Biosystems & Biorobotics

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Aims & Scope

Biosystems & Biorobotics publishes the latest research developments in three main areas: 1) understanding biological systems from a bioengineering point of view, i.e. the study of biosystems by exploiting engineering methods and tools to unveil their functioning principles and unrivalled performance; 2) design and development of biologically inspired machines and systems to be used for different purposes and in a variety of application contexts. The series welcomes contributions on novel design approaches, methods and tools as well as case studies on specific bioinspired systems; 3) design and developments of nano-, micro-, macro-devices and systems for biomedical applications, i.e. technologies that can improve modern healthcare and welfare by enabling novel solutions for prevention, diagnosis, surgery, prosthetics, rehabilitation and independent living.

On one side, the series focuses on recent methods and technologies which allow multiscale, multi-physics, high-resolution analysis and modeling of biological systems. A special emphasis on this side is given to the use of mechatronic and robotic systems as a tool for basic research in biology. On the other side, the series authoritatively reports on current theoretical and experimental challenges and developments related to the "biomechatronic" design of novel biorobotic machines. A special emphasis on this side is given to human-machine interaction and interfacing, and also to the ethical and social implications of this emerging research area, as key challenges for the acceptability and sustainability of biorobotics technology.

The main target of the series are engineers interested in biology and medicine, and specifically bioengineers and bioroboticists. Volume published in the series comprise monographs, edited volumes, lecture notes, as well as selected conference proceedings and PhD theses. The series also publishes books purposely devoted to support education in bioengineering, biomedical engineering, biomechatronics and biorobotics at graduate and post-graduate levels.

About the Cover

The cover of the book series Biosystems & Biorobotics features a robotic hand prosthesis. This looks like a natural hand and is ready to be implanted on a human amputee to help them recover their physical capabilities. This picture was chosen to represent a variety of concepts and disciplines: from the understanding of biological systems to biomechatronics, bioinspiration and biomimetics; and from the concept of human-robot and human-machine interaction to the use of robots and, more generally, of engineering techniques for biological research and in healthcare. The picture also points to the social impact of bioengineering research and to its potential for improving human health and the quality of life of all individuals, including those with special needs. The picture was taken during the LIFEHAND experimental trials run at Università Campus Bio-Medico of Rome (Italy) in 2008. The LIFEHAND project tested the ability of an amputee patient to control the Cyberhand, a robotic prosthesis developed at Scuola Superiore Sant'Anna in Pisa (Italy), using the tf-LIFE electrodes developed at the Fraunhofer Institute for Biomedical Engineering (IBMT, Germany), which were implanted in the patient's arm. The implanted tf-LIFE electrodes were shown to enable bidirectional communication (from brain to hand and vice versa) between the brain and the Cyberhand. As a result, the patient was able to control complex movements of the prosthesis, while receiving sensory feedback in the form of direct neurostimulation. For more information please visit http://www.biorobotics.it or contact the Series Editor.

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Preface

Ambient 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 in September 2014 at Catania, Italy during the Fifth Italian Forum on Ambient Assisted Living (ForItAAL), one of the most important annual showcase events for researchers, professionals, developers, policy makers, producers, service providers, carriers and end user organizations working in the different fields of AAL, who want to present and disseminate their results, skills, prototypes, products and services.

This book presents the refereed proceedings of the Forum and reviews the current 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.

Moreover, 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 both our current and future society.

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Part I
Models and Algorithms for AAL

A Quality Model for Service Delivery in AAL and AT Provision

Claudio Bitelli, Lorenzo Desideri and Massimiliano Malavasi

Abstract The effectiveness of services providing assistive technology (AT) and Ambient Assisted Living (AAL) solutions is crucial to the success of any intervention. Centres specialized in AT and AAL are generally part of a complex network of public services and are integrated within the rehabilitation, education and assistance processes aimed at people with disabilities and the elderly which require the involvement of different professionals. The service of providing AT and AAL solutions is therefore a complex process which needs a multidisciplinary approach requiring specific models for the analysis of quality. To date, there is a lack of research in the AAL field targeting quality assessment of AAL interventions. The present paper describes a model for AAL quality assessment and provides preliminary data on its usefulness in practice.

1 Quality in Service Delivery for AAL and AT Solutions Provision: Reference Scenario

In recent years, there has been a growing interest in the concept of the quality of health services (henceforth called QOC, Quality of Care), with the aim of increasing the effectiveness of the interventions, thereby improving the health of the users [20].

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The concept of "quality" in health care can be defined as: "Do only what is useful (effective theory), in the best way (effectiveness), with the lowest cost (efficiency), to those (accessibility), and only to those who really need it (appropriateness), operating care so as to assign it to those who are competent to do so (competence), thereby obtaining the best results considered (satisfaction)" [6].

The effectiveness of services providing assistive technology (AT) and Ambient Asssited Living (AAL) solutions is crucial to the success of any intervention, and this is of fundamental importance to ensure the quality of service to users every step of the way.

Centres specialized in AT and AAL are generally part of a complex network of public services and are integrated within the rehabilitation, education and assistance procedures aimed at people with a disability and the elderly, which require the involvement of different professionals. The service of providing AT and AAL solutions is therefore a complex process that needs a multidisciplinary approach that requires specific models for the analysis of quality.

Currently, such models for measuring the quality of services that supply this kind of solutions do not exist. Services organization for the provision of AT and AAL depends largely on factors specific to each country or region in which they are located, such as health policies, the organization of social services, funding procedures. This makes it difficult to develop general models of quality assessment which can be applied to everyone, with the result that this field of research, in the specific case of AT&AAL, is extremely poor in studies. In the field of research about services for AT&AAL, in fact, there is a lack of studies that correlate the characteristics of the supply process of solutions, on the one hand, and the results (outcomes) of the intervention, on the other [16].

The literature shows that the non-use or abandonment of AT&AAL solutions is extremely high. In Europe and North America it is estimated that about one out of three do not use the aids that are provided [see e.g. [17], and this is due to a failure to meet the user's needs. The reasons for this phenomenon can be traced, among other things, to the failure on the part of the services responsible for the provision of AT&AAL dedicated to monitoring the quality of service offered. This lack is joined to the low use of evidence-based practices applied to each stage of the supply procedure, from the evaluation of the needs of the user characteristics to the evaluation of the outcomes of the intervention.

2 The Proposed Model

On the basis of these considerations, starting from May 2011, the team of the Area Ausili has been developing a framework for assuring the quality of the AT&AAL interventions. The framework we have adopted is based on the Donabedian triadic model [14, 15] for the evaluation of the quality of health care and the quality criteria for service delivery defined by the AAATE Position Paper on AT Service Delivery Systems in Europe [1]. According to the Donabedian model [9–12], information about quality of care is of three distinct kinds: it concerns the *structure*, *process*, or *outcomes* of health care. Details of the resulting conceptual framework are provided below (see also Fig. 1):

- *Structure* [9] refers to "the attributes of the settings in which care occurs", and in the context of AT&AAL service delivery, it includes financing schemes, legislation and health system regulations for obtaining and implementing AT devices and concurrent interventions made by the Local Health Authority (ASL).
- *Process* [9] refers to "what is actually done in giving and receiving care". It refers to the activities performed by AT&AAL professionals in the assessment, selection, implementation, management and follow-up of the solution. The quality of the process is defined in our framework as the degree to which six indicators (accessibility, user-centredness, competence, efficacy, coordination, flexibility) described by the HEART study [7] satisfy target performance criteria (e.g., waiting times for accessing the AT/AAL service or obtaining the solution).
- *Outcomes* [9] refers to the end results of health care practices and the changes that are produced by AT&AAL solutions in the lives of users and in their environments (see also Table 1). In order to account for the complexities of the AT&AAL service delivery and the different agencies involved, we distinguish between three different levels of outcomes assessment: effects produced by the AT&AAL solution (*micro level*); effects produced by the AT&AAL Centre (*meso level*); and effects produced by the AT&AAL service delivery system (*macro level*).

In Table 1, we provide a list of AT&AAL outcome measures which have been incorporated into our model for quality assessment.

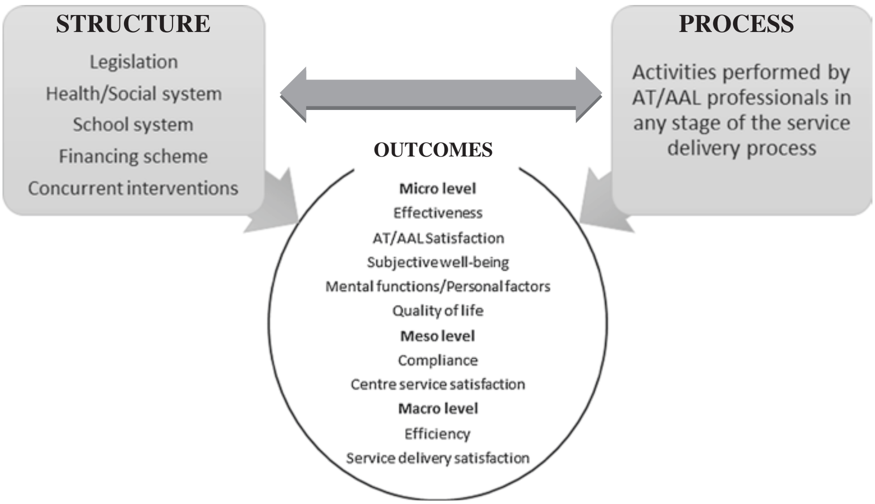

Fig. 1 Framework for AT&AAL service delivery quality assessment

Table 1 Measures and related instruments employed by the three centres of area ausili, for AT&AAL service delivery outcomes assessment

Outcome level	Outcome measure	Instrument
Micro level	Effectiveness of the AT/AAL solution	e.g., Individual prioritized problem assessment [19]; canadian occupational performance measure [5]; goal attainment scaling [18]
	Users' satisfaction with the AT/AAL solution	Quebec user evaluation of satisfaction with assistive technology (QUEST 2.0) [8]
	Impact of AT/AAL on users' quality of life (ICF-based)	Questionnaire developed *ad hoc* by the specific Centre
Meso level	User's satisfaction with the AT/AAL service	CAAD-KWAZO (adapted from [13]) [10]
Macro level	Social costs savings for the healthcare system	SIVA cost analysis Instrument (SCAI) [2–4]

Though not represented in the framework depicted in Fig. 1, demographic, personal and psychosocial factors related to users, their families and other stakeholders may act also as mediating and moderating factors in the measurement of specific AT&AAL service delivery quality assessment categories. For this reason, these variables should always be considered in the interpretation of the quality assessment results.

3 The Experimentation of the Proposed Model: Quality Measurement Activities

In recent years a model for quality measure has been developed within the three centers of the Area Ausili located in Corte Roncati. The choice was to gradually introduce the various tools offered in the three-levels model, in a way based on the characteristics of the center.

The first phase was dedicated to an extensive experimentation of the SCAI instrument for the measurement of the savings in social costs, because these data are considered a priority by local and regional policy makers of the public healthcare system. In this article we will delve into the analysis linked to the second step, which focuses on the quality of service delivery according to Micro and Meso levels of analysis as described in Table 1. The main center for the actual implementation of home adaptation and AAL solutions is CAAD Bologna, whose principle mission is to improve the characteristics of domestic environments in a personalized way, proposing both architectural adaptations and technological solutions. Our experimental analysis of service quality has involved 51 cases followed by the multidisciplinary team from 2008 to 2013. The intended audience suits all the age ranges: 3–17 years old (16 %); 18–79 years old (38 %); over 80 years old (46 %). The tools used in this phase were three:

- QUEST 2.0 (Micro Level) for measuring users' satisfaction with the proposed solutions.
- CAAD-KWAZO (Meso Level) for the evaluation of users' satisfaction with the CAAD services.
- A tool built ad hoc and based on the ICF framework, to assess the impact on quality of life (Micro Level).

Information about QUEST 2.0 and CAAD-KWAZO are provided in the references reported in Table 1. As to the ICF-based questionnaire, it is an instrument developed ad hoc within the CAAD service and consists of three subscales each containing three sentences belonging to ICF domains (Activity and Participation; Environmental factors; Personal factors). Respondents are asked to indicate their level of agreement to each sentence on a 3-point scale (completely; in part; not at all; see Table 4 for the list of sentences). Interviews were conducted by phone.

3.1 Data Analysis

Frequency distributions were used to describe the sample recruited. Item by item analyses were conducted on the QUEST 2.0 and scores were grouped into three categories: "Satisfied" (scores 4 and 5 combined), "Not fully satisfied" (scores 2 and 1 combined) and "In part satisfied" (scare 3). This method is recommended when the evaluator seeks to identify those areas where improvements should be made. Frequency scores distributions for each item of the CAAD-KWAZO and ICF based questionnaire were calculated .

4 Results

4.1 Satisfaction with Service Delivery and the Solution

The results are summarized in Tables 2, 3 and 4. From the questionnaires, overall it emerges a general satisfaction both with the solution provided (see Table 2 "solution") and the services received by users (see Table 2 "service delivery"). The KWAZO scale investigates aspects related to the whole service delivery process. As for the QUEST 2.0, also for the KWAZO the opinions of the users suggest a positive attitude towards all aspects of the process except for the item belonging to the efficiency of the service delivery.

Table 2 QUEST 2.0 scores frequency distributions

Item	% Not satisfied (1–2)	% Partially satisfied (3)	% Fully satisfied (4–5)
Solution			
Dimensions	11,1	11,1	77,8
Weight	50,0	0,0	50,0
Adjustment	14,3	0,0	85,7
Safety	3,1	15,6	81,3
Durability	3,3	3,3	93,3
Ease of use	3,1	9,4	87,5
Comfort	6,3	9,4	84,4
Effectiveness	3,2	0,0	96,8
Service			
Service delivery	9,7	19,4	71,0
Maintenance	6,7	20,0	73,3
Professional services	3,1	3,1	93,8
Follow-up	6,7	20,0	73,3

Table 3 KWAZO scores frequency distributions

Item	% Not satisfied	% In part satisfied	Satisfied (%)
Accessibility	2,0	16,0	82,0
Information	0,0	4,0	96,0
Coordination	0,0	9,8	90,2
Know-how	0,0	5,9	94,1
Efficiency	4,0	28,0	68,0
Participation	0,0	4,0	96,0
Instruction	0,0	2,0	98,0

4.2 Effectiveness of Recommended Solutions

From the results of the ICF-based questionnaire a positive picture of the overall opinions of the users about the effectiveness of the solutions provided emerges and no major issues have been identified (see Table 4). However, since the scale was developed for the purposes of the study and has not been validated, our results should be considered with caution.

Table 4 ICF-based questionnaire scores frequency distributions (each sentence begins with *The solution propose…*)

Item	% Not at all	% In part	% Completely
Activities and Participation			
…allowed you to better perform the activities for which you make a request to our service	3,1	18,8	78,1
…facilitated the relationships within the context of your life	6,3	25,0	68,8
…improved your social participation	14,3	35,7	50,0
Environmental factors			
…decreased your need of assistance	18,8	59,4	21,9
…improved the attitudes of others towards you	3,1	50,0	46,9
… caused problems to others in your life context(s)	59,4	15,6	25,0
Personal factors			
…increased your self-confidence	15,6	40,6	43,8
…increased your desire to face new challenges	25,9	51,9	22,2
…improved your well-being	6,3	6,3	87,5

5 Conclusions

The results have shown that the tools proposed in the model can be used in the daily practice of services dedicated to finding personalized AT&AAL solutions.

The positive results of the quality evaluation lead to positively evaluate the personalized service provided to the users by the multidisciplinary team of the CAAD.

In our model, we propose to use tools for the measurement of outcomes originally developed in the field of AT, in which solutions are often composed of a single device/aid. Since the AAL solutions are frequently an integration of different systems and home adaptations and not a single device, a higher accuracy in the measurement of outcomes will be possible through the development and use of new and validated multidimensional tools, taking into account the greater complexity and several factors related to this type of solution.

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Pedestrian Simulation: Considering Elderlies in the Models and in the Simulation Results

Stefania Bandini, Luca Crociani and Giuseppe Vizzari

Abstract This paper presents improvements to the computational model of MakkSim aimed at allowing the simulation of aged people and persons with mobility impairments. In particular, a method for modelling heterogeneity in speed is discussed and two special objects of the environment (i.e., stairs and seats), have been defined; in addition, a proposal for modelling the presence of a caretaker is described as a particular type of group of pedestrians. Finally, the paper presents a way of computing social costs implied by the environment taking into account the characteristics of pedestrians moving throughout the related facilities. The overall objective is to achieve a system usable for the evaluation of the usability and accessibility of planned environments and facilities by means of simulation, by also taking into account this category of people.

1 Introduction

Urbanization is one of the most significant tendencies of the present times: according to a recent forecast [8] by 2025 the 58 % of the global population will live in cities and urban agglomerates. This trend is even more relevant considering two additional tendencies: (i) the decrease of the fertility rate and (ii) the increase of

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life expectancy. The combination of the latter leads to the well-known phenomenon of the *Ageing Society* [9], which represents one of the main challenges of the more economically developed countries, since the working class will no longer be able to sustain the social and economical costs of aged/not working people. The concept of *Age-Friendly city*, introduced by the World Health Organization [12], describes a framework for the development of cities which encourages the *active ageing* of their citizens, allowing them to maintain an active and productive status in the society, in order to delay the time in which they will become a social cost. This perspective represents a challenging framework for Ambient Assistent Living research, but also technologies improving urban mobility represent important contributions, being significant with respect both to transportation and walkability of facilities.

Computer models for simulating the pedestrian dynamics can help designers performing analyses of the implications of designs, allowing them to populate and simulate environments by configuring the so-called *what-if* scenarios that support their evaluation and improvement. Given the importance of this kind of analysis, several commercial simulators have been recently developed and can be currently found on the market.[1] These tools provide simulation frameworks whereby it is possible to configure sufficiently heterogeneous populations of pedestrians (e.g. with a different walking speed) and, in some cases, even to simulate the presence of groups of people (modelled with an attractive force among members, although this feature is generally not systematically documented and evaluated). However, although some significant results have been achieved, the overall issue of simulating large and heterogeneous crowds of pedestrians still presents open challenges, since the crowd is a complex system and all of these mathematical/computational models can be improved for obtaining more microscopic and realistic simulations.

The work described in this paper is focused on the realization of a computational model specifically tailored to simulate the presence of pedestrians with restricted mobility (elderly people as well as persons with physical impairments), basically characterized by a lower walking speed [11], but with potentially a number of additional requirements for a realistic model definition (they will tend to avoid crowded situations, they will need seats during waiting situations and so on) and the need of a different way to evaluate normal metrics for the evaluation of environments and plans, like travel times. Finally, in fact, the paper presents a proposal for the elaboration of a form of "social costs" which considers the actual usage of the environment by pedestrians. The presence of *not comfortable* elements (e.g. stairs) or situations (e.g. waiting in a queue) in the navigable space, in fact, can increase stress and fatigue of people and especially fragile ones. In addition to this, this kind of facility and the need to employ it can lead to falls that can have significant negative effects for aged people and, therefore, imply health-care costs sustained by the society (in a different way according to local policies) therapies.

The paper will, first of all, introduce the modelling approach to show how it can be applied to simulate the presence of particular categories of pedestrians like

[1]see http://www.evacmod.net/?q=node/5 for a large list of simulation platforms.

elderlies and people with mobility impairments, sometimes moving with an accompanying person. Then, a proposal for a comprehensive way to evaluate social costs implied by the plan of an environment will be introduced and discussed.

2 A Discrete Model with Heterogeneous Speeds

The method described in this paper has been developed on the computational model described in [10]. For reasons of space, we will only explain the general characteristics of the discrete environment, fundamental for the understanding of the proposed method for managing speed heterogeneity.

First **Environment**—MakkSim is discrete both in space and time. The environment is represented as a grid of squared cells with side of 40 cm, respecting the average space occupied by a pedestrian. We adopted a *floor field* approach [6] supporting agents' navigation in the environment. Three kinds of fields are defined: (i) the *path field* indicates for every cell the distance from one destination area, driving pedestrians towards it (static); (ii) the *obstacles fields* describes for every cell the distance from neighbour obstacles or walls (static); (iii) the *density field* indicates for each cell the local pedestrian density at the current time-step (dynamic).

Agents—The life-cycle of a MakkSim agent is divided into four steps: *perception, utility calculation, action choice* and *movement*. The *perception* provides to the agent all the information needed to evaluate the desirability of a cell. The choice of each action is based on an utility value assigned to every possible movement according to the following function:

$$U(c) = \frac{\kappa_g G(c) + \kappa_{ob} Ob(c) + \kappa_s S(c) + \kappa_c C(c) + \kappa_i I(c) + \kappa_d D(c) + \kappa_{ov} Ov(c)}{d}$$

The first three components employ information derived by floor fields and they consider (i) goal attraction, (ii) geometric and (iii) social repulsion. The fourth and fifth components model the social attraction element of the pedestrian behaviour, by increasing the utility of positions closer to group members. We consider two types of group: *simple* (iv), that indicates any small group characterised by a strong and simply recognisable cohesion (e.g. family or friends); *structured* (v), a larger group, that shows a slight cohesion but that is naturally split into subgroups (e.g. tourists). Finally, two special factors consider two additional phenomenologies: (vi) helps an agent to maintain the current direction, while (vii) allows to move to a cell already occupied by one pedestrian in high density conditions. An adaptive mechanism is also defined to tune the parameters of this utility function, in order to preserve the cohesion of simple groups even in high density situations. After the utility evaluation for all the cells in the neighbourhood, the choice of action is stochastic, with the probability to move in each cell c as (N is the normalisation factor): $P(c) = N \cdot e^{U(c)}$. On the basis of $P(c)$, agents chooses a cell according to their set of possible actions, defined as list of the eight possible movements in the Moore neighbourhood. Finally, update of agents intentions and positions at each step are managed with the parallel update strategy, with rules for conflict management based on the notion of friction [4].

In the literature, discrete models generally assume only one speed profile for all the population and this is considered a strong limitation of this approach; efforts towards the modelling of different speed profiles consider two main approaches: (i) *increasing agents movement capabilities* [3] (i.e. they can move more than 1 cell per time step), according to their *desired speed*; in this way, given k the side of cells and n the maximum number of movements per step, it is possible to obtain n different speed profiles, less or equal to $n \cdot k$ m/step; (ii) modifying the current time scale, making it possible to cover the same distance in less time and achieving thus a higher maximum speed profile but at the same time allowing each pedestrian to *yield their turn in a stochastic way* according to an individual parameter, achieving thus a potentially lower speed profile.

The method supporting movements of more than a single cell can be effective, but it leads to complications and increased computational costs for the managing of micro-interactions and conflicts: in addition to already existing possible conflicts on the destination of two (or more) pedestrian movements, even potentially illegal crossing paths must be considered, effectively requiring the modelling of sub-turns. In addition, the expressiveness of this method is still limited: the maximum number of movements allowed per time step determines the number of speed profiles reproducible with simulations (e.g., with $v_{max} = 4$ cell per step and a turn duration of 1 s, simulations can be configured with 0.4, 0.8, 1.2 and 1.6 m/sec).

For these reasons, we decided to retain a maximum velocity of one cell per turn, allowing the model to reproduce lower speed profiles by introducing a stochastic yielding mechanism. The baseline computational model has been modified in several parts. Each agent is also characterised by a new parameter $Speed_d$ in its *State*, describing its desired speed. For the overall scenario, a parameter $Speed_m$ is introduced for indicating the maximum speed allowed during the simulation (described by the assumed time scale). In order to obtain the desired speed of each pedestrian during the simulation, the agent life-cycle is then *activated* according to the probability to move at a given step $\rho = \frac{Speed_d}{Speed_m}$. By using this method, the speed profile of each pedestrian is modelled in a fully stochastic way and, given a sufficiently high number of step, their effective speed will be equal to the wanted one. But it must be noted that in several cases speed has to be rendered in a relatively small time and space window (think about speed decreasing on a relatively short section of *stairs*).

In order to overcome this issue, we decided to consider ρ as an indicator to be used to decide if an agent can move according to an *extraction without replacement* principle. For instance, given $Speed_d = 1.0\,\text{m/s}$ of an arbitrary agent and $Speed_m = 1.6\,\text{m/s}$, ρ is associated to the fraction 5/8, that can be interpreted as an **urn model** with 5 *move* and 3 *do not move* events. At each step, the agent extracts once event from its urn and, depending on the result, it moves or stands still. The extraction is initialised anew when all the events are extracted. The mechanism can be formalised as follows: (i) let $Frac(r) : \mathbb{R} \rightarrow \mathbb{N}^2$ be a function computing the minimal pair $(i,j) : \frac{i}{j} = r$; (ii) let *Random* be a pseudo-random number generator in [0,1]; (iii) given ρ the probability to activate the life-cycle of an arbitrary agent, according to its own desired speed and the maximum speed configured for the simulation scenario. Given (α, β) be the result of $Frac(\rho)$, the update procedure for each agent is described by the pseudo-code of Algorithm 1. The method *updatePosition*() describes the attempt of movement by the agent: in case of failure (because of a conflict), the urn is not updated.

This basic mechanism allows synchronisation between the effective speed of an agent and its desired one every τ steps, which in the worst case (informally when $\frac{Speed_d}{Speed_m}$ cannot be reduced) is equal to $Speed_m \cdot 10^{\iota}$ step, where ι is associated to the maximum number of decimal positions considering $Speed_d$ and $Speed_m$. For instance, if the desired speed is fixed at 1.3 m/s and the maximum one at 2.0 m/s, the resulting $Frac(\rho) = \frac{13}{20}$, therefore the agent average velocity will match its desired speed every 20 steps.

Algorithm 1 Life-cycle update with heterogeneous speed

```
if Random() ≤ α/β then
    if updatePosition() == true then
        α ← α − 1
    else
        β ← β + 1
    end if
end if
β ← β − 1
if β == 0 then
    (α,β) = Frac(ρ)
end if
```

As discussed in [5, 7], an effect of the discretisation of the environment is the fact that diagonal movements generate a higher movement speed. In order to face this issue, this mechanism can be improved by considering these movements as a different kind of event during the extraction. With this strategy, each diagonal movement carried out by an agent decreases its probability to move in the next steps according to the ratio $\Delta = \frac{0.4 * \sqrt{2} - 0.4}{Speed_d * timeScale}$, where $timeScale = 0.4/Speed_m$ (considering the adopted scale of spatial discretisation). This fraction represents the relationship between the additional covered space, due to the diagonal movement, and the desired speed of the agent expressed in step. In this way Δ represents the exact number of steps the agent will have to stand still to achieve a synchronisation of desired and actual speed. In order to discount diagonal movements, therefore, we introduced in the agents' state a parameter *diagPenalty*, initially set to 0, which is increased by Δ each diagonal movement. Whenever $diagPenalty \geq 1$, the probability to move is decreased by adding in the urn of extraction one *do not move* event or, in reference to Algorithm 1, by increasing of 1 unit the parameter β after *updatePosition*() invocation, decreasing *diagPenalty* by 1.

