foresi G, Freddi A, Monteriù A, Ortenzi D, Pagnotta DP (2018) Improving mobility and autonomy of disabled users via cooperation of assistive robots. In: IEEE International conference on consumer electronics. IEEE, pp 1–2

16. Cavanini L, Cimini G, Ferracuti F, Freddi A, Ippoliti G, Monteriù A, Verdini F (2017) A GR-code localization system for mobile robots: application to smart wheelchairs, pp 1–6
17. Quigley M, Conley K, Gerkey B, Faust J, Foote T, Leibs J, Wheeler R, Ng AY (2009) ROS: an open-source robot operating system. In: Workshop on open source software, vol 3
18. Cavanini L, Benetazzo F, Freddi A, Longhi S, Monteriù A (2014) Slam-based autonomous wheelchair navigation system for AAL scenarios. In: IEEE/ASME 10th International conference on mechatronic and embedded systems and applications, pp 1–5

Personal Health E-Record—Toward an Enabling Ambient Assisted Living Technology for Communication and Information Sharing Between Patients and Care Providers

Giovanni Dimauro, Francesco Girardi, Danilo Caivano and Lucio Colizzi

Abstract In this paper, we propose the Personal Health Electronic Record (PHER), a new type of Patient Health Record. This record aims to help physicians shift from a medical practice that is often based on their personal opinion or experience towards one of evidence based medicine, thus improving the communication among patients and their care providers and increasing the availability of personal medical information. The PHER can be considered an enabling Ambient Assisted Living technology because it allows patients and care providers to file and share all types of medical data and useful clinical information so that they can access whatever they need, whenever they need it. The development of diagnostic and therapeutic algorithms that are able to support the physician in planning treatment using the data stored in the PHER is also discussed.

Keywords Electronic health record · Medical application · Medical data interoperability

1 Introduction

With the expansion of medical science, it has become increasingly difficult for individual practitioners to manage all the information they need [1]. In 1992, three years later, the beginning of the Internet era of "Evidence Based Medicine" was born [2]. Many scientific associations started to release guidelines to diagnose the most widely spread pathologies with graduated recommendations using supporting evi-

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dence. By 2008, more than 12,000 new medical papers were added to Medline every week, and 300 of them were randomized control trials [3]. It is now impossible for a single doctor to keep up with all the updates; in fact, to remain fully updated, an epidemiologist would need to spend more than 160 h a week studying. However, the lack of validity in the scientific literature underpinning medical choices leads to inadequate and inappropriate care of the patient, causing damage both to the patient and to the health system as a result of unnecessary expenses [4]. It is likely on the basis of similar considerations that IBM launched the Watson Health program with the aim of expanding a physician's ability. This system, defined as an "Integrated Health Cognitive Platform", is intended to be powered by both patient and literature information [5]. Medical progress has led to an increase in life expectancy in all industrialized countries, allowing for healing or survival for prolonged periods in the presence of pathologies that previously had a poor prognosis, which was unthinkable only a few decades ago. As a result of this progress, patients are more complex to manage because they are older and are often affected by more than one disease. Some authors estimated the average duration of a medical visit to be approximately 15 min, where the time spent to address the main problem was approximately 5 min, and more or less a minute was dedicated to each other issue [6, 7]. It is evident that physicians are unable to complete a full check-up, and having reduced time to acquire information about patients increases the probability of making an error in diagnosis or therapy. In 1999, an IOM report stated that every year, predictable and avoidable medical errors caused between 49,000 and 98,000 deaths in US hospitals [8]. A 2012 review, basing on autopsy studies, showed that there were approximately 40,000 victims of medical errors in ICUs in the United States per year [9]. In 2013, more than 577,000 deaths could have been avoided in Europe if the health systems had operated in an optimal way, while medical errors in the United States were the third highest cause of death [10, 11]. A large number of patients who are affected by widespread pathologies such as hyper-tension, diabetes or dyslipidemia, which are the leading causes of morbidity and mortality, are not diagnosed or adequately treated [12]. The health systems designed for the hospital-centered medicine of the twentieth century are showing serious inefficiencies to adapt to the new needs of people affected by long term diseases with different grades of disabilities who would be better treated at home in a more cost-efficient manner. More and more financial resources have been spent on healthcare in the attempt to maintain previous levels of care, but this has only caused a consistent and widespread reduction in available hospital beds (Fig. 1), which is motivated by rationalization and efficiency of the hospital network [13].

In Italy, hospital beds were approximately 5 for every 1,000 inhabitants in 1998 and have been reduced to 3.3 per 1000 people in 2012, while at the same time, the population over 65 years old increased by almost 2 million in the period from 2002 to 2012 [14].

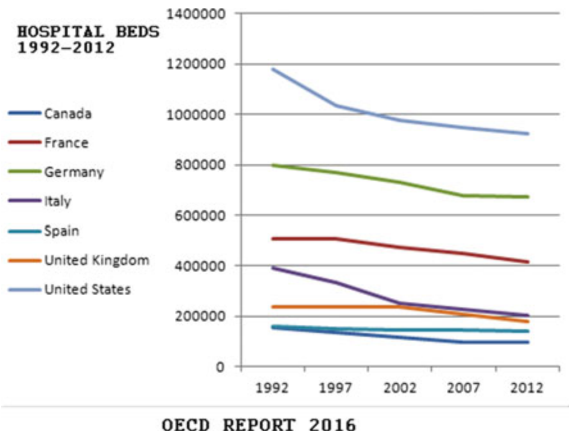

Fig. 1 Hospital beds decrease

The use of ICT in medicine is a good opportunity to solve the growing crisis that many health systems in the world are experiencing. As seen in Table 1, most of the medical examination repetitions were due to poor communication between hospital and personal physicians or patients; as a matter of fact, many tests were recommended more than once, despite already being performed during hospitalization or local follow-up [15]. There would be much larger savings using a decision support system that would help to reduce diagnostic and therapeutic errors as well as their resulting economic and health damages. Clinical data are produced every time a patient visits a clinic, is visited by a physician or undergoes diagnostic investigations. To date,

Table 1 Inappropriate requests in the tuscany region (Italy) and cost estimate

Exam type	% Inappropriate requests	Yearly savings estimated in € for the Tuscany region
Cholesterol	0.5	466.000
Triglycerides	4.6	690.000
PSA	10.5	1,518.000
Occult blood l stooled	19.8	200.000
Protegogram	1.7	7.000
INR	4.1	1,181.000
TSH	0.6	5.000
B12	0.5	5.500
Venous withdrawal	5.2	908.500
RMN knee > 65 y	1.3	54.500
Total amount		5,035.500

Table modified from [16]

much of this clinical information is reported on paper and often is not recorded. The use of an Electronic Health Record (EHR) has been increasingly popular for saving and retrieving this information.

EHRs, because of the different architecture and features, have names such as the Computerized Medical Record (CMR), Electronic Medical Record (EMR), and Patient Health Record (PHR). An EHR, or an EMR, refers to the systematized collection of patient and population health information stored in a digital format [17]. An EHR can be used for much more complex purposes than digital storage of medical information intended for a quick search. An EHR can allow one to order inquiries, exchange messages among people involved in the treatment process, facilitate telemedicine, support medical decisions, and generate reminders and alarms, as seen in Fig. 2.

The European Union has repeatedly activated initiatives that promote the use of ICT in the healthcare field. The European Parliament in October 2006 [18] wrote: "wider deployment and more effective use of digital technologies will thus enable Europe to address its key challenges and will provide Europeans with a better quality of life through, for example, better health care, …" [19]. The European Commission's

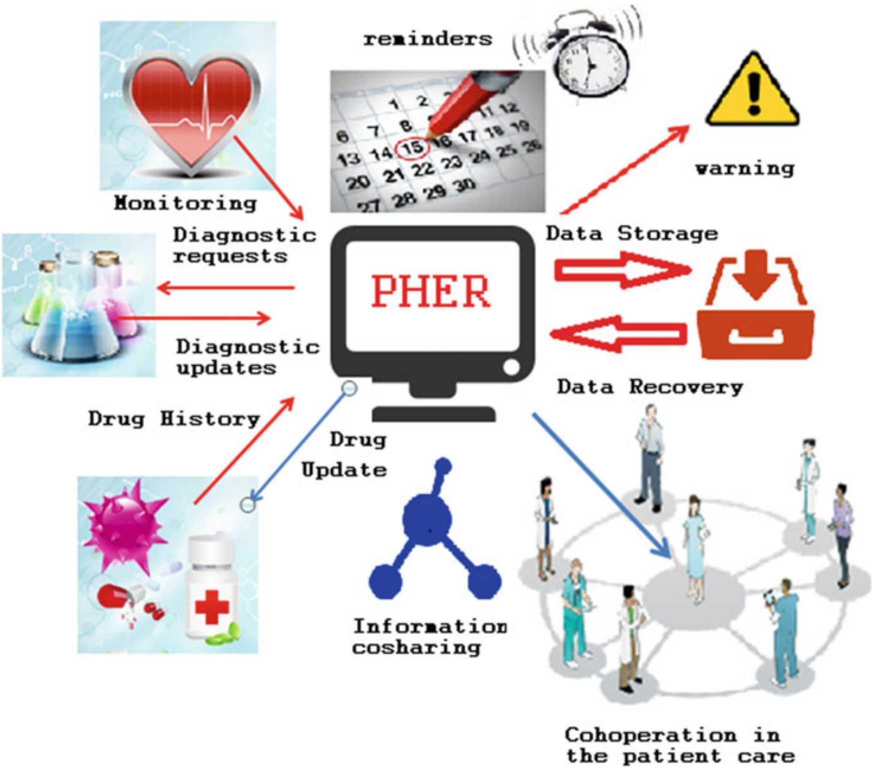

Fig. 2 Hospital beds decrease

"eHealth Action Plan 2012–2020—Innovative healthcare for the 21st century" states that "information and communication technologies applied to health and healthcare systems can increase their efficiency, improve quality of life and unlock innovation in health markets" [20]. Many states in the European Union have agreed to implement and use Electronic Health Records to improve the efficiency of their health systems. None of these states, with the exception of Spain, has had success, and, in many cases, an impressive amount of money was wasted [21–23]. The Italian government stated [21] that local administrations will activate their own EHR, called "Fascicolo Sanitario Elettronico (FSE)" by June 2015, but until now, only a few regions have implemented their FSE. This current situation in the EU is demoralizing.

2 PEHR Description and Functions

2.1 Target and Stakeholder

The main goal of the PHER is the patients' health protection. While patients are the primary targets and stakeholders, health professionals have to be considered stakeholders too. Our idea was to design a system suitable for all medical fields that is easily adaptable to the needs of specialists. As an example, emergency workers often have to decide on treatment in critical conditions, knowing nothing about the patient history; this specific class of health professionals could greatly benefit from the use of PHER.

2.2 Functions

The PHER client side recognizes user-type at login (physician, patient, administrator) and shows the appropriates homepage, as shown in Figs. 3 and 4.

The collection of all the relevant clinical information about the patient being accessible via web and patient-physician interaction characterizes the PHER.

Information is not limited to text but includes images, audio, and video; clinical examinations and clinical objectivity can be stored and reproduced. The patient may decide to adjust the privacy level of each uploaded file, in accordance with the HL7 standard, and can also choose the care providers who are allowed to view the documentation (Fig. 5).

Patients make use of a "notebook" (Fig. 6) in which to introduce apparently minor clinical events that sometimes could be of importance. The notebook allows the patients to represent painful symptomatology by describing the intensity, with a visual scale on stylized figures.

Some of the patient activities are as follows:

- send messages to other PHER users (patients and care providers) subscribers;

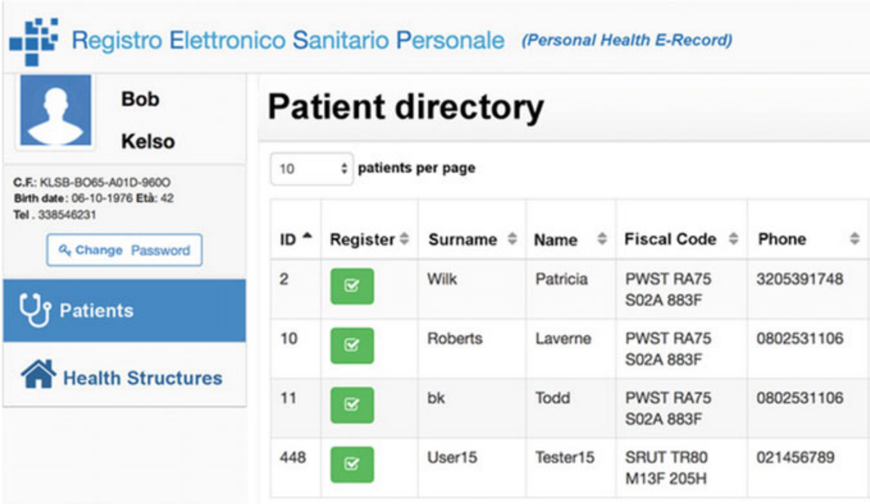

Fig. 3 Care provider's homepage: it shows the patient list and, on the left, the photo and some personal data of the current user

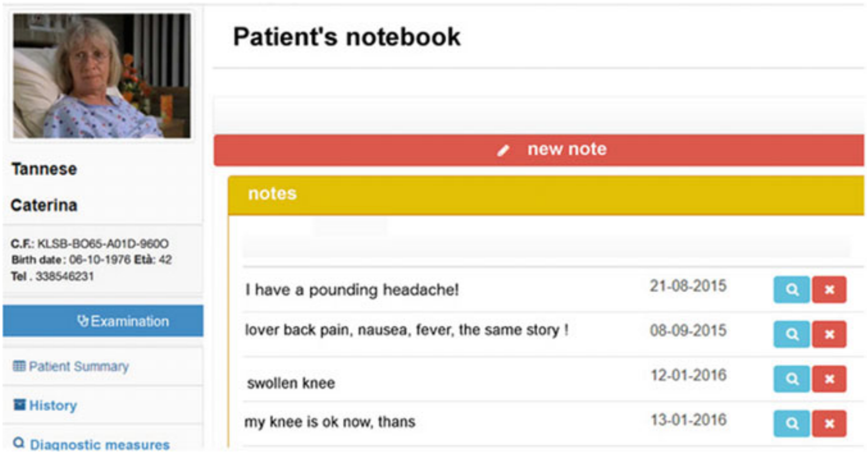

Fig. 4 Patient's homepage showing personal data and a photo, the links to the patient extended status description, the history and diagnostic investigations (on the left), and the notebook with personal problems registered over time (in the center of the page)

Files Caricati

	Nome File	Commenti	Data creazione	Caricato da:
	coronarografia1low.wmv		19-09-2015	Tannese
	20170211-Ecg-bancaDelCuore_.pdf	Ritmo sinusale; fc 60	12-02-2017	Tannese
	auscultazioneFocolaioAortico.wav	eKuore-aorta	12-02-2017	Tannese
	auscultazioneFocolaioMitralico.wav	eKuore_auscultazioneMitrale	12-02-2017	Tannese
	2012-11-25 16.32.11.jpg		18-03-2017	Tannese
	artrite-reumatoide-mani-500x340.jpg	Mano dall'Atlante Netter	24-03-2017	ospedale
	lupus.jpg	manifestazione clinica della malattia sul volto	24-03-2017	ospedale

Fig. 5 The PHER file-page containing all the media files or documents uploaded by the patient, the doctor or the care provider

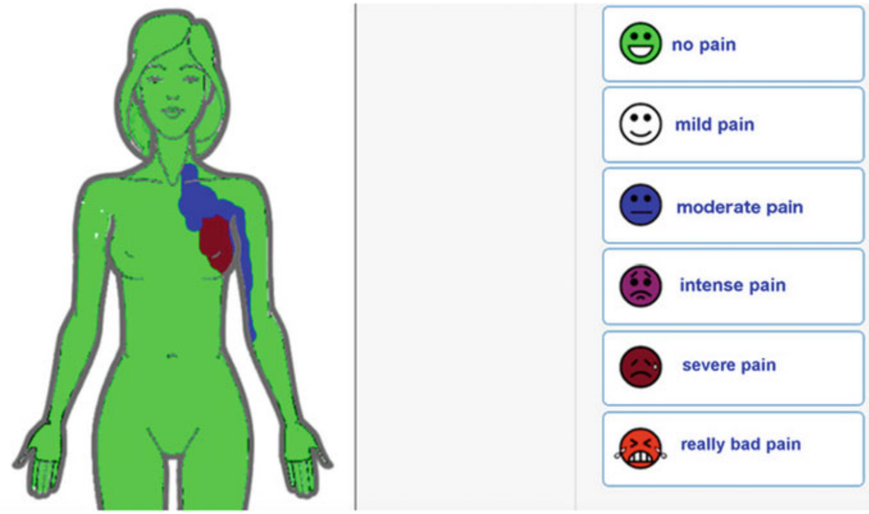

Fig. 6 The PHER patient's notebook: in the active map, the patient can describe the grade of the afflicting pain and its location

- request the server to create and send a PDF report containing all the information in the Health Record, with links to text, image, audio and video files stored on the server;
- upload the results of the visits and display the last five visits with each of the clinic report;
- update the "patient summary" containing personal data, the willingness to donate his organs and contact details, including the emergency contacts
- update clinical history
- upload the requested diagnostic investigations, the ones already programmed, and the completed ones
- report the suspected, confirmed or excluded diagnoses; for each diagnosis, it is possible to attach the files related to the investigations carried out
- add new files and change their visibility level
- select from the list of "care providers" who can access PHER by assigning a level of permission related to what they will be able to see and manage. On the same page, there are telephone numbers of facilities and a button that allows direct mailing to the care provider
- use the medical calculator to check the posology of drugs and calculate the renal function.

The doctors, after logging in, display the list of patients who chose them as "personal care providers". The doctors can manage this list and can quickly search each patient. By accessing the patient's registry, physicians perform the same operations as the patient, except for changing the will to donate organs, modifying confidentiality levels or deleting files and working on the list of the care providers. The patient's telephone number and e-mail address are immediately available, allowing the physician to send an email directly from the PHER and to produce and download a full.pdf report. It is possible to view diagnostic structures, outpatient clinics, hospitals, and radiology centers where care providers who have an account in the PHER operate. The physician can add to the list the locations where he works. Both the physician and the patient can benefit from simplified interactions with other software systems, such as Voxtester [24] and HgbMeter [25], which are designed to monitor patients at home (to evaluate changes in dysphonic patients by recording their voice and to monitor the hemoglobin value in the anemic patients by taking an image of eyelid conjunctiva). Inexpensive devices allow for continuous monitoring, such as the smart electronic stethoscope "eKuore Pro" [26], which allows for recording of the heart and lung auscultation for diagnosis or follow-up and for the easy sharing of recorded audio files with one or more professionals (Fig. 7). The digital analysis of the recorded and stored sounds in the patient's PHER could allow for timely and objectively detected variations that may lead to severe clinical manifestations. Wearable electrocardiographs, such as the "Cardio-C Pocket ECG—3 canals" of GIMA [27], allows the physician to save the electrocardiogram in jpeg format and store it in the PHER.

Instruments such as these allow the patient to perform tests even without the physical presence of a physician and, in case of urgency, to share them in real time

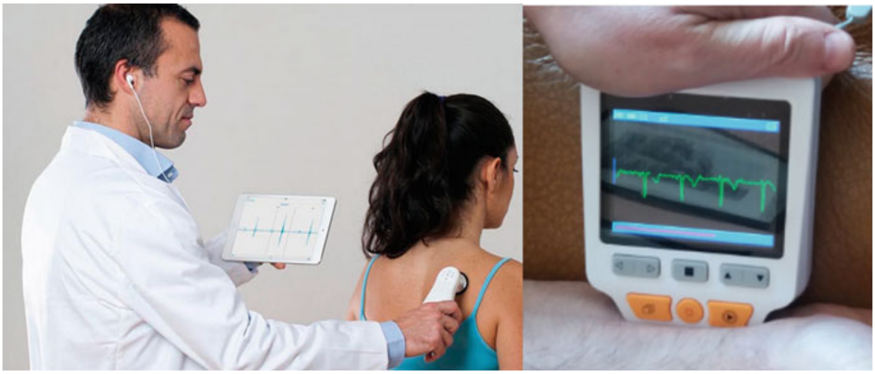

Fig. 7 The electronic stethoscope "eKuore Pro" (left) and the wearable electrocardiograph (right)

with the relevant care providers. The PHER substantially amplifies these benefits, as it immediately compares the latest images with the ones previously obtained and with all the patient's clinical documentation. Functions supporting the doctors in the decisions related to diagnostic-therapeutic therapy are going to be tested. Due to the international codes implemented in the PHER, we are implementing algorithms that, based on a patient's stored information, show a list of the most likely diagnoses and support the physician by suggesting diagnostic tests to confirm or exclude the suspected diagnoses. The results of the tests update the list of possible diagnoses and their relative probability. Additionally, therapeutic algorithms have been implemented that suggest possible therapies. Physicians who use the support decision system provided by the PHER can verify the algorithms used, their updates, and the degree of evidence of the underlying studies due to the presence of links to sources used for the algorithm implementation. The PHER is a sophisticated software system implemented on a client-server architecture, but the user (patient or care provider) does not perceive the complexity and articulation of the system since it is designed to facilitate interaction and use. All the components reside on the server side, and a normal browser is sufficient to access the application [28]. Safety and privacy are preserved by the use of specifically designed procedures. The identity of care providers who are allowed access to the patient data is guaranteed. In fact, patients can activate their PHER through a secure online registration and can choose whether to use this system as a personal repository of their own history and clinical documentation or whether they prefer to share them with their care providers. In the latter case, an email is sent to the system administrator, who contacts the patient to confirm the choice of data sharing and then enables that feature. The PHER also handles security by sending an email to the user in the case of repeated suspect access attempts. The acknowledgment allows user interface and domain activity customization.

3 Other Solutions and Usability

Since it has now been many years since the possible advantages deriving from the digital organizing of clinical data for each patient have been recognized, it is now possible to cite several attempts made by public health care systems and private companies to achieve this goal. Among the large private companies, we note that Microsoft created HealthVault, a Web platform for storing health information, in 2007, and Google introduced Google Health 10 years ago with the same goal. Google Health was launched to create a service to allow people to access their personal health and wellness information. Google wanted to replicate its consumer-centered success in health care and wanted to have a real impact on the daily experiences of millions of users. After a few years, they noted that Google Health had not had the broad impact they hoped for. Google Health had been used by some user groups, such as tech-savvy patients, and by fitness and wellness fans. However, they had not found a way to translate this limited use into a widespread adoption in the daily routine of millions of people; thus, the service was stopped in 2011. Other solutions are available, such as AdvancedMD [26]. The EHR AdvancedMD solution includes a complete set of software tools for clinical and medical billing on the cloud and is designed to improve patient care and profitability of the practice; it is interoperable and cloud-based and seems to be a good software solution for creating a paperless doctor's office. This technology also offers benefits such as customizable templates, mobile access and an integrated web-based patient portal. It keeps graphs electronically and consistently, manages and integrates different systems and data, engages and informs patients online and allows remote access to patient data. OpenEMR is a free open source electronic medical record. The authors say that it allows the modification of electronic medical records, prescriptions, billing, monitoring of patient demographics, patient registration and maintenance of fully updated electronic medical records. It can be used to print receipts that can be sent by fax or e-mail. OpenEMR has several interfaces that allow for accurate invoicing. It also makes the portal available for patients. A first attempt to unify the EHR was carried out in the UK. As reported in [21], "in 2005, the National Health System (NHS) started to implement EHR systems, with the aim of all patients having a centralized electronic record by 2010. The registration systems of the Lorenzo patients were adopted in a number of NHS trusts, while many hospitals have acquired electronic patient registration systems in this process, but there has been no exchange of national health information. Finally, the program was dismantled after a cost to UK tax payers of over $24 billion and is considered one of the most expensive IT failures". National health services in both France and England introduced systems to provide online access to summarized health data. The English system was called the "Summary Care Record (SCR)" and was made accessible to patients through "HealthSpace". The French system was called Dossier Médical Personnel (DMP) [29] and was a patient-controlled record. Both systems did not meet patients' needs, were not integrated in the physician workflow and have been considered failures. We suggest the reading of two papers: "Adoption and non-adoption of a shared electronic summary record in England: a mixed-method case study," [30] for a better understanding of the English failure, and "Adoption of a Nationwide Shared Medical Record in France: Lessons Learnt after 5 Years of Deployment", [31] for an understanding of the French one. In our opinion, one of the main reasons for the lack of success of many systems is due to the lack of acceptance by the doctors, partly linked to cultural problems, as reported in the two previously cited works but also to the reduced attention paid to usability in different care settings. Particular attention was given to the doctors in the design of the PHER so that they would find it convenient to adopt and would be able to save time in the overall performance of their work. Both in the initial planning phase and in testing the prototypes in the various development phases, we collaborated with numerous physicians active in different parts of the health system (e.g., hospital, outpatient specialists, family doctors).

4 Perspective, Conclusions and Future Developments

The PHER has been designed and achieved, taking into consideration the important goal of exploiting current ICT technologies to allow patients and doctors to benefit from the potential of streamlined diagnostic and therapeutic progress. This outcome has been achieved by facilitating the filing and examination of clinical information and by facilitating their sharing and communication among all actors involved in the healing process. The implementation of the international codes related to diagnosis, procedures, clinical and laboratory observations in the PHER has allowed for the development of diagnostic and therapeutic support algorithms that can be readily updated with the emergence of new clinical evidence. This technology might be a way to help the physicians stay up-to-date on all the possible issues they face in daily practice. It is already possible that a sufficient diffusion of such a system could facilitate the enrollment of patients in experimental studies and could carry out studies to evaluate the effects of different diagnostic and therapeutic protocols in the real world. It will be easier, using the information of the many patients stored in the PHER, to compare the effectiveness of expensive treatments against inexpensive ones. It will be possible to implement functionalities that show the real incidence of a diagnostic procedure or therapeutic treatment in a particular population for the purpose of reducing complications and the number of hospital admissions, as well as prolonging survival or catching the early emergence of associations between drugs and adverse events. Since the PHER is designed so that all patients can actively participate in the management of their clinical data, the objectives to be achieved include making it accessible to users with various degrees of physical disability. We can therefore plan to develop the implementation of voice recognition for navigation within the system, to insert data into the forms, to vocally synthesize page reading, to resize the characters for the visually impaired and to change the colors for color blind subjects. It is relevant the benefit that this project can bring to the Ambient Assisted Living Technology.

References

1. Shortliffe EH (1977) Mycin: a knowledge computer program applied to infectious diseases. In: Annual meeting of the Society for Computer Medicine, Las Vegas, pp 66–69
2. Guyatt G et al (1992) Evidence-based medicine. A new approach to teaching the practice of medicine. JAMA 268(17):2420–2425
3. Glasziou PP (2008) 2008, Information overload: what's behind it, what's beyond it? Med J Aust 189:84–89, PMID: 18637773
4. Dri P (2016) La lettura critica dell'articolo scientifico; in Quesiti Clinici–anno 7, n. 5, marzo 2016
5. Agnello A. Sistemi Cognitivi e Salute IBM Watson Health. http://milanosservatorio.it/wp-content/uploads/2016/10/VE-2c-AGNELLO-IBM-Watson-Health-Legal-002.pdf. Accessed 04 June 2018
6. Tai-Seale M, McGuire TG, Zhang W (2007) Time allocation in primary care office visits. Health Serv Res 42(5):1871–1894. https://doi.org/10.1111/j.1475-6773.2006.00689.x
7. Peckham C (2017) Medscape physician compensation report. https://www.medscape.com/features/slideshow/compensation/2016/public/overview. Accessed 04 June 2018
8. Kohn LT, Corrigan JM (2000) To err is human: building a safer health system. National Academies Press (US). https://doi.org/10.17226/9728
9. Winters B, Custer J, Galvagno SM et al (2012) Diagnostic errors in the intensive care unit: a systematic review of autopsy studies. BMJ Qual Saf 21:894–902. https://doi.org/10.1136/bmjqs-2012-000803
10. Bourgeais B, Clerc M (2016) Avoidable deaths in 2013 one death out of three in the EU could have been avoided in the light of current medical knowledge and technology. In: Eurostat news release. http://ec.europa.eu/eurostat/documents/2995521/7335847/3-24052016-AP-EN.pdf. Accessed 04 June 2018
11. Martin AM, Michael D (2016) Medical error—the third leading cause of death in the US. BMJ 2016(353):i2139. https://doi.org/10.1136/bmj.i2139
12. Banegas JR et al (2011) Achievement of treatment goals for primary prevention of cardiovascular disease in clinical practice across Europe: the EURIKA study. https://doi.org/10.1093/eurheartj/ehr080
13. Organisation for economic cooperation and development, 2016, Organisation for economic co-operation and development report 2016 Health Care Resources Hospital beds. http://stats.oecd.org/index.aspx?queryid=30183. Accessed 04 June 2018
14. Sistema statistico nazionale Istituto nazionale di statistica, 2015, Sanità e salute cap 4 in Annuario statistico italiano (2015)
15. Salvadori P (2016) La frequenza dell'inappropriatezza, ovvero l'appropriatezza per decreto in Toscana Medica 10, 2016, pp 13–18
16. Italian Law n° 221, 17/12/2012, 2012, Conversione in legge, con modificazioni, del decreto-legge 18 ottobre 2012, n. 179, recante ulteriori misure urgenti per la crescita del Paese. (12G0244), in Gazzetta Ufficiale della Repubblica Italiana (GU Serie Generale n. 294 del 18-12-2012 - Suppl. Ordinario n. 208)
17. Gunter TD, Terry NP (2005) The emergence of national electronic health record architectures in the United States and Australia: models, costs, and questions. J Med Internet Res 7(1):e3. https://doi.org/10.2196/jmir.7.1.e3
18. European Commission (2006) DECISION No 1639/2006/EC of the European Parliament and of the Council of 24 October 2006 establishing a competitiveness and innovation framework programme (2007–2013). Official J Eur Union, L 310/15. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32006D1639&from=GA. Assessed 04 June 2018
19. European Commission (2015) eHealth action plan 2012–2020—innovative healthcare for the 21st century. https://ec.europa.eu/digital-single-market/en/news/ehealth-action-plan-2012-2020-innovative-healthcare-21st-century. Assessed 04 June 2018

20. European Commission (2012) Competitiveness and innovation framework programme (CIP) ICT policy support programme, In: CIP ICT PSP work programme 2013. http://www.brusselsnetwork.be/eu-news-m/864-on-line-consultation-on-digital-agenda-for-europe.html. Assessed 04 June 2018
21. Electronic Health Record. https://en.wikipedia.org/wiki/Electronic_health_record. Assessed 04 June 2018
22. MacDougall J. France-still-seeks-an-electronic-health-record. healthcare-in-europe.com. www.healthcare-in-europe.com/en/article/14069-france-still-seeks-an-electronic-health-record.html. Assessed 04 June 2018
23. www.out-law.com/en/articles/2015/july/new-digital-health-laws-passed-by-german-law-makers/new-digital-health-laws-passed-by-german-law-makers in out-law.com. https://www.out-law.com/en/articles/2015/july/new-digital-health-laws-passed-by-german-law-makers/
24. Dimauro G et al (2016) VoxTester, software for digital evaluation of speech changes in parkinson disease. In: 2016 IEEE international symposium on medical measurements and applications (MeMeA), Benevento. https://doi.org/10.1109/memea.2016.7533761
25. Bevilacqua V et al (2016) A novel approach to evaluate blood parameters using computer vision techniques. In: IEEE international symposium on medical measurements and applications (MeMeA), Benevento. https://doi.org/10.1109/memea.2016.7533761
26. www.ekuore.com
27. www.gimaitaly.com
28. www.fsem.eu
29. de Lusignan S, Seroussi BA (2013) A comparison of English and French approaches to providing patients access to summary care records: scope, Consent, Cost. Stud Health Technol Inform 186:61–65. https://doi.org/10.3233/978-1-61499-240-0-61
30. Greenhalgh T et al (2010) Adoption and non-adoption of a shared electronic summary record in England: a mixed-method case study. BMJ 340:c3111. https://doi.org/10.1136/bmj.c3111
31. Séroussi B, Bouaud J (2016) Adoption of a nationwide shared medical record in France: lessons learnt after 5 years of deployment. In: AMIA annual symposium proceedings, vol 2016, pp 1100–1109, PMID: 28269907, PMCID: PMC5333332

Seminal VOCs Analysis Investigating Sperm Quality Decline—New Studies to Improve Male Fertility Contrasting Population Ageing

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Abstract The world is impacting with a drastic demographic change that is reflected in a progressive ageing population. If on the one side increasing health care for older people is important, stimulating the level of birth becomes decisive. The principal goal of this work is to set up of new method for early diagnosis of male infertility based on analysis of seminal Volatile Organic Compounds (VOCs), potentially biomarkers of infertility status. The identification of the volatile metabolite patterns in semen samples was done by an unconventional GC/[−MS + gas sensor] system. Once validate this approach could integrate and improve traditional semen analysis based on physiological parameters and addressed to the development of novel medical devices based on gas microsensors for male infertility screening.