This method is now consistent for reproducing different speeds for pedestrians in a discrete environment also considering the Moore neighbourhood structure. It must be noted, however, that if it is necessary to simulate very particular velocities (consider for instance a finer grained instantiation of a population characterised by a normal distribution of speed profiles), $Frac(\rho)$ is such that a large number of turns is needed to empty the urn, that is, to achieve an average speed equal to the desired one. This means that locally in time the actual speed of a pedestrian could differ in a relatively significant way from this value. To avoid this effect, during the life of each agent the fraction describing the probability is updated at each step and in several cases it will reach unreduced forms, with $GCD(\alpha, \beta) > 1$. These situations can be exploited by splitting the urn into simpler sub-urns according to the *GCD* value. For example, given a case with $Frac(\rho) = \frac{5}{11}$, after one movement the urn will be associated to $\frac{4}{10}$; since $GCD(4, 10) = 2$ the urn can be split into 2 sub-urns containing 2 *move* and 3 *do not move* events that will be consumed before restarting from initial urn. The effect of this subdivision is to preserve a stochastic decision on the actual movement of the pedestrian but to avoid excessive local diversions from the desired speed. Improvements obtained with this method (from here called *sub-urn* method) are discussed in the next section.

2.1 Special Objects of the Environment

In order to evaluate the accessibility and usability of an arbitrary environment by means of simulations, the computational model must be enriched also in the *Environment* component, with special objects which act on the overall perceived comfort. Obviously, until now it is only possible to make assumption since there are no consistent empirical data about this issue, but it is possible to retain that element like stairs are inconvenient and they increase the social costs, while other elements such as the presence of seats can reduce them in areas where it is necessary to wait.

Firstly, the **stairs** have been considered for this purpose, whose presence in the environment has been modelled by means of an additional type of spatial marker (*Stairs*). In particular, in order to recognize and differentiate the direction of movement (i.e., if agents are going upstairs or downstairs), the extremes of the marker on the top and bottom sides are signed in a special way, as shown in Fig. 1a.

According to empirical data from the literature [1], the agents inside the *Stairs* marker fix their desired speed to 0.5 (0.4 for elderly people) m/sec, if they are going up, or to 0.7 (0.6 for elderly people) m/sec if they are going downstairs, until they reach the end of it.

For modelling the usage of the **handrail** by elderly persons, we used the *obstacles field* in the reverse way inside the marker, in order to get this kind of agents attracted towards the walls surrounding the stairs. Therefore, agents of type "elderly" are changing the sign of their κ_{ob} during the usage of stairs. Effects are qualitatively displayed in Fig. 1b.

The second special object that has been considered with this work are the **seats**, whose introduction described more additional elements for the model: stairs can be placed in the environment by means of another spatial marker (*Seats*) and, in order to design its possible perception by nearby agents, another *dynamical* floor

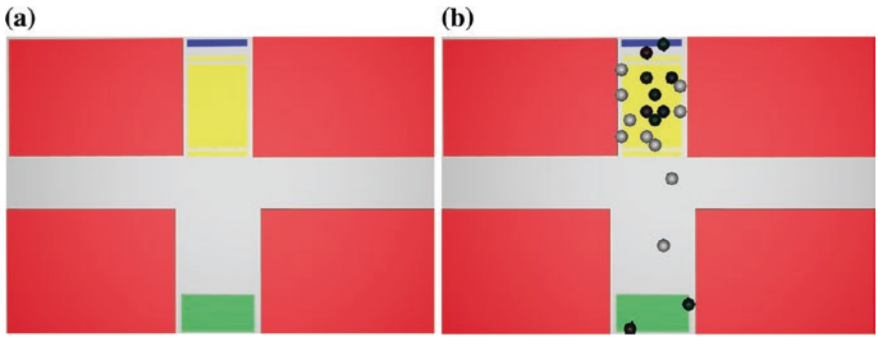

Fig. 1 A scenario with a marker of type *Stairs* (**a**) and its effects on the behaviour of agents (**b**): the white ones, representing aged people, are attracted also by the walls, for simulating the use of handrails

Fig. 2 Two groups formed by an aged person and a caretaker. Their walking path will be practically the same

field has to be introduced. This field is quite similar to the *density field*, with differences residing in values update: their values are spread within a fixed radius of distance from each *Seats* cell, which defines exactly one seat, but only when this ones are free. If an agent temporary occupies one of them, the others must not be able to perceive it.

2.2 Presence of a Caretaker

Another relevant aspect which can characterize a person with moving disabilities can be the presence of an accompanying person, which drives him/her through the environment. This situation clearly describes a group of type *simple*, but also a special case of it, since they will walk strictly together (see Fig. 2), like they were a single entity.

In order to model this phenomenon, a first proposal meant to use the adaptation mechanism of the behaviour of group members regarding their dispersion in a very strict way for this special kind of group. Results of this tests have shown that this method is not suitable for a good simulation of the interested phenomenon: since the probability to have a distance greater to one cell cannot be set to 0 with this mechanism, an high cohesion of the simulated group has been achieved in this way, but in several situations the simulated couple has fragmented itself anyway, even if in a very limited way (around 1 meter of distance).

Since the walking path of the two persons in analysis will be practically the same, because the aged person in this situation cannot walk by him/herself, an alternative and more effective method can be to abstract this situation by representing the couple with a single, special, agent whose shape occupies 2 cells. Naturally, this modelling assumption leads to complications in the computational model, since new rules for managing its behaviour and its interactions with other entities.

3 A Proposal for Social Costs Analysis

The model features presented so far represent a viable approach for the simulation of the behaviour of aged people, whose presence in our society is becoming more and more important. The basic simulation outputs can already give information to decision makers about what is the *perceived comfort* of the planned environment: *space utilisation* and *cumulative mean density* maps are well suited for identifying critical zones of the scenario, while statistics about average travelling times and flows are able to describe their impact in its overall security, by also granting an estimation of the evacuation times.

Notwithstanding, the definition of additional outputs in the simulator (e.g. length of stair travelled, waiting times in queues) can be useful for understanding the *usability* of the environment from the perspective of its “users”. These additional indicators must actually be considered in a different way for young, healthy adults and elderlies or persons with restricted mobility or other disabilities. The definition of parameters for estimating probabilities of injuries on one hand, like falls or faints due to stress and excessive fatigue, and for obtaining an indicator of the overall perceived comfort of the environment on the other, can be exploited for the calculation of these *social costs*. By analysing these costs, users and decision makers will be able to act on the planned environment in order to find solutions which can lead to either less expenses, more benefits, or both. For giving an example, the application of heating systems for the snow removal in side-walks is able to maintain the street clean and to allow persons, especially aged ones, to easily use them. In this way, possible falls are prevented, directly decreasing social expenses (for public healthcare system or for families); in addition, the accessibility of the city areas is improved, allowing aged people to normally move themselves inside the city and to maintain an active status, which implies benefits also for the local economy (in addition to being a useful action in the direction of an implementation of active ageing policies, which in turn also aim at reducing social costs in the long run).

A general indicator should describe these average expenses paid by the society for the treatment of injuries happened inside pedestrian facilities, or to pedestrian in general, but also the implications of uncomfortable and non-accessible environments on the reduced activities of elderlies, which might be deciding not to go to certain places to carry out their tasks because of perceived unpleasant conditions in the environment. Two elements are composing the indicator, both dependent from the overall comfortability of the space: bad settings or situations leads to accidents, directly causing social expenses, while perceived discomfort during the navigation of the setting can lead fragile types of people to avoid its usage. The idea is to calculate them with a two steps method, firstly calculating the different social costs and then grouping them for obtaining an overall index of the space comfort, which can be used for estimating the lack of incomes due to a reduction of potential customers of the space. Regarding the first step, that is, *social cost estimation*, we must consider that accidents can naturally occur with different probabilities regarding different situations (walking in stairs, walking outside, etc.), different configurations (e.g. temperature) and different types of pedestrian (i.e., younger ones will have a lower probability). Provided that statistics about these accidents were available, the overall cost can be estimated by means of microscopic simulation with our model.

Formally, the method for the social costs analysis must consider the expenses for each type of agent and single situation/activity performed in the scenario navigation. This concept can be described as the following:

$$SocialCosts = \sum_{a \in \overline{P}} \sum_{C_i \in \overline{S}} C_i(a), \quad \overline{S} = \{C_0, \cdots, C_n\}$$

with $\overline{S}$ the set of all situations considered for the social costs calculation. Each of these ones are described by an additional function able to quantify the single element $C_i(a) = \tau_{a,i} \cdot AvgCost_{a,i}$ where $\tau_{a,i}$ describes the quantity, in the respective measurement unit, of the condition i (e.g. time passed in the queue) in the simulation for the agent a. $AvgCost_{a,i}$ represents the average cost estimation[2] generated per each unit and for the category the agent a belongs to.

By means of this function, each pedestrian travel can be evaluated regarding elementary situations given by interesting components of the environment: stairs, elements which usually generate queues (e.g. ticket machines), parts of the floor which are usually wet and so on. In particular, for evaluating parts of the environment $\tau_{a,i}$ will represent the covered space, while for situations like queues the measurement unit will be the time. On the other hand, complex situations can

[2]It must refer to statistics about the average number of accidents, with respect to the measurement unit of $\tau_{a,i}$ and their average cost.

be evaluated by splitting them into simpler ones, until they reach an elementary level: for instance, waiting areas where the presence of a sufficient number of seats can be significant, it is necessary to divide the costs evaluation regarding the time passed stood up and seated down. In addition, an extension of the analysis to crowded zones in the scenario can be very important, since they are uncomfortable and can also cause faints, especially to elderly people. A thorough costs analysis has to consider the time passed in them, weighted by means of average local density in that part of the environment.

4 Conclusions and Future Works

This paper has introduced a simulation model considering aged people as well as persons with mobility impairments. The overall objective is to make the system usable for evaluating planned environment by taking them into consideration, in order to understand also their fatigue assumed through the navigation of the environment, knowing if something could be done to make it more *age-friendly*. In addition, a method for the estimation of *social costs* has been proposed. This kind of analysis allows to understand the entity of the costs for the healthcare of accidents like falls or faints which can be generated by the configuration the environment, as well as lack of incomes derived by people who are not using environment for excessive discomfort. On the other hand, a precise and feasible estimation of social costs can be done only once having enough statistical data about accidents and perceived discomfort in the environmental setting, therefore additional studies must be performed in this direction. This line of work must also try to integrate existing approaches and results of the so called *walkability* analysis of the built environment [2].

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User-Oriented Services Based on Sensor Data

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Abstract This paper explores the issue of creating end-to-end services for older adults and their caregivers starting from a continuous gathering of sensor data from their living environment. The described work is part of the GiraffPlus project in which an intelligent AAL environment has been developed. The whole system

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relies on a state-of-the-art middleware for sensor data gathering and the pursued perspective is the one of designing added value services based on such data. The paper presents the general project concept and its different ingredients then presents two different services: a reasoner for person tracking, and an interaction service that connects the human network involved in a given application environment.

1 Introduction

In recent years there is an increasing attention on the topic of "prolonging independent living". Several initiatives all over the world have focused on the problem of helping aging population with technology [3, 7, 12] and funding programs have been triggered like the Ambient Assisted Living (AAL), promoted by the European Commission together with the topic "ageing well" within the FP7 research area. Such an attention for the problem has been increased in the starting Horizon 2020 program. The general aim is the one of promoting a healthier society that constitutes a main social and economic challenge. In fact, most elderly people aim at remaining in their homes as long as possible as this is in general conducive of a richer social life and paramount to maintaining established habits. To adhere to this wish is also positive from an economic perspective as the cost of care at home is almost always much less than the cost of residential care. Several issues need to be addressed in order to prolong independent living. One is the early detection of possible deterioration of health so that problems can be remediated as soon as they are arising with a timely involvement of health care providers and family [9]. A second issue consists in providing adaptive support to assist in coping with age-related impairments [2, 4, 11]. Third, ways of supporting preventive medicine must be found as it has been increasingly recognized that preventive medicine can contribute to promote a healthy lifestyle and delay the onset of age-related illnesses.

Observing the current efforts in the AAL projects, and the trends in the "internet of things" [1, 10], an amount of R&D effort exists in issues like the gathering of continuous information at home, the standardization of formats in order to create environments more easily, the extraction of further information from raw data using different techniques to reconstruct context, etc. This paper aims at contributing a particular perspective to the general debate by posing the attention toward the work needed to bring an intelligent environment in continuous use in a real home. It points the attention to the need to an end-to-end perspective in organizing an intelligent environment, keeping into account the services offered to the users of such systems in which the key services are organized and tested. Following this vision, this paper introduces the general ideas of the intelligent environment pursued by the GiraffPlus project, points out its components and services then describes the core choices for the basic level and the work done for achieving more challenging capabilities at the "enhanced level". The GiraffPlus system has been developed also thanks to an incremental test of the complete system in laboratory, in a pilot site and currently in a complete deployment in 15 real homes in three different European Countries (Italy, Spain and Sweden).

2 The GiraffPlus System Functionalities

Figure 1 offers a conceptual schematization of the GiraffPlus components of the system and allows to identify some key concepts relevant in the project work and useful to contextualize the current paper.

Given the attention to human actors that use the intelligent environment we first identify the different users of the system services: (a) the *primary user* is the older adult living at home, mostly alone, that the system is supposed to actively support; (b) the *secondary users* are a network of people who participate in the support of the older adult from outside his/her home. Such users can be formal caregivers (a doctor, the nurse, etc.), informal caregivers (a son, a group of generic relatives, etc.) or simply friends that want to maintain a contact with the old person.

The GiraffPlus system is basically composed of four parts: (1) a network of sensors deployed in the home that continuously gathers data; (2) a data management infrastructure that guarantees either data gathering in a permanent data store or direct information delivery to some external user in real time. A central role in the infrastructure is played by the middleware software; (3) a telepresence robot (the Giraff) that guarantees communication between people outside the house and the primary user inside the house, enriching such dialogue with the possibility of moving in the home environment and performing visual monitoring through a camera connected to the robot [5]; (4) a personalizable interaction front-end that allows to visualize data from the house, to call the robot from outside the house, and to access some specialized services, like those of reporting and reminding.

A first result has been presented in [6] where the choices for the middleware and the data store have been demonstrated as the key building block for the initial version of the GiraffPlus intelligent environment and AAL services. Then, given these ingredients, a key aspect for creating a useful tool for real people are the

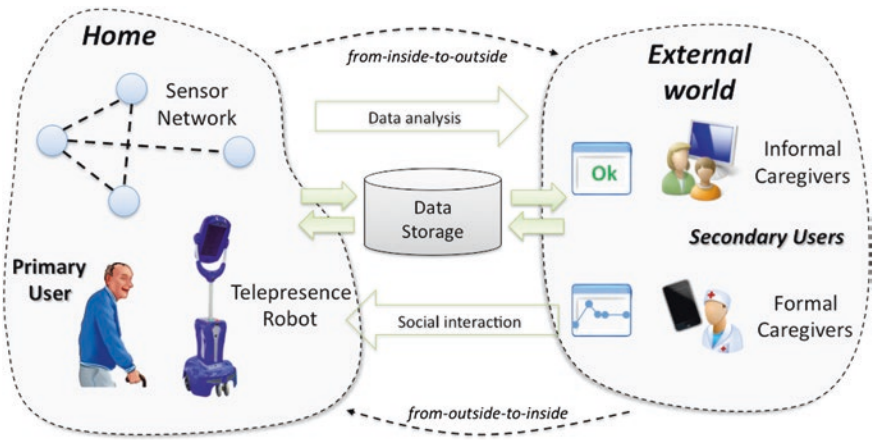

Fig. 1 The general information flow inside the GiraffPlus system

services that the complete system can deliver to the different users. Looking again at the figure it is worth highlighting that there are two different action paths: from inside the house to outside, and viceversa. If we consider the *from-inside-to-outside* path we can say that we are: (a) exporting data for a long term data analysis (storing them first in a data storage service). Notice that the secondary users usually are heterogeneous people having different "social goals" toward the old person, hence a doctor may be interested in physiological data and general information on the daily activities connected to health, an informal caregiver may be interested in a daily summary that says "everything is OK", "the windows were left open", etc. (b) exporting data for a real time use (hence, for example, for issuing alarms). In fact, the system can rise alarms and/or send warnings, for instance, in case of falls or in case of abnormal physiological parameters. Here a problem exists of delivering them timely and to the right person. On the other hand, if we explore the *from-outside-to-inside* path we can say that: (c) the communication through the telepresence robot is the basic media for social communication from outside into the house; additionally (d) having such a general set up, the system offers now a channel from the secondary to the primary user for messages and reminders created through the visualisation front-end and delivered on the robot screen (also other media are possible but here we are focusing on the basic GiraffPlus components). This information exchange is stored by the data storage service for subsequent analysis.

In addition, it is worth underscoring how there are also other services that are possible given the infrastructure in Fig. 1: (e) long term data from the home sensor network are available in the data storage and can be also shown, with some attention, to the primary user; (f) having the home sensor network and a communication media in the home through the robot screen opens up the possibility of reasoning on those data and synthesize different messages (for the moment we assume precompiled messages) triggered by such a reasoning (for example, to react to some information contained in the data).

3 Managing Sensor Data to Synthesize Additional Information

In order to satisfy the requirements of easy installation and acceptance of the system, in GiraffPlus commercially available sensors are used to guarantee a good appearance and form factor, battery-powered, and durability for the long-term monitoring. The environmental sensors used in the GiraffPlus system are provided by Tunstall.[1] FAST Passive Infrared (PIR) motion detectors, Electrical Usage Sensor, and Universal sensor that can be configured according to different needs (Door Usage, Bed/Chair Occupancy) have been used.

[1] http://www.tunstall.co.uk/.

This section shows how the information coming from such kind of sensors deployed in the environment can be processed in order to infer more meaningful input for context analysis. An important information about the user context is its localization in terms of the room in which the user is. Hence a first service introduced here is a simple reasoner for continuous person tracking.

The fundamental studies of target tracking often focus on networks composed of sensor nodes with the most elementary sensing capabilities that provide just binary information about the target, indicating whether it is present or absent in the sensing range of a node [8]. These so-called binary sensor networks constitute the simplest type of sensor networks that can be used for target tracking. Each sensor has the ability of indicating the presence of a user in a room. For instance, when a magnetic sensor puts on the door indicates that the door has changed its status (open/closed), this means that the user is near to the sensor itself. However, each sensor has different features that must be individually treated in order to infer the user's position.

Each sensor, when is individually leveraged, does not give a lot of information. However, these sensors have different properties which, when exploited together, can reveal a surprising amount of information. Thus, in order to detect the position of the user in the house, each signal provided by the sensor has been first filtered and later processed together with the other signals by the proposed algorithm. In particular, signals coming from the magnetic contacts and from the electrical usage sensors have been processed in order to obtain information on when they change their status i.e., when the users is in front of them. Moreover, the spikes produced by the electrical usage sensor of the personal computer has been filtered by using the median filter. The median filter is a nonlinear digital filtering technique, typically used in image processing in order to reduce the noise. In order to eliminate spikes, the median filter slides the entire signal, entry by entry, replacing each entry with the median of the sample in the time window T.

After the filtering process, the samples coming from the binary sensor network deployed in the environment are processed by the "where is" (WHIZ) algorithm (Algorithm 1).

Algorithm 1 The WHIZ room-level localization technique

$T \leftarrow$ time window [s]
$W \leftarrow$ weights $e_i, w_i = length(e_i)$ for each sensor
$R \leftarrow []$
for $i \leftarrow 0$ **to** T **do**
  $\bar{S}_{t-i} \leftarrow S \times W$
  $R_{t-i} \leftarrow room(\bar{S}_{t-i})$
  $R \leftarrow [R, R_{t-i}]$
end for
$R \leftarrow sort(R)$
$idxs \leftarrow find(diff([R, realmax]) > 0)$
$[length, i] \leftarrow max(diff([0; idxs]))$
$r^* \leftarrow R(indices(i))$
return r^*

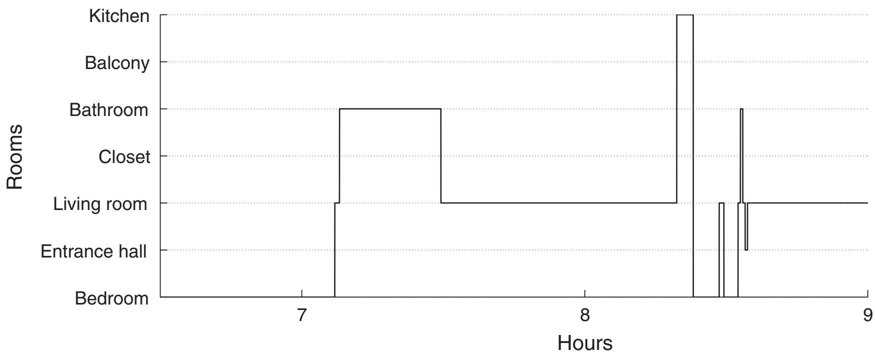

Fig. 2 The results of the WHIZ room-level localization technique

For each second t in the time window T, WHIZ collects the data coming from each of the N sensors deployed in the environment $s_i, \forall i \subseteq \{1, 2, \cdots, N\}$, then the number of occurence of s_i is weighted with the parameter w_i according to Eq. 1 obtaining the vector $\bar{S}$. Indeed, the algorithm weights more the information coming from sensors that directly provide the user's position (such as the force/pressure sensors).

$$\bar{S} = [s_1 \quad s_2 \cdots s_N] \times \begin{bmatrix} \mathbf{e_1} & 0 & \cdots & 0 \\ 0 & \mathbf{e_2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & e_N \end{bmatrix} \tag{1}$$

where e_i is a ones array of length w_i. Latter, $\bar{S}$ is translated into R, where each r_j represents one of the M room in which the sensor is deployed ($r_j \forall j \subseteq \{1, 2, \cdots, M\}$). Finally, the WHIZ algorithm evaluates the mode (the most frequent value in the data set) of the vector resulting from the concatenation of the T vectors $R_{t-i} = [r_{\mathbf{1}}^{t-i}, r_2^{t-i}, \cdots, r_{\mathrm{M}}^{t-i}]$, where $i = 1, \cdots, T$. The main idea of using the mode is due to the fact that the presence of a user in a given room will affect a greater number of sensors in that room. Therefore we obtain the room occupied by the user r^* applying Eq. 2.

$$r^* = mode(R_t, R_{t-1}, \cdots, R_{t-W}) \tag{2}$$

Figure 2 shows the results of the WHIZ algorithm applied on a subset of data coming from one of the GiraffPlus testsites.

4 User Interaction Services

After having obtained reliable data it is important to endow the system with an effective capability to transform data in services for users. In GiraffPlus we have designed and realised a set of interactive services that aims at going beyond simple visualization capabilities of the raw data. A specific module called the Data Visualization, Personalization and Interaction Service (DVPIS) has been realized to manage interaction with the different actors involved in the AAL scenario. In particular, two different instances of the DVPIS have been created: one devoted to serve secondary users (DVPIS@Office), and another dedicated to the primary users (DVPIS@Home). The basic goals pursued by the two GiraffPlus parts are tailored to the diversity of users: secondary users need to be supported by a flexible and efficient monitoring tool; primary users may take advantage from being aware of the information on their own health condition to foster them better manage their health and lifestyle, but also would benefit from an enriched set of communication features from their assistive social network.

Figure 3 illustrates the general idea of the DVPIS. The module is composed of a **back end** part that is devoted to both organize the content of the information to be shown to the users and also to offer different services tailored to classes of users. The DVPIS back end is responsible for preparing "personalized information to the users" and to offer support for different types of services like *reminders*, *reports* and *alarms* (and also the *proactive suggestions* and *warnings*). The **front end** part is responsible for presenting the information and services to the different categories of users. The project has developed two modules: (1) the @Office devoted to the secondary users and currently runs on their personal computer ("their office workstation") and (2) the @Home dedicated to the primary users that runs as an additional service on the Giraff robot.

In the rest of this section we introduce some of the relevant features that have been included in the more recent release of the DVPIS services.

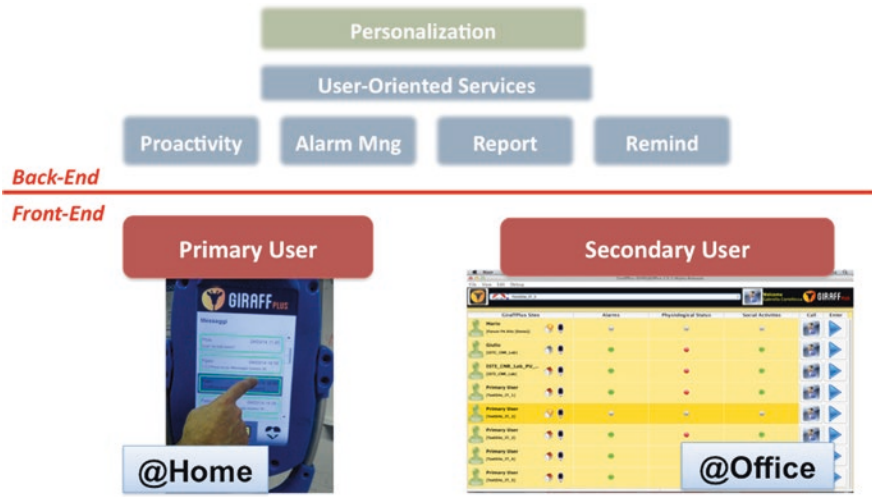

Fig. 3 The data visualization and personalization services

4.1 The @Office Environment

Figure 4 shows a composition of screens from the @Office service. Specifically, the module is adapted to different type of end-users, hence medical doctors may access different GiraffPlus houses that they while a parent may access exclusively his/her relative. The @Office environment for the single home is subdivided in three sub environments (accessible by the three buttons highlighted with label (1) in the figure): (a) an environment (button "Long Term") contains different services that interacting with the data storage of GiraffPlus allow to inspecting long term data on all the sensors active in the home; (b) a second environment (button "Real Time") enable a visualisation of current data from the house; (c) a third, button called "People", creates a communication service for all the people involved in the assistance with the house.