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Keywords Population ageing · Male infertility · Semen volatile organic compounds · GC-MS · Gas sensors

1 Introduction

The world is in the midst of a major demographic transition. Not only is population growth slowing, but the age structure of the population is changing, with the share of the young falling and that of the elderly rising [1]. This means that the world's population is aging: virtually every country in the world is experiencing growth in the number and proportion of older persons in their population [6].

Economic impact of demographic change is very strong and regards mainly the increased government spending on health care and pensions, shortage of workers, changing sectors within the economy with a bigger market for goods and services linked to older people (e.g. retirement homes) and higher savings for pensions may reduce capital investment [5]. Furthermore, population ageing causes a social imbalance because there will be less and less young people who will be able to take care of the old peoples.

The immediate cause of population ageing and of many related problems, is fertility decline. The number of children for women was very high in the past century. Globally, up to 1965 the average woman had more than 5 children. Over the last 50 years the global fertility rate has halved and globally the average woman has fewer than 2.5 children today (Fig. 1).

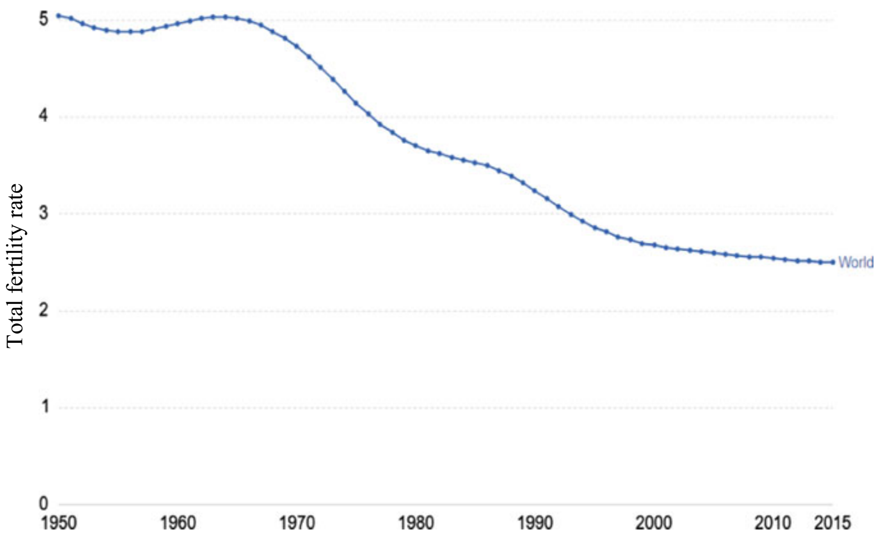


Fig. 1 Total fertility rate in the last 65 years

Infertility represents a major crisis for most couples, with both partners experiencing loss in ways that affect them as individuals, as family members and as members of society as a whole. The spectrum of these losses is very large and regards the loss of the experience of pregnancy and birth, of chance to contribute to the next generation, of chance to parent or become a grandparent, of family stability, of sense of control over destiny of sense of hope for the future [4].

Infertility and related terms have ambiguous meanings in different disciplines. In demography, the terms fertility and infertility refer to the actual reproductive performance in a purely descriptive manner. These terms are used according to whether there was actual childbearing or not during a certain period of time, not taking into account whether or not the couple wished to have a child. In contrast, in reproductive medicine the term infertility is used for women (or couples) who have had unprotected, regular intercourse for 1 years and who fail to achieve a pregnancy [4].

Almost 8–12% of couples in reproductive age is affected by complications related to infertility, so that this global health emergency [2]. Male factors contribute to approximately 40% of all cases of infertility and male infertility alone accounts for approximately one-third of all infertility cases. The main factors associated with male infertility are defined by European Association of Urology [3] and summarized in Fig. 2.

Semen analysis, known as seminogram, is the gold standard technique for semen analysis and should follow the WHO guidelines, Laboratory Manual for the Examination and Processing of Human Semen [8]. Semen analysis may show a decreased number of spermatozoa (oligozoospermia), decreased motility (asthenozoospermia), and many abnormal forms on morphologic examination (teratozoospermia) [3]. Seminal volume and pH can hint about conditions such as agenesis of seminal vesicles and vasa deferentia.

Despite the great amount of information that can be obtained from the macroscopic and microscopic analysis of the spermiogram, about 6–27% of infertile men show good parameters and so these cases result inexplicable through traditional methods.

In this work, we propose an innovative dual method in which seminal volatile organic compounds (VOCs) are detected in dual mode by two gas chromatography detector: a mass spectrometer (MS) and gas sensor, thanks to the presence of a two-way splitter, that splits the gas flow, eluting from the chromatographic column, in 1:1 ratio towards the two detectors.

Really, this study represents the first approach to the analysis of VOCs in seminal fluids. Other papers are focused on traditional metabolomics and its link with pathological situations [9].

Fingerprinting the pattern of VOCs in semen samples and, subsequently, identify those volatile metabolites candidate to be biomarkers of different conditions of male infertility may be a powerful method to achieve a male population stratification in population classes at risk and/or infertile according to the different pathologies related to male infertility. In the future this novel approach may lead to a new scenario for the management, and possibly the treatment of male fertility.

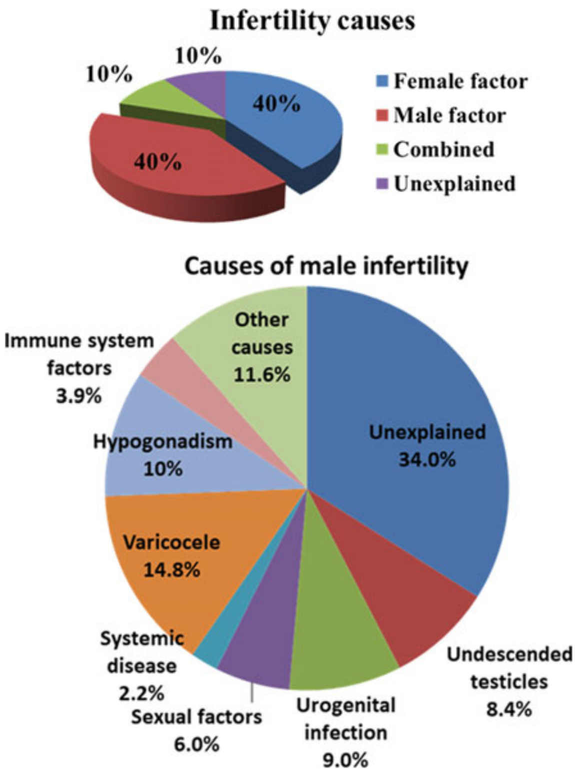


Fig. 2 Percentage of general and male infertility causes

2 Methods

2.1 *Semen Analysis*

The study was focused on 57 reproductive-age men. Semen analysis (seminogram) was carried out on semen samples collected from subjects at the Biological Medical Center "Tecnomed" (Nardò, Lecce—Italy). The examined parameters have been: volume and appearance of ejaculate, pH, time of liquefaction, semen viscosity, sperm motility and concentration.

2.2 *VOCs Extraction and Separation*

The seminal VOCs were extracted by Solid-Phase Microextraction (SPME) technique; SPME was carried out by a Carboxen®/Polydimethylsiloxane (CAR/PDMS) fiber (cod. 57,318, Supelco) which was exposed to each human semen sample headspace overnight [7]. The gas chromatograph/mass spectrometer (GC/MS) analysis of the extracted seminal volatiles was performed using a GC (6890 N series, Agilent Technologies) coupled to a MS (5973 series, Agilent Technologies) equipped with a ZB-624 capillary column (Phenomenex) with the injector temperature set at 250 °C to allow thermally desorption of VOCs. The carrier gas was high purity helium with a flow of 1 ml/min.

GC/MS analysis was carried out in full-scan mode with a scan range 30–500 amu at 3.2 scans/s. Chromatograms were analyzed by Enhanced Data Analysis software and the identification of the volatile compounds was achieved by comparing mass spectra with those of the data system library (NIST14, $p > 80\%$).

2.3 Compound Identification and Data Analysis

For GC/sensor analysis the capillary column was inserted, by a splitter (Agilent G3180B Two-Way Splitter), into a tiny chamber, made in Teflon, hosting a VOC sensor (MiCS-5521, e2v technologies, UK) and it was positioned close to the sensor surface. The metal oxide (MOX) sensor operating temperature was 400 °C. The MOX sensor traces (resistance vs. time, i.e. "sensorgrams") were used for data analysis.

The MS analyses were carried out in full-scan mode with a scan range 30−500 amu at 3.2 scans/s. Chromatograms were analysed by Enhanced Data Analysis software and the identification of the volatile compounds was achieved by comparing mass spectra with those of the data system library (NIST14, $P > 80\%$).

Experiments and physiological data, classified in relation to sperm motility, were elaborated by multivariate data analysis techniques using web-based tools available with open access server MetaboAnalyst (version 4) to perform principal component analysis (PCA).

3 Results

Semen analysis allow to classify sperm sample in two classes: on the hand asthenozoospermic samples with a progressive motility lower of 32% and normozoospermic samples with highest motility.

The new developed system, represented in Fig. 3, allow to analyze in parallel results obtained by GC-MS and GC-MOX sensor system.

In particular, 165 VOCs are identified in 57 semen samples by MS. Because of the high biological variability, we mainly consider VOCs present at least in two samples. Among 165 compounds, the 64% are present only in a sample and the 34% are most common.

By GC-MOX sensor system, resistance variations are recorded in correspondence of 49 VOCs. This evaluation is possible by overlapping of chromatograms obtained by the two systems. In this case, common VOCs are the 57%, while the remaining part is present only in one man.

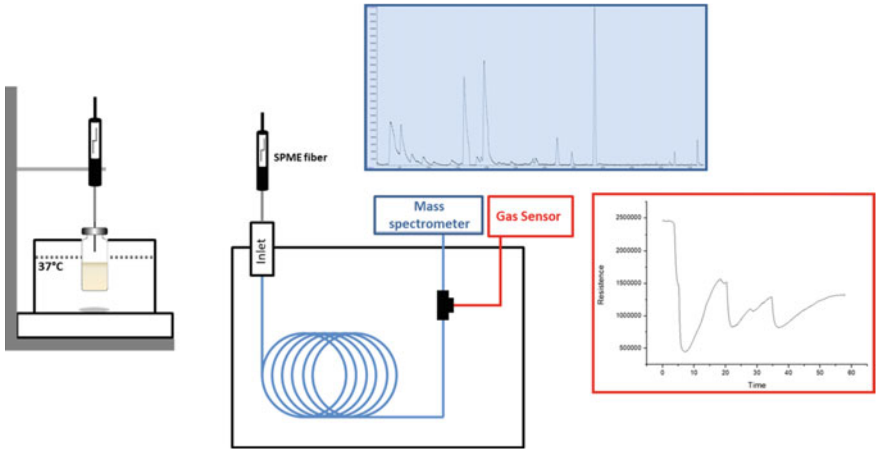
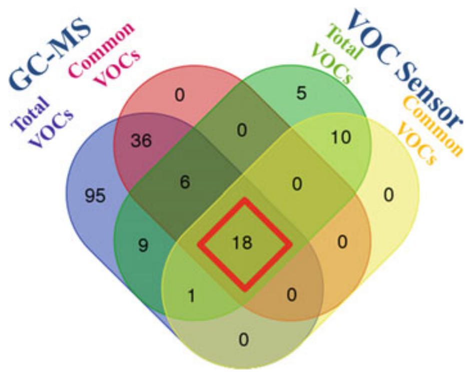


Fig. 3 Scheme of set up of method

Fig. 4 Set of detected VOCs by dual system



Crossing total compounds and common compounds detected by both systems (Fig. 4), we have identified 18 VOCs which are often detected by both MS and gas sensor.

Eighteen crucial compounds are: 1-Butanol; Ethanol; Heptane, 4-methyl-; Pentanal; Butanal, 2-methyl-; 2-Cyclopenten-1-one, 2-hydroxy-; Butanal, 3-methyl-; Butanal; 2-Butenal, 2-ethyl-; Ethyl Acetate; 1-Butanol, 3-methyl-; 1-Propanol; 2-Pentanone; Pyridine; 2.4-Dimethyl-1-heptene; Acetone; Pyrrole; 1H-1,2,4-Triazole.

PCA biplot in Fig. 5 show that VOCs with higher discriminant capacity of semen samples in bases of sperm motility are six: Butanal, 2-methyl-, Butanal, 3-methyl- and 1H-1,2,4-Triazole for asthenozoospermic samples and Ethanol, Pyrrole and Acetone for normozoospermic samples.

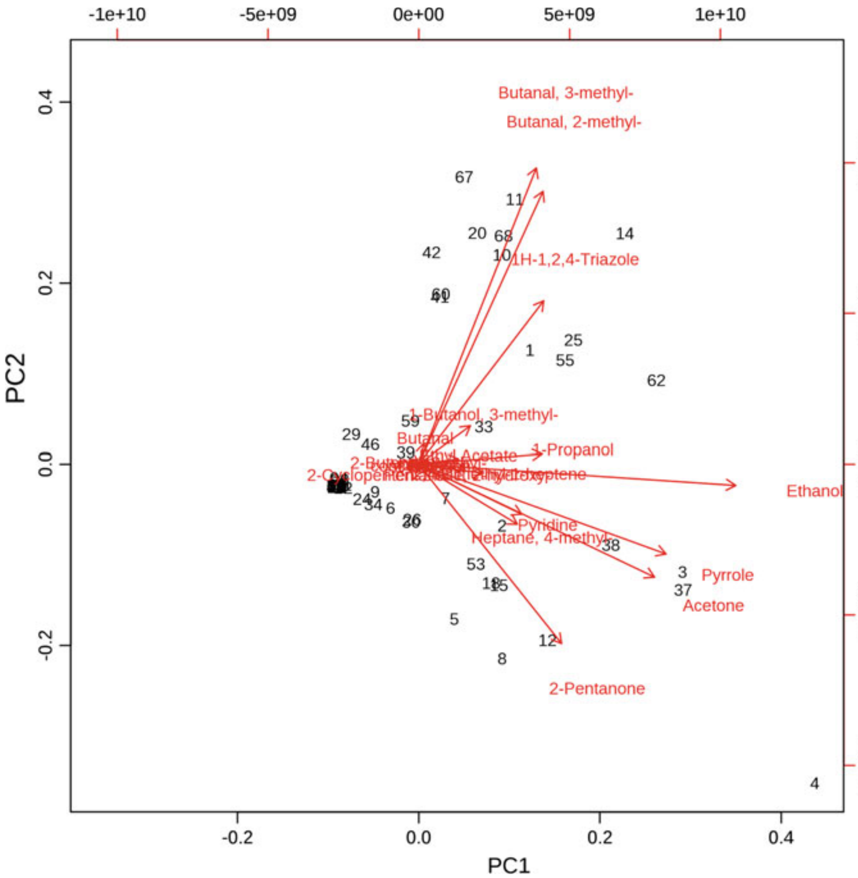


Fig. 5 PCA biplot of 18 VOCs

4 Discussion and Conclusion

In this work, for the first time, we propose a new approach to value sperm quality through VOCs analysis by a dual detection system. In particular, GC-MS method allow to separate and identify different molecules. Once volatile pattern has been defined, it is possible to link a resistance variation detected by MOX sensor to a specific compound by overlapping of chromatograms and sensorgrams. This allow to train sensor to seminal VOCs analysis.

Sensor capacity to discriminate specific molecules into seminal samples will allow to set up a new device able to analyze the volatile content of sperm fluid and early diagnose infertility male, also in the cases in which seminal parameters are into limit value. Diagnosis timeliness is very important because change in life style and/or administration of food supplements can help to get over some infertility cases. These actions are most efficient if carried out in a younger age. Exactly for this reason, today devices for early and in large scale diagnosis are very important.

This work fits in a largest research fields of our institute that face up change demographic problem from more points of view: on a hand by development of enabling technologies for healthcare, on the other by set up of device to male infertility diagnosis.

Early intervention of male infertility can improve chances of fertilization and embryo quality and, consequently, live-birth rate. Birth increase could balance ageing population and strongly impact in social and economic fields.

References

1. Callen T, McKibbin JW, Batini N (2006) The global impact of demographic change. IMF Working Paper, pp 1–36
2. Inhorn MC, Patrizio P (2015) Infertility around the globe: new thinking on gender, reproductive technologies and global movements in the 21st century. Hum Reprod Update 21(4):411–426
3. Jungwirth A, Giwercman A, Tournaye H, Diemer T, Kopa Z, Dohle G, Krausz C (2012) European association of urology working group on male infertility. European association of urology guidelines on male infertility: the 2012 update. Eur Urol 62(2):324–332. https://doi.org/10.1016/j.eururo.2012.04.048
4. Lunenfeld B, Van Steirteghem A (2004) Infertility in the third millennium: implications for the individual, family and society: Condensed Meeting Report from the Bertarelli Foundation's second global conference. Human Reprod Update 10(4):317–326. https://doi.org/10.1093/humupd/dmh028
5. Pettinger T. The impact of an ageing population on the economy. https://www.economicshelp.org
6. UN/DESA Department of economic and social affairs population division: world population ageing (2015)
7. Vas G, Vékey K (2004) Solid-phase microextraction: a powerful sample preparation tool prior to mass spectrometric analysis. J Mass Spectrom 39(3):233–254
8. World Health Organisation (2010) WHO laboratory manual for the examination and processing of human seme, 5th edn. WHO, Geneva, Switzerland
9. Zhang X, Diao R, Zhu X, Li Z, Cai Z (2015) Metabolic characterization of asthenozoospermia using nontargeted seminal plasma metabolomics. Clin Chim Acta 450:254–261. https://doi.org/10.1016/j.cca.2015.09.001

MARIO Project: Validation in the Hospital Setting

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Abstract In the EU funded MARIO project, specific technological tools are adopted for the patient with dementia (PWD). In the final stage of the project, two trials were completed as shown below: first trial was performed in September 2017, and second trial was performed in October 2017. The implemented and assessed applications (apps) are My Music app, My News app, My Games app, My Calendar app, My Family and Friends app, and Comprehensive Geriatric Assessment (CGA) app. The aim of the present study was to assess the acceptability and efficacy of MARIO companion robot on clinical, cognitive, neuropsychiatric, affective and social aspects, resilience capacity, quality of life in PWD, and burden level of the caregivers. Twenty patients (M = 8; F = 12) were screened for eligibility and all were included. In Pre- and Post-MARIO interaction, the following tests were administered: Mini-Mental State Examination (MMSE), Clock Drawing Test (CDT), Frontal Assessment Battery (FAB), Neuropsychiatric Inventory (NPI), Cornell Scale for Depression in Dementia (CSDD), Multidimensional Scale of Perceived Social Support

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(MSPSS), 14-item Resilience Scale (RS-14), Quality of Life in Alzheimer's Disease (QOL-AD), Caregiver Burden Inventory (CBI), Tinetti Balance Assessment (TBA), and Comprehensive Geriatric Assessment (CGA) was carried out. A questionnaire based on the Almere Acceptance model was used to evaluate the acceptance of the MARIO robot. In Post-MARIO interaction, significant improvements were observed in the following parameters: MMSE ($p = 0.023$), NPI ($p < 0.0001$), CSDD ($p = 0.010$), RS-14 ($p < 0.0001$), QoL-AD patients ($p = 0.040$), CBI ($p = 0.040$), SPMSQ ($p = 0.040$), and MNA ($p = 0.010$). The Almere Model Questionnaire presented a higher acceptance level in first and second trial.

Keywords Building resilience for loneliness and dementia · Comprehensive geriatric assessment · Caring service robots · Acceptability · Quality of life · Quality of care · Safety

1 Introduction

In the EU funded MARIO project (Managing active and healthy Aging with use of caRing servIce rObots), specific technological tools are adopted that try to create real feelings and affections making it easier for the patient with dementia (PWD) to accept assistance from a robot and, in specific situations, with the presence of a human supporting the operations made by the machine.

MARIO builds upon the Kompaï 2 robot developed by Robosoft [1]. It is a robot equipped with a camera, a Kinect and two LiDAR sensors for indoor navigation, objects detection and obstacle avoidance. A tablet PC is located on the robot torso for interaction. Mario's controller and interface technologies support software easy plug and play development; moreover, it includes a speech recognition system to interact with natural voice during daily life. Novel IoT technologies, based on Big Data, are integrated to deliver behavioural skills. The novelty of the project is the idea to integrate, in a single robotic platform several capabilities well-known in the literature but that so far have been tested in isolation.

Therefore, MARIO has been designed to support and manage "robotic applications" (apps), which are shown below:

- My Music app: the effect of music on neuropsychiatric symptoms in patients with dementia has been shown [2–4], in particular for anxiety and agitation [2]. Reducing these symptoms is fundamental for independent living and for the quality of life of people. My Music app is focused on allowing PWD to listen to and remember their favourite songs.
- My News app: the aim of this app is to allow PWD to keep in touch with daily news. Moreover, My News app allows the people to select which news they wish to read or hear MARIO read, through vocal or touchscreen selection of the news categories or directly through titles.

- My Games app: the aim of this app is to carry out cognitive stimulation and entertain the PWD. Cognitive stimulation is encouraged by the game “Simon”. This is an electronic game of memory skill invented by Baer and Morrison [5]; the device creates a series of tones and lights and requires a user to repeat the series (if the user succeeds the series becomes progressively longer and more complex). In comparison, the entertainment function is facilitated by the provision of the following games such as: card games (as Briscola, Scopa, and Tressette), chess and ping-pong.
- My Calendar app: the aim of this app is to improve the temporal orientation of the PWD, and to remind them of their daily appointments.
- My Family and Friends app: this app was developed to keep the PWD in contact with their relatives and friends in order to reduce their isolation and improve their socialization.
- CGA app: in older people, especially those with multimorbidity, the Comprehensive Geriatric Assessment (CGA) approach is recommended and validated worldwide. One of the aims of the MARIO project from a clinical point of view is to develop an innovative robotic module to perform an automated CGA using systems capable to explore different health domains that allow the determination of the current health status of the PWD through the use of a Multidimensional Prognostic Index (MPI) [6]. The app therefore may support the reduction of adverse outcomes thus prolonging independence.

In the final stage of the project, two trials were completed as shown below: first trial was performed in September 2017, and second trial was performed in October 2017. This paper addresses the impact of the apps described above, when they were delivered by MARIO. We also explored the impact of robot embodiment and how this affected the interactions between PWD and the robot [7–10].

The aim of the present study was to assess the acceptability and efficacy of MARIO companion robot on clinical, cognitive, neuropsychiatric, affective and social aspects, resilience capacity, quality of life in dementia patients, and burden level of the caregivers. Moreover, further aims were to assess the functionality of the apps in the first trial, in which improvements were suggested before to begin the second trial. In this final trial, a re-assessment of the app functionalities were performed.

2 Materials and Methods

This study fulfilled the Declaration of Helsinki, guidelines for Good Clinical Practice, and the Strengthening the Reporting of Observational Studies in Epidemiology guidelines. The approval of the study for experiments using human subjects was obtained from the local ethics committee on human experimentation. Written informed consent for research was obtained from each PWD or from relatives or a legal representative. PWD were consecutively recruited in the Department of

Geriatrics, Casa Sollievo della Sofferenza Hospital (San Giovanni Rotondo, Italy), and were screened for eligibility.

Twenty patients (12 females and 8 males) were screened for eligibility according to the inclusion/exclusion criteria shown below and included in the trials (Trial 1 and Trial 2).

Inclusion criteria were: (1) patients with diagnosis of dementia according to the criteria of the National Institute on Aging-Alzheimer's Association (NIAAA) [11] and the Diagnostic and Statistical Manual of Mental Disorders—Fifth Edition (DMS-5) [12]; (2) presence of mild cognitive impairment (Mini Mental State Examination (MMSE) $\geq$ 18) [13], and (3) the ability to provide an informed consent or availability of a proxy for informed consent. Exclusion criteria were: patients with serious comorbidity, tumors and other diseases that could be causally related to cognitive impairment (ascertained blood infections, vitamin B12 deficiency, anaemia, disorders of the thyroid, kidneys or liver), history of alcohol or drug abuse, head trauma, psychoactive substance use and other causes of memory impairment.

The MARIO robot was shown to all patients and the applications were demonstrated. After preliminary training, the PWD interacted with MARIO during their hospitalization.

In Pre- and Post-MARIO interaction, the following parameters, explained in details in the text, were collected by a systematic interview, clinical evaluation and review of records from a psychologist: demographic data, clinical and medication history and a complete multidimensional and cognitive-affective assessment.

2.1 Diagnosis of Dementia, and Cognitive-Neuropsychiatric-Affective Assessment

Dementia was diagnosed by the Diagnostic and Statistical Manual of Mental Disorders—5 Edition (DMS 5) criteria [12]. Diagnoses of possible/probable Alzheimer's disease were made according to the NIAAA criteria [11] and supported by neuroimaging evidence (CT scan and/or NMR).

In all PWD, cognitive status was screened by means of the MMSE [13], Clock Drawing Test (CDT) [14], and Frontal Assessment Battery (FAB) [15].

Neuropsychiatric symptoms were evaluated with the Neuropsychiatric Inventory (NPI) [16] including the following 12 domains: delusions, hallucinations, agitation/aggression, depression mood, anxiety, euphoria, apathy, disinhibition, irritability/lability, aberrant motor activity, sleep disturbance and eating disorder.

Affective status was evaluated using the Cornell Scale for Depression in Dementia (CSDD) [17].

2.2 Evaluation of Social Aspects and Resilience

In all PWDs, social aspects were assessed by the Multidimensional Scale of Perceived Social Support (MSPSS) [18]. The 14-item Resilience Scale (RS-14) [19] was used to assess the ability to bounce back or recover from stress.

2.3 Quality of Life and Caregiver Burden Level Assessment

The Quality of Life in Alzheimer's Disease (QOL-AD) [20], a 13-item measure test, was used to obtain a rating of the persons quality of life from both the PWD and the caregiver. Moreover all caregivers were administered the Caregiver Burden Inventory (CBI) [21].

2.4 Clinical Assessment

The Tinetti Balance Assessment (TBA) tool was used to evaluate mobility and stability of the PWD.

A CGA was carried out evaluating the following domains: functional status with activities of daily living (ADL) index [22], and by instrumental activities of daily living (IADL) scale [23]; cognitive status with the Short Portable Mental Status Questionnaire (SPMSQ) [24]; comorbidity with the Cumulative Illness Rating Scale (CIRS) [25]; nutritional status with the Mini Nutritional Assessment (MNA) [26]; the risk to develop pressure sores with the Exton-Smith Scale (ESS) [27]; the number of drugs used by patients and the co-habitational status.

2.5 Acceptability and Usability Assessment

Almere Model Questionnaire [8] was used to evaluate the acceptance of the MARIO robot. This questionnaire was specifically developed to test the acceptance of assistive social technologies by older users.

The questionnaire was administered to the PWD and a questionnaire was performed by person who supervised the trial session (MARIO Questionnaire) designed to find out the perceptions about companion robots, especially what the PWD would like the robot to do for them, and how robot can improve their clinical status by using the apps.

2.6 Statistical Analysis

All the analyses were made with the SPSS Version 20 software package (SPSS Inc., Chicago, IL). For dichotomous variables, differences between the groups were tested using the Fisher exact test. This analysis was made using the 2-Way Contingency Table Analysis available at the Interactive Statistical Calculation Pages (http://statpages.org/). For continuous variables, normal distribution was verified by the Shapiro–Wilk normality test and the 1-sample Kolmogorov–Smirnov test. For normally distributed variables, differences among the groups were tested by the Welch 2-sample t test or analysis of variance under general linear model. For non-normally distributed variables, differences among the groups were tested by the Wilcoxon rank sum test with continuity correction or the Kruskal–Wallis rank sum test. Test results in which the p value was smaller than the type 1 error rate of 0.05 were declared significant.

3 Results

3.1 Pre-MARIO Interaction Outcomes

The characteristic outcomes of first trial are shown in Table 1.

The average age of the PWD was 77.00 ± 8.12 years. The patients had a mean educational level of 6.78 ± 2.44 years, and a mean number of years with memory problems of 1.11 ± 0.33. The participants interacted with MARIO in mean 166.11 ± 34.17 min per day (min/die) for a mean of 5.44 ± 1.24 hospitalization days (range = 4–7 days). The total number of interactions was 3 for all patients.

The characteristic outcomes of second trial are shown in Table 2.

Table 1 Baseline characteristics of the patients with dementia that had used MARIO robot during the first trial

	(n = 9)
Gender—Males/Females	4/5
Males (%)	44.40
Age—Mean ± SD	77.00 ± 8.12
Educational level—Mean ± SD	6.78 ± 2.44
Number of years with memory problems—Mean ± SD	1.11 ± 0.33
Hospitalization days—Mean ± SD	5.44 ± 1.24
Time of interaction with MARIO (min/die)—Mean ± SD	166.11 ± 34.17
Number of interactions—Mean ± SD	3.00 ± 0.00

Table 2 Baseline characteristics of the patients with dementia that had used MARIO robot during the second trial

	(n = 11)
Gender—Males/Females	4/7
Males (%)	36.40
Age—Mean ± SD	76.91 ± 7.67
Educational level—Mean ± SD	8.36 ± 4.29
Number of years with memory problems—Mean ± SD	1.18 ± 0.40
Hospitalization days—Mean ± SD	5.82 ± 1.60
Time of interaction with MARIO (min/die)—Mean ± SD	167.27 ± 31.49
Number of interactions—Mean ± SD	4.36 ± 0.50

Table 3 Cognitive, neuropsychiatric, and affective scores of the patients with dementia, before and after the use of MARIO robot, during the two trials

	Before	After	P value
MMSE—Mean ± SD Range	20.99 ± 1.32 19–23	21.39 ± 1.14 20–23	**0.023**
CDT—Mean ± SD Range	2.25 ± 0.64 1–3	2.25 ± 0.64 1–3	1.00
FAB—Mean ± SD Range	12.15 ± 3.36 6–16	12.00 ± 3.58 6–16	0.18
NPI—Mean ± SD Range	5.40 ± 4.83 0–18	4.75 ± 3.49 0–12	**<0.0001**
NPI-D—Mean ± SD Range	2.75 ± 2.43 0–9	2.45 ± 1.93 0–6	0.16
CSDD—Mean ± SD Range	7.00 ± 3.77 1–15	6.15 ± 2.56 2–11	**0.01**

The average age of the PWD was 76.91 ± 7.67 years. The patients had a mean educational level of 8.36 ± 4.29 years, and a mean number of years with memory problems of 1.18 ± 0.40. The participants interacted with MARIO 167.27 ± 31.49 min per day (min/die) in mean for a mean of 5.82 ± 1.60 hospitalization days (range = 4–8 days). The mean number of interactions was 4.36 ± 0.50.