The **Long Term** environment for visualisation (not shown in the figure) allows to access several information. A main distinction concerns the one between *environmental* data (from the sensors distributed in the house) and *physiological* data (from a set of tools that allows to measure physical parameters (e.g., blood pressure, glucose level, weight). The interested user can also access a specific environment, called "Context Reasoner", that creates abstractions with respect to raw data in the attempt to infer additional context features by checking combination of raw sensor values over time (such capability is developed by our Swedish colleagues [13]). Furthermore we created a "Report Capability" that through a dialogue window allows for the generation of aggregated statistics over period of times,

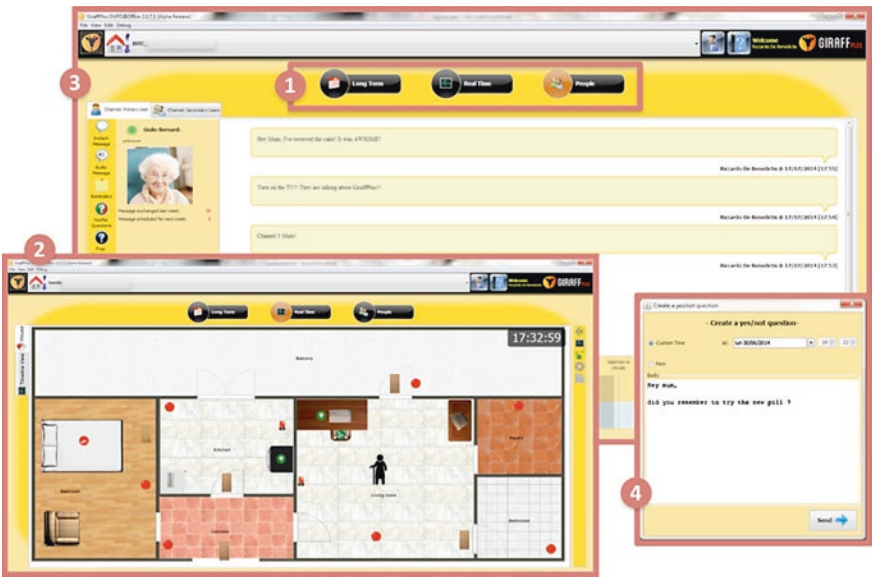

Fig. 4 Some screenshots of the @Office environment

offering again a more abstract representation of the average activities in the house. The combination of the different capabilities is aims at giving the user a view of the person at home over time.

A screenshot of the **Real Time** environment accessible through the button with the same name is shown in Fig. 4 identified with number (2). This service is dedicated to give an immediate feeling of what is going on in a monitored house in the specific moment a user is accessing @Office. For this service we have developed a representation based on a map (screen (2) in the figure) using colour to distinguish sensors that are not active (red) from those that are active (green). Additionally using color blinking for few seconds we highlight the current change of state. Furthermore, a small puppet graphically represents the position of the old person according to the tracking algorithm introduced in Sect. 3.

The third environment, the **People**, offers a different type of service, namely to facilitate communication among the *network of people* related to a primary user. Specifically, this environment represents a dialogue space to allow the social networking of people who assist the same primary user. The environment allows the different actors, involved in the care of a primary users, to exchange information and opinions so as to maximize the overall care for the old person at home. The People functionality essentially customise the concept of social network to the case of the assistance. Specifically the environment puts available a message board for leaving communication to other secondary users, allowing to send messages to specific secondary user (peer to peer modality). A different functionality set a peer to peer communication channel from secondary user to the primary. It is possible to send messages and/or set reminders to the primary users at home that will be delivered through the Giraff telepresence robot. This functionality is connected to the @Home service (next section). Figure 4 (3) and (4) shows two aspects of this environment: in particular (3) shows a message board while (4) shows a dialogue box to set a message with a question for the primary user.

4.2 The @Home Environment

We decided to use the telepresence robot as a means to provide further services to the primary users in the attempt of studying the enlargement of its use with respect to the telepresence. This part of our work is also in line with what emerged from the feedback gathered during the iterative evaluation session sperfored within the project.

Figure 5 shows the main services provided to primary users through the @ Home:

- *Avatar*: this functionality preserves the “traditional telepresence” service that the Giraff robot provides. The Giraff application has been indeed embedded within the @Home module so as to maintain the possibility for secondary users to visit the older user’s apartment through the telepresence robot.

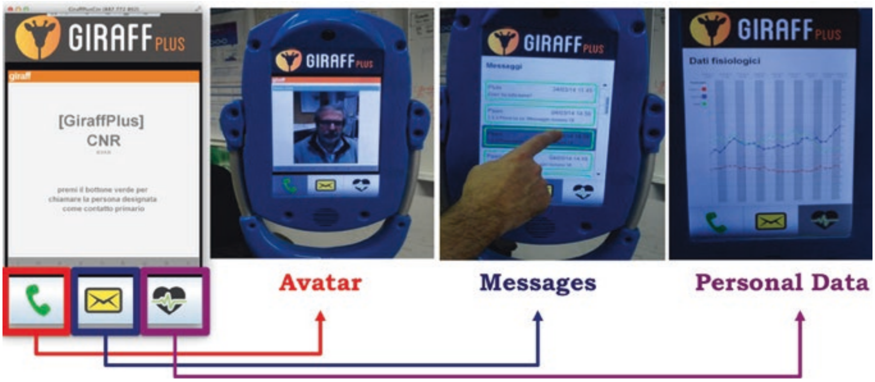

Fig. 5 A representation of the @Home environment

- *Messages*: an additional environment has been added to allow the primary user to receive messages from secondary users or reminders and recommendations. Messages and reminders are provided in both textual and spoken form. Specifically we have developed a message listener that collects messages coming from the middleware and gathered them with a specific panel that "mimic" the functionality of a mail client or a messenger on a smartphone. In addition to adapting the font size to the user we have decided to integrate an off-the-shelf text-to-speech translator to give the user the possibility of "reading aloud" the messages and re-reading them again and again (most older adult have sight problems).
- *Personal Data*: this environment is intended to allow primary users to visualize personal data (e.g., physiological measures) and, more in general, to endow the system with a shared space between the primary user and the secondary users that could foster a discussion on the health status and habits of the old person. The general aim is to improve his/her awareness and also to encourage responsible behaviors for increasing his/her well being. The idea is that a secondary user (e.g., an Health Professional) calls a primary user via the Giraff robot and then uses this environment to discuss about the health related data to both explain them to the assisted person and possibly deepen the understanding of them through questions to the old person.

It is worth emphasizing that this module has been produced according to the user requirements elicitation and a first run of evaluation in real homes. We are running now a quite intensive evaluation, both within the test sites and with ad hoc evaluation sessions in the lab, in order to better validate the current achievements and to receive feedback for further improvements before the end of the project.

5 Conclusion

This paper describes features of the GiraffPlus project according to the particular perspective that led the project to deliver its intelligent environment in 15 different homes (equally distributed among Italy, Spain and Sweden). We have now 6 homes running since 12 Months and additional 9 homes running since 5 months. To achieve a robust continuous delivery in real homes a stratified effort was required, first guaranteeing a basic cycle that gathers data and distributes them to data storage and end users, then building better and reliable user-oriented services to better serve diversified users of such data intensive technological solution.

The advantages coming from the use of the GiraffPlus system have been analyzed focusing on the possibility given by the system to collect elderly people's movements, behavior and physiological measurements. A dedicated methodology for the localization and monitoring of elderly has been studied and integrated. Noninvasive wireless solutions that expose binary information regarding the interaction of the user with environment have been exploited and tested in real test sites where the sensors have been deployed together with the installation of the GiraffPlus system.

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Investments and Sustainability of Public Expenditure in the Health Sector

Maurizio Ciaschini, Monica De Angelis, Andrea Monteriù, Rosita Pretaroli, Francesca Severini and Claudio Socci

Abstract The impact of the Italian expenditure for the health care on Gross Domestic Product (GDP) and on total public expenditure, is in line with those of the major industrialized countries, and somewhat lower than the European average. The issue of the Italian health sector is not simply related to the contraction of the expenditure: in effect, it should be highlighted that Italy currently does not spend "a lot" and, above all, invests "little" in the mentioned sector. Nevertheless, the health sector can be a very important flywheel for the economic recovery but, in order to make this possible, it is necessary to pay a lot of attention, and to invest the best resources. In this work, the authors intend to develop an analysis of the desirability of investment on Information and Communication Technologies (ICT)

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in the health sector, and the consequent compatibility with current expenditure, by identifying at the outset the channels multipliers related to the resources at present allocated to the current health expenditure and capital account.

1 Introduction

At the beginning of the twenty-first century, WHO ranked the Italian health system among the three best in the world. A dozen years later, among the 34 countries surveyed by the EuroHealth Consumer index,[1] the same system is ranked at 21st place for quality of care. The reasons for this drop can be attributed to several factors, among which we can include the lack of investment and expenditure restraint.[2]

Surely years of crisis and negative expectations about the economic system recovery still make the curbing of public expenditure a priority.[3] The need to restore public finances and to re-balance the weight of the health sector on government expenditure has often led to consider the health system as a source of potential costs and inefficiencies, rather than as a strategic sector that plays a crucial economic and social importance for the entire country. This has been triggering the sequence of public control operations mainly oriented to the short term, with a logic of linear expenditure cuts, which have tended, however, to fundamentally weaken the areas where public health has more difficulty and to fail to distinguish the virtuous areas from the non-virtuous ones as well as to reward the virtuous.

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[1]EuroHealth Consumer index 2013 in http://www.healthpowerhouse.com/index.php?Itemid=55.

[2]It is worth paying attention to the details that are stressed in the report by the OECD Health Division prepared following a request for clarification from the Hygiene and Health Commission of the Italian Senate (the report has come in the first months of 2014 to the attention of parliamentarians) (http://www.quotidianosanita.it/allegati/create_pdf.php?all=1683299.pdf). The report underlines that in the current government, "the data provided in support of health care expenditure reductions proposed in the expenditure review does not allow you to fully appreciate the situation of increasing disadvantage of the National Health Service with respect to the health care systems of other European countries". It is also highlighted that "Italy has a public health expenditure per capita more than a third lower than the average of other countries in the Eurozone considered in the expenditure review, and the gap has tripled since the early 2000 s". But this is not enough. According to the OECD, "the level of health services provided in Italy is significantly lower than that observed in almost all other countries in the Euro area considered in the expenditure review". For this reason "any expenditure reductions aimed not only for the recovery of inefficiencies would affect further on access to healthcare, on the levels and quality of health care, particularly for the most disadvantaged citizens". Not to mention that the benchmark for the public health expenditure (5.25 % of GDP) suggested by the Working Group on the Review of public expenditure is not compatible with the existing model of the Italian National Health Service.

[3]By reading the history of the Italian health since 1978 (the date of creation of Italian national health system) one can easily notice how financial difficulties have been a feature of the system and have also been affecting the organization and the decisions of policy makers [1].

What is worth highlighting is that the impact of the Italian public health expenditure on GDP and on total public expenditure is in line with those of more industrialized countries and somewhat lower than the European average. The issue of health sector is not simply related to the contraction of the expenditure: you must be well aware, in fact, that Italy currently does not spend “a lot” and, above all, invest “little” in the mentioned sector.

According to the latest available data from Istat (2012), in Italy public health expenditure per capita is well below the average of OECD countries.[4] Perhaps, then, it is necessary to focus attention on issues related to the redistribution (reallocation) of the expenditure rather than on the simple policy of contraction.

The immediate requirement is therefore to address the issue of “how to spend” (what is important is to spend better and focus on quality of expenditure) and at the same time to prepare the system to support future demand [2][5]: these are the elements that make up the ratio of the future direction of policy maker who is responsible for the political accountability of health care expenditure. In the absence of these structural interventions you would risk worsening the economic sustainability of the system of cares and to return to an accounting statement out of control. You cannot ignore, for example, that the issue of sustainability of public expenditure is also linked to the development of social and demographic factors. Italy is the European country with the highest percentage of population over 65 and in the coming years, due to the aging of the population, the demand for health services will grow inexorably [3].

Accordingly, it is not just a problem of economic sustainability of public finances, then, but also of competitiveness of the economic system: for instance, with the new rules on cross-border healthcare, the countries with a range of services that do not match the needs of people will be bound to lose competitiveness. In this respect, the demand for health services that will not be satisfied on the Italian territory will impact hard on the balance of payments precisely because of imports of care services [4]. The imported services will trigger a drain of economic resources, both public and private, giving benefit to other health systems with significant consequences for the Italian economy, in particular for the ability to generate income and employment with unfavorable outcomes on the quality of human capital of national health sector.

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[4]According to the latest data presented by ISTAT, the Italian public health expenditure amount to 111 euro billion, that is 7 % of GDP: € 1867 year/inhabitant. But Italy is in the second half of the ranking of European countries in per capita expenditure, below France, England and Germany, that are our reference countries. Essentially, let alone other problems, the funding allocated to public health care is not sufficient. It is therefore unsurprising that a group of citizens, gathered by the Association Giuseppe Dossetti, has decided to promote a class action and to sue the State, because it does not guarantee the LEA, the essential levels of assistance in 12 regions out of 21. According to the data, it will ask for a compensation for not complying with the law and the “Patto sulla salute”. See http://www.sanita.ilsole24ore.com/art/dibattiti-e-idee/2014-02-10/dallassociazione-dossetti-class-action-130644.php?uuid=Ab0MKYMJ.

[5]The authors argue that the problem is not the sustainability of the system rather than its survival.

Indeed, health sector can be a very important flywheel for the economic recovery, but to make this possible it is necessary to pay a lot of attention and invest the best resources.

Tangible experiences along this direction are rapidly growing and show how the production of health services play the role of key productive sector within a local context.

In this sense, for example, you can highlight the need to create health districts that play the role of very supply chains where the main activity made by healthcare services it is able to trigger the production of goods and services from different sectors (chemical, engineering, transport, etc.) with obvious advantages in terms of employment.[6]

Economic policies in the health sector, moreover, should not only meet the need to find resources in view of the containment of the main indicators related to structural public deficit and debt; rather they should be (and create an occasion to remove structural inefficiencies and prevent the system from being vulnerable in front of protracted crises that could seriously undermine its stability.[7]

Unfortunately, due to the difficulty of decision-making and layering regulations, health sector is now at risk of losing gradually in quality and efficiency [5].

In the latest report of the Court of Auditors, the Chairman reported that "the health care system has confirmed the progress already highlighted in recent years in cost containment and absorption of unjustified deficits in the management.[8]

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[6]An example is the industrial district wellness spa: http://ideario.formez.it/content/distretto-produttivo-del-benessere-termale-siciliano.

[7]A serious policy of investments in ICT, in fact, may generate significant improvements both from the point of view of the ability of care and with respect to containment of expenditure. For example, one of the cornerstones to a more effective and efficient health care system is digital innovation: according to the data, if the Italian health system realized completely the potential of digital technologies, it could save 6.8 billion a year—much more than the cuts expected in 2015 and 2016 for financing public health sector. In contrast to the cuts, however, "the digital" innovation would achieve transparency and appropriateness, would reduce many errors (just think of the interpretation of recipes written by doctors) and would improve the quality of services provided to citizens (think of the queues that could be avoided by allowing you to download the reports from home). Even if the investments to be implemented would be limited (we are speaking about millions of euros and not billions in the maneuvers of stability), Italy does not appear to be keen on digital healthcare. There are several ongoing trials but the total expenditure allocated to digitization is estimated to decrease as compared to 2011 and in proportion Italy spends a third in comparison with countries such as France or England. See the case of the Region "Marche": http://www.ecommunity.marche.it/AgendaDigitale/tabid/174/Default.aspx.

[8]The key elements are: "an evaluation network that allows an effective monitoring capable of making the benchmarking technique a tool to control and effectively manage the system; a redesign of accounting rules that gradually helps to strengthen the reasons for a structural adjustment; a central government that, in comparison to the local government, accompanies the pursuit of cost containment interventions with structural adjustment, with improvements in equipment and with investments in human resources training".

Report 2013 on the Coordination of the Public Finance—28.05.2013 in http://www.regioni.it/it/show-presentazione_del_rapporto_2013_sul_coordinamento_della_finanza_pubblica_-_28052013_/news.php?id=299026.

However, health system is still facing challenging choices, but there are worrying indicators concerning the quality of services provided to citizens."

The fact that the new "Patto della salute" (an agreement between state and the regions for public expenditure containment and for basic healthcare standards assurance) has not yet been finalized is an evidence of the "difficult phase that still lies ahead for healthcare despite the progress that has been made in recent years".

Hence "the importance and urgency of strengthening the tools available to local government to accelerate action of re-adjustment of structures and improvement of the appropriateness of the services provided to citizens and to bring up to speed the review of the mechanisms that govern the operation of the sector".

Despite the size of the overall deficit, there are encouraging signs of reduction thanks to more effective expenditure review.

More concretely, in the shortest possible time the Italian health care system will face, therefore, the issue of sustainability, which remains strongly correlated to population dynamics.

The aging of the population and the natural pressure that it exerts on the progress of expenditure requires that the policy makers to be able to use the innovation to bring out gaps and productive inefficiencies, especially in those systems where the public presence is relevant.

In addition, the investment policy should not only be able to respond to the growing demand for health care that characterizes the elderly population, and generally "the weaker", but mainly to the change in the type of demand for services, given the new needs that emerge in the last period of people's life.

These are the critical factors that can create, from the economic point of view, large diseconomies of scale, of variety and location; diseconomies that must be tackled with the introduction of innovations of both process and product.

Just with regard to the benefits that can bring innovations of process and/or product, in this work we intend to develop an analysis of the desirability of investment in ICT in the health sector and the consequent compatibility with current expenditure by identifying at the outset the channels multipliers related to the resources at present allocated to the current health expenditure and capital account. In this way it will be possible to identify the different multiplicative intensity of investment expenditure compared to current expenditure.

This first result is the premise to justify and support the choice of policy makers to redistribute resources from the pockets of inefficiency in current expenditure towards programs for research and innovation in ICT (in other words: it is not beneficial to spend less but you need to spend better).

As a result this not only generate immediate and positive effects on income and employment, but you would have in addition a structural change of the production processes of health care services towards greater efficiency and effectiveness.[9]

[9]This paragraph has been authored by Monica De Angelis.

2 The Health Care System and the Main Areas of Digital Innovation

The Information and Communication Technologies applied to Italian health sector is a possible innovation but especially needed. In effect, in this sector, the ICT can significantly help to improve the offered care services with savings opportunities for the citizens and for the National Health Service, in terms of time and especially money. Numerous studies have been carried out, and by the introduction of ICT in healthcare, it has been proven to save, at European level, billions of euros. Moreover, the quality and efficiency of health services must be improved, and ICT can help in this process. In this section, we analyze the main, significant and priority areas of ICT with high desirability of investment in the Italian health sector.

Firstly, it is necessary to understand how the limited ICT resources are used on the Italian health care system. About this, it has been identified the main areas of innovation, analyzing not only current investments associated with them, but also the strategic importance attributed to the various areas and their development barriers (e.g., complexity of realization, high required investments, resistance to change, etc.). This analysis [6] reveals three main clusters of ICT innovation:

- *Breakthrough:* radical innovation fields with strong strategic benefits that, however, require major changes in the processes and organization. These include Electronic Medical Records (EMRs), document management systems, digital services for the citizen, clinical governance solutions, business intelligence solutions for medication management, business continuity systems, disaster recovery and interoperability solutions integrated with regional and/or national health care digital systems.
- *Must-have:* fields with limited benefits and impacts on the key performance of the health structures, but without barriers to development. Some examples are: the administrative management systems, human resources management systems, front-end systems and ward management systems.
- *Challenge:* fields that appear to be less important to the pursuit of the strategic objectives, and which require significant changes for their implementation, such as overcoming high cultural barriers. Among these fields, there are the mobile health, cloud computing, ICT solutions to support medicine and care (including tele-medicine), ICT solutions for social assistance and electronic social record (that is, however, extremely important for the 94 % medical directors).

where, the *Breakthrough* is the cluster on which the important is strongly perceived. The *Must-have* cluster is the most consolidated one because referring to available ICT solutions, also coming from other public medicine sectors. Conversely, the *Challenge* cluster contains areas which currently are identified as

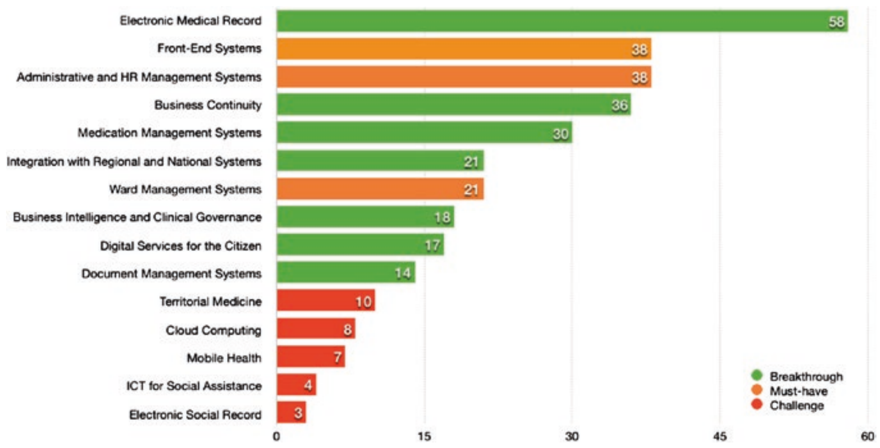


Fig. 1 Budget (Mln) on different ICT fields of the Italian health system in 2013

most problematic, but which can represent the real challenge for the development of the italian health sector in the near future.

In order to determine the significant and priority fields of ICT with high desirability of investment in the Italian health sector, it is crucial to determine how the limited ICT resources are now allocated. The research study carried out by the "ICT in Health Observatory" [6] shows not only the overall ICT spending on health care, but also the budget allocated to the different ICT fields, that is the ICT budget that the Italian health authorities have allocated in 2013 for each field. These results are resumed in Fig. 1.

From this analysis, it is evident that the Italian investments on ICT are strongly oriented to the development of hospital care solutions, while to the territorial and social developments are devoted only few resources. This is mainly due to the fact that the decision-makers have limited vision on the challenging ICT solutions based on cloud computing, on mobile health and on innovative ICT digital solutions. In the next, we analyze the compatibility with current spending to invest on these challenging and crucial ICT fields, by identifying at the outset the channels multipliers related to the resources at present allocated to the current health expenditure and capital account.

3 Relationship Between ICT and Human Health Services in Economic National Account

The increase in efficiency and quality of producing health is deeply linked with the possibility to introduce ICT in the process of creation of Health services [7]. As for the other services sectors the industry of Health care services is ruled by innovation and it was shown that a proper policy of investment in ICT for health care procedure has the potential to drive economic growth and innovation [8, 9].

The relevance of Health care services and its relation with the ICTs production can be stressed given a proper data showing the production setting by mean it is possible to measure the incidence of ICT expenditure on total public health expenditure. Actually, public health system spent in ICT about 1.3 billion euro for the year 2011 [6]. This value is affected by the cyclical trend of the economic variables that has substantially been reduced. In per capita terms the total expenditure on ICT in public health services is around 22 euro per inhabitant. Comparing this value to those of the main European countries, it is possible to show a clear difference. In Germany, in fact, the per capita expenditure in ICT in health is about 36 euro, in France rises to 40 euro and Britain reaches a value of 60 euro. The countries of northern Europe and especially Sweden and Denmark, are above these prices with a per capita total expenditure on ICT by 63 and 73 euro.

According to the definition of ICT [10, 11], we can quantify the absorption of ICT in the production of health care services using the available data base represented by the Social Accounting Matrix for Italy, 2009 [12]. The quantification of ICT absorption is made considering the entire production of health services (both public and private) and taking into account that some ICT productions are included in activities that are more traditional. The approximation does not affect the results of the analysis.

We include in ICT the following sectors: Computer, electronic and optical products (17), Electrical equipment (18), Wholesale trade services, except of motor vehicles and motorcycles (29), Publishing services (37), Motion picture, video and television program production services, sound recording and music publishing (38), Telecommunications services (39), Computer programming, consultancy and related services; information services.

Using the USE table (the table of intermediate absorption) it is possible to identify the amount of intermediate goods of the ICT typology purchased by health industry according the definition of ICT industry. In the year we are interesting to simulate the investment policy the production of Health care services is around 107,412 million of euro which are divided into 61.53 % in terms of value added and 38.47 % in terms of absorption of intermediate goods. Then the value added is represented by compensation of employees (69.7 %), mixed income (16.3 %), gross operating surplus (9.5 %) and finally other taxes less subsidies on domestic production (4.5 %). Within the intermediate consumption the absorption of ICT goods are stressed in Fig. 2.

The absorption of ICT in order to produce Human Health care services is 2,816 million of euro that represents the 2.6 % of the whole health care production. As it can be seen in Fig. 2 ICT goods that play a major role in the production of Human Health care are: Computer programming, consultancy and related services; information services (37.03 %), Computer, electronic and optical products (33.10 %) e Telecommunications services (24.93 %).

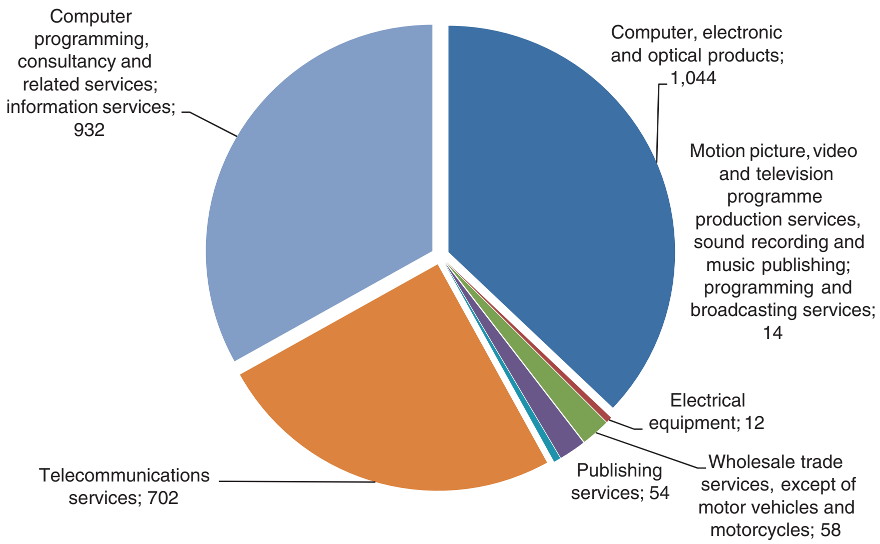


Fig. 2 ICT intermediate expenditures by human health care services

4 Dynamic CGE: The Economic Impact on ICT Through Human Health Services Demand

This study develops the recursive dynamic Computable General Equilibrium (CGE) model where the behaviour of agents depends on adaptive expectations. It is calibrated on the basis of SAM structure and the blocks of the SAM determine the blocks of the equations in order to replicate and provide a fast check of macroeconomic aggregates. The model is characterized by nested production function (CES technology to determine VA, LEONTIEF to aggregate the intermediate goods and VA to determine the domestic production), equalization between supply and demand across all the interconnected markets in the economy. The dynamic component in the model is introduced following the logic of the Ramsey model, according to which all the Institutional Sectors maximise the present value of their intertemporal utility function, which depends on final consumption expenditure and gross saving subject to the lifetime budget constraint. According to the market clearing condition for capital, any change in gross fixed capital formation must affect the capital yearly growth given a constant rate of capital depreciation [13].

The time horizon is finite and considers a time period from 2014 to 2020. Given that ICT and related productions show frequent changes, this does not allow to go beyond short-term time horizons.

Given the interaction of Health care services with other production processes and Institutional Sectors, as highlighted in the SAM for Italy (year 2009), we can calibrate a dynamic CGE model in order to assess the impact of an increase in final demand of Health services on ICT sectors. In particular, it is possible to highlight the impact on GDP, Value Added by commodity and Income by Institutional Sectors resulting from an increase of 2 % in Health final demand. To be more specific, we simulate two different scenarios: in the first (SIM1) we assume an increase in Health services demand by Government of 17,962 millions of Euro; in the second scenario (SIM2) we consider an increase in final demand of Health services by Households for 2,752 millions of euro. In both scenarios the fiscal policy is made under budget constraint.

In Fig. 3 we observe the real GDP path from 2014 to 2020 without any policy (benchmark), with the increase of final demand of the Human Health services from the Government (SIM1) and Household (SIM2). When the policy is devoted to increase households final demand in health services, the overall effect on the economy over time is positive in terms of GDP change. Looking at the results showed in Fig. 3, in a quite short time horizon (6 years from 2014 to 2020), it appears that the economic system reacts more when the health services are stimulated by the private demand instead of public demand. In other words, the private health care expenditure is connected more with the other production processes and with the economic system than the health care expenditure sustained by Government.

In disaggregate terms we observe the effects of the manoeuvres on Value Added by commodity and look in particular to the impact on ICT commodities. As showed in Table 1, the value added by ICT commodity has a better performance when the policy is implemented using resources from the Government to finance the Households expenditure in health services.

Finally, it is possible to observe the difference between the value added in Benchmark path and the value added resulting from the policies for each of the commodities included in ICT sector. Looking at Figs. 3 and 4 we observe that in both scenarios the effects of the policies runs out in a period of 6 years. Moreover, the results emphasizes a strong impact on Computer, electronic and optical products (17) and none effect on Wholesale trade services (29) because it encompasses a portion not associated with ICT production (Fig. 5).

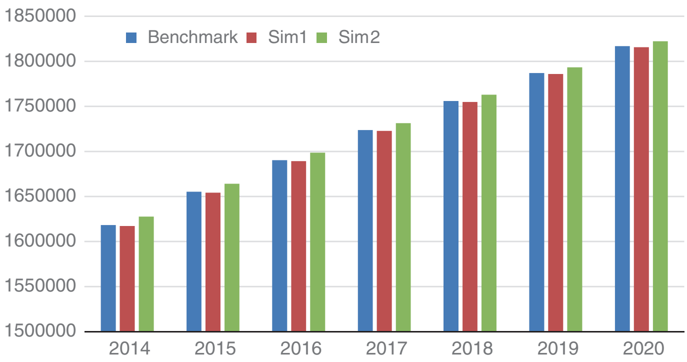


Fig. 3 Gross domestic product from 2014 to 2020 (millions of Euro)

Table 1 ICT value added growth (million of Euro) for the Italian economy

	2014	2015	2016	2017	2018	2019	2020
ICT VA growth (benchmark = B)	139,809	148,372	156,940	165,404	173,657	181,599	189,139
	difference between two scenario respect to benchmark						
B-Sim1	−0.106	−0.109	−0.110	−0.111	−0.110	−0.108	−0.106
B-Sim2	941.44	879.93	815.06	749.00	683.99	622.15	565.45
	difference between two scenario						
Sim1-Sim2	941.54	880.04	815.17	749.12	684.10	622.26	565.55

Fig. 4 Simulation 1—Changes in ICT commodities value added from 2014 to 2020 (differences form benchmark—millions of euro)

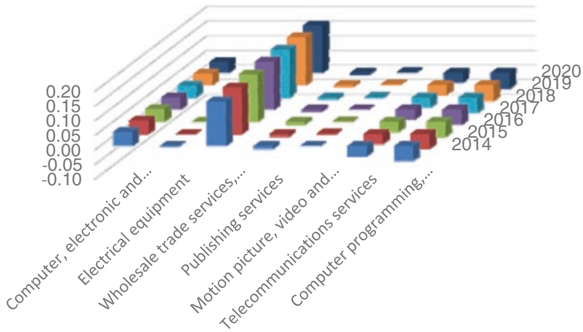
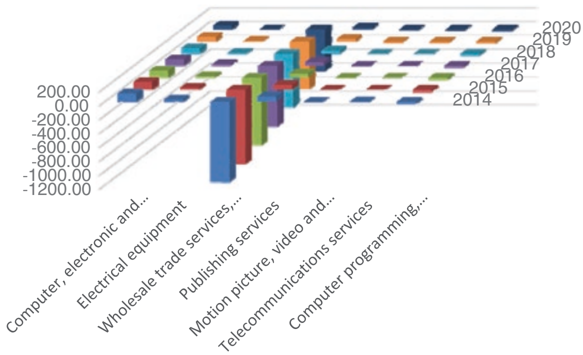


Fig. 5 Simulation 2—Changes in ICT commodities value added from 2014 to 2020 (differences form benchmark—millions of euro)



5 Conclusion

In this work, an analysis of the desirability of investment on Information and Communication Technologies in the health sector has been developed. In order to accomplish this study and to assess the impact of an increase in final demand of health services on ICT sectors, a recursive dynamic Computable General Equilibrium model has been calibrated where the behavior of agents depends on adaptive expectations. Two different scenarios with the fiscal policy made under budget constraint, have been considered: in the first it has been assumed an increase in health services demand by Government of 17,962 millions of Euro; in the second scenario, it has been considered an increase in final demand of health services by Households for 2,752 millions of euro. The result is that, when the policy is devoted to increase households final demand in health services, the overall effect on the economy over time is positive in terms of GDP change. Moreover, it appears that the economic system reacts more when the health services are stimulated by the private demand instead of public demand. In addition, the value added by ICT commodity has a better performance when the policy is implemented using resources from the Government to finance the Households expenditure in health services.

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Design Adaptable and Adaptive User Interfaces: A Method to Manage the Information

Francesca Gullà, Silvia Ceccacci, Michele Germani and Lorenzo Cavalieri

Abstract Designing a multi-user adaptive interface means designing for diversity in end-users and contexts of use, and implies making alternative design decisions, at various levels of the interaction project, inherently leading to diversity in the final design outcomes. Nowadays Adaptive User Interfaces (AUIs) is becoming one of the major objectives addressed by Human Computer Interaction research. The present study provides an overview about the methods currently applied to the definition and development of AUIs. In order to study and develop adaptive user interfaces with the purpose to guarantee socialization, safety and environmental sustainability in a domestic day-by-day living space, a new method of holistic and adaptive user interface is proposed to support the modeling of information related to the user and the context of the interaction. In order to generate the user profiles, subjects older than 40 years with different levels of technology affinity will be considered. These prototypes will be tested through different use cases in the context of smart home environments. The final goal is to produce smart objects and consumer goods able to automatically satisfy the different skills, abilities, needs and human preferences, in an environment where each solutions address different individuals.

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1 Introduction

Designing a multi-user adaptive interface means designing for diversity in end-users and contexts of use, and implies making alternative design decisions, at various levels of the interaction project, inherently leading to diversity in the final design outcomes. Towards this end, a method leading to the construction of a single interface design instance is inappropriate, as it cannot accommodate for diversity of the resulting dialogue artifacts. Therefore, there is a need for a systematic process in which alternative design decisions for different parameters may be supported. The outcome of such a process implements a design space populated with appropriate designed dialogue patterns, along with their associated parameters (e.g. user- and usage-context-attribute values).

The present study provides an overview of the methods currently applied to the definition and development of AUIs. To support the definition of a novel user interfaces able to react with the human psychophysical states, and interact in accordance with the environmental conditions monitored by local sensors, a new method is proposed.

2 Research Background

2.1 Adaptive & Adaptable User Interfaces

The concept of a system able to adapt itself depending on requirements or criteria other than, or even at user's request, is not new. The research literature describes many approaches that can be used to design flexible user interfaces, which can be classified into two broad categories: adaptable and adaptive.

Benyon [1] defines Adaptive Systems as systems, which can alter aspects of their structure or functionalities in order to accommodate different users' needs and their changes over time. Adaptive systems are based on the principle that the system should be capable of identifying those circumstances that necessitate adaptation, and accordingly, select and effect an appropriate course of action.

Accordingly, AUIs are able to adjust their displays and available actions to the user's current goals and abilities by monitoring user status, the system state and the current situation, at run time, according to an adaptation strategy [2].

On the other hand, Adaptable systems offer to users the capability to select, or set between different alternative presentation and interaction characteristics, among the ones built into the system. Adaptable User Interfaces (AdUIs) can be defined as systems in which the activation and selection of user-computer interaction, is performed by the final user through the selection of a specific user profile from a predefined list. Adaptability is based on user characteristics and preferences that are known prior to interaction and, in any case, are assumed to remain static throughout a single interaction session.

The separation between the adaptivity and adaptability is very thin. Both approaches have their pros and cons. The most important advantage of adaptable systems is that the users are in total control of the individual appearance and interface. Otherwise, the use of adaptive user interface seems to help to improve user interaction with systems by facilitating user performance, minimizing the need to request help, easing system use, helping users deal with complex systems and avoiding cognitive overload problems ([3, 4]). Some studies indicate that an intermediate level of adaptivity should be consider as a good compromise, as it can help to keep users involved in the task and help them to become more skilled to perform routine and non-routine tasks [5].

2.2 Advantages and Disadvantages of the Principal Types of Interface

Currently, the main methods used to manage user interface adaptation can be classified in [6]:

- Adaptable/Manual: the user manages the process and performs all actions;
- Adaptable with system support/User Selection: the user dominates the adaptation process and the system supports it;
- Adaptive with user control/User Approval: the system dominates the adaptation process under the supervision of the user. The system initiates the action and notifies the user about the alternative that he/she has to choose;
- Adaptive/Fully adaptive: the whole process is managed by the system, which decides and implements the action based on the preferential model and the main uses.

In this context, due to the complexity of the issues and the lack of careful experimentation, it is difficult to determine the best method.

Founding ourselves on experimental data coming from the literature is however possible to provide a list of advantages and disadvantages related to the different types of interface (Table 1).

The most important advantage of *adaptable interfaces* is that the users are in total control of the individual appearance of the user interface. However, this advantage is at the same time the main shortcoming of adaptable user interfaces: for example, users with disabilities and lower levels of ICT (information and communication technology) literacy would benefit most from personalized user interfaces, as they often have severe problems with standard configurations. However, customization dialogues often are a significant barrier even for skilled users [7].

An *adaptable with system support interface* is more efficient than previous: it provides support to the user during the performance of duties. In this case the management of the interface is delegated mainly to the user, while the system plays a limited role of support. It is often used in complex systems where the consumer is assisted in the decision, in order to support the decision making process.

Table 1 Summary diagram

Types	Advantages	Disadvantages
Adaptable interface	Simpler	Requires learning
	Easy to learn	Don't available for complex systems
	Used in systems easy-to-use	
	Can be organized by the user	
Adaptable with system support interface	Very efficient	Need learning
	Support to the user	Can harm privacy
	Easy to adapt	
Fully adaptive interface	Not disturbing	Most invasive
	Predicting human behaviour	Can harm privacy
	Based on user's profile	Unwanted information
	Reduces the user's cognitive load	
Adaptive interface with user control	Provides means to enable and disable adaptation	Disturbing/distracting
	Control over privacy	Can harm privacy
	Adaptation in the form of a proposal	Need learning
	Helped to remember	Confused notices

Fully adaptive interfaces are the most interesting for researchers, but are also the most invasive. Such interfaces are potentially able to provide more increase in terms of effort and to reduce the cognitive load. In fact, they refer to systems capable of predicting human behaviour, as they are capable of learning the user's profile and preferences. However, they can be considered invasive in terms of privacy. In addition, the exclusion of the user from the adaptation process can lead to unwanted information.

Finally, *adaptive interfaces with user control* can be considered a good compromise between adaptive and adaptable interfaces: in this case, the system manages the adaptation process under the user's supervision. Nevertheless there are different opinions about the benefits provides by this kind of interfaces: some believe that this type of interface may have a negative impact on privacy too, and that the continued demand for confirmations from the user can create frustration and confusion. On the other hand, others believe that the user involvement is a positive thing, as it avoids the complete control of the system.

3 Design an Adaptive User Interface

The Adaptive User Interface research field aims to provide highly usable systems for people with different needs and characteristics in different context of use. Consequently, Adaptive User Interfaces constitute one of the major direction of Human Computer Interaction research.

The Adaptive User Interface design is not a simple task. In fact, its development requires:

- Assessing the user state of mind, state of psychology and level of awareness; it means to operate with nondeterministic data, increasing the complexity of the system;
- Defining an appropriate interface adaptation behaviour [8];
- Assessing the timeliness of the adaptation [9];
- Defining a general method in the absence of a experimentation;
- Assessing the usability and acceptability of a user interface without an established methodology;
- Avoid to damage user's privacy, and give unwanted information.

In general, the Design of an AUI requires several fundamental choices to make:

- Establish who should adapt and what should be the role of User Interface in the adaptation process;
- Define what goals should be mainly considered in the adaptation process;
- Define a proper set of rules to manage the adaptation;
- Define what level of the interaction should be considered and what are the adaptation variables;
- Define methods in the adaptation process, an inference mechanism for the user's choice.

The term adaptivity goals is intended for those particular objectives we want to pursue due to the process of adaptation (e.g. in order to minimize the number of errors, optimize efficiency and effectiveness, in accordance with the type of application and user for which the final system is intended). Most adaptive systems, nowadays aim to simplify and speed up the activity in a complex system, or to minimize the costs in terms of time and computational resources and to maximize the user's satisfaction.

The design of an interface able to meet the various objectives is not an easy task; in case of developing adaptive system capable to improve the usability of the user interface or heterogeneous groups of users with different needs and abilities.

Extremely complex systems for some may result more user friendly and understandable for others. It is necessary to assess user's ability in early stages, so as to identify appropriate targets fitting in accordance with each user profile.

The Adaptation rules guide the aspects of interaction based on the user's characteristics, on the main task or on the nature and objective of the application. In general, the rules that guide the adaptation are strictly related to the system's characteristics. Some of these rules are available in literature such as:

- "If what has to be displayed is a structural analysis of a complex abstract domain, then use network charts" [10];
- "If the task sub-goal requires spatial information—prefer visual media resource" [11];

- "Condition: composition of whole into parts of types, Chart Reference: pie chart" [12];
- "Condition: judging accurate values; Chart reference: table" [13].

These rules are usually in hardcode mode in the user interface, therefore are not easily adaptable to different applications. Moreover, these rules are monolithic; as a matter of fact the selection of the interaction aspects that will be adapted (e.g. the information content), do not depend on the adaptivity goals, but only upon the factors that drive the adaptivity process, such as the characteristics of the user.

This is a strong limitation for the development of adaptable user interfaces. In fact, this would lead to have in the case of users with varying skill levels, the need to define different rules even for the same goals. In this case the challenge concerns the development of a method that allows to change even "a posteriori" adaptation rules depending on the objectives and independently from the characteristics of the users or by the context of use.

According to the Rothrock's methodology the interfaces adaptation should be activated by several factors; in order to define the adaptation it is necessary first to outline the "adaptation variables".

The following is a list of variables referenced as trigger factors in literature [14]:

- User Performance: defined as an error percentage in performing a task, in order to minimize number errors and minimize cost in term of resources and time;
- User Goals: consist of level goal structures to accomplish a task;
- User Knowledge is generally used in Human Computer Interaction domain: information about generally shared knowledge applicable across different domains business world, office work, human communication, etc.;
- Cognitive workload: this should neither be too complex, otherwise the user will not be able to perform the task; the cognitive workload should not be homely otherwise not stimulate the user;
- Situation and task variables: the interface should help the operator to find the problem and solve it; situation variables include system state, environmental conditions, etc.;
- Interaction level: user presentation of input to the system, system presentation of information to the user, access to capabilities, task simplification.

Once goals, rules and variables are described, it is necessary to design a Computational Model to store the user's profile and to develop the Adaptation Mechanism (AM).

There are several methods to develop AM: the most used are reported hereafter:

The "Artificial Neural Network" (ANN) represents a nonlinear statistical technique, principally used for the prediction. The ANN is a model constituted by a group of interconnections of artificial neurons and processes, using a connectionist approach to computation. An artificial neural network is an adaptive system that changes its structure, based on external or internal information that flows through the network during the learning phase. The ANN can be used to simulate the inputs/outputs (other analytic functions fail to represent) complex relationships.

In addition ANN is able to detect the relationship between different variables without any assumptions or any postulate model and to manage the data unreliability. However, the ANNs are significantly limited by the fact that it requires important database dimensions. Indeed, it is really important to train the ANN with an exhaustive learning basis, including representative and complete samples (e.g. samples in different seasons or in different moments of the day or during weekend).

The "Support Vector Machine" (SVM) is an artificial intelligence technique, usually used to solve classification and regression problems. Classification is a technique allowing to divide a set of data in several categories, whose characteristics are given by the user. Regression method allows one to describe a set of data by a specific equation. The complexity of the regression equation is given by the user. The main difficulty in the SVM technique is to select the best kernel function corresponding to a dot product in the feature space and the parameters of this kernel function. The main advantage of the SVM is the fact that the optimization problem is based on the structural risk minimization principle (SRM). It deals with the minimization of an upper bound of the generalization error consisting of the sum of the training error.

The "Bayesian networks" (BNs) represent another adaptation mechanism; the Bayesian rational provides a probabilistic inference approach. BNs are directed acyclic graphs where nodes relate to random variables. The nodes are connected by directed arcs, which may be seen as causal links from parent to children nodes. Each node is associated with a conditional distribution probability, which assigns a probability to each possible value of this node for each combination of its parent nodes.

The adaptive user interfaces require the software to be very flexible and quickly adaptable to any change in user behaviour.

BNs are more flexible than the models discussed above in the sense that they provide a compact representation of any probability distribution, they explicitly represent causal relations, and they allow predictions to be made about a number of variables (rather than a single variable, which is the normal usage of the above models). In addition, BNs can be extended to include temporal information [15] and utilities.

4 Proposed Method: Adaptive Management Interface

In order to study and develop an adaptive user interfaces with the purpose to guarantee socialization, safety and environmental sustainability in a domestic day-by-day living space, (e.g. a kitchen environment), new design methodologies have to be taken into account domotics environments related to different user's profiles, so as to ensure addressing knowledge development, innovative technical solution and equipment.

This implies the definition and development of holistic and adaptive user interfaces aiming to satisfy the different utilization profiles/contexts and user requirements/skills.

Our target is the development of new methodologies for human-machine interaction and for user interfaces, according to the “design for all” paradigms. The user interfaces will be adaptive, in the sense that they will be easy and friendly for all including, to elderly and weak users. The novel user interfaces will react with the human psychophysical states, and interact in accordance with the environmental conditions monitored by local sensors. Moreover these interfaces will have to be able to define and represent user behavioural models with respect to the identified scenario.

The adaptation management system is based on the knowledge provided by three information models: the User Model, the Environment Model (or Domain Model) and the Interaction Model (Fig. 1).

The User Model provides the description of the user’s profile pattern, according to its cognitive and physical structure, status and preferences. The user’s profile pattern it is outline according to the coding provided by the International Classification of Functioning, Disability and Health (ICF) [16]. The ICF is a valuable tool to classify and evaluate the psychological and physiological ability of an user. It has a universal application [17]: it does not focus only on disable people but allow to describe the health condition of any person. The domains contained in ICF are described from the perspective of the body, the individual and society in two basic lists: “Body Functions and Structures” and “Activities and Participation”. The domains for the Activities and Participation cover the full range of life areas (from basic learning or watching to composite areas such as interpersonal interactions or employment) (Fig. 2).

The environment model supplies the information pattern necessary to describe the environment of the human-machine interaction. Such information are related

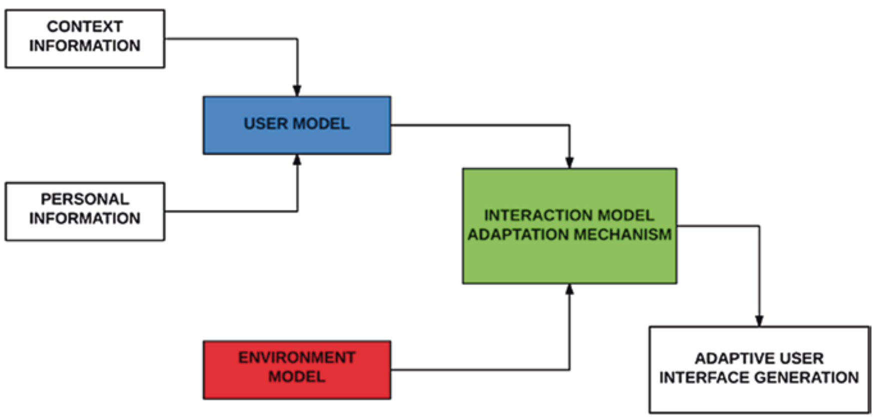

Fig. 1 Method to manage adaptive user interface

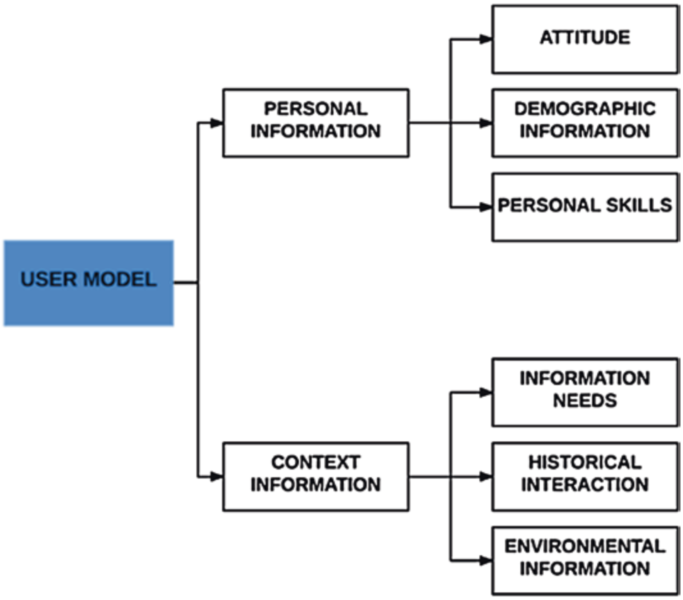

Fig. 2 The user profile in according to the coding provided by the ICF

to its physical characteristics (e.g. typology of interactive devices, available means of interaction, etc.) as so as to its functionalities (e.g., supported activities or tasks) and its logical characteristics (e.g., information relates to management of the system functionalities performed by the adaptive interface) (Fig. 3).

To support the definition of the environment model a Functional Modeling (FM) approach [18] can be adopted. Such approach is normally used by designers to represent the design problem in terms of functions that the product must support. The essential feature of any FM approach, is given by a decomposition process that, starting from the definition of an activity allows you identify the basic functions (or tasks or actions) needed to carry out it.

The Interaction model is the core of the whole adaptive process; as a matter of fact this model is in charge of the user and environmental model data management. The IM must recognize the user, store it's needs and preferences. In addition it must be able to extract human-computer interaction information, provide the correct logical and task interpretation, allow a much more suitable environmental usability and define the event activation schedule.

Such complex adaptive systems require inference and evaluation mechanisms, which need to learn and interact with the local environment.