3.2 *Post-MARIO Interaction Outcomes*

As shown in Tables 3, 4 and 5, at post-MARIO interaction, significant improvements were observed in the following parameters: MMSE ($p = 0.023$), NPI ($p < 0.0001$), CSDD ($p = 0.010$), RS-14 ($p < 0.0001$), QoL-AD patients ($p = 0.040$), CBI ($p = 0.040$), SPMSQ ($p = 0.040$), and MNA ($p = 0.010$).

Table 4 Depression, resilience, quality of life and social scores of the patients with dementia before and after the use of MARIO robot, during the two trials

	Before	After	P value
MSPSS total score—Mean ± SD Range	56.00 ± 5.51 48–60	56.40 ± 5.01 48–60	0.16
MSPSS family—Mean ± SD Range	18.80 ± 1.88 16–20	19.20 ± 1.64 16–20	0.16
MSPSS friends—Mean ± SD Range	18.40 ± 2.01 16–20	18.40 ± 2.01 16–20	1.00
MSPSS Special Person—Mean ± SD Range	18.80 ± 1.88 16–20	18.80 ± 1.88 16–20	1.00
RS-14—Mean ± SD Range	26.10 ± 3.66 22–32	28.00 ± 3.70 23–35	**<0.0001**
QoL-AD (Family)—Mean ± SD Range	37.50 ± 2.78 29–39	37.90 ± 3.93 29–42	0.13
QoL-AD (Patient)—Mean ± SD Range	33.25 ± 5.36 26–40	34.10 ± 4.61 29–40	**0.04**
CBI—Mean ± SD Range	5.10 ± 5.38 0–14	4.20 ± 4.17 0–12	**0.04**

Table 5 Clinical, functional, nutritional and social scores of the patients with dementia, before and after the use of MARIO robot, during the two trials

	Before	After	P value
TBA—Mean ± SD Range	9.20 ± 0.41 9–10	9.20 ± 0.41 9–10	1.00
ADL—Mean ± SD Range	5.60 ± 0.50 5–6	5.60 ± 0.50 5–6	1.00
IADL—Mean ± SD Range	3.00 ± 1.03 2–5	2.85 ± 0.75 2–4	0.46
SPMSQ—Mean ± SD Range	1.85 ± 0.49 1–3	1.65 ± 0.48 1–2	**0.04**
ESS—Mean ± SD Range	17.80 ± 2.42 15–20	17.70 ± 2.36 15–20	0.66
MNA—Mean ± SD Range	22.85 ± 2.72 18–27	23.60 ± 2.64 19–28	**0.01**
CIRS—Mean ± SD Range	2.45 ± 0.95 1–5	2.55 ± 1.05 1–5	0.16
N of medications—Mean ± SD Range	3.90 ± 1.37 2–7	3.80 ± 1.19 2–7	0.48

The Almere Model Questionnaire (Table 6) results show a higher acceptance level in the following domains: Attitude (90%), Facilitating condition (100%), Intention to use (70%), Perceived adaptivity (80%), Perceived enjoyment (100%), Perceived sociability (80%), Perceived usefulness (90%), Social Influence (60%), Trust (60%), and Use/Usage (60%).

Table 6 Distribution of Almere model questionnaire domains in patients with dementia during the two trials

Code	Construct	Definition	%
ANX	Anxiety	Evoking anxious or emotional reactions when using the system	0
ATT	Attitude	Positive or negative feelings about the appliance of the technology	90
FC	Facilitating condition	Objective factors in the environment that facilitate using the system	100
ITU	Intention to use	The outspoken intention to use the system over a longer period in time	70
PAD	Perceived adaptivity	The perceived ability of the system to be adaptive to the changing needs of the user	80
PENJ	Perceived enjoiment	Feelings of joy or pleasure associated by the user with the use of the system	100
PEOU	Perceived Ease of use	The degree to which the user believes that using the system would be free of effort	30
PS	Perceived sociability	The perceived ability of the system to perform sociable behavior	80
PU	Perceived usefulness	The degree to which a person believes that using the system would enhance his or her daily activities	90
SI	Social influence	The user's perception of how people who are important to him think about him using the system	60
SP	Social presence	The experience of sensing a social entity when interacting with the system	20
TRUST	Trust	The belief that the system performs with personal integrity and reliability	60
USE	Use/Usage	The actual use of the system over a longer period in time	60

4 Conclusion

The two trials aimed mainly at drawing clear conclusions on the interaction between the user and the MARIO robot and on the acceptability level and efficacy of MARIO companion robot on clinical, cognitive, neuropsychiatric, affective and social aspects, resilience capacity, quality of life in dementia patients, and burden level of the caregivers.

These data are of great importance since they not only give useful indicators to assess what has been accomplished up to now, but they also provide important guidelines in order to improve the system capabilities while specific experimentation stages focused on the clinical aspects are expected to be carried out in the next months.

The really interesting and fascinating aspect of this project is the possibility to create a robotic platform that not only helps with cognitive stimulation and daily living but also, in parallel, detects premature changes in subject health status using algorithms based on the CGA approach.

In MARIO, a novel approach was developed to employ companion robots, build a unique evidence-based 'toolkit' of resilience strategies that foster social inclusion and create a network to advance knowledge about ways of fostering social inclusion. The effect has been to facilitate and support connectedness for persons with dementia and their communities, reduce social exclusion, isolation and stigma, while also helping to shape and prioritize outcomes for resilience by supporting others (such as family, carers and the community).

MARIO positions itself as a tool to help policy makers and the medical community to manage the increasing costs and additional stress placed on the health care system associated with the wide, heterogeneous and complex aging population. The promotion of interventions capable to increase independent living are a must and a certainty, which are mirrored in the literature and the policy. In the realization of interventions that promote independent living, one of the more accepted and validated approaches is CGA that is a multidimensional, usually interdisciplinary, diagnostic process intended to determine an elderly person's medical, psychosocial, and functional capacity problems.

These service-robot enabled innovations was set up to obtain improved diagnostic accuracy, optimization of medical treatment and health outcomes, improved function and quality of life, reduced costs and improved long-term care management.

As part of the evaluation, MARIO was been used to collect information that enables the integration of many different domains of data into a single score that can represent synthetically the health status of a person. MARIO is intended to be the first prototype of a new generation of robots able to communicate with humans on a natural language basis as well as to detect, interpret, and express emotional expressions, and to react to such interactions with a behaviour that adapts and evolve dependently on the environment they live in, i.e. ambient sensors, and the specific humans they interact with. In conclusion, MARIO project represents a novel approach employing companion robots, and its effect will be: (1) to facilitate and support persons with dementia and their caregivers, and (2) reduce social exclusion and isolation.

The collected and above mentioned data confirm a satisfactory integration between the PWD and the system along with a great level of acceptability of MARIO robot by the end-user, both patients themselves and caregivers or medical providers, those who, day by day, take care and assist their patients.

The limitation of the study is mainly represented by the low sample of recruited participants.

In a future perspective, further end-users could be recruited and further functions could be implemented, in addition to interesting reports which could be brought out by MARIO Apps in order to obtain increasing amounts of data in user behaviours. For example, MyCalendar App could report how many times the patient manifested the need to remember drug assumptions or his scheduled appointments. In MyReminiscence App, MyMusic App and MyNews App, correct replies or number and type of played songs or number of news read by the patient could produce more insight in his behaviour and attitudes. These capabilities could in the future foster new Big Data studies in the field of personalized Healthcare.

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References

1. KOMPAÏ Robotics (2017) KOMPAÏ robots help frail people and caregivers. https://kompai.com. Accessed 23 May 2018
2. Cooke M, Moyle W, Shum D, Harrison S, Murfield J (2010) A randomized controlled trial exploring the effect of music on quality of life and depression in older people with dementia. JHP 15:765–776
3. Lin Y, Chu H, Yang CY, Chen CH, Chen SG, Chang HJ et al (2011) Effectiveness of group music intervention against agitated behavior in elderly persons with dementia. Int J Geriatr Psychiatry 26:670–678
4. D'Onofrio G, Sancarlo D, Seripa D, Ricciardi F, Giuliani F, Panza F et al (2016) Non-pharmacological approaches in the treatment of dementia. In: Moretti DV (ed) Update on dementia. InTech, Rijeka, Croatia, pp 477–491
5. Baer RH, Morrison HJ. Microcomputer controlled game. US patent 4207087, Issued 10 June 1980
6. Pilotto A, Ferrucci L, Franceschi M, D'Ambrosio LP, Scarcelli C, Cascavilla L et al (2008) Development and validation of a multidimensional prognostic index for 1-year mortality from the comprehensive geriatric assessment in hospitalized older patients. Rejuvenation Res 11:151–161
7. Heerink M (2010) Accessing acceptance of assistive social robots by aging adults. In: Faculteit der Natuurwetenschappen, Universiteit van Amsterdam
8. Heerink M, Krose B, Evers V, Wielinga B (2010) Assessing acceptance of assistive social agent technology by older adults: the Almere Model. Int J Soc Robot 2(4):361–375
9. Tapus A, Tapus C, Mataric M (2009) The role of physical embodiment of a therapist robot for individuals with cognitive impairments. In: RO-MAN 2009—the 18th IEEE international symposium on robot and human interactive communication, pp 103–107

10. Cohen-Mansfield J, Thein K, Dakheel-Ali M, Rigier N, Marx M (2010) The value of social attributes of stimuli for promoting engagement in persons with dementia. J Nerv Ment Dis 198(8):586–592
11. McKhann GM, Knopman DS, Chertkow H, Hyman BT, Jack CR Jr, Kawas CH et al (2011) The diagnosis of dementia due to Alzheimer's disease: recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guide-lines for Alzheimer's disease. Alzheimers Dement 7:263–269
12. American Psychiatric Association (2013) Diagnostic and statistical manual of mental disorders, 5th edn. Washington, American Psychiatric Association
13. Folstein M, Folstein S, McHugh PR (1975) Mini-mental state: a practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 12:189–198
14. Rouleau I, Salmon DP, Butters N et al (1992) Quantitative and qualitative analyses of clock drawings in Alzheimer's and Huntington's disease. Brain Cogn 18:70–87
15. Dubois B, Litvan I (2000) The FAB: a frontal assessment battery at bedside. Neurology 55:1621–1626
16. Cummings JL, Mega M, Gray K, Rosenberg-Thompson S, Carusi DA, Gornbein J (1994) The neuropsychiatric inventory: comprehensive assessment of psychopathology in dementia. Neurology 44:2308–2314
17. Alexopoulos GS, Abrams RC, Young RC, Shamoian CA (1988) Cornell scale for depression in dementia. Biol Psychiatry 23(3):271–284
18. Zimet GD, Dahlem NW, Zimet SG, Farley GK (1988) The multidimensional scale of perceived social support. J Pers Assess 52:30–41
19. Callegari C, Bertù L, Lucano M, Ielmini M, Braggio E, Vender S (2016) Reliability and validity of the Italian version of the 14-item Resilience Scale. Psychol Res Behav Manag 9:277–284
20. Logsdon RG, Gibbons LE, McCurry SM, Teri L (2002) Assessing quality of life in older adults with cognitive impairment. Psychosom Med 64:510–519
21. Novak M, Guest C (1989) Application of a multidimensional caregiver burden inventory. Gerontologist 29:798–803
22. Katz S, Downs TD, Cash HR, Grotz RC (1970) Progress in the development of an index of ADL. Gerontologist 10:20–30
23. Lawton MP, Brody EM (1969) Assessment of older people: self-maintaining and instrumental activities of daily living. Gerontologist 9:179–186
24. Pfeiffer E (1975) A short portable mental status questionnaire for the assessment of organic brain deficit in elderly patients. J Am Geriatr Soc 23:433–441
25. Parmelee PA, Thuras PD, Katz IR, Lawton MP (1995) Validation of the cumulative illness rating scale in a geriatric residential population. J Am Geriatr Soc 43:130–137
26. Vellas B, Guigoz Y, Garry PJ, Nourhashemi F, Bennahum D et al (1999) The Mini Nutritional Assessment (MNA) and its use in grading the nutritional state of elderly patients. Nutrition 15:116–122
27. Bliss MR, McLaren R, Exton-Smith AN (1966) Mattresses for preventing pressure sores in geriatric patients. Mon Bull Minist Health Public Health Lab Serv 25:238–268

Active Aging by Continuous Learning: A Training Environment for Cultural Visits

Amedeo Cesta, Gabriella Cortellessa, Riccardo De Benedictis and Francesca Fracasso

Abstract The "Città Educante" project aims at radically rethinking the learning environments through the application of the most advanced ICT technology. Among the different aspects of the project, the *LECTurE* module aims, by exploiting artificial intelligence techniques, at proposing contextualized lessons, as well as interaction requests, to the involved users. In particular the lesson's content, is specifically tailored for the older adults and personalized by taking into account users' psycho-physiological aspects as well as geo-localization information and temporal constraints. In this paper, after a generic introduction to the "Città Educante" project, the *LECTurE* module is presented and instantiated in two relevant use cases: the *on-site training*, in which the system is used as a support to the classical teaching methodologies within a classroom, and the *distributed training*, in which the technology aims at moving and animating the teaching experience, also, "outside the classroom", with additional stimuli for the users during a practical experience (e.g., a real visit in a museum to complement a theoretical art history lesson). The paper describes, then, the choices made for the realization of a first prototype and its embodiment into a concrete scenario which, by implementing a "treasure hunt" like game, aims at fostering older adults' physical and cognitive activity.

Keywords Intelligent tutoring system · Active assisted living · Active ageing Planning and scheduling

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1 Introduction

By exploiting the most advanced ICT technology, the "Città Educante" project[1] (the name, in Italian, means "city that educates") aims at completely rethinking the concept of *learning environment* while reshaping it according to a smart city perspective. The project, specifically, proposes new educational approaches, while enriching and innovating methods and tools, by providing a learning environment which acts in time (e.g., lifelong) and space (e.g., at school, in an outdoor environment, during leisure, etc.) hence overcoming the classical systems and the traditional "lessons".

The theme of *learning* is, through the project, framed in relation to the response to social challenges linked to the renewal of the educational system, to be achieved by means of the implementation of new learning/teaching models and/or the optimization of the existing ones on the various areas of life and knowledge, as well as new systems/evaluation processes, in which the technology (platforms and web) becomes an enabling factor.

Specifically, the authors' goal in the project has been the one of thinking an incarnation of the "Città Educante" for the continuous education of older people. In particular, considering the more recent experiences in the interaction of elderlies with complex machines [4], keeping in mind previous experience in training, specifically tailored for crisis managers [1], we are currently pursuing the goal of building an Intelligent Tutoring System (ITS) [9, 10], called *LECTurE* (for Learning Environment "Città Educante"), aimed at improving the active aging and the participation in the social life of the elders living at home, in the community, and at work.

This paper represents an introduction to authors' effort in designing and building the *LECTurE* learning subsystem. After introducing, in Sect. 2, the main ideas underlying the learning subsystem, Sects. 3.1 and 3.2 describe a proposal for the modeling of students and lessons. A preliminary system architecture is proposed in Sect. 4. Section 5 describes the application of the *LECTurE* system to a concrete example. Finally, some conclusions and a discussion about future works close the paper.

2 Using AI to Personalize Lessons for Older Users

While pursueing the objective of the project, which aims at reformulating the learning environments through the creation of platforms, services and ICT applications, we got in touch with several volunteering organizations addressing, specifically, elderlies' needs. Among the different organizations, in particular, Televita[2] is a volunteering association whose main objective is to maintain the elderlies active and motivated, leveraging upon individual aptitudes and/or competencies [3]. Televita's volunteers, in fact, are, themselves, elders who want to keep active by offering their abilities

[1] http://www.cittaeducante.it.

[2] http://www.televita.org.