In the formal logic based systems it is assumed that available information and conclusions resulting from inferential rules are simply true or false. In an adaptive mechanism there is no direct access to the whole domain reality; the system to be developed must act within a range of uncertain data: such as unreliable, missing

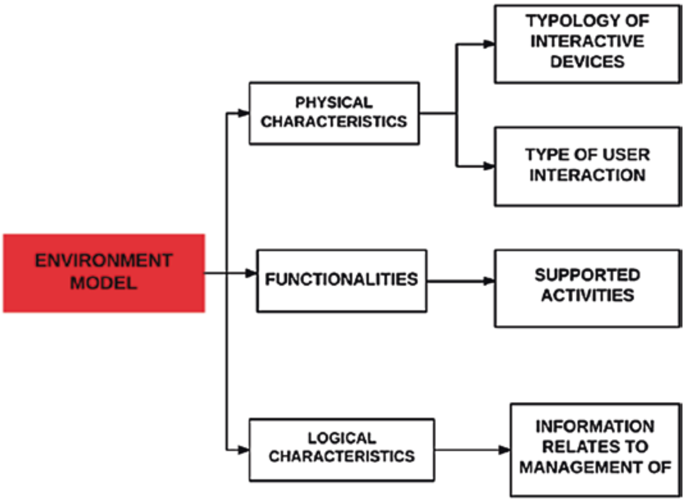

Fig. 3 The environment model

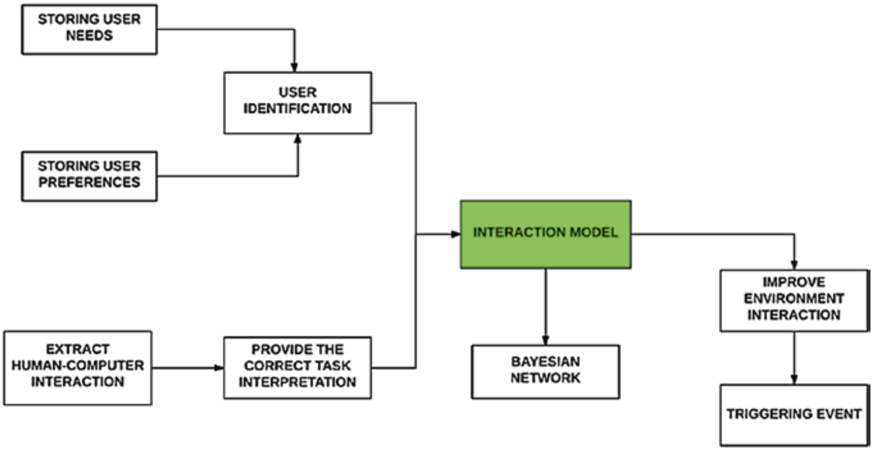

Fig. 4 The interaction model, the core of the whole adaptive process

and inaccurate data. In addition incorrect environmental data may raise inaccuracy. Probabilistic theories provide the methods to correctly deal with inaccurate data systems, resulting from lack of domain knowledge (Fig. 4).

The Bayesian approach, mentioned above, provides a robust theory that merges together different technologies.

Its approach to probability may be extended to the learning aspects. Merging the results is very powerful theory that provides a general solution for learning and optimal forecasting Automatic learning is based on the idea that experience may improve the "agent" capability behaviour and future events, providing the ability to automatically update users profiles and predict users behaviours.

5 Conclusions and Future Developments

In order to develop a novel AUI according to the "design for all" paradigms, a new method of holistic and adaptive user interfaces is proposed to support the modeling of information related to the user and the context of the interaction.

Such method will be implemented by developing suitable software architectures and tools to simulate the adaptive user interfaces.

In a context in which the adaptation mechanism has not access to the reality of the whole domain and taking into account that the system developed will act in uncertainty cases, our effort to implement the user interfaces will focus on the following two aspects:

- Accessibility according to user profile;
- Adaptivity according to the utilization profile in order to improve efficiency and usability.

To generate the user profiles, subjects older than 40 years with different levels of technology affinity will be considered. In this way we will obtain a significant number of users which allows to characterize different levels of usability and functionality interface.

In accordance with the project, some areas of weakness have been highlighted; these outline the specific characteristics of the user such as: sensory disturbances/ perceptual, cognitive and mood disorders.

The adaptation protocol, currently being implemented, will be based on a complex Bayesian network written by Java/C API (Netica software support).

The whole system will be managed centred on the user psychophysical profile and on man-machine interaction.

This work aims to implement in the "design for all" context an approach based exclusively on the user.

The final goal is to produce goods able to automatically satisfy the different skills, abilities, needs and human preferences, and not simply finding a single solution for everyone.

These prototypes will be tested through different use cases in the context of smart home environments. Possible application scenarios will be the living room and the kitchen that are characterized by a large number of household appliances.

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Part II
Sensing Technologies for AAL

Predicting Freezing of Gait in Parkinson's Disease with a Smartphone: Comparison Between Two Algorithms

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Abstract The freezing of gait (FOG) is a common and highly distressing motor symptom of patients with Parkinson's Disease (PD). Effective management of FOG is difficult given its episodic nature, heterogeneous manifestation and limited responsiveness to drug treatment. Clinicians found alternative approaches, such as rhythmic cueing. We have built a smartphone-based architecture in agreement with acceptability and usability requirements which is able to detect FOG and provide acoustic feedback to the patient. The aim of this work is to compare the reliability of a real-time FOG detection using two different algorithms implemented on the smartphone.

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1 Introduction

The most important change in demographic situation in recent years is the transition towards a much older population. For this reason monitoring and assistive devices spread out in order to increment elderly independence, safety, security and quality of life [5–7]. Such increase in aging population causes an increment of chronic and neurodegenerative diseases, which generally include motor disorders.

Among these Parkinson's disease (PD) is the second most common neurodegenerative disorder and is expected to impose an increasing social and economic burden on the community due to motor disability and complications caused by gait and balance impairment [1]. The freezing of gait (FOG) is defined as a "brief, episodic absence or marked reduction of forward progression of the feet despite having the intention to walk" and it is a highly distressing motor symptom that is common in patients with PD, reaching the 80 % in the later stages of the disease [28]. FOG pathogenesis is largely unclear, because of its episodic, heterogeneous and erratic nature, that makes it difficult to be observed in the clinical setting [20]; however, both motor and cognitive factors have been acknowledged as possible determinants of FOG [31]. Clinical management of this disabling symptom is limited in large part by the difficult nature of assessing FOG severity. A phenomenological study using video analysis [25] has observed that, at least, three kinds of leg motion can occur during FOG: (i) small shuffling steps with minimal forward movement (shuffling with small steps), (ii) leg trembling without effective forward motion (trembling in place), and (iii) complete akinesia, i.e., no observed leg motion. In the quoted study, 'small steps' and 'trembling in place' appeared to be much more common than 'akinesia'. FOG represents a common cause of falls in PD and significantly impairs quality of life [25], furthermore its response to current treatments (including dopamine replacement therapy) is at best limited and more often ineffective.

To overcome the drug-resistance, clinicians found alternative approaches: [12] there is good agreement among researchers that auditory cues (e.g. walking at the rhythm of music or metronome) are the most efficient at enhancing gait [29, 32]. Therefore, in order to prevent FOG, a system, delivering suitable and effective cues, has to be able to predict the FOG occurrence in every daily living situation and independent of patient attention. A number of wireless body sensor networks have been proposed to monitor FOG and provide a quantitative and objective assessment of FOG [3, 14–17, 30]. All of them need to place sensors on patient's body and often need to transmit data to a computing unit, which must be always nearby the patient. They are used in a rehabilitation facility context, while no solutions seems apt to be used during the daily living (DL). Only, Mazilu et al. [15] proposed a wearable assistant, composed of a smartphone as wearable computer and wearable accelerometers (hip, knee, ankle), for online detecting of FOG. When FOG is detected, the assistant provides rhythmic auditory cueing or vibrotactile feedback. The system is based on machine learning techniques. The classifier must be trained offline on a base station, the data is stored in a file and copied to the mobile-phone for its online use.

Development of medical products is often guided by medical necessity, technical feasibility, and economic interest, disregarding aspects of humans' technology acceptance as well as the understanding of usage motives and barriers [8]. Since the major part of systems described above required additional and unknown technology to be worn by the patient, they scarcely satisfy usability and acceptability requirements. Instead, the Information and Communications Technology (ICT), particularly smartphones and other mobile technology, does not elicit oppressive or embarrassing feelings because of their popularity. They also offer customizable user interface to increment perceived ease of use and inertial sensors to collect motion data. For this reason, we developed a smartphone based architecture for FOG detection [22]. The aim of this work is to compare the reliability of real-time FOG detection using two different algorithms implemented on the smartphone.

2 Materials and Methods

The architecture for FOG detection is composed of a smartphone for both sensing and processing and an elastic belt with a socket to hold the smartphone in the right position at patient's hip (i.e. accelerometer axes aligned with anatomical axes). In the following paragraphs data processing algorithm and experimental set up are explained.

2.1 Data Processing

Acceleration data are acquired at 100 Hz through the accelerometer integrated on the smartphone. A sliding window (256 samples Hamming window) is applied to the accelerometer data; the window shift is 40 samples. Firstly, on each window, the Fast Fourier Transform (FFT) and the power spectrum are calculated, than the features, used by the FOG detection algorithm, are considered.

Two kind of algorithm are tested:

- Algorithm 1: the first is the same algorithm described by Bächlin et al. [3], which compute freeze index and energy. We have already applied it in a previous experience [24]. Freeze index was defined as the ratio between the integral of the power spectrum in the band 3–8 Hz and the integral in the band 0.5–3 Hz [16], while energy was defined as the integral of the power spectrum of acceleration signal in the entire band 0.5–8 Hz [3].
- Algorithm 2: the second algorithm adds to the Bächlin's [3] algorithm the computation of the cadence by taking the second component of the power spectrum.

By the use of the first algorithm, FOG is detected when both freeze index and energy exceed a threshold value. In the literature [3, 17], threshold values are set as universal for all subjects. One of the novelties, introduced in this work, is the adoption of user-specific thresholds computed as the mean plus one standard deviation of parameters acquired in a 20 s period of standing posture.

By the use of the second algorithm, FOG detection is determined when freeze index and energy exceed their threshold during a cadence variation. We define a cadence variation when cadence value is different for three consecutive windows, that is 1.2 s. The algorithm doesn't consider a FOG event finished until cadence regularity has been restored.

All the information collected by the smartphone app (features calculated, FOG events detected and threshold values) is stored locally and used later for statistical analysis.

2.2 Subjects' Recruitment

Eighteen patients consecutively referred to the Movement Disorders Centre, Department of Neurological Sciences, Neurorehabilitation Clinic, United Hospitals of Ancona, were recruited based on the following inclusion criteria:

- age $\leq$ 80 years;
- diagnosis of probable idiopathic PD [10];
- independent ambulation, at least gait needing verbal supervision or help from one person without physical contact, under drug therapy that was chronically undertaken (ON-condition)
- Mini-Mental State Examination (MMSE) $\geq$ 20, [9]
- clinical history of FOG confirmed by a third person, i.e. caregiver ("probable freezer" as defined by Snijders et al. [27]).

The study was approved by local Ethics Committee and written informed consent was obtained.

Patients were assessed in the practically-defined 'on' state following their own chronic morning dose of the dopaminergic therapy. Three patients were being treated with deep brain stimulation (DBS). Patient characteristics were as follows: 5 female and 13 males, mean age 69.0 [SD 9.7], disease duration 14.1 years [SD 4.6], Hoehn and Yahr stage [27] 3.4 [SD 1.1], UPDRS (Unified Parkinson's Disease Rating Scale) total score 36.1 [SD 13.5], UPDRS Section II 17.2 [SD 5.5], UPDRS Section III 15.5 [SD 7.7], UPDRS Section II item "Freezing of gait" 2.5 [SD.6], LEDD (Levodopa equivalent daily dose) 799.7 [SD 220], MMSE (Mini Mental State Examination) 26.5 [SD 3.2], FAB (Frontal Assessment Battery) 12.1 [SD 2.9]. Two patients described an increase in freezing behavior following the administration of their usual dopaminergic therapy (named ON freezing).

In order to compare the two algorithms we applied both the detection rules to all the trials: Algorithm 2 worked online, Algorithm 1 was applied on the same data records offline. The study was conformed to the Helsinki protocol for clinical trials; it was approved by local Ethics Committee and a written informed consent was obtained.

2.3 Experimental Assessment Protocol

Throughout the assessment protocol, the constant aim of the investigators was to obtain a sequence of videos depicting a wide range of FOG types and severities, in order to define the architecture reliability and the external validity of the study, that is to say the transferability of results to all daily living situations. Therefore, patients were assessed, in the morning and under the effect of their own chronic dopaminergic therapy, while they were performing different types of video-recorded Time Up and Go (TUG) test, as described in the following section. Patients performed three kinds of TUG tasks designed to provoke FOG on a standardized course of 5 m: (1) the standard TUG test modified (5 m) by Shumway-Cook et al. [26], (ii) the Cognitive Dual Task Timed Up and Go test as described by Hofheinz et al. [11] and, finally, (iii) the Manual Dual Task Timed Up and Go test, which was inspired to Lundin-Olsson [13] and Baker's et al. [4] experimental protocols. Walking trials were recorded on a digital video camera from a consistent vantage point for later analysis, and each video showed a complete TUG trial starting and ending in the seated position. Simultaneous acceleration data was acquired from the trunk during the TUG trials described above. Synchronization of the video and accelerometer recordings was performed prior to data collection by alignment of the video camera and data acquisition computer clocks.

Data Analysis. The distribution of demographic and clinical variables in the whole sample has been described using mean, standard deviation (SD), median, range and interquartile range (IQR) for continuous variables, while percentage rates were used to describe categorical parameters. System performance, for each algorithm, represented the primary outcome of this work and it was evaluated as sensibility and specificity of the detection. In order to maximize the reliability of the specificity definition, data analysis has been performed on the overall patients' sample, and in subgroups represented by both the defined "freezers", i.e., patients who demonstrated at least one FOG episode during the video recording, and by "not freezers", i.e., patients who did not show FOG episodes during the assessment [27]. Sensitivity was calculated according to the following formula: $Se = \frac{tp}{tp+fn}$, where true positives (tp) were the windows correctly classified as FOG and false negatives (fn) the windows classified as non-FOG despite the patient manifest the symptom in that time instant.

For what concerns specificity, we defined true negative (tn) the windows correctly classified as non-FOG and false positives (fn) the windows wrongly classified as FOG despite his absence. Based on these definitions specificity was calculated as $Sp = \frac{tn}{tn+fp}$.

3 Results

Fourteen (77.78 %), out of the 18 enrolled patients, were defined as "freezers" showing at least one freezing episode during the proposed video assessment. We observed 73 FOG events in total, as recognized by clinicians based on video

Table 1 Results. Se1 and Sp1 are sensibility and specificity of Algorithm 1, while Se2 and Sp2 are sensibility and specificity of Algorithm 2

Pat. id	Gender	N° FOG	Se1 (%)	Sp1 (%)	Se2 (%)	Sp2 (%)
1	M	2	81.25	98.94	93.75	99.75
2	M	14	65.54	58.21	78.00	87.49
3	M	3	81.11	98.46	93.33	99.23
4	F	1	40.00	96.52	90.00	98.30
5	F	9	49.16	98.36	74.08	99.43
6	M	1	100.00	38.79	100.00	68.80
7	M	7	64.86	90.57	85.38	96.06
8	M	8	48.81	91.23	72.77	98.39
9	F	13	92.68	31.55	97.29	81.72
10	M	–	–	85.64	–	91.58
11	M	–	–	99.51	–	99.79
12	M	1	100.00	89.74	100.00	94.93
13	F	–	–	43.49	–	97.81
14	M	4	38.59	95.62	76.63	97.59
15	F	6	76.79	90.40	100.00	98.04
16	M	–	–	97.47	–	99.25
17	M	2	87.50	98.35	100.00	98.87
18	M	2	80.00	95.40	100.00	97.99
		73	**74.02**	**85.46**	**88.31**	**94.72**

The last row represents the average of these indicators

recordings. During the online performance the application failed to recognize only 1 event of FOG, which means that only in one case the application didn't give the acoustic feedback at all to the patient while he was freezing.

For Algorithm 1 sensibility reached 74.02 % and specificity reached 85.46 %; while for Algorithm 2 we found 88.31 % of sensibility and 94.72 % of specificity.

In Table 1 results for single subjects are reported.

4 Discussion and Future Work

Results confirm previous data on the reliability of Algorithm 1 [24] and indicate that the evolution of this architecture is capable of identifying FOG episodes with a high sensitivity and specificity.

The two algorithms have been developed on the basis of the work of Bächlin et al. [3] making some changes that have ensured firstly and foremost a good reliability (even if it was loaded on a smartphone and not on a complex triaxial monitoring system of the acceleration) and also has improved specificity and sensitivity. In particular, the Algorithm 2 showed significantly better performance and reliability and less variability than those of the previous algorithms. The variability of the performance of such kind of real-time FOG detecting algorithm had already been showed in the work of Moore [16] and Bächlin et al. [3] and in our previous studies [23, 24], where it was related to different walking styles across subjects, the presence of tremor and different kinds of FOG in term of phenomenology and responsiveness to dopaminergic therapy. The implementation that we made on the Algorithm 2 has been proposed on the basis of some studies [18, 19] which demonstrated that FOG could be related to the disruption of temporal, other than spatial, characteristics of gait. Moreover, Auvinet et al. [2] showed that the first power spectrum harmonic concerns stride frequency, while step frequency (double of stride frequency) is the second power spectrum harmonic.

Both the high score of performance results and the unobtrusiveness demonstrate the potential use of the architecture in monitoring, gait assistance during daily living and rehabilitation therapy.

The better performance shown by Algorithm 2 has been explained with the addiction of step cadence information as well as adding complexity to the detection rule. Based on these findings we tried to stress the intelligence of the detection rule by using a fuzzy logic algorithm, in order to see the effect on the performance [21]. As expected the system showed further improvements.

The proposed architecture can be easily applied to similar scenarios involving patients affected by atypical parkinsonisms. Clinicians can benefit from the information brought by aggregate and synthetic clinically important parameters, improving their knowledge and patient management.

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A Wireless Sensor Insole to Collect and Analyse Gait Data in Real Environment: The WIISEL Project

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Abstract In Europe 30 % of population will be aged 65 or more in 2060. Falls are a major health problem for older adults with immediate effects, such as fractures and head injuries, and longer term effects, as fear of falling, loss of independence and disability. Therefore, falls are a huge social and economic problem. The goals of the WIISEL project is to develop an unobtrusive, self-learning and wearable system aimed at assessing gait impairments and fall risk in the home setting of older adults; assessing activity and mobility in daily living conditions; identifying decline in mobility performance and detecting falls in the home setting.

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A high-tech insole with wireless communication capabilities will be worn by the elderly, monitorizing their posture and evaluating gait dynamics via a matrix of printed pressure sensors.

1 Introduction

Falls are a major health problem for elderly people causing both immediate effects like fractures and head injuries as well as longer term problems such as disability, fear of falling and loss of independence [1]. In the elderly population the most common risk factors for falls are muscle weakness, history of falls, gait deficit and balance deficits [2].

The share of people aged 65 years or over in the total European population is projected to reach 30 % in the year 2060 [3]. Early detection of individuals at risk of falls and prevention is thus a major challenge for the European health and social systems, leading to longer independence, self-confidence and quality of life for elderly persons, their carers and relatives [4, 5], and at the same time reducing costs related to falls, contributing to more sustainable healthcare systems [6].

In response to this situation, the main goal of the European project WIISEL (Wireless Insole for Independent and Safe Elderly Living, G.A. no: 288878) is to develop a flexible research tool to collect and analyze gait data from real users and correlate parameters related with the risk of falls from the elderly population.

This tool will consist of a combination of a flexible software platform together with wearable insole device collecting data related with gait. Each insole comprises 14 pressure sensors for studying posture and inertial sensors, (3D accelerometers and gyroscopes), for measuring the trajectories of the feet. Both pressure and inertial sensors are off the shelf components that are integrated in flexible insoles. A commercially available smartphone is used to wirelessly collect data in real time from the insoles and transfers it to a backend computer server via mobile internet connection. Transfer of sensor data from the insoles to the smartphone is implemented using the Bluetooth Low Energy wireless standard.

Risk of falls will be calculated as a new Fall Risk Index based on multiple gait parameters and gait pattern recognition. WIISEL will allow quantifying activity, assessing the quality of gait under real life conditions and will enable researchers to evaluate and monitor fall risk in elderly patients, in the home and community environment, mostly reflecting everyday life behaviour.

WIISEL is a 40 months research project started on 2011 November 1st, which focuses on the development of the technology itself. The clinical studies are designed to demonstrate mainly potential utility, validity and “proof-of-concept”, involving relatively few subjects.

At month 32 (June 2014), fully functional insole prototypes were built to perform bench tests, durability tests and safety tests. The results from these tests were satisfactory and more prototypes were manufactured to carry on with the functional trials and the characterization of the system. During these tests the system was improved and new prototypes are currently being manufactured.

2 Prototype Components

2.1 Integrated Insole System

The WIISEL insole is designed to contain a complex system of sensor electronics embedded in a wearable insole. To ensure flexibility of the insole, electronic components are mounted on a flex-rigid printed circuit board and a less than 1 mm thick semi flexible battery is used to power the system.

For protection from moisture and from mechanical damage and comfort, the electronics system is entirely encapsulated in materials typically used for custom made insoles. Since the entire system is encapsulated, the battery is charged using the inductive Qi standard that is getting popular for wireless charging of mobile phones and other consumer product.

2.1.1 Sensors Layer

It contains 14 thin-film resistive pressure sensors, which are encapsulated into polyurethane material (Fig. 1).

2.1.2 Electronics Layer

It contains inertial sensors than can be used for observing a multitude of different gait parameters. Temporal parameters such as step time, stance time and swing time can be recorded using accelerometers that are relatively cheap and consume little power. To extract spatial parameters like step-length and foot-clearance over the ground one must on the other hand combine data from accelerometers with data from gyroscopes that are used to keep track of the orientation of the accelerometers relative to the ground.

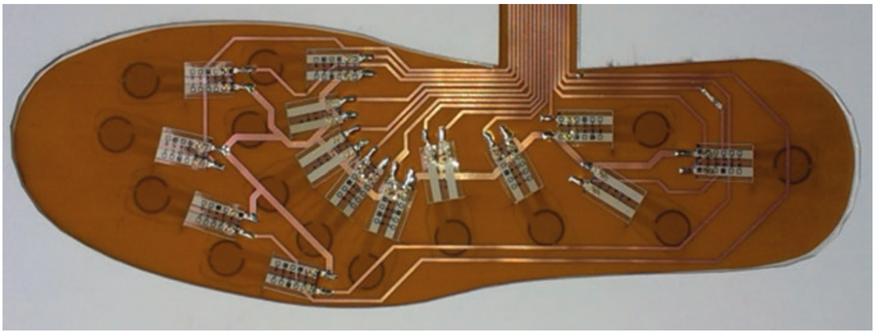

Fig. 1 Pressure sensor layer

To this purpose, each WIISEL insole includes a combined 6D accelerometer and gyroscope integrated circuit. It has a serial data interface that allows a microcontroller to read inertial data in digital form directly. Furthermore it has the lowest power consumption of any inertial sensor currently on the market that includes gyroscopes.

2.2 Wireless Communications

The WIISEL system is designed to continuously monitor the gait of a user wearing the sensor insoles throughout the day. A commercially available smartphone is used to collect the data wirelessly in real time from the insoles and to transfers it to a backend computer server via mobile internet connection. Transfer of data from the insoles to the smartphone is most conveniently implemented using a wireless standard already found on available smartphones.

Most modern smartphones have Bluetooth for enabling short range exchange of data with external devices. The classic Bluetooth protocol is not however optimized for power conservation and was for that reason deemed unsuitable for the WIISEL system since the batteries used in the insoles must be thin and flexible and therefore have limited capacity to store energy. The Bluetooth Core Specification v4.0 adopted in 2010 introduced the so called Bluetooth Low Energy (BLE) standard that is optimized for devices with limited power supplies. The maximum effective application data throughput of BLE is not higher than ~64 kBit/s but it is sufficient for the WIISEL system.

2.3 Power System

A rechargeable single-cell Lithium Polymer battery is used to supply power to the WIISEL insole system. The battery is flexible to some degree but to reduce wear due to flexing, the battery is placed in the heel area of the insole. The energy storage capacity of the battery is enough to power the WIISEL system in full sampling mode for about 20 h.

Hence the battery must be charged wirelessly and preferably using chargers that are readily available on the market, the insoles comply with the Qi standard for wirelessly charging electronic products. Energy is transferred inductively to a coil embedded in the insole that is coupled to an integrated receiver that stores the energy in the battery.

2.4 Smartphone Application

A smartphone application is developed to function as a control interface for the WIISEL system and to collect and store sensor data from two insoles in real time. The user of the system will be able to connect wirelessly to his insoles when he puts on his shoes in the morning and the smartphone will store all data collected during the day on the smartphones internal flash memory. At the end of the day the user will take off his shoes and charge the insoles. At the same time he will connect the smartphone to a charger and while it is being charged it will transfer the sensor data collected during the day to a backend server using mobile internet connection (WiFi or 3G). The usability and acceptance of this device was tested in the preliminary phase of the project via a use case analysis.

The application is developed for the Android operating system and it is also open-sourced which gives the developer a lot of freedom in customizing the application to run continuously throughout the day.

2.5 Data Analysis Platform

Data storage will take place at a backend server and a gait analysis tool will analyse the data and visualize the results. It is the server's job to collect the data from all mobile devices associated with it and to distribute the data to the gait analysis tool.

Pattern recognition algorithms will look to establish a measure of fall risk of a patient by extracting different gait parameters from the data. Once patterns have been established, they will be presented in the form of a fall risk measure in the gait analysis tool. This will be a customizable interface, where clinicians involved in the patient's case can go into various levels of detail. A traffic light system indicating imminent risks will make up the front page of the fall risk interface. Furthermore, the patient's details will be available on the gait analysis tool including their medical and fall history.

While the detection of a fall will be based on simple statistical algorithms, a complex pattern recognition algorithm will be used to elaborate the "Fall Risk Index". In a learning phase, the system analyses several gait parameters within fallers and non-fallers available datasets [7, 8] and thereby finds patterns, markers and thresholds that differentiate these two groups. In the working phase with new users, fall risk index is extracted on the basis of the patterns that have been found. The system is constantly learning with new data coming for predicting falls.

3 Clinical Validation

The clinical validation trails will include trials in a structured environment and in the home of the participant. Usability, human factors and user experience, as well as user safety, will also be closely observed.

The clinical validation studies will be divided into 2 steps: the pilot phase (which is going to take place in July and August 2014) and the validation phase (from September 2014 until January 2015). For both sections a multi-disciplinary staff including a physician, a physiotherapist, a psychologist, a user-acceptance analyst and a technical expert will assist the volunteers to avoid any kind of problems that may emerge. Both phases of the clinical validation will include the user perspective, as such inclusion criteria in the studies will be similar as well as the recruitment methods. Quantitative methods will be used in each phase in order to gather data and results will be available at the end of January 2015. Validated questionnaires and ad hoc interviews will be used to gather feedback on the system and its functionality.

3.1 Participants

The clinical centres will recruit 60 elderly volunteers in Israel (20), Ireland (20) and Italy (20) who meet the study inclusion/exclusion criteria to participate in both phases of the study. From this pool of subjects, 15 will participate in the pilot and 45 will participate in the validation. A reserve list of potential participants will be constructed in each site as a back-up reserve to be used in the event of drop-outs or failure to attend the study.

Inclusion Criteria:

1. Age between 65–90 years
2. Ability to walk for 5 min while unassisted
3. Intact cognitive function (Mini Mental State Examination [9] score above 24)
4. Living independently in the community

Exclusion Criteria:

1. Diagnosed psychiatric co-morbidities
2. Severe hearing or visual loss (based on the Snellen and Whisper tests)
3. Unstable cardio-vascular disease or contradictions
4. Unstable medical conditions (assessed by an experienced clinician)

3.2 Pilot Study Phase

The WIISEL system is designed to evaluate daily living activities in the home and community environment and as such should address the changes in gait performance and its association with fall risk. The use of different tasks and conditions could inform on changes in gait patterns or hesitation in performance of challenging situations. The pilot phase of the study will consist of a total of 3 days of assessment, including 1 day in a structured controlled laboratory environment and 2 days in the participant's home.

3.2.1 Structured Environment

A study researcher/clinician will present the WIISEL insole and explain to the participants how to wear it, how to place the insoles in the shoes and how to operate the system including how to charge the insoles. In addition information will be provided as to type of information that is gathered by the insole including a detailed explanation of the fall risk smartphone application. The subjects will then be encouraged to wear the system for the remaining of the assessment in the laboratory.

Evaluation will be performed while the participants wear the WIISEL system. Standardized performance based measures will be assessed to provide an indication of baseline function as well as to enable a correlation of known clinically validated measures of fall risk and the data obtained by the insoles.

3.2.2 Home Environment

Participants will use the system in the home during daily activities. No specific instruction will be provided for tasks to be performed in the home as the intention of this phase is to assess the ability of the subjects to use the system and home and the acceptability of the participants to use such a device. In this way it is possible to evaluate the pattern recognition algorithm to detect specific tasks and fall risk in an unstructured environment. The participants will be asked to fill in a detailed diary on the amount (hours) of use and any problems during wearing time and a short questionnaire relating to their impressions during the use of the WIISEL system.

The information obtained from these questionnaires will be projected to the technical partners in order to address concerns by end users and try and better the system before the validation trials.

3.3 Validation Study Phase

This phase is intended to further establish the feasibility, usability and validity of the final WIISEL system for continuous monitoring of fall risk in older adults. The validation study will use a pre-post-test design in order to better validate the system in terms of test-re-test reliability of data collected as well as validate the system against known measures of fall risk. A total of 45 subjects (30 subjects with a history of falls and 15 healthy age-matched older adults) will use the WIISEL system for 2 weeks during daily life. This will enable a wide range of gait patterns and data to be used and validated and a comparison between ‘high risk patterns’ and normal patterns of older adults with minimal fall risk. The functionality of the system will also be evaluated during this phase and will include effectiveness of the system in terms of:

- Mobility assessment
- Fall risk assessment
- Fall detection
- Long lie syndrome detection and avoidance
- Fear of falling

Subjects will be instructed to wear the system as much as possible during waking hours during the period of the trial. No specific instruction will be provided for specific tasks to be performed in the home as the aim to assess natural living conditions and performance and not interfere with the participants patterns of gait. The participants will receive a manual for use of the system and a diary which they will be requested to fill out. The diary will include information on duration of use during each day, problems with the system/person that prevented use, etc. This information is imperative to also validate the accuracy of the detection algorithms. In addition the subjects will be asked to complete a fall calendar on a daily basis which will be used as a follow up of falls for 6 months.

The participants and caregivers or family will also be trained on the use of the smartphone, the necessity to wear the smartphone during the day (for the fall detection) and the information provided by the system to the participants (i.e., fall risk feedback and reports and alarm system). Regular calls will be set by the clinical partners to the participant (once a week) to receive information on use and satisfaction by the participant and encourage use of the system.

Analysis of information collected by the system will be done in real-time and provided to the participants in a simple way on a weekly basis and to the clinicians in more details upon request. If a fall occurs, a message will be sent to the clinical partners to be aware of the event and an alarm will be provided to the participant using the smartphone. In such a case the clinical partners will contact the participant and his caregivers to obtain information relating to the reason for the fall and its consequence and if there is a need for treatment. Such event will be considered an adverse event which will require reporting and managing based on a set procedure.

4 Impacts Expected from the Project

Based on the societal and technological issues and needs detected, WIISEL is expected to achieve impact in the following fields (see Table 1).

The main expected outcome from the project is a flexible research tool that will have a significant impact within the scientific community with the following elements:

1. **A constant monitoring system** for elderly people through the sensing insole connected to a data analysis system.
2. **Intelligent algorithms** which will use data analysis including pattern recognition to quantify fall risk and provide useful information on fall risk assessment. With these results the project will contribute with a self learning analysis framework as a basis for further research in optimizing fall risk prediction and identifying fall risk factors. In parallel, other approaches based on machine learning will also be developed to better evaluate fall risk.

Table 1 Project logical framework table

Societal or technological issues and needs	WIISEL objectives related to the needs	WIISEL expected impacts	Means to sustain the expected impact
Need for a wearable and unobtrusive system allowing continuous monitoring of activity and mobility in daily living conditions	Continuous monitoring of elderly people by pressure sensor insole connected to data analysis system	Impacts measurable in the frame of the WIISEL project	Scientific and technical excellence of the consortium
		Assess gait impairments and fall risk in the home setting of older adults	End user involvement
			Testing and validation
		Assess activity and mobility in daily living conditions	Holistic system evaluation
			Risk management
Need of assessing elderly risk of fall	Fall risk assessment through fall risk index, data analysis and pattern recognition	Early identification of decline in mobility performance (for assessment of motor fluctuations and disease progression for example)	Technical performance
			Economic feasibility and cost efficiency
			Operative sustainability
		Fall detection (in the home setting)	Sound dissemination and exploitation plan etc.

3. **A Fall Risk Index** based on multiple gait parameters and gait pattern recognition to assess and quantify the risk of fall of elderly population. By incorporating parameters derived from multiple sensors, and a diverse array of metrics, classifiers and techniques, this index should represent a significant step beyond the State of the Art for the evaluation of fall risk and the prediction of falls.
4. **Real-life and long term human gait data** useful for the scientific community to enrich existing databases, enable answering key questions relating to off-site assessments, daily activity fluctuations, disease states and disease progression etc.
5. A **fall detection algorithm** to feed gait pattern recognition. This algorithm may be used in the future as a single algorithm or combined with existing systems, and for the prediction of fall risk.

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MuSA: Wearable Multi Sensor Assistant for Human Activity Recognition and Indoor Localization

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Abstract In this paper a wearable multi-sensor device is used for a Behavioral Analysis (BA) focused on Human Activity Recognition (HAR) and Indoor Localization (IL). The analysis exploit a wearable device equipped with inertial sensors like accelerometer, gyroscope and compass in order to evaluate quantity and quality of movements.

1 Introduction

In a context, such as Europe, in which the population is becoming increasingly older, technology plays a fundamental role. The *Ambient Assisted Living* (AAL), a combination of technologies focused on making active, cooperative and smart the environment for an independent and self-sufficient life and the *Assistive*

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Technologies (AT), that enable people to perform tasks that they were formerly unable to accomplish, are possible approaches, generally processed independently, to deal with the problem.

Fusing together AAL and AT, new type of information can be obtained such as a sort of *Behavioral Analysis* (BA) of the user. This aims at evaluating a person's health status and behavioral evolution and, in case of particular variation of the parameters, providing information to the doctors and/or the caregivers. An example of the BA approach is described in [1, 2]. Here a PIR (Passive InfraRed) sensor is placed on a bathroom entrance in order to detect a person access.

During a two year long period, it was possible to collect the data from the sensor: information underlined user habits during the day and eventually showed a decline of his/her activity during months. Although this approach is simple and reliable, it has few limitations: firstly ambient sensors are fixed to a particular position of the house and secondly they are not able to distinguish which person has been detected. For such reasons, the BA approach could be expanded to wearable sensors as well.

This article focuses on *Human Activity Recognition* (HAR) and *Indoor Localization* (IL). The first is a recognition system based on a decision tree. It classifies particular activities exploiting inertial sensors (accelerometer, gyroscope and compass): first it distinguishes between static and dynamic activity and after it identifies an action in each class of activities: for example walking or running for dynamic activity and sitting or standing for static ones. An *Indoor Localization* (IL) system has also been implemented based on step detection, walking distance and a heading estimations.

For this project, MuSA (Multi Sensor Assistant) [3], conceived for personal activity and vital parameters continuous supervision, has been used.

2 MuSA

MuSA is based on a CC2531SoC [4] and is compliant with ZigBee 2007 Pro standard protocol [5]. It is designed to be worn on a belt and it features small dimensions and light weight (Fig. 1).

MuSA basic functionalities are fall detection and a call button that asks for immediate assistance. MuSA has been extended with further functions, hosted by the same hardware platform: a single-lead ECG system is used to evaluate heart rate and respiration rate using EDR technique [6] and a NTC thermistor is included to evaluate body temperature. A third version of this device features an inertial measurement unit (IMU) composed by an accelerometer, a gyroscope and a compass [7]. In Fig. 2 the coordinates system of the inertial sensor unit available on MuSA are showed. Signal acquisition and processing are carried out by MuSA on-board circuitry: only information about detection of abnormal behaviors or deviation of vital signs from their "normal" range are sent through the network. Radio communication is hence kept at a bare minimum (alarm messages

Fig. 1 MuSA

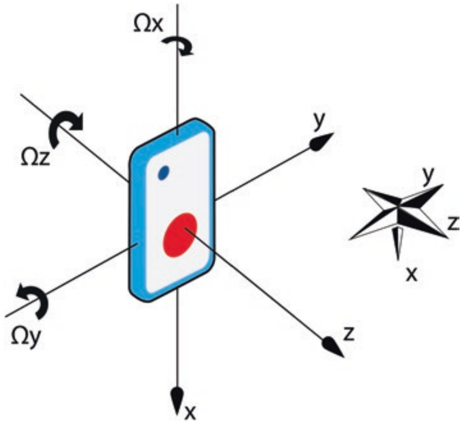

Fig. 2 MuSA inertial sensor coordinates

and network management), saving battery energy. Two basic building blocks can be identified: a IEEE 802.15.4 radio transceiver, and the CC2531 microcontroller taking care of ZigBee stack management.

3 Human Activity Recognition

Regarding the BA context, the focus of this project relies on *Human Activity Recognition* (HAR) [8]. The aim of this approach is to distinguish general activities such as walking, run, postures, etc. or, also via data fusion from other sensors, specific actions like sitting on armchair, open fridge, cooking, go to the toilet, etc. Daily activity analysis is useful in order to evaluate physical and behavioral changes in the person, especially elderly and people suffering from chronic diseases. Suitable parameters for this analysis can be divided in four principal groups: environmental values (temperature, humidity, occupancy, etc.) and personal ones (accelerations, positions) and vital signs (heart-beat, breathing rate, etc.).

As for every machine learning approach, HAR techniques rely on two phases: training and testing. During the first, acquired sensors data are processed in temporal windows in order to extract relevant features from the raw signal. Later, during the second phase, an automatic feature detector has to be implemented on the device in order to work autonomously.

Since inertial sensors are available on MuSA, here the HAR focuses on user movements. Relevant importance resides on the position where the inertial sensor, i.e. accelerometer, is applied on the human body. It can be applied on arms, wrists, ankles, thighs [9], feet [10], back [11], waist [12]. The more the sensors the more activities can be detected.

Extraction feature techniques rely on *supervised learning*, whereby acquired data are manually labeled and then extracted features are automatically detected using a proper algorithm. Different solutions are available: decision trees are hierarchical models in which every branch corresponds to a classification rule [13]; Bayesian methods gives the probability of every actions from a training set [14]; *Instance Based Learning* (IBL) methods perform the distance of two sets in order to evaluate the similarity [13, 14]; finally Support Vector machines (SVM) and artificial neural networks set a more complex set of rules than the previous approaches [15].

Activity recognition can be performed *offline* in which processing is later run on a computer or *online* on the device where actions are real-time detected.

Since MuSA features a low-power SoC, the HAR algorithm is based on a decision tree solution [16]. As depicted in Fig. 3, in the top level the algorithm

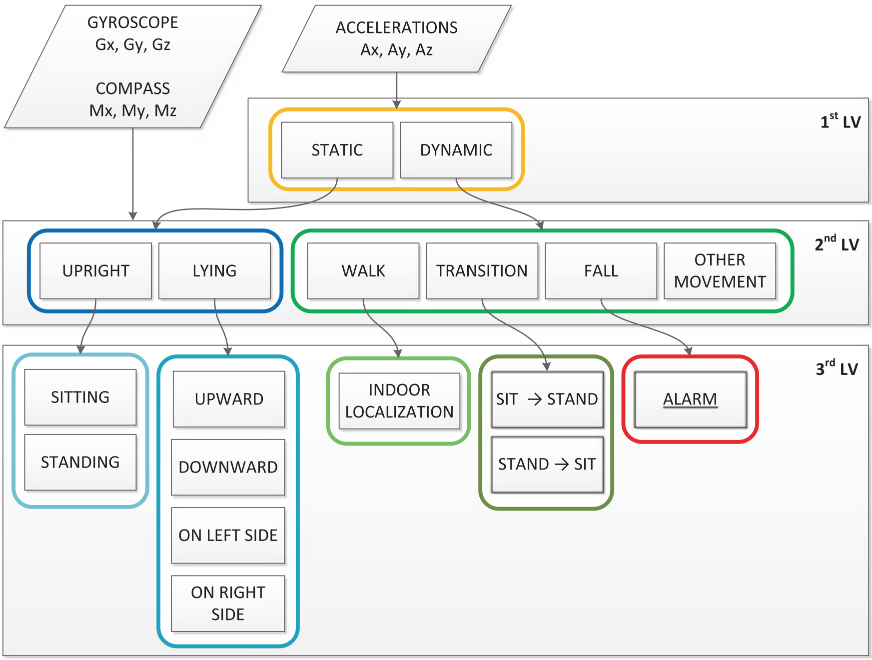

Fig. 3 HAR: binary decision tree

classifies broad activities and recognizes more detailed activities in the lower. In the first stage the system process the acceleration data in order to distinguish static and dynamic cases. After that, it needs gyroscope and compass information to evaluate for example the direction of walking or the orientation of a posture. During the static phase the framework classifies upright or lying positions: the firsts happens when the user is sitting or standing, the seconds are different due to the body orientation. On the contrary dynamic movements are classified as walk, transitions, falls and other movement.

In order to classify resting and activity states the algorithm processes the acceleration components through a high-pass FIR and these are used to compute the acceleration modulus. By integrating the modulus over a 1 s window it is possible to obtain a measure of the metabolic energy expenditure (EE) [16]. It is possible thus to distinguish static from dynamic activities by comparing the EE to a proper threshold: if below, a rest situation is detected, otherwise a dynamic activity is inferred (Fig. 4).

After that, the algorithm proceeds to the proper branch of the decision tree. During a static phase it is possible to observe the posture of the person carrying MuSA. For example, by simply computing the arctangent of the ratio between two accelerations orthogonal to the gravity component (y and z in this case), the tilt angle (body orientation) can be extracted.

An example is depicted in Fig. 5, where the user is in the upright position (sitting and standing). The same results can be inferred from the gyroscope: by integrating the angular rate Ω_y (pitch angle), the orientation can be obtained.

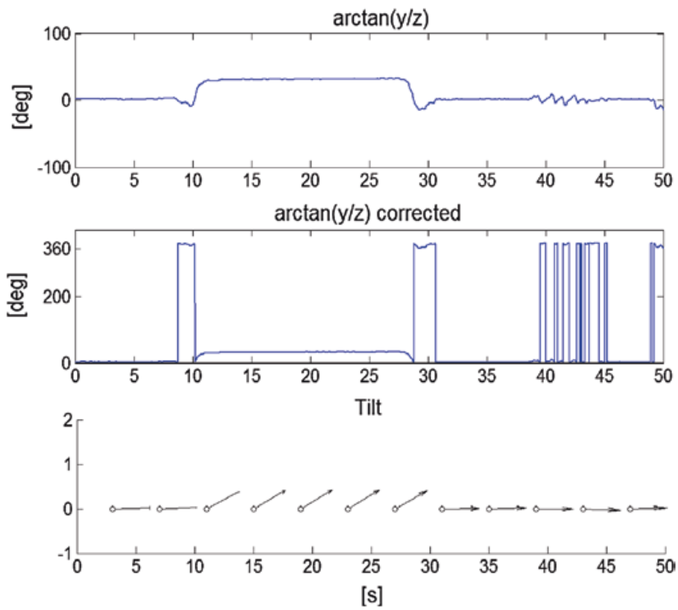

Fig. 4 Body orientation angle evaluation

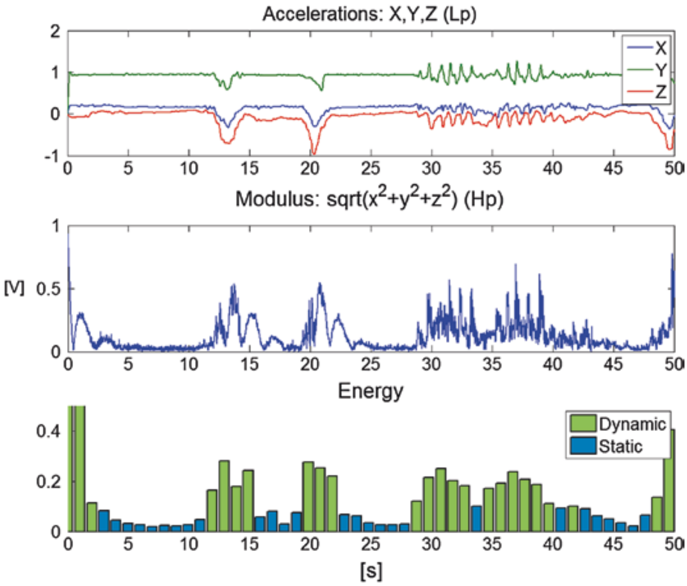

Fig. 5 HAR 1st level: static/dynamic activity recognition

Thus is possible to recognize if a person is sitting/standing or he/she is lying. In order to properly discern if a person is sitting or standing the system needs to look back in the activity history. For example if the systems knows a sitting transition has occurred right before a static phase, this last will have high probability to be classified as a sitting phase.

If otherwise a dynamic activity is detected, the algorithm operates in order to distinguish few actions. So far, movements can be classified as walk, transition (sit/stand, stand sit) and other activity. Here the algorithm first looks for maximums observing the modulus of the low-pass filtered accelerations (3rd FIR, 3 Hz). Maximums closer than 3 s are labelled as "steps" and these belong to a walking series. If isolated maximums are detected, the algorithm looks for a possible transition (stand to sit or sit to stand). Here an assumption has been made: by looking the training set acquired during tests, it is clear that actions like sitting or raising take more time than a single step. For such reason, the system observes the dynamic interval in which the maximum has been found. If this time is big enough the action is then classified as transition, otherwise as other movements. The classification just described is depicted in Fig. 6. Although this process, MuSA runs the fall detection algorithm showed in [3] independently: since a fall occurrence is a major problem its management requires the highest priority.

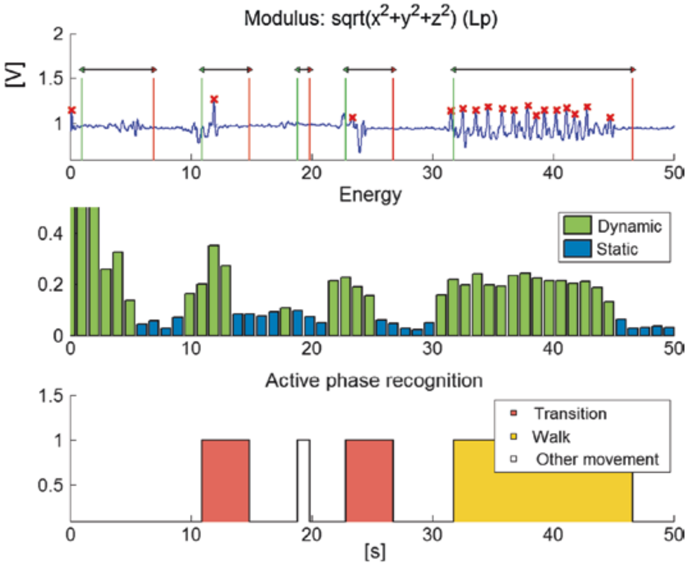

Fig. 6 HAR 2nd level: walking and transition detection

4 Indoor Localization

Indoor localization is useful to know the exact position of a person and avoid loss due to chronic diseases as Alzheimer or to quickly assist the user if an alarm has arisen.

In the previous paragraph a step detection exploiting a tri-axial acceleration has been introduced. In order to implement a localization system, a gyroscopes and a magnetic sensor are necessary to evaluate the direction of the user during the walk.

Human gait (passo-andatura) can be described by an inverted pendulum model [17]. Each step is characterized by different phases. When a heel is touching the floor, the height of the waist is in its lowest position, as a consequence the vertical velocity is equal to zero and the vertical acceleration has reached the maximum. When one foot is totally on the floor and the other is moving forward the waist is at the shortest distance from the equilibrium. When the foot on the ground is now on its tiptoe, body is pushed up and the vertical acceleration changes to the opposite direction.

Instead of computing a double integral the vertical acceleration (a_X) in order to measure the walking distance executed, here an empirical relation on a_X with the stride length is used [18]:

$$Step\,Length = K \cdot \sqrt[4]{a_{MAX} - a_{MIN}}$$

where a_{MAX} is the maximum and a_{MIN} is the minimum of the first harmonic of a_X and K a calibration constant that has to be extracted from experimental data (Fig. 7). Here K is different for every user.

Last phase of the localization system needs to process gyroscope and magnetic sensor data to evaluate the orientation. Gyroscope vertical component is integrated to obtain the orientation angle Ω_X (yaw). For the same purpose the arctangent of ratio of the orthogonal magnetic sensor components to the ground (y and z) is computed. Figure 8 shows the heading direction obtained from both sensors.

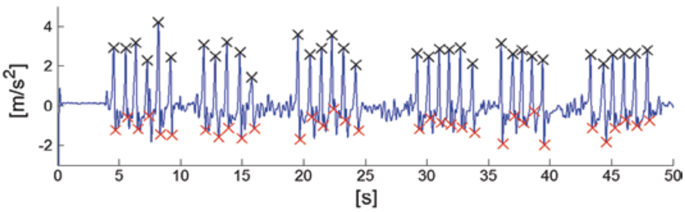

Fig. 7 Maximum and minimum detection

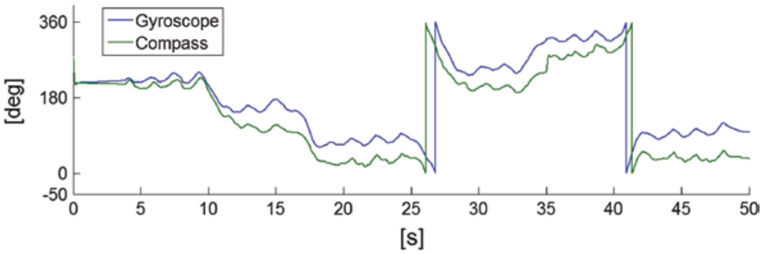

Fig. 8 Yaw angle: gyroscope (*blue*) and compass (*green*)

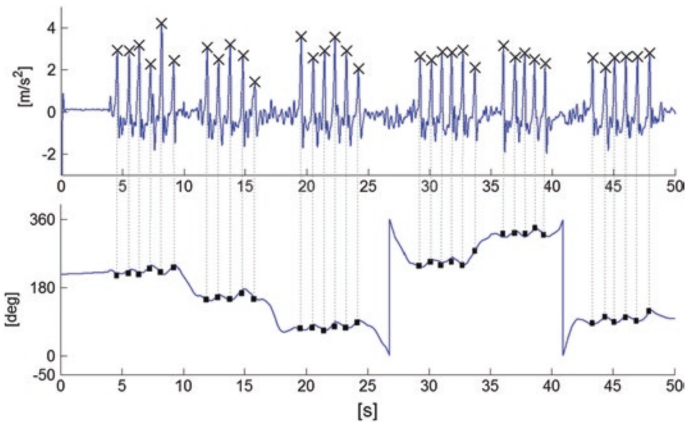

Fig. 9 Step detections (*above*) and average yaw (*bottom*)

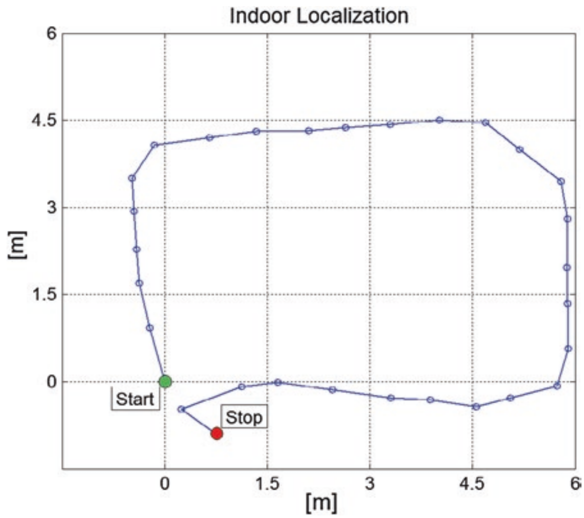

Fig. 10 IL experiment on a rectangular path

Heading values have been obtained measuring the yaw at the exact time when the peak of the step has been detected (Fig. 9). Due to the drift caused by the integration on the gyroscope signal, the heading is corrected by the compass values.

Through step detection, walking distance estimation and heading estimation, the framework is able to provide the result of the localization system (Fig. 10). In the example, the user walked in a room along a rectangular path (6 m x 4 m).

5 Results and Conclusions

In this paper a wearable multi-sensor device oriented at the behavioral analysis has been described. This is based on Human Activity Recognition (HAR) which detects particular activities and on Indoor Localization (IL) that is useful to know where the user is if a quick assistance is needed.

The HAR framework is a solid algorithm based on a binary tree and is able to recognize main activities as walking, sitting/standing, fall and rest situations as upright and lying positions. Preliminary tests state that the algorithm easily distinguishes static and dynamic situations and also detects walking phases with a very high accuracy (99.6 %). More problems arise when the framework has to distinguish between step and a sitting/standing transition: here the accuracy of the walking phase reduces to 95.2 % and the sitting/standing transition accuracy is 96.3 %. So far, the algorithm is not able to distinguish if a person is sitting or standing, thus it needs a history of activities to understand what happened before. A useful solution is to exploit information coming from ambient sensors, i.e. a pressure sensor placed on a sofa capable to detect if a person is seated.