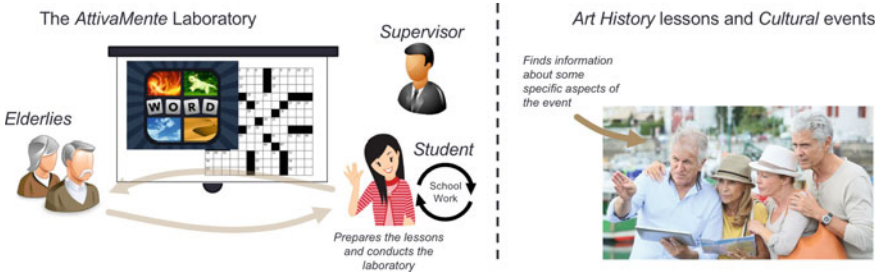

Fig. 1 The *LECTurE* general idea

and competences to the organization. Although Televita's main activity consists in providing tele-assistance services (tele-friendship) and a 24/7 active helpline devoted to lonely elders who need support, it also manages several laboratories that involve elders both as attendees and "teachers". Examples include a computer lab, a tailoring lab, a cooking lab and an Italian language teaching for foreign people. Furthermore, the association organizes cultural events as concerts, museum visiting, theater, etc.

Among the offered services, we focused in particular on two specific activities that were both in line with the "Città Educante" concept and that are outlined in Fig. 1:

- The *AttivaMente laboratory*: aims at keeping elders mentally active, so as to limit the cognitive decline associated with the advancement of age, by proposing them cognitive stimuli. Such stimuli, mostly consisting in general culture quiz and/or crosswords, are proposed to the elders in a context similar to a school lesson. Specifically, by relying on some previous knowledge of the involved persons, as well as on their interactions during the lesson, a teacher, a volunteer himself, yet with more experience than others, controls the course's progress and slightly adapt it to the specific context's needs. Since the stimuli are predetermined, however, such adaptations tend to be limited to the possibilities of the case. The use of artificial intelligence techniques, in this case, could support the personalized delivery of stimuli by taking into account previous knowledge of the participants as well as their interactions with the AI system increasing, compared to the classical case, the personalization capabilities.
- The *Art History lessons and cultural events*: analogously to the AttivaMente case, before attending to cultural events, some of the participants, according to their abilities and competencies, are asked to find information about some specific aspects of the event (e.g., a particular work of art within a museum, relevant historical happenings related to a visited site, etc.). Such information are then shared, in a "sort of" lesson with other participants in a classroom context and also outside, during the event, enriching the overall knowledge of the group while encouraging the interaction among the members. Similarly to the AttivaMente case, such information may result to be limited and/or not customized to the specific members of the event. AI techniques, in this case, might offer the opportunity to

enrich the cultural events experience by providing further personalized stimuli to the event participants, as well as interaction requests to test the level of engagement and actively stimulate them.

Combining the above activities represents an opportunity for the elders to keep themselves active while learning in time and space. Additionally, the use of AI can support the development of more effective and engaging learning experience.

2.1 The LECTurE *Learning Subsystem*

The idea of developing the *LECTurE* system has arisen as a consequence of a field experience. Specifically, by taking inspiration from a previous work [2], in which students were trained for managing crisis, the approach used within *LECTurE* is based on the idea of dynamically composing lessons through the use of a technology related to a subfield of artificial intelligence called *automated planning* [6]. In particular, starting from a static representation containing an high-level lesson track, initially stored in a database, the lesson is *planned* and dynamically adapted and personalized to the involved users. The idea of using the technology related to automated planning comes from the need to create a sufficiently extensive didactic experience to reproduce a large number of different situations which are, at the same time, characterized by a high variability of stimuli, aimed at increasing the involvement level of users. Automated planning, indeed, favors the generation of different lessons that would be too complicated to obtain with a simple pre-compilation of stories. The timeline-based approach to automated planning [8], in particular, represents the unifying element of the various modules by ensuring the dynamic adaptability of plans by promoting experiential learning.

From a high-level point of view, the main modules of the system are described in Fig. 2. In particular, it is possible to distinguish between two kinds of **involved users**: the *students*, i.e., a group of people, potentially, of any age, interested in using the learning services offered by the *LECTurE*, and the *teachers*, i.e., users with special privileges who have the opportunity to observe students, monitoring the progress of the lessons and of the overall learning environment. The above users interact with the *LECTurE* system which is composed of three functional blocks, intended as architectural subsystems, implementing the corresponding high-level functionalities: (i) the *user modeling*, whose goal is to create and maintain a user model and provide guidance for improving the learning process; (ii) the *lesson modeling*, whose role consists in combining the information from the previous subsystem and to create the customized lesson as well as to control its evolution; (iii) the *lesson presentation*, whose purpose is to effectively represent the lesson.

It is worth highlighting that the proposed system provides users, whether students or teachers, the opportunity to change the learning environment's evolution in real time by interpreting their decisions. In fact, the architecture is based on a sense-plan-act paradigm implementing, in a continuous loop, the three primitives (a) *sense*, in

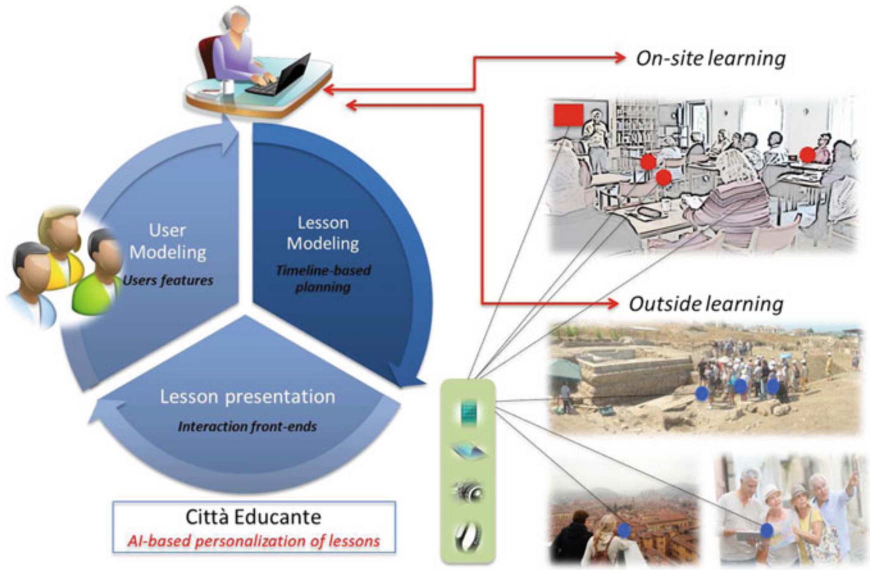

Fig. 2 The *LECTurE* general idea

which information is collected from sensors, (b) *plan* where a world model is created using the information available to plan the next move to do, and (c) *act*, in which the move, chosen by the planning process, is actually executed. Furthermore, by mimicking the different cases implemented by the Televita organization, the *LECTurE* system provides training through different modalities depending on the chosen use case. In particular, it is possible to distinguish between two different modalities: (a) *on-site learning*, closer to the classical teaching, in which technology is used as a support to the teaching in a classroom, with the aim to create richer lessons, and (b) *distributed learning*, in which technology aims to support lessons outside the classroom during a practical experience. The following sections describe, more in detail, the above modalities.

2.2 *On-Site Training*

In the on-site training modality, the system can be used by a group of students, at the same time, previously contacted by the teacher. This mode represents an extension to the classical learning method in which a teacher teaches to a group of students. In this case, however, compared to the classical approach, the teaching is enhanced by the introduction, within the lesson, of the *LECTurE* technology.

Specifically, each lesson is instantiated by the teacher by defining the specific *learning objectives* [7]. The system processes the lesson and presents the information to the students through the available tools. Students interact directly with the system, providing their answers to certain circumstances proposed by the system, and transmitting data from sensors available on the adopted devices (e.g., physiological parameters) enriching the users' models.

Depending on the sensors' inputs and on the students responses, both the teacher and the system can autonomously decide, based on the observations, whether and how to modify the current lesson. Finally, at the end of the lesson, the system can generate several reports, for example, one for each student, which can be used for debriefing purposes.

2.3 Distributed Training

In the distributed training case, the system exploits different types of web technologies. This means that the lesson does not happen in a single physical room and is distributed among the students who are remotely connected to the system. The lesson can still be instantiated by the teacher defining the specific learning objectives but may have variable, potentially infinite, duration.

This kind of approach, compared to the previous one, is more innovative. Students interact directly with the system while wandering, by their own, within the city, providing their answers to certain circumstances proposed by the system as well as constantly transmitting data from the sensors available on the chosen devices (e.g., geographic location, physiological parameters, etc.). Sensor data, in particular, enriches the users' models which, in turn, adapt the lesson to the students resulting in a highly personalized learning experience.

Again, based on the inputs from the sensors and on the students' feedback, both the teacher and the system can autonomously decide, based on the observations, whether and how to modify the lesson in progress. Similarly to the on-site case, the *LECTurE* system can generate, during the lesson, several reports, for example, one for each student, which can be used both for debriefing purposes and for a further tuning of the lesson.

3 The *LECTurE* System

As already mentioned, the *LECTurE* users interact with the system which is composed of different functional blocks. In particular, the user modeling module aims at creating and maintaining a model of the users which is used as a starting point for the personalization of the lessons. The following sections describe, in more detail, how students and lessons are modeled and how the two models interact so as to guarantee the customization of the learning experience.

3.1 Modeling the Students

By pursuing the overall goal of enhancing the learning experience, it is necessary to keep a user model up-to-date in order to consider how their emotional, psychological, physiological and geographical parameters can influence the learning process. Specifically, the student modeling module has three main objectives:

- Select, model and monitor relevant human factors, as well as psychological, physiological, or other user-related variables;
- Develop a model that can represent the user's profile;
- Provide a high level guidance for customizing learning objectives.

The set of considered relevant factors include, among the other things, personality traits, past experience, the perceived effectiveness in performing complex tasks, the perceived fatigue, the level of engagement and the current performance assessment. The use of Blue-tooth bracelets (e.g. the Empatica E4), for example, allows the extraction of physiological values such as temperature, skin conductance, heart rate and heart variability. Additionally, it is possible to leverage on geo-localization services to get a good estimate of the users position in time. The initial evaluation of these variables, used as a baseline to initialize the didactic experience and as a reference point for subsequent measurements, can be done through the use of standardized psychological questionnaires or physiological measurements performed off-line before the lesson. It is worth to notice, however, that the profile of a student can also be updated exploiting the interactions of the users with the system asking them, for example, to answer to sporadic questions. As an example, the users' *engagement* is measured through a five levels Likert-type scale which is administered to the users at regular intervals.

Among the dynamic parameters, particular emphasis is given to the students' *performance* which is monitored and observed by recording input data such as the different actions taken by the users. Specifically, this information is processed and interpreted in order to plan the subsequent actions of the lesson as well as to support the debriefing phase. By processing the users' profiles, the system generates a user model that is constantly updated to perceive and represent significant changes in the emotional state (note that parameters can generally change over time). In addition, students' performance is analyzed and processed in order to gather further usable information to customize even more the lesson. The teacher can access this information in order to supervise and control the customization. For this purpose, this component can provide guidance on how to customize the lesson. Personalization of a training course can therefore be done automatically, but it can also be suggested to a teacher who independently decides whether to adapt the training course (i.e., according to a mixed-initiative style).

Since the different users are characterized by properties that are closely related to their role, their work or, more generally, their psychophysiological state during the lessons, each user that interacts with the system feeds the *LECTurE* system with personal data. The system, in turn, builds a user model that is used to synthesize custom lessons responding to the specific status of each student. The output of this process is passed to a second module that, on the basis of these indications and on the particular didactic path chosen, synthesizes a sequence of appropriate stimuli for the group (shared information between the different students in a lesson) and for the individuals (tailored information for a specific student).

3.2 Modeling the Lessons

Lesson modeling is the key feature of the *LECTurE* system since it creates and manages the network of events that guides the entire learning session. Nodes on this network are intended to represent temporally annotated stimuli (e.g., videos, text messages, questions, etc.) to be sent, at appropriate time, to their associated users while edges represent causal and temporal relations among such stimuli. Additionally, the network allows to the teacher to maintain a high-level vision of the lesson while providing sufficient granularity of the information sent to the students.

It is worth noting that although the above network is initialized in order to represent an abstract blueprint of a lesson, it is afterwards customized and dynamically adapted to the profile of the involved user. Specifically, adaptations to the network are made thanks to the application of a set of pre-compiled first-order-like *rules* which define how to "react" to the users' profile, to their updates and to their actions (e.g., answering to a question). Such rules, in particular, are intended to create the "conditions", in terms of events and their relations within the network, for other events to be present. An example of rule can be "in order to stimulate the cognitive activity of the group, either propose a simple crosswords and the group's performance is low, or propose a complex crosswords and the group's performance is high". Notice that by taking advantage of the possibility of defining disjunctions within the rules and being able to combine such rules sequentially, it is possible to obtain a great wealth of possible lessons' evolutions. Finally, since some of these rules may contain conditions which concern the user model, not all of them are applicable (e.g., in the above example, in case the group's current performance is low, only the simple crosswords is proposed), resulting in an overall network which is always compatible with the current users' profiles.

Broadly speaking, the teacher loads the chosen lesson from a database resulting in the construction of an initial event network (i.e., the set of events, positioned over time, communicated to users like videos, text messages, questions, etc.). The network is, through the application of the rules, afterwards customized to the users participating in the lessons. By executing the lesson, then, events, representing stimuli and requests, are dispatched, at proper time, to the users associated to them. It is worth noticing that in order to foster interaction and collaboration among them, the distributed information may be partial, requiring users the need to send messages to other students so that they can build an overview and respond appropriately to the challenges posed by the system fostering, thus, cooperation. Whenever the profile of a user changes because, for example, his/her level of fatigue increases, specific rules are

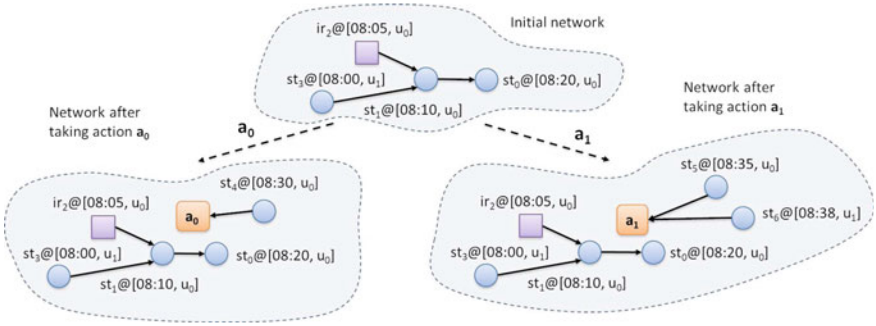

Fig. 3 An example of *LECTurE* dynamic lesson adaptation in case either action a_0 or action a_1 is performed by a user

applied resulting in an update of the network so as to bring it back to be "consistent" with the current status of the users. Similarly, updates might happen as a consequence of the users' actions, resulting in a network which is always representative of the initial lesson while being dynamically adapted to the specific context.

As an example, Fig. 3 shows, at its top, an initial network containing three stimuli (i.e., st_0, st_1 and st_3) and an interaction request (i.e., ir_2) representing, for example, a question. Each event has its own execution time and its target user (e.g., st_0 will be dispatched at 08:20 to the user u_0). In the figure, the arrows represent the causal relations among the events that emerge from the application of the rules. In other words, the st_1 event is in the network "because of" the st_0 event. Another way of looking at it, from a causal point of view, is to consider the st_1 event as a "condition" for the existence of the st_0 event. Finally, notice that in order to simplify the explanation and make the speech clearer we have omitted the information regarding the temporal constraints which, however, can be considered embedded within the arrows.

At 08:05, the interaction request ir_2 requires the user u_0 to take some action (i.e., either a_0 or a_1). Suppose, as an example, that the action a_0 is performed, the network is updated to the one on the left by adding the new stimuli st_4 at 08:30 for user u_0. Again, the st_4 stimuli is added within the network "because of" the a_0 action. Conversely, in case action a_1 is performed, the network is adapted to the one on the right by adding the new stimuli st_5 at 08:35, for user u_0, and the new stimuli st_6 at 08:38, for user u_1. As already mentioned, it is worth noticing that this type of adaptation occurs in a similar way as a consequence of the actions carried out by the users as well as for the dynamic changes that occur to their profile, ensuring a discrete availability of flexibility and adaptation to the particular conditions that may arise in the different lessons.