The indoor localization system has also been tested. Users were asked first to walk back and forth on a straight line and later to complete a rectangular open path and a closed one. The last two experiments are showed in Figs. 11, 12, here only three users are showed for simplicity.

The IL major problem of error consists on the integral operations on the inertial sensor components. Thus is necessary to support MuSA with another system capable to reset the error and give a precise position from time to time. A solution could be to use localization techniques using wireless technologies. For this

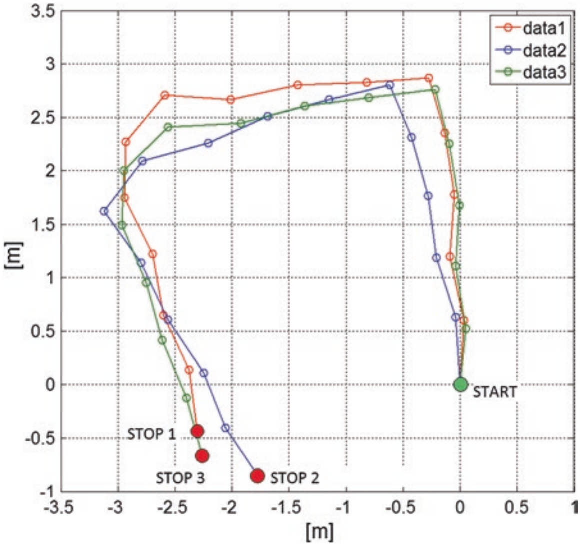

Fig. 11 Tests on open rectangular path

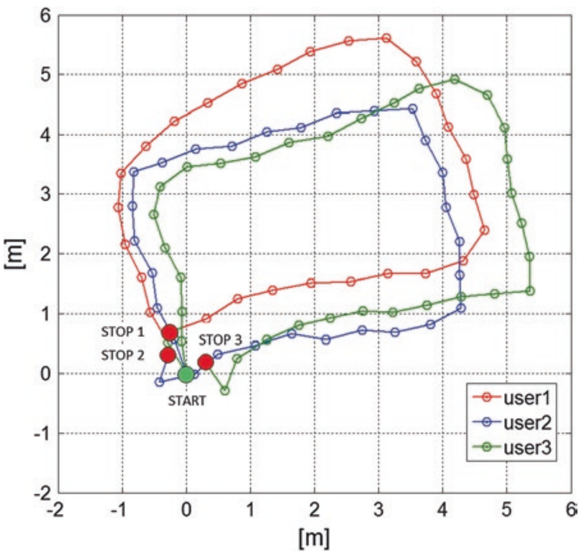

Fig. 12 Tests on closed rectangular path

purpose the ZigBee communication is suitable since this protocol is already in use on MuSA. A solution relies on the Received Signal Strength Indicator (RSSI) evaluation [19]. In principle it is possible to realize a gate capable to detect if a person has passed by placing two ZigBee nodes close to each other on a door. These two nodes send messages to each other and evaluate the RSSI value for every message. It is known that whenever a person passes through the gate, due to physical causes, the evaluated RSSI parameters will have lower values. For the same principle, exploiting the RSSI of MuSA, the gate can recognize which person has been detected and thus update its location coordinates.

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Tools for Behavior Monitoring: An Ambient Assisted Living Real Experience

Agostino Losardo, Ferdinando Grossi, Guido Matrella, Ilaria De Munari and Paolo Ciampolini

Abstract In recent years, sophisticated technologies for personal monitoring are rapidly spreading. Mainly, these devices are medical sensors for domestic use, that allow for monitoring the most important physiological parameters. These smart devices enable to detect information closely related to the user's health. Despite the effectiveness of these tools, such approaches do not allow for the detection of the personal wellness state, in a wider sense. From this point of view, more information can be detected by the analysis of user's behavior. Especially in the case of elderly users, changes of behavior may be clues of situation of uneasiness or worsening of health condition. To support the monitoring of wellness conditions, tools and techniques for behavioral analysis have been developed at Information Engineering Department of University of Parma (ITALY). In this paper, a non-invasive and cost-effective technology is presented: the CARDEAdomus Ambient Assisted Living System. Eventually, results related to a experimentation, carried out by means of the System in a real context, are showed.

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1 Introduction

In an AAL context, home environments equipped with smart technologies can enable to monitoring the well-being of users [1].

In some experiences, specific sensors are used to monitor particular diseases [2]. In other case, raw data provided by a network of sensors can be stored and analyzed to extract meaningful information about habits and changes of behavior [3].

This approach can be useful to foster the safety and autonomy of frail people as, for example, elderly living alone.

The availability of tools that allow for the identification of trends and changes in behavioral assessments can be exploited to prevent diseases: a decrease in daily living activities or behavioral changes, may reveal an early onset of a disease, despite the regularity of the main physiological parameters.

Moreover, in a long run, the analysis of the user's behavior can highlight slow changes, hardly detectable by day-by-day observations performed by caregivers.

Devices dedicated to behavioral analysis should not be considered as substitute, or alternative, of medical instruments but, rather, as complementary tools: the goal is provide aid to caregivers (physicians, family assistants or relatives) for a constant monitoring of the users, even remotely.

The Information Engineering Department of University of Parma has developed a system, called CARDEAdomus, specifically designed to support the caregivers in the monitoring activities of frail elderly living alone. CARDEAdomus is an AAL System that offers an high degree of reliability, low costs, and low intrusiveness and is easily customizable according to the needs of users.

Unlike other systems AAL, CARDEAdomus is not devised to monitor parameters relating to a specific disease: medical devices may be included but are not necessary. The main purpose of the System is the monitoring of the user's well-being status in a wider sense.

Events detected by the network of environmental sensors belonging at the CARDEAdomus System, are stored in a web-based database. The recorded data are processed by a software to produce information about user's behavior [4].

Moreover, CARDEAdomus System provides a web application in which a variety of services and information are accessible by the caregivers (for example, a relative) to monitor the user's activities all day long.

The information provided by the CARDEAdomus System not require special technical skills to be interpreted. They are displayed in a graphical interface easy to understand.

In case abnormal or dangerous events are detected, the system is able to generate automatic alerts on the basis of customizable rules, modeled on the needs of the user (and his family).

In this article, CARDEAdomus tools for behavioral analysis are presented. Starting from the raw data that the environmental sensors detect in time, it is possible to extrapolate patterns and activity indicators that allow for identify irregular behavior or significant changes. In particular, a real experience of use of the CARDEAdomus system is described in details.

2 Methods

An home automation system for assistive purposes, aimed to implement several useful AAL services, has been developed by the researchers of the Information Engineering Department at University of Parma. Such a system, called CAREAdomus, by means of wearable and environmental sensors connected to a Central Unit (typically, a small PC), provides a continuous monitoring. The results of such activity are accessible even by remote, through a simple web page.

CARDEAdomus is an evolution of the CARDEA System [5], developed by the same research group and installed in several pilot sites since 2007.

In fact, otherwise of the majority of AAL Systems in literature (typically tested in special living-lab or demo-room), the CARDEA System has been installed in a number of real contexts. In most cases, the CARDEA system was installed in sheltered housing for the elderly located in Apennine villages of the Province of Parma. The technology of the CARDEA system was devised precisely for that particular context and was based on the use of wired, standard and low cost environmental sensors.

In a domestic environment the installation of wired sensors can be a drawback from several point of view: for example, the installation costs could become a predominant related to the technology costs. Also, in general, elderly do not easily accept changes affecting their living environment.

A better approach to introduce non-invasive smart sensors in a domestic ambient is the exploitation of possibility offered by wireless technologies. In the CARDEAdomus System, wired sensors have been replaced by a wireless sensors network based on a ZigBee technology. This development enables reduced installation time, costs and intrusiveness. In addition, the components of the system can be easily removed and eventually re-deployed when no longer of interest for the user or his caregivers.

The wireless sensors network is coordinated by a Central Unit that hosts the main application and a web-server.

The typical set of wireless sensors coordinated by CARDEAdomus is composed by:

- motion sensors (called PIR, Passive Infra-Red), for detecting the presence of a person inside a room of the home (for example, the bathroom or the kitchen);
- magnetic contacts for detecting the opening of doors or windows;
- a remote control with 5 buttons and an embedded temperature sensor;
- bed and armchair occupancy sensors;
- a smart power outlet for the measurement of consumption (useful to detect if a particular household appliance is on, for example the TV);
- a sensor of smoke/gas presence and a flooding sensor.

The main application, hosted on the Central Unit, performs the following functions:

- it communicates with the wireless sensors to retrieve their status
- it records in a MySQL database every event or information detected by the sensors installed in the home environment

- it provides a web-based graphical interface accessible by the caregiver
- it verifies the occurrence of potentially dangerous situations on the base of programmable rules, defined by the caregivers
- it activates warning messages on the web application
- it generates automatic emergency call, if needed, by means of an optional phone dialer.

Using the web interface, accessible via web browser (using a PC or even through a smartphone, or a tablet, connected to the Internet), the caregivers can easily know the activities carried out by the user in his/her home. No camera are needed, the monitoring is done in an indirect and non-invasive way.

In Fig. 1 a screenshot of the web interface is proposed.

Information expressed by the interface are immediately understandable even to an operator without special technical skills. In the case showed in the Fig. 1, the caregiver is informed that the user:

- got up from the bed about 5 h and half before;
- occupied the armchair since 5 min before;
- does not enter the bathroom since about 1 h before;

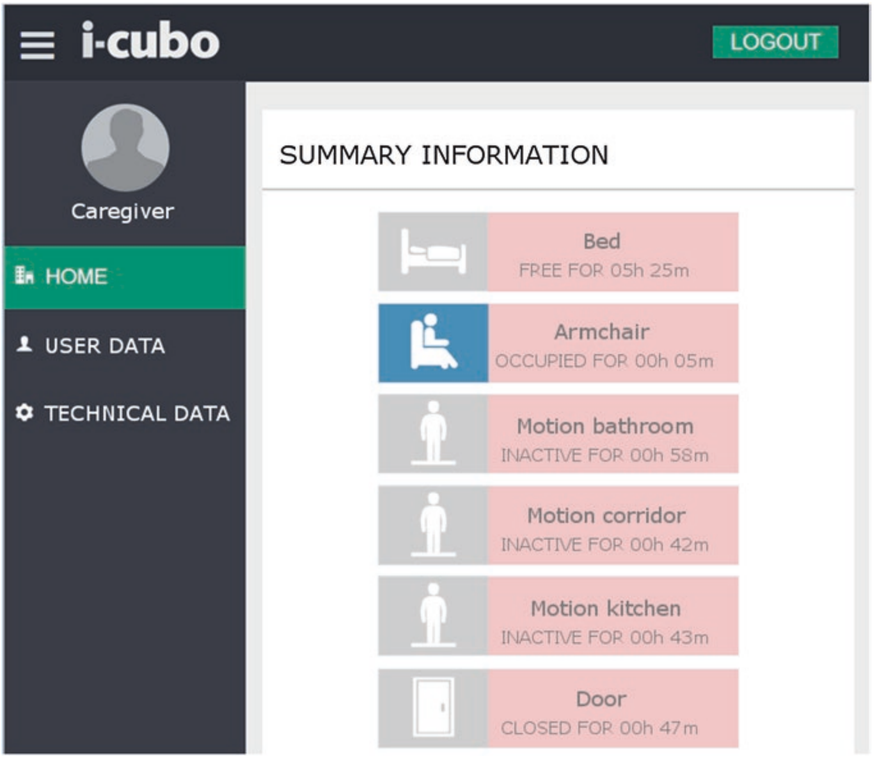

Fig. 1 The screenshot of the caregiver control panel interface

- does not walk the corridor since 42 min before;
- does not occupy the kitchen since 43 min before;
- does not open the main door since 47 min before.

The great amount of raw data stored in the database enables to analyze and elaborate these trivial information in order to extract behavioral patterns related to the user's habits. Changes in behavior can be detected in order to foster prevention actions and to obtain early diagnosis of physical or cognitive decline.

In this article, a real experience in which CARDEAdomus was installed and tested, is presented. The pilot installation was carried out in the home of a 92 year old lady, living alone in Milan (Italy). This experience is the first real experimentation of the CARDEAdomus technology in an actual domestic context. From this point of view, the reliability and the acceptability of the system have been tested and stressed.

The user was constantly monitored by the system and the web control panel was visited by caregivers both professional (or formal, i.e. operators of a small company that offers services dedicated to elderly people) and informal (the daughters of the lady, in this case). Furthermore, for a few hours a day, the lady is assisted by a family assistant, that helps her in some domestic activities (like cooking or cleaning).

The AAL tools provided by CARDEAdomus allow for a more continuous and reliable control of the user's well-being.

The installed system was composed of:

- 3 motion (PIR) sensors (for bathroom, corridor and kitchen)
- 1 bed occupancy sensor
- 1 armchair occupancy sensor
- 1 opening sensor (magnetic contact) for the main door of the apartment
- 1 flooding sensor in the bathroom
- 1 emergency button, installed near the bed
- 1 phone dialer for the automatic emergency calls
- 1 Central Unit (a PC).

Most of sensors are battery powered, and all data are sent to the central unit using wireless radio communication. This will remove the need for cumbersome cabling in the user home.

The use of this kind of approach allows also for easy and fast integration/variation of sensors during the use, depending of the specific needs for information of caregivers.

The system delivers to the caregivers three main assistive services:

1. the access at the web control panel (Fig. 1) to monitor, by a synoptic interface, the current status of sensors and recent activity (for example: how long user has occupied the bed or how long user does not accedes to the bathroom);
2. the generation of automatic emergency calls when particular situations occur (for example, in case of flooding in the bathroom) or according to programmable rules (for example: "IF the user leaves his bed during the nighttime—between 23:00 and 06:00—AND he does not go back to bed within 30 min, THEN the System actives a phone call to assistants or relatives");

3. the possibility of detecting anomalous situation by observing the results of the elaborations of trivial data stored in the database. At this moment this services is available only to expert users, who can have a direct access to the database; this service is not provided to informal caregiver.

The system realized is devised to be used by both formal and informal caregivers, who gets appropriate information, with more or less details, relatively to his specific role. A readily available set of easy to understand and to use information is directed to the informal caregivers, relieving the anxiety usually connected with the need to care for a loved one. This is done with a dynamic summary of current relevant information related with the user activity and well-being.

At the same time a relatively big amount of information in continuously recorder, allowing for a more detailed analysis of the information by professional caregivers and medical doctors, who can evaluate various aspect of the user well-being with very little intrusion in the user daily life.

The system allows also for a number of configurable automatic analysis tools and for the setup of automatic triggers to help the review work of the raw data.

3 Results

The experience presented in this paper lead to the first validation of the technology behind the CARDEAdomus system with regard to four fundamental issues:

1. *Acceptance*.
   The installation and the configuration of the system required a limited time (about 2 h). No work of masonry was needed. From a practical point of view, the presence of the system is almost completely transparent to the end user (the lady of 92 years).
2. *Usability*.
   The informal caregivers (i.e. the daughters of the lady), after a short training, have learned to read properly the information provided by the web interface: the information are self-explanatory.
3. *Effectiveness*.
   By programming suitable rules, personalized alarms were defined. The System has provided answers and solutions to the requests and issues of the informal caregivers (in this case, the daughters of the lady).
4. *Reliability*.
   No particular malfunction has been detected during the trial.

To formal caregiver an additional monitoring opportunities is offered. The availability of tools for analysis of data recorded in the database enables to identify behavioral changes in a "short" or "long" period.

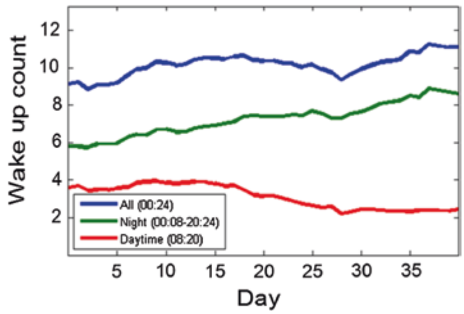

Fig. 2 Number of "got up from the bed" events

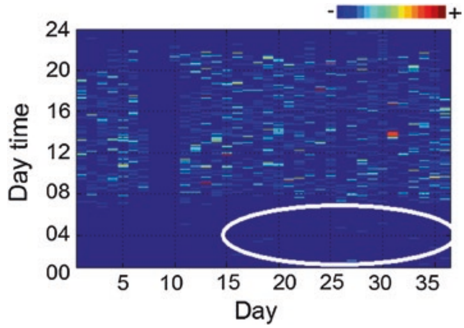

Fig. 3 Armchair occupancy 2D density map

In Fig. 2, the number of "got up from the bed" events, for a period of 40 days, is plotted: in particular, the blue curve covers all 24 h of the day, the green one concerns only the night activity (20:00–08: 00) and the red one concerns only the daytime activity (08:00–20:00).

Looking at the green line, an increase in the number of events related the night is easily detectable. The increase in the number of risers out of bed at nighttime is a typical indicator of an uncomfortable situation by the user.

This trend is confirmed by the 2-D density map covering the events associated with the use of the armchair (see Fig. 3). In the Fig. 3, the color scale maps the activity intensity during the hours of the day during a period of 40 days. Cool colors are related to less activity; warm colors are related to intense activity.

In the highlighted area of Fig. 3, an abnormal use (during the nighttime) of the armchair can be observed. In the white oval, a particular density of events "occupation of the armchair", which has not previously occurred, were recorded by the armchair occupancy sensor. The presence of an alteration of the wake-sleep cycles can be the symptom of a prolonged state of malaise. Using the CARDEAdomus tools, the formal caregiver is enabled to investigate the possible causes of this abnormal situation, which otherwise would not have been identified, because at nighttime the lady is left alone.

4 Conclusions

The experience described in this paper, represents a concrete example of application of an AAL system well suited for a domestic approach, carried out by the use of the CARDEAdomus System.

The system allows for a continuous supervision of the well-being state of the user, using a low cost and non-invasive technology, based on the use of a easy-to-install wireless sensors network.

Using a web based graphical interface, accessible via PC or by the means of a smartphone/tablet connected to Internet, caregiver can be informed about user's behavior, 24 h a day.

In the real experience presented, an optional phone dialer was used to provide automatic emergency call in case of:

- pressure of the emergency button installed near the bed;
- presence of a flooding in the bathroom;
- opening of the main door during the nighttime;
- prolonged absence (greater than 30 min) from the bed during the nighttime;

The proposed approach, implemented with the CARDEAdomus technology, has proven to be an excellent solution from several points of view: low costs, ease of installation, reliability, acceptance by final user, usability of the web interface (both by PC and mobile devices), effective respect of the caregiver's expectations.

The more sophisticated functionalities of CARDEAdomus System, related to advanced behavior analysis, are still under development. The main issue is to implement an automatic recognition of potential anomaly. However, behavioral analysis does not pretend to provide any clinical interpretation about the well-being of user, but merely highlight situations that are potentially "abnormal", enabling the intervention of the caregivers or physicians when it is believed that the user status is critical.

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Integration of Real-Time Metabolic Rate Measurement in a Low-Cost Tool for the Thermal Comfort Monitoring in AAL Environments

Gian Marco Revel, Marco Arnesano and Filippo Pietroni

Abstract The work presented illustrates a methodology to integrate the continuous estimation of metabolic rate in a monitoring tool for the indoor thermal comfort in AAL environments. The monitoring tool adopts an infrared (IR) sensor to retrieve indoor temperatures and evaluate the mean radiant temperature for multiple positions in the space. Other sensors embedded in the central unit allow the estimation of the PMV (Predicted Mean Vote) index. Beyond the ambient quantities, an accurate estimation of the personal parameters (clothing insulation and metabolic rate) allows a reliable assessment of the indoor thermal conditions. According to standards, heart rate measurement can provide an accurate estimation of metabolic rate, but the need of measuring it continuously made this method not applicable in real scenarios. However, in Ambient Assisting Living applications it is easy to monitor vital signs from the existing equipment, e.g. wearable sensors. Therefore, this paper presents the results of the integration of low-cost heart rate sensors in a tool for the monitoring of thermal comfort. The solution turned out to have an uncertainty for the metabolic rate of ±7 % of the reading in a range from 0.7 to 3.4 m, considering that the sensor used has a discrepancy of ±1.3 bpm with respect to a reference measurement system. An accuracy of ±0.05 in the PMV computation was found as result of the uncertainty in the estimation of *M*.

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1 Introduction

In recent decades, information and communications technology has become ubiquitous throughout society. The advancement of sensor technology and the Internet of Things have created new ways of delivering health and social care services. Assistive technologies embrace a wide variety of devices that can be classified according to their role (supportive, responsive and preventive technologies to help individuals perform tasks they may find difficult, manage risks, predict dangerous situations and raise alarms). From a thermal point of view, the temperature is controlled within the indoor environment by HVAC (Heating, Ventilation and Air Conditioning) systems, which receive feedbacks from the single point temperature measurement provided by thermostat in order to switch on or off the heating/cooling. Standard ISO 7730 [4] suggests that thermal comfort should be evaluated in indoor environments by means of the PMV index, which is not only based on air temperature and humidity. This index represents, in a 7-point scale (from -3 cold to $+3$ hot), the thermal sensation of the subject within a moderate indoor environment. To compute accurately the PMV, it is fundamental to assess the effective thermal sensation that affects the body's heat balance by taking into consideration personal parameters (clothing thermal insulation I_{cl} and the metabolic rate M). Some studies [1, 15, 16] found discrepancies in the heat balance or preferences for higher or lower temperatures between the old and the young. In addition, as stated in [2, 6, 18], older adults do not perceive thermal comfort differently from younger adults but there is an effect related to personal parameters (i.e. they show a lower activity level, and thus metabolic rate, than younger). The classical thermostat is not able to provide such a measurement and perform a control according to this aspect. As a consequence, the resulting HVAC control may lack of the real thermal sensation of the end-user and this can induce an increase of the energy consumption for the climate control or bring to inadequate environments. In [11] the authors proposed a detailed methodology to provide a continuous monitoring of indoor thermal comfort and developed an innovative low-cost tool, which is currently patent pending, with potential for PMV analysis in multiple positions in the room [12, 14]. In this paper, the improved version of the system respect to [13] is presented, with the integration and experimental validation of a methodology to provide the real-time measurement of M. Standard ISO 8996 [5] provides several methodologies to assess the metabolic rate of a subject, which adopt standard constant values or perform some indirect measurements: above these, it describes a comprehensive methodology for the estimation of M by recording the heart rate at different stages of defined muscular load during an experiment in a neutral climatic environment. This method requires the continuous measurement of the heart rate, which is feasible only in specific applications. One of them is the AAL field where it is possible, in most of the cases, to have vital signs continuously. Other scenarios could be sport facilities, where there is the need to adapt the thermal comfort to changes in personal parameters according to the different activities performed [9, 10].

2 Materials and Methods

The following sections present a quick description of the monitoring system, together with the sensors adopted for the *HR* continuous measurement and the annexed methodology to derive *M*, as suggested by standard.

2.1 Description of the Thermal Comfort Monitoring System

The device developed for the thermal comfort monitoring is a low-cost tool composed of an IR scanning sensor and a central unit with sensors embedded providing the measurement of air temperature, relative humidity, air velocity and solar radiation. The core device is a simple array of thermopiles, assembled and installed on the ceiling of the occupied room. The microcontroller (Arduino Mega board) together with the software implemented allows the automatic scanning of each indoor surface to evaluate the temperature distribution. Algorithms provided by [3, 4] are also embedded so that thermal and comfort parameters (as the PMV) can be estimated for several positions in the environment. A software tool based on Android platform allows the end user to control the monitoring device and manage the data acquired. The system outputs real-time PMV maps, which are suitable to provide feedbacks for modular control, not achievable with standard thermostats. A low-cost version for AAL was presented in [13], where the authors described the possibility for the end-user to interact with the monitoring tool with a dedicated GUI for Android devices. In this way, it was possible to adapt continuously the thermal comfort evaluation according to changes in *M* and clothing level, which the user needs to provide as input for the PMV computation. However, it is to notice that the possibility to interact with the Android device is not always possible, especially in specific contexts as AAL and there is the need to reduce the man-machine interaction as much as possible. This paper presents the improved version of the system, which includes the continuous metabolic rate estimation (Fig. 1).

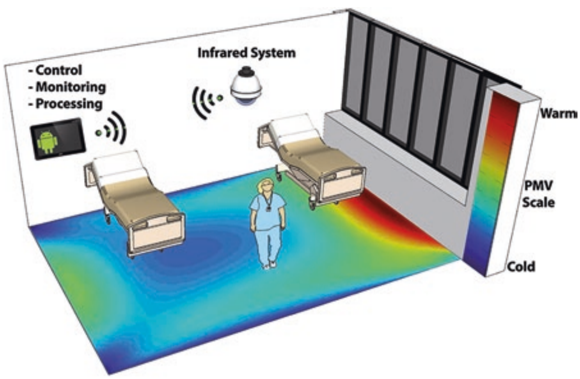

Fig. 1 Concept of the solution for the monitoring of the PMV in multiple positions in the space as proposed in [13]

2.2 Methodology for the Continuous Metabolic Rate Estimation

The metabolic rate is defined as the amount of daily energy that a person consumes while at rest in an environment that is temperate and neutral, and while in a post-absorptive state. The chemical and physical reactions that occur in an organism are reversible and depends on changes in the energy status. Uncertainty analysis applied to all the parameters affecting PMV showed clearly that *M* is one of the most important for an accurate estimation of thermal comfort [1, 13]. Notwithstanding this, it appears that in practical monitoring there is no equipment able to measure directly that personal parameter, but the assumption of constant value is adopted from tables provided by standards. According to standard ISO 8996, the metabolic rate can be derived recording the heart rate at different stages of defined muscular load during an experiment in a neutral climatic environment and then applying the relationship between *HR* and *M*. The method proposed should provide a measurement of *M* with an accuracy of $\pm 10\ \%$. Since the type of work, the sequence and duration of the load stages have an influence on both *M* and *HR*, it is necessary to use a standardized measurement protocol. The procedure requires the measurement of subject heart rate at rest (HR_0), under neutral thermal conditions. Then, the signal coming from the *HR* sensor (e.g. photopletysmography, wearable sensor, etc.) is processed to compute instantaneous *HR* values. Finally, the following equation allows the estimation of continuous metabolic rate at time *t*:

$$M(t) = \frac{1}{RM}(HR(t) - HR_0) + M_0 \tag{1}$$

where *RM* [bpm m^2/W] is the increase in the heart rate per unit of metabolic rate and M_0 [W/m^2] is the metabolic rate at rest. ISO standard provides all the equations to derive the previous parameters, as function of the weight [kg], age [years] and depending on the gender. This methodology assumes the resting metabolic rate M_0 to be constant independently from the subject, but this could represent a strong approximation. A modified algorithm proposed by Ugursal in [17] presented a formula to compute M_0 with the calculation of the subject resting energy expenditure (REE) [kcal/day], in function of weight, age, height and gender of the subject. Both these algorithms require the knowledge of several physical parameters of the subject to be used for a correct identification of the unknown variables.