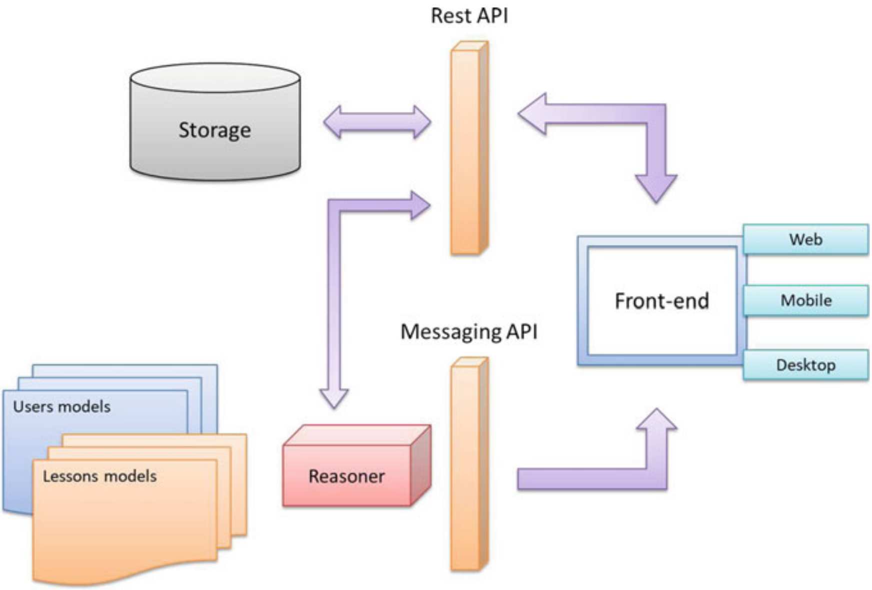

Fig. 4 The *LECTurE* main modules

4 The System Architecture

This section briefly introduces the *LECTurE*[3] system software architecture. In particular, Fig. 4 sketches the modules described earlier, introducing some standard components, responsible for the communication among the different modules, which act as a glue.

Specifically, the architecture contains a module for the permanent storing of relevant information. A reasoner, constituted by a timeline-based planner [5], works to orchestrate the different models, specified by means of first-order rules, of the users and of the lessons. Such rules, in particular, are responsible for fulfilling the updates to the network as described in Sect. 3.2. A front-end module deals with providing (web, mobile, and/or desktop) graphical interfaces to the users. Finally, it is worth noticing that the communication among the different modules happens by means of two different software interfaces:

- A REST interface allows the creation, updating, and viewing of permanently stored information. The same interface is used to notify any changes to a user's profile (e.g., the user has moved around a site of historical interest) or possible actions by the user (e.g., answering a multiple-choice question) or, furthermore, messages sent to other users.

[3] https://github.com/pstlab/LECTurE.

- A messaging interface, made through WebSocket and/or MQTT, allows to send different types of messages to the users. A typical example of a message is a stimulus like, for example, an interaction request consisting of a multiple response question, a questionnaire, a map, a question for detecting the psychological state of the user, etc.

5 An example of *LECTurE* at work

This section introduces a concrete example intended to show the *LECTurE* system at work. As already mentioned, we aim at fostering physical and cognitive activity while reducing social isolation of elders. In addition, we always keep in mind we are addressing a segment of the population subject to social disadvantage due to their physical condition. To achieve this we can exploit some architectural elements of Rome. One of the characteristics of Rome, indeed, consists in the presence, on walls or on the corners of historic buildings, of a number of Madonnas painted under canopies. The idea consists in sending stimuli to users so as to guide them to visit such shrines, customizing the path to their psychophysiological state. By exploiting georeferencing, the *LECTurE* system asks users to take pictures of the shrines to be used, afterwards, to build games which, played together, reduce social isolation and stimulate cognitive activity. It is worth noticing the similarity of this scenario with the activities currently carried out by the Televita association. In particular, visiting the shrines mimics the *Art History lessons and cultural events* activity. Analogously, the automatically built games are intended to reinforce the *AttivaMente laboratory*.

The first step for the implementation of a scenario of this kind consists in collecting information about the shrines like, for example, a brief history about each of them and their GPS coordinates. Additionally, a customized questionnaire, administered to users, is intended to extract an initial profile to be used as a baseline. This information is sufficient to generate a series of paths to which we can associate different difficulty levels measurable in terms of the path length. The different paths can be computed, in a pre-processing step, by solving a top-k Traveling Salesman Problem (TSP) (where k is the number of shrines which are planned to be visited) and encoded into rules. Additionally, the number of shrines can be reduced by filtering out those that are too far from a certain point which is considered as the starting point of the excursion (e.g., consider only those shrines which are closer than 3 km).

Starting by the initial profile, a path, compatible with the profile, is selected like, for example, the dashed one in the center part of Fig. 5. The path is then, step by step and at proper time, suggested to the user by means of customized stimuli (e.g., "go to pos1", "the shrine at pos1 has been built in 1796", "take a picture at the shrine in pos1", "go to pos4", etc.). Additionally, by taking into account physiological data, the system can adapt the route switching, for example, once the *LECTurE* system realizes that the user is not too tired, to the solid one, fostering physical activity and a prolonged interaction with the other involved users. Finally, once back from the trip, the *LECTurE* system builds a "memory" game, challenging the participants to

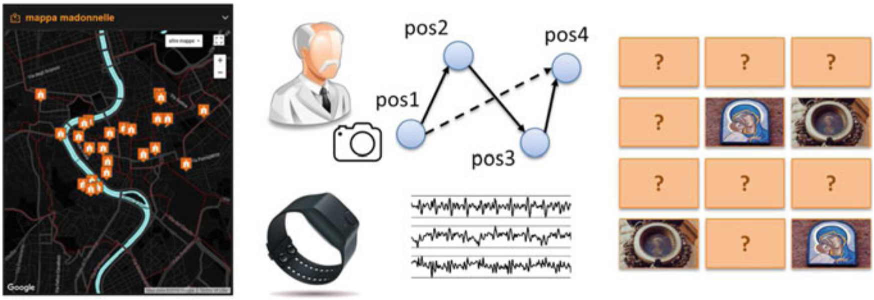

Fig. 5 The *LECTurE* system at work

discover, in the fewest possible steps, hence stimulating cognitive activity, pairs of the taken pictures hidden under the tiles.

6 Conclusions and Future Works

This paper introduces the *LECTurE* system as an AI-based Intelligent Tutoring System specialized for supporting active aging. The paper defines the *LECTurE*'s initial functionalities, the architectural entities and a specification of the technological components. We have introduced the general idea of supporting older people in maintaining themselves mentally and physically active being helped by some intelligent technology both during a class and during excursions. The ICT intelligent core makes use of a specific kind of artificial intelligence technology, called automated planning, which is responsible for orchestrating the different modules of the *LECTurE* system, resulting in the creation of a baseline "lesson" which is dynamically adapted to the actions taken by, as well as to profile updates of, the users, so as to integrate both personalized stimuli and requests to the users over time. Although the application is currently under development, the constant contact with Televita's volunteers is allowing the transition from a lab prototype to an incrementally more robust version of the system to be tested in realistic scenarios.

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References

1. Bacon L, Cesta A, Coraci L, Cortellessa G, De Benedictis R, Grilli S, Polutnik J, Strickland K (2012) Training crisis managers with PANDORA. In: Proceedings of the 20th European conference on artificial intelligence, pp 1001–1002. IOS Press
2. Cesta A, Cortellessa G, Benedictis RD (2014) Training for crisis decision making—an approach based on plan adaptation. Knowl Based Syst 58:98–112

3. Cesta A, Cortellessa G, De Benedictis R, Fracasso F (2017) A tool for managing elderly volunteering activities in small organizations. In: Esposito F, Basili R, Ferilli S, Lisi FA (eds) AI*IA 2017: advances in artificial intelligence
4. Cortellessa G, Fracasso F, Sorrentino A, Orlandini A, Bernardi G, Coraci L, De Benedictis R, Cesta A (2017) ROBIN, a telepresence robot to support older users monitoring and social inclusion: development and evaluation. Telemed e-Health
5. De Benedictis R, Cesta A (2015) Integrating logic and constraint reasoning in a timeline-based planner. In: AI*IA 2015— XIVth international conference of the Italian association for artificial intelligence
6. Ghallab M, Nau D, Traverso P (2004) Automated planning: theory and practice. Morgan Kaufmann Publishers Inc
7. Gronlund NE, Brookhart SM (2009) Gronlund's writing instructional objectives. Pearson/Merrill Prentice Hall
8. Muscettola N (1994) HSTS: integrating planning and scheduling. In: Zweben M, Fox MS (edS) Intelligent scheduling. Morgan Kauffmann
9. Ohlsson S (May 1986) Some principles of intelligent tutoring. Instr Sci 14(3):293–326. https://doi.org/10.1007/BF00051825
10. Wenger E (1987) Artificial intelligence and tutoring systems: computational and cognitive approaches to the communication of knowledge. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA

The TV-AssistDem Project: A TV-Based Platform for Coping with Mild Cognitive Impairment

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Abstract This paper describes the work pursued within the TV-AssistDem project, an AAL initiative, the aim of which is to develop a technological tool to facilitate remote support to patients affected by Mild Cognitive Impairment (MCI). The idea is to exploit TV-based transmission of data and video-interactivity among health-professionals, patients, caregivers and family members to support MCI older users. The objective of TV-AssistDem goes beyond the realisation of the necessary technological effort, and extends to the delivery of a longitudinal experimentation on an

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European scale. The paper gives an overview of the project and presents the results of the user requirements elicitation effort carried out during the first phase involving users to gather valuable indications for the platform development. A presentation of the platform functionalities is also provided and the current status of the implementation effort is finally presented.

Keywords Mild cognitive impairement · TV-based solution · Continuous support from remote

1 Introduction

Population ageing within Europe has major social and economic consequences. Although many older people are able to support themselves and continue to make important contributions to society, the burden of non-communicable disease and disability increases with age, exerting pressures on health services and support systems for older people. One of the most devastating conditions that predominantly affects older people is dementia [16]. Dementia is not exclusively a condition of older people, but its prevalence increases sharply with age. It is an umbrella term describing a set of symptoms that occurs when various diseases or conditions affect the brain, the most common cause of dementia being Alzheimers disease (AD). The symptoms that comprise dementia can vary greatly, with people often experiencing memory loss but also problems in communication and attention as well as anxiety and depression [4]. Treatment options currently remain centred on symptomatic treatment, the main class of drugs prescribed to people with mild to moderate AD dementia being cholinesterase inhibitors. There are currently about 10.5 million people in Europe

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with dementia, costing around 275 billion annually. Given that the number of people with dementia in Europe is expected to rise to 13.4 million by 2030, the challenge of dementia is likely to remain formidable [15]. Health care policies are therefore focused on extending the ability of older people to continue to live independently, as one way of meeting these challenges. This entails maintaining the quality of life (QoL) of people with dementia, as well working to reduce the costs of their care. The negative impact that people with dementia can experience in regards to their QoL is well established and helps explain why people with dementia are increasingly voicing their desire to get on with life and to be provided with the support they need to do so [1, 3, 6, 7, 9]. Living with dementia in the early stages can be burdensome for both those affected as well as their relatives [2, 8]. Caring for persons with dementia can compromise the informal carers own well-being and health due to a feeling of being overloaded in the caregiving role [5]. The central role the informal carers play for people with dementia lifts the importance of the well-being of the informal carers themselves, and provision of support to the informal carers is therefore essential [17].

1.1 The TV-Assistdem Project Idea

The term Mild Cognitive Impairment (MCI) has been introduced to fill the gap between regular aging and dementia. It refers to seniors with no severe limitations of daily functioning, who suffer however from mild cognitive deficit, potentially evolving into AD [12, 14], with an estimated annual converse rate of MCI to dementia of about 11% [10]. The term MCI describes a set of symptoms, rather than a specific disease. A person with MCI has mild problems with one or more of the following:

- memory—for example, forgetting recent events or repeating the same question
- reasoning, planning or problem solving—for example, struggling with thinking things through
- attention—for example, being very easily distracted
- language—for example, taking much longer than usual to find the right word for something
- visual depth perception—for example, struggling to interpret an object in three dimensions, judge distances or navigate stairs.

The aforementioned deficits can be differently associated among each other and this can produce different typologies of MCI [11, 12]:

1. MCI with memory deficit and impairment on other cognitive functions (aMCI multiple domain),
2. MCI with deficit in one cognitive function, but memory (non aMCI single domain),
3. MCI with deficit in more cognitive functions, but memory (non aMCI multiple domain).

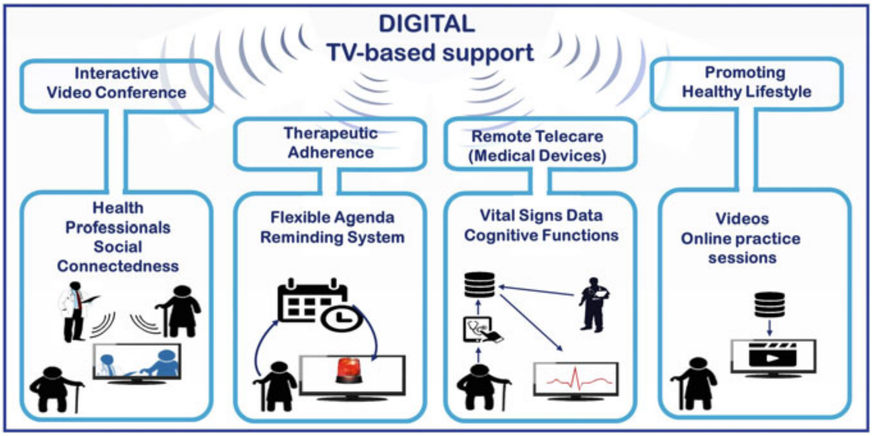

Fig. 1 The TV-AssistDem idea

For people with MCI, these changes may cause them to experience minor problems or need a little help with more demanding daily tasks (i.e. paying bills, managing medication, driving). However, MCI does not cause major problems with everyday living. If there is a significant impact on everyday activities, this may suggest dementia [13].

For this reason the TV-AssistDem project focused on patients with MCI who still do not have a claimed diagnosis of dementia and still live at their home independently. Additionally, in TV-AssistDem project, caregivers are foreseen to be involved as well.

The TV-AssistDem project aims at developing a technological tool to facilitate remote support to patients affected by Mild Cognitive Impairment (MCI), exploiting TV-based transmission of data and video-interactivity among health-professionals, patients, caregivers and family members.

As shown in Fig. 1, the system aims at providing four main functionalities: *Interactive video conference* with Health Care professional; *Monitoring of Therapeutic Adherence* with reminders for pills and appointment; *Monitoring of Vital signs* and cognitive functions; *Promotion of healthy life style* with educational material and training.

Overall the project's objective is twofold: (1) developing a TV-based platform for supporting the patients with MCI and providing relief to their caregivers; (2) carrying out a long term clinical trial in order to assess the efficacy of the TV-AssistDem system by involving both patients at home and their caregivers.

Although the goal of TV-AssistDem is not to provide clinical support to caregivers too, the hope is to provide relief to those caring of MCI patients by facilitating their living at home. For this reason, the stakeholders considered in the project are the MCI patients, their caregivers, and the health care professionals in charge of the patients.

In the following sections, the efforts carried out during the first year of project will be presented, namely, the involvement of end users pursued for eliciting the requirements for developing the platform.

2 User Requirements Elicitation

The main objective of the users requirements elicitation phase was to gather feedback to better design the functionalities of the TV-AssistDem platform. In fact, while the main aim of the system was already conceived at proposal time, the involvement of all typologies of users has been instrumental to guide and refine the definition of the various functionalities of the system. Users involvement is crucial while designing innovative technology especially devoted to people with MCI. In this respect representatives of the various users were recruited. Additionally, this investigation was aimed at identifying a level of priority of the various functionalities in order to plan the development of the tool for the clinical trial on the one hand and produce the commercial version at the end of the project on the other hand.

2.1 Method

A preliminary meeting with a psycho-geriatrician have been conducted, in order to gather insight for the development of a proper grid for leading the focus groups. Beside valuable information for a better refinement of the grid used in the focus groups, some insights for user requirements have been collected, thus contributing to the definition of the final user requirements list. Focus groups with patients and caregivers, and health care professionals were conducted in Spain and Romania in order to collect the perspective from users on their needs and what is important to observe to support independent living. The aim of the focus groups was to go through the platform services with the participants and elicit their discussion about possible services and functionalities, the best way of interaction and get some suggestions on the interface. Additionally, participants have been invited to express their opinions and feelings about technology as a supportive means for MCI management.

2.1.1 Participants

Three types of participants have been recruited to get feedback from representatives of each category of users involved in the clinical trial foreseen in the TV-AssistDem project. Some focus groups have involved health care professionals with specific expertise in dementia and cognitive decline, while other focus groups were dedicated to gather information from patients and their close caregivers (i.e. family members). More specifically, both in Spain and Romania, two focus groups with experts and

Table 1 Participants in the 4 focus groups with experts in Spain and Romania

Spain	Romania
7 geriatricians	2 general practitioners
7 registered general nurses	6 registered general nurses
1 neurologist	1 medical personnel area coordinator
6 general practitioners	1 health unit recepionist
1 social worker	2 social workers
	1 conunselor
	1 psychologist
	5 formal cares
	3 kinesiotherapists
	1 other
TOT. 22	TOT. 23

Table 2 Participants in the 4 focus groups with patients and caregivers in Spain and Romania

Spain	Romania
Patients: 3 males, 6 females	Patients: 5 males, 16 females
Caregivers: 5 males, 4 females	Caregivers: 3 females
TOT. 18	TOT. 24

two with patients and caregivers have been conducted. Detailed information on the participants are provided in Tables 1 and 2.

2.1.2 Procedure

At first the moderators started with a brief description of the project and explained to the participants the reason of the meeting and the expectations upon their participation. Following this brief introduction, the moderators followed a discussion guide to generate interest in the topic, involve all the participants, and keep the discussion on track. One or more observers assisted the moderator. The role of the observer was to listen to the discussion, take notes and interact with the moderator when necessary. Notes from the observer could be used in directing the moderator in one way or another. Each focus group addressed a long discussion about the platform with a threefold goal: (1) investigating additional services tailored for mild dementia management; (2) gathering feedback for the redesign of the interface in order to make it accessible to the users with mild cognitive impairment; (3) gathering feedback to define the services provided by the platform. In Figs. 1 and 2, the reader can have an idea of the setting kept during the focus groups, while participants had the possibility to familiarize and interact with the platform by themselves.

Fig. 2 Focus groups in Spain

Fig. 3 Focus groups in Romania

During the meetings, the moderators followed a guide and went through the platform by showing the main services already available, asking for feedback and for suggestions. There was one discussion guide for the professional group and one for patients/caregivers with slight differences. The focus group discussions were tape-recorded and transcribed verbatim.

2.1.3 Method of Analysis

The aim of analysis was to identify examples and suggestions linked to the possible services provided through the platform. The specific point of view of users has been considered in order to gather any information strictly linked to the needs of people with MCI and their caregivers (both formal and informal). Additionally, any suggestions for a proficient interaction with the platform have been considered, especially with regard to the peculiarity of user interaction and interfaces design. A manifest qualitative analysis was used. This means that the analysis was close to the direct wordings in the text without deeper interpretation of latent meanings. The analysis was done by reading the text of transcribed focus groups back and forth to get a picture of how the participants talked about different aspects of the identified factors. First of all, the text was read through to get a whole picture of the content. Secondly, suggested factors/services/comments that were mentioned by the participants were identified and marked in the text. The next step was to identify in the text if the focus group expressed that the marked data was an important factor to observe. If considered as important, the suggested data was put in a table according to the following categories (Fig. 3):

- General impressions
- Vital signs measurements
- Healthy habits (reminders)
- TV support (video conference with the doctor)
- Other applications
- General on the interface (interaction/graphics)
- Others.

2.2 Indications for Developers

Starting from the results of the focus groups, a list of user requirements has been produced in order to provide the developers with punctual indications. Priority has been given accordingly to the frequency of occurrence among focus groups, and the feasibility for the clinical trials. In this paper, we only report those requirements that obtained the highest level of priority, since these will be effectively implemented on the TV-ASSISTDEM platform. Beside some general indications on how ensuring the implementation of accessible and usable interaction modalities, the importance of getting personalized services has been raised in order to design a solution able to meet different needs according to different persons. Additionally, more punctual indications have been collected for a better design of the foreseen services and functionalities. For example, a number of suggestions for improving the communication service through the videoconferencing functionalities have been provided. Moreover, the involvement of health care professionals brought some valuable indications for the monitoring of the health status through vital signs, mood, and cognitive functions, and the modalities of delivering and setting reminders and alarms have been adjusted according to the specific needs of patients with MCI. Further suggestions have been made for additional functionalities which might have been interesting considering the target users. The exploitation of reminiscences for both monitoring and training the cognitive functions has been suggested, as well as the possibility to provide the patients with recreational applications dedicated to the cognitive training. Moreover,

Table 3 List of key/desirable requirements for the platform's development

Capability descriptor	Requirement statement
Interface and user interaction	
Ease of use	Information included in the platform should be basic, easy for the user
Accessible graphic interface	Interface should be accessible to frail users as well. Specific attention to visual impairment and age-related deficit should be taken into account
Audio interface	Visual input from the platform should be accompanied by audio feedback
Speech interaction	Speech interaction could be used beside the use of the remote control
Simplified remote controller	The remote control is too complicated to be used as it is and it need to easier
Communication service	
Socialization through the video call	The video call service could serve for maintain contacts between the patients and friends/family
Camera use	The use of the webcam is well judged, but some measures have to be taken in order to preserve the patients privacy
Personalization issue	
Tailored services	The additional services provided by the applications should be tailored according to the patients needs and preferences
Tailored available information	It should be up to the doctor the decision on which data can be available to the patients
Vital signs measurements	
Notifications to doctors and caregivers of abnormal values	Abnormal values should be notified to the caregivers and doctors
The HELP button providing different type of information	It should provide instruction regarding what is displayed on the screen at the moment
Reminders and appointments	
Alarm settings	The possibility for the patients to set alarms by themselves should be regulated accordingly to the different cases
Drinking water reminder	Since dehydration seems to be a common issue in seniors, this should be a common reminder in the platform
Reminders time setting	The platform should allow to set repeated reminders for appointments more times in advance
Vocal reminders	Reminders should be both displayed on the screen and conveyed acoustically
Notification on therapy adherence	Notifications on therapy adherence would be appreciated by doctors, specialists and field workers
Other services	
Short educational videos	Additional services as videos can be included in the platform
Recreational applications based on reminiscences	Beside health focused services, some recreational services could be added
Cognitive stimulation	Specific exercises for cognitive stimulation (memory exercises, games) could be included in the platform
Reminiscences for cognitive status monitoring	Based on personal memories recall it can be used in order to monitor the cognitive status of the patient
Healthy diet	Among different applications, there should be one devoted to providing healthy dietary habits
Social service connections links	Some links to community services could be provided within this section

it has been suggested the delivery of healthy tips (i.e. dietary suggestions, educational videos), and the attempt to keep the patients involved in the social life of the neighborhood by keeping them up to date with related news. In Table 3 a list of the requirements which had the highest priority of implementation is reported.

3 The TV-AssistDem Platform: Architecture Design

The feedback collected from the end users provided valuable information for the development of the architecture of the platform. The first choice made according to such feedback was to realize a distributed architecture providing client-side services for the end-users and back-end services for the medical staff. Figure 4 shows an overview of the envisaged distributed architecture and the needed functional elements. The main architectural elements composing the envisaged architecture are: (i) a set-top-box (STB) which is responsible for allowing end-users to enjoy TV-AssistDem services; (ii) a (centralized) back-end server which is responsible for managing and storing information about users and providing the basic functionalities needed to realize TV-AssistDem services; (iii) a web-based user interface which allows the medical staff to manage general information, events and appointments concerning the associated primary users.

The key idea of the STB is to integrated user-oriented monitoring services with the TV which represents a "familiar" device to the targeted primary users. Thus, a user can enjoy classical TV functionalities and TV-AssistDem services in a *transparent way* through an enhanced remote control. As Fig. 4 shows, the client-side services of the STB can be grouped into two distinct sets. The set of *core services* is composed by general communication functionalities and other specific functionalities that allow the system to collect information about a user. Videoconferencing functionalities allow users to make video calls with the associated medical team during fixed temporal windows. Calendar and reminders functionalities allow the system to

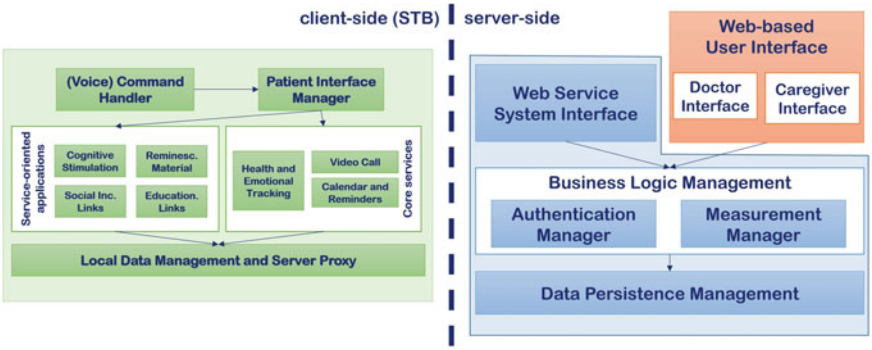

Fig. 4 Distributed architecture in the TV-AssistDem platform

manage all the appointments about a user and to dynamically notify users to remind such events. Then, other functionalities allow the system to track several parameters concerning the mental as well as physical status of a user like e.g., heart rate, blood pressure (health-related parameters) or the mood (emotional parameter). The set of *service-oriented applications* is composed by more specific functionalities that aim at monitoring and evaluating the cognitive status of a user. More specifically, this set consists of a number of game-oriented applications a user can enjoy through the TV in order to train and evaluate his/her cognitive status.

The "business logic" of the server-side of the architecture provides functionalities for collecting and managing all the information gathered through STBs. Particularly relevant are the data concerning the health and cognitive status of end-users. Such information is useful for *off-line* analysis in order to discover and/or posticipate cognitive degradations. In addition, a web-based interface facilitates the access to the collected data. It provides medical teams with dedicated interfaces for reading and managing information concerning the health and cognitive status of their patients as well as their events and appointments.

4 Current Status and Conclusions

The TV-AssistDem platform is currently under refinement and is supposed to be subjected to an internal testing before being deployed in real houses for testing with end users. After a technical refinement the system will be tested in clinical trials that will take place in Spain and Romania. In fact, around 216 dyads (person with MCI and the caregiver) are being recruited for participating to the clinical trial which will last 18 months. More specifically, 108 dyads will represent the intervention group which will use the TV-AssistDem platform, while the other 108 will represent the control group. While a stable version of the platform will be used during the clinical trial, a parallel thread in the project will be devoted to collect additional feedback during this testing period, in order to provide further indication for the development of additional services and functionalities which will be included in the commercial version of the platform foreseen for the end of the project.

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References

1. Beerens HC, Zwakhalen SM, Verbeek H, Ruwaard D, Hamers JP (2013) Factors associated with quality of life of people with dementia in long-term care facilities: a systematic review. Int J Nursing Stud 50(9):1259–1270. http://www.sciencedirect.com/science/article/pii/S0020748913000448, special Issue IMPROVING THE CARE OF OLDER PERSONS

2. Bleijlevens MH, Stolt M, Stephan A, Zabalegui A, Saks K, Sutcliffe C, Lethin C, Soto ME, Zwakhalen SM (2015) Changes in caregiver burden and health related quality of life of informal caregivers of older people with dementia: evidence from the european righttimeplacecare prospective cohort study. J Adv Nurs 71(6):1378–1391. https://onlinelibrary.wiley.com/doi/abs/10.1111/jan.12561
3. Brady R, Weinman J (2013) Adherence to cholinesterase inhibitors in Alzheimer's disease: a review. Dement Geriatr Cogn Disord 35:351–363
4. Calleo J, Stanley M (2008) Anxiety disorders in later life: differentiated diagnosis and treatment strategies. Psychiatr Times 25(8):24–27
5. Fisher GG, Franks MM, Plassman BL, Brown SL, Potter GG, Llewellyn D, Rogers MAM, Langa KM (2011) Caring for individuals with dementia and cognitive impairment, not dementia: findings from the aging, demographics, and memory study. J Am Geriatr Soc 59(3):488–494. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1532-5415.2010.03304.x
6. Giebel CM, Sutcliffe C, Stolt M, Karlsson S, Renom-Guiteras A, Soto M, Verbeek H, Zabalegui A, Challis D (2014) Deterioration of basic activities of daily living and their impact on quality of life across different cognitive stages of dementia: a European study. Int Psychogeriatr 26(8):1283–1293
7. Howe E (Aug 2008) Improving the quality of life in patients with Alzheimer's disease. Psychiatry (Edgmont (Pa. : Township)) 5(8):51–56. http://europepmc.org/articles/PMC2695741
8. Johansson MM, Marcusson J, Wressle E (2015) Cognitive impairment and its consequences in everyday life: experiences of people with mild cognitive impairment or mild dementia and their relatives. Int Psychogeriatr 27(6):949–958
9. Leroi I, McDonald K, Pantula H, Harbishettar V (2012) Cognitive impairment in Parkinson disease: impact on quality of life, disability, and caregiver burden. J Geriatr Psychiatry Neurol 25(4):208–214. https://doi.org/10.1177/0891988712464823, pMID: 23172765
10. Mitchell AJ, Shiri-Feshki M (2008) Temporal trends in the long term risk of progression of mild cognitive impairment: a pooled analysis. J Neurol Neurosurg Psychiatry 79(12):1386–1391. http://jnnp.bmj.com/content/79/12/1386
11. Petersen RC (2004) Mild cognitive impairment as a diagnostic entity. J Intern Med 256(3):183–194. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2796.2004.01388.x
12. Petersen RC, Stevens JC, Ganguli M, Tangalos EG, Cummings JL, DeKosky ST (2001) Practice parameter: early detection of dementia: mild cognitive impairment (an evidence-based review). Neurology 56(9):1133–1142. http://n.neurology.org/content/56/9/1133
13. Petersen R (2002) Mild cognitive impairment: transition from aging to Alzheimer's disease, chap. 14, pp 141–151. Wiley-Blackwell. https://onlinelibrary.wiley.com/doi/abs/10.1002/0470846453.ch14
14. Petersen R, Smith G, Waring S, Ivnik R, Tangalos E, Kokmen E (1999) Mild cognitive impairment: clinical characterization and outcome. Arch Neurol 56(3):303–308
15. Prince M, Wimo A, Guerchet M, Ali GC, Wu YT, Prina M (Aug 2015) World Alzheimer report 2015. The global impact of dementia. An analysis of prevalence, incidence, cost and trends
16. WHO: Dementia: a public health priority. World Health Organization, Geneva, Switzerland (2012)
17. Winblad B, Amouyel P, Andrieu S, Ballard C, Brayne C, Brodaty H, Cedazo-Minguez A, Dubois B, Edvardsson D, Feldman H, Fratiglioni L, Frisoni GB, Gauthier S, Georges J, Graff C, Iqbal K, Jessen F, Johansson G, Jnsson L, Kivipelto M, Knapp M, Mangialasche F, Melis R, Nordberg A, Rikkert MO, Qiu C, Sakmar TP, Scheltens P, Schneider LS, Sperling R, Tjernberg LO, Waldemar G, Wimo A, Zetterberg H (2016) Defeating Alzheimer's disease and other dementias: a priority for european science and society. The Lancet Neurol 15(5):455–532. http://www.sciencedirect.com/science/article/pii/S1474442216000624

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