In this paper, the authors propose to adopt a simplified version of the equation, which is based on a first order polynomial curve relating the metabolic rate (provided by table) and the continuous deviation between *HR* and HR_0:

$$M(t) = a * (HR(t) - HR_0) + b \tag{2}$$

where *a* is the sensitivity of the curve [met/bpm] and *b* its offset [met]. In this case, the two parameters are retrieved from a calibration on several subjects and different activities, as described in the next section. The Eq. 2 requires only the value of heart rate at rest and the continuous measured value of *HR* to derive the metabolic rate. The three methods were investigated within the tests conducted and discussed in the next section.

3 Validation

3.1 HR Measurement: Comparison to Reference System

In order to demonstrate the potential of using the information of subject heart rate to improve the determination of its thermal perception (by means of PMV comfort index), a low-cost pulse sensor was first adopted to provide real-time *HR* measurement. It consists of a small printed circuit board of 16 mm diameter, an ambient light sensor as receiver and a green super bright reverse mount LED as emitter, together with on-board electronics for power line protection and active filtering (Fig. 2a). PPG (Photopletysmography) is the working principle of the sensor, where changes in light absorption allows for the measurement of *HR*. Each cardiac cycle appears as a peak, as in Fig. 2b. The shape of the PPG waveform differs from subject to subject and varies with the location where the sensor is attached (i.e. ear, thumb).

The microcontroller was programmed to record and store the PPG signal into a SD card, with a sampling frequency of 100 Hz. An implicit routine in MATLAB software was adopted to identify the peaks of the PPG signal and the resulting heart rate [bpm] is computed as:

$$HR(i) = \frac{60}{t(i) - t(i-1)} \quad (3)$$

where $t(i)$ and $t(i-1)$ are the time instants in which peaks i and $i-1$ occur. As discussed in [7], PPG signal is able to measure the subject *HR*, but artefacts due to the movement generally influence the quality of the signal: this is the case, for example, where the subject has to perform some continuous movements (like walking, ironing). In order to overcome this limit, a second solution was adopted and tested, which is based on a commercial smart strap with conductive electrodes and embedded wearable component. The principle is similar to ECG (Electrocardiography)

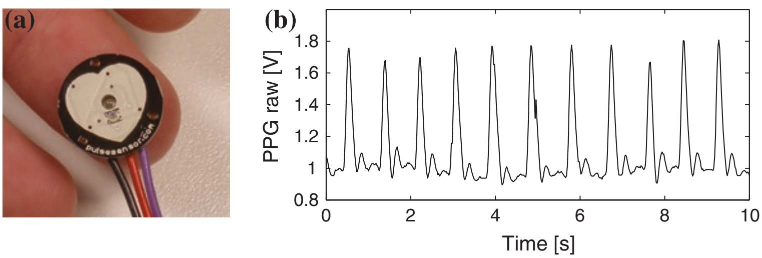

Fig. 2 Low-cost *HR* sensor. **a** Sensing element. **b** Example of raw PPG data from the sensor

and the system performs all the computation embedded, so to output directly the *HR* via Bluetooth communication. The manufacturers provide the protocol that allows the system to communicate with any Android device, together with an SDK (Software Development Kit) to develop personal applications. A simple graphical user interface was developed to acquire the *HR* data within the tests and store them into the internal memory of the device for future processing.

Some initial tests were performed to validate the reliability of the sensors adopted for the *HR* measurement. The results obtained from a measurement campaign in a population of 10 subjects (students from university, 5 males and 5 females) were compared to that of a reference system, which consists of a piezoelectric sensor (ADInstruments Pulse Transducer MLT-1010), together with an acquisition board (ADInstruments PowerLab 15T) for signal pre-amplification and active filtering. The tests consisted of a continuous recording of about 2 min each, while the subject was seated on a chair. Each test was repeated 3 times. Data were stored into a PC and different analysis were performed in both time and frequency domain to compare the results (i.e. the algorithm from Pan and Tompkins [8]). Time domain analysis proved to be the most accurate method for a correct estimation of HR. The discrepancies resulting from these experiments are:

- 0.0 ± 1.2 bpm (with a coverage factor of 2σ), for the PPG sensor;
- 0.3 ± 1.3 bpm (with a coverage factor of 2σ), for the wearable solution.

3.2 Metabolic Rate Methodologies Comparison

Several recordings of subject heart rate were made while performing different kind of activities to apply the methodology to estimate *M* following the algorithm of ISO 8996. The trials covered a range of *M* from 0.7 met (subject resting) to 3.4 met (5 km/h walking on tread mill), considering that this parameter should not exceed 4.0 met for a correct thermal assessment by means of PMV index. The tests involved eight subjects, four males and four females, from 22 to 61 years old. The tests conducted were: subject relaxing on bed, sitting and watching television, playing on a PC game, walking on tread mill, from 2 to 5 km/h (1 km/h step). Five acquisitions were performed for each subject attending the test and the resting heart rate was measured just before each consecutive recording and under conditions of thermal neutrality. Authors proposed and validated a different approach with respect to the algorithms provided by ISO 8996 or Ugursal, which allows the computation of *M* directly by the instantaneous difference between the *HR* of the subject and his HR_0 (*dHR*) using calibrated coefficients. Figure 3 shows the resulting calibration curve with the computed coefficients of the first polynomial curve which fits the data acquired in the different tests.

The metabolic rate computed applying each of the presented methodologies were compared to the standard values provided by tables, as in [5]. Figure 4 shows the curves retrieved with the three methods, while Table 1 summarizes the results obtained.

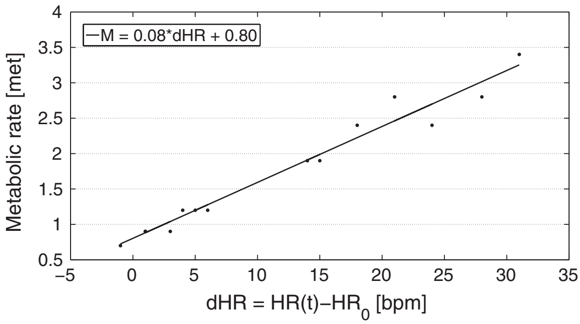

Fig. 3 Calibration curve for the methodology proposed by authors to estimate *M*

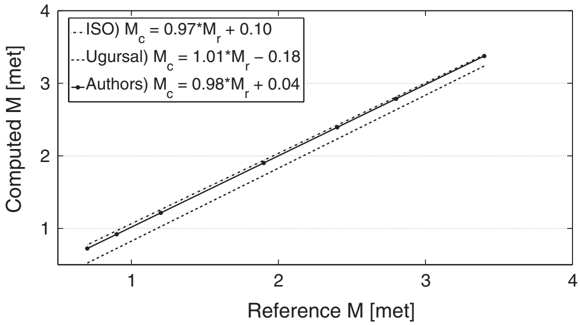

Fig. 4 Comparison of the calibration curves obtained with the three methods

Table 1 Results of the different methodologies for the continuous estimation of *M*

Parameter	ISO 8996	Ugursal	Authors
Sensitivity	0.97	1.01	0.98
Offset (m)	0.10	−0.18	0.04
STD of residuals (%)	±11.8	±12.4	±7
R^2 [%]	97.6	97.4	98.5

Although the methodology proposed requires less input parameters to be estimated with a specific calibration for each application as the one shown in Fig. 3, it is affected by a smaller uncertainty with respect to the other methods in exam as shown in Table 1. If we propagate these uncertainties in the respective uncertainty in the PMV estimation according to *M*, the results are:

- ±0.14 for ISO 8996 algorithm;
- ±0.16 for Ugursal method;
- ±0.05 for the one proposed by authors.

This algorithm can be easily integrated into the thermal comfort monitoring system and can be adopted to derive deviations in the personal perception (its thermal comfort) according to changes in the basal deviation of the heart rate signal.

3.3 Integration with the Complete Monitoring System

According to the results from the tests conducted, the methodology based on the estimation of M from the difference between HR and HR_0 was chosen to be integrated with the complete solution for thermal comfort assessment. An embedded algorithm was added into the Android GUI developed and the wearable sensor was adopted. The application of such methodology requires the end-user (e.g. elderly people) just to wear the sensor without any need of interaction with the monitoring system. The Android device integrates the information from the thermal comfort monitoring tool and the wearable sensor to provide the PMV index, calculated with the continuous measurement of M through subject heart rate. Figure 5 shows two examples of real-time measurements of M relating to the condition of low activity in (a) (e.g. no mobility) and a typical daily home activity, ironing, in (b). The measurements were conducted on two female subjects, 61 and 54 years old.

The continuous metabolic rate estimation proposed in this paper presents some advantages and potentials for the improvement of the perceived thermal comfort assessment. First of all, the fact that the system is able to identify different activities without the need for the end user to provide these data as input for the monitoring. This is the case, i.e. in AAL, where the interaction man-machine could not be always feasible. In addition, the methodology takes into account the real perception of the subject (the same activity can be performed differently from subject to subject). These advantages are clearly evident considering the application of the overall approach to calculate the thermal comfort index as shown in Fig. 6. The PMV was calculated for the two cases considering the same environmental conditions and clothing insulation. The subject with the lower activity, due for example to a disability, perceives a colder thermal sensation with respect to the subject performing typical home activity.

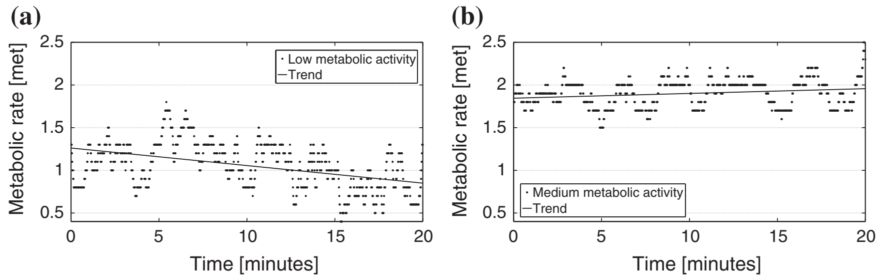

Fig. 5 Continuous metabolic rate measurements of resting subject (**a**) and daily home activity (**b**)

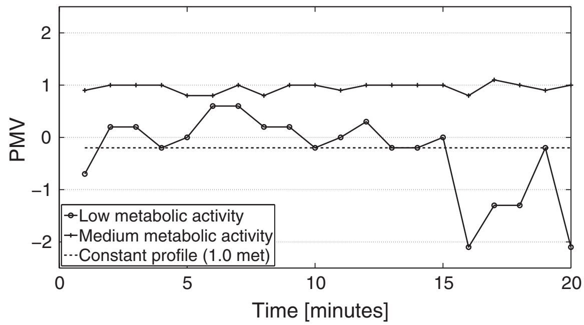

Fig. 6 Comparison of the PMV calulated for two subjects with the different activities of Fig. 5

4 Conclusions

The continuous monitoring of the metabolic rate improves the estimation of comfort conditions. Since it is based on the heart rate measurement, its accuracy is relevant for the right application. In the study presented, low-cost sensors have been tested to be integrated with a tool for the real-time monitoring of the thermal comfort. They showed a discrepancy of ± 1.2 and ± 1.3 bpm with respect to a reference system. This measurement performance turned out to give ± 7 % of deviation on the computed M with respect to values provided by ISO 8996 tables, with a resulting ± 0.05 in the PMV computation. Based on this result, the solution proposed is able to provide an improvement in the measurement of the thermal comfort, suitable for different contexts and scenarios. In particular, a calibration curve was obtained with the measurements conducted and presented in this paper. This was useful to demonstrate the feasibility of the methodology proposed. Thus, the same procedure can be applied in AAL environments where a calibration curve has to be derived for each specific application.

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Wearable Sensors for Human Movement Monitoring in Biomedical Applications: Case Studies

Michela Borghetti, Alessandro Dionisi, Emilio Sardini and Mauro Serpelloni

Abstract The research on wearable sensors for human movement monitoring is motivated by the diffusion of the reduction of the motor skills in a large part of European and World population. With the ageing of the population, this figure is expected to rise dramatically in the next 10 years. Wearable sensor systems aid and assist the patients during their rehabilitation programs, also at home, and support the doctor during both rehabilitation therapy and monitoring operations, giving him/her quantitative values of human movements. Therefore, wearable sensors can be the answer to the need for patient care, reducing the costs of the health facilities and promoting at the same time the health and wellbeing. In this paper, an analysis of different case studies regarding wearable sensors for human movement monitoring is proposed. The aim is to identify the common characteristics and give at the same time different common design strategies that can be adopted and considered in the design of these wearable sensors.

1 Introduction

A large part of European and world population is affected by a reduction of motor skills caused by different diseases with the ageing of the population; this figure is expected to rise dramatically in the next years [1, 2]. In general, the increase in life expectancy will lead to an increased incidence of senile diseases typical affecting the musculoskeletal [3]. It will also grow in parallel the request of a support for the

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rehabilitative reduction of disability [4, 5]. In this paper, the conducted research aims to analyze different case studies regarding wearable sensors for human movement monitoring; these systems can aid and assist the patients during their rehabilitation programs also at home. Wearable sensors can provide physicians with quantitative information on the patient; this allows having a feedback on the health status and improves the rehabilitation process monitoring, even from a remote center, the movements during normal patient activities. New wearable sensor monitoring systems used at home by patient allow high savings in terms of money to the National Health System and in terms of time to transfer the patient from home to clinic and vice versa. The possibility to perform therapy monitoring outside the clinic by wearable sensors, helps, moreover, the continuity and frequency of the therapy. In addition, the well-being of the patient is increased since he/she can perform daily activities in an independent way despite the obligations due to limited mobility. In addition, the possibility to perform therapy at home permits to relieve congestion problems in health care facilities. Furthermore, a rehabilitation system equipped with wearable sensors permits to perform complex personalized exercises together with the monitoring of the activity giving instruments to the doctor to evaluate the patient's progress. The wearable sensor systems can be equipped with communication capabilities in order to be directly in contact with a remote medical center. It is possible to forecast more exciting scenarios where the therapy can be executed in a home environment under the remote control of a doctor by exploiting the support of the ICT technology or in cooperation with the help of robotic systems [6]. In the next chapter, three case studies are presented and the main features and design strategies are analyzed. Conclusions and final discussions are trying to draw the guidelines and provide some strategies for the design of these wearable sensors.

2 Wearable Sensor Characteristics

In general, a system consisting of wearable sensors may have the following characteristics: (a) Wearable electronics composed of hardware detection and data collection of the physiological data. (b) Data analysis techniques to extract clinically relevant information from the physiological data. (c) Wireless communication to transfer the raw data from the sensors to the receiver. (d) Real-time operation to provide the patient with immediate feedback. (e) Portability, the components of the system may have small dimensions and weight, allowing good mobility. (f) Easy to use, the sensors should be easy to apply and reapply on the body; in addition, the system may include an intuitive user interface that makes it friendly. (g) Automation, the system can automatically collect and store the data of patient movement.

All these features have undergone deep improvements that have allowed the design of wearable devices increasingly efficient. The miniaturization of sensors and electronic circuits based on the use of microelectronics has played a key role in the development of wearable systems. One of the main obstacles to the adoption of sensing technology, in particular for wearable applications, was the size of the sensors and electronics front-end that, in the past, has made the hardware to collect physiological data and moving too obtrusive to be suitable for applications of long-term monitoring. Micro-electro-mechanical system (MEMS) technology has enabled the development of miniaturized inertial sensors that have been used in physical activity and other systems in monitoring the health status. Advances in materials science have enabled the development of systems based on e-textile. These systems integrate sensing capabilities in garments. The sensors can be incorporated into a garment to collect, for example, electrocardiographic data and electromyographic electrodes using conductive wires weaved in the fabric and/or to collect motion data using conductive elastomers on the fabric and then their resistance change associated with the elongation due to subject movement can be detected. The rapid progress in this field promises to provide the technology that will soon enable to print a complete circuit of the fabric. In the next three chapters, wearable system examples showing the previous characteristics are reported: an instrumented glove for finger movement monitoring, an instrumented vest for evaluating classical human movements and an instrumented T-shirt for posture monitoring. For each case, the state-of-the-art is reported with the aim to explain the proposed design and suggest design strategies.

2.1 Instrumented Glove for Finger Movement Monitoring

This paragraph reports the development of an autonomous wearable system (data glove) for the measurement of flexion and extension of the fingers, with particular attention to low-cost, low-power and ease in wearing it [7]. This device can have different applications: interaction with virtual reality to the diagnosis of the state of health of the hand, the control of the robotic system for rehabilitation. Data gloves are available on the market, as Cyber Glove, 5DT Data Glove, Humanglove [8]. These devices guarantee high measurement accuracy and stability with a considerable cost. Nowadays, some research groups have investigated and developed different data gloves in order to guarantee low-cost but also good measurement performance. Some examples are reported in [9, 10]. Additionally respect the previous, in [7], the challenge of low power consumption has been added, using the sensors manufactured by Flexpoint Sensor Systems (FLXT) [11]. The sensitive part is a type of carbon-based ink deposited on a flexible plastic substrate; bending the substrate, the electrical resistance changes. The sensor positioned above a joint varies its resistance depending on the rotation of the same joint. Six 2 in. and four 3 in. resistive sensors have been sewn on an elastic glove (Fig. 1), above the five joints falangei metacarpophalangeal (MCP) and the five interfalangei proximal (PIP) joints. The measurement setup (Fig. 2) defines the relationship between the sensor resistance and the joint flexion angle; it uses an optical system as calibration system, and measures a variety of parameters, such as the power consumption

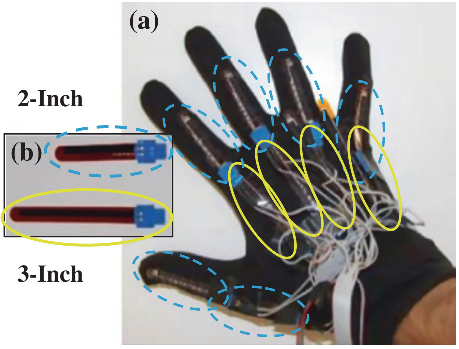

Fig. 1 **a** Arrangement of sensors and **b** type of sensors used

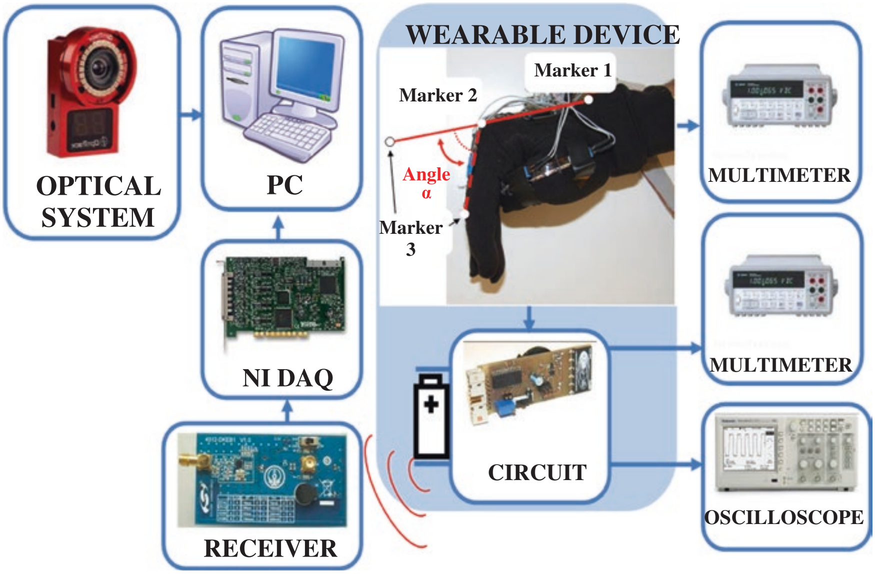

Fig. 2 Measuring system and system characterization glove and conditioning electronics

and the transmission timing. The resistance of the each sensor is calculated measuring the charging time of a commercial capacitor. The design of the conditioning board for the sensors and the development of a LabVIEW Virtual Instruments (VI) are also included in this project. The board is battery powered to ensure the wearable system autonomy. The microcontroller placed on the board manages the sequential measurement of each sensor and the data transmission to a receiver connected with a personal computer. The transmission uses the simple and low-power On-Off Key (OOK) modulation. The VI loaded on the PC reads the data

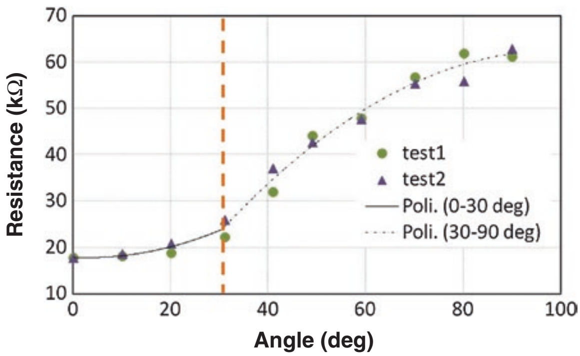

Fig. 3 Characterization curve of the resistive sensor using an optical system, which determines the angle of deflection

from the receiver; it calculates displays and saves the data of each finger joint. Using a multimeter, it has been established that this board can operate between 1.9 V and 3.6 V, whereas the maximum current consumption (which is obtained when the sensors have the minimal resistance) stands at around 3.6 mA; with a CR-2477 battery, the system works for 2 weeks. To obtain a calibration curve for each sensor, three markers detectable by an optical system are positioned on the glove (Fig. 2). A high-resolution optical system measures the positions of three markers and the data are managed by the same VI. For example, in the case of the sensor located above the index MCP joint, the results shown in Fig. 3 were obtained repeating the measures for two times. The characteristic curve between the joint angle and the sensor resistance is split in two polynomials of the second order, above and below 30°. In Fig. 4, the main signals of the conditioning board are reported as example. SENS3 is the input/output of the microcontroller and connected to the third sensor; from 50 to 72 ms its resistance was measured, after that other sensors had been measured; the EN is the transmit enable line and TX and RX are the transmitter input and the receiver output binary code. The each measure transmission lasts about 10 ms, whereas the delay of receipt is around 6 ms.

2.2 *Instrumented Vest for Evaluating Classical Human Movements*

The research focuses on the development of a T-shirt with embedded sensors for the measurement of the physical status of a person exploiting the main biomedical parameters as electrocardiogram (ECG), respiratory rate and movements and postures. Some examples about smart-shirts are reported in the literature. In [12], it is described a jacket that integrates some sensors for monitoring physiological parameters, but it does not measure accelerations and positions of the subject. In [13], the authors present a smart shirt, which measures ECG and acceleration signals for real time health monitoring. In our previous work [14], an instrumented wearable belt for wireless health monitoring is presented. This belt measures some biomedical

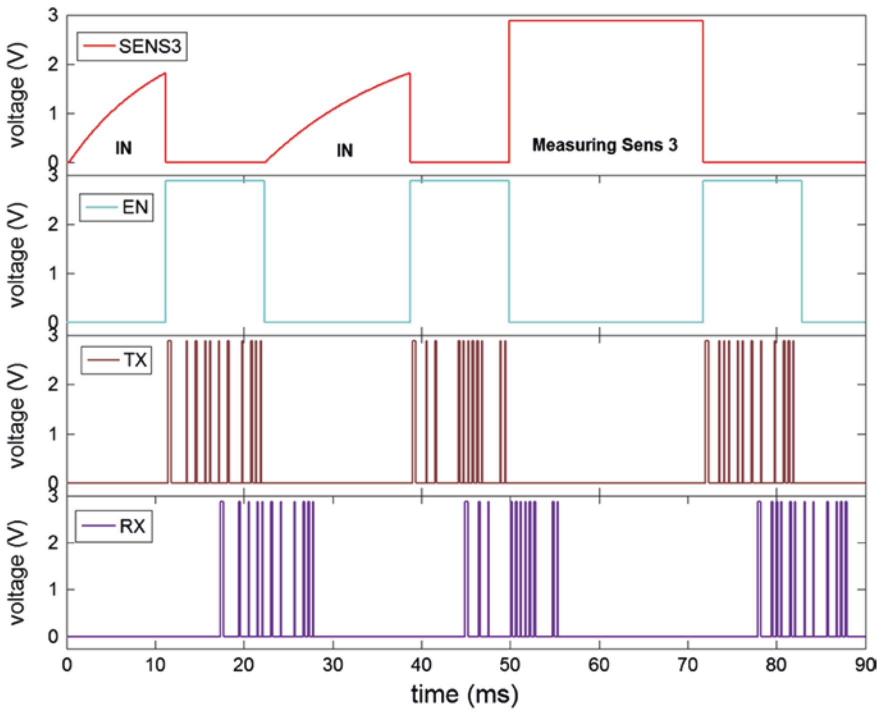

Fig. 4 Example of the main signals of the circuit board

signals, such as ECG, respiratory, body accelerations and temperature. Some common characteristics can be identified in the previous works, the acquired data are sent wirelessly to a remote monitoring station located separately and connected to the internet for telemedicine applications. The physiological parameters can be recorded and analyzed continuously during the rehabilitation activities. Proper evaluation of these parameters allows the physician to know the vital signs immediately assessing sudden changes in subject's health status. This work focuses on the analysis and evaluation of patient's movements systems using a single accelerometer and with respect the previous works the main body angles were calculated. In particular, exploiting the signals produced by the accelerometer it is possible to monitor positions and movements of the subject measuring the antro-posterior and medio-lateral angles of the body. In designing the system, important parameters were analyzed such as portability, comfort, energy consumption. In Fig. 5, the architecture of the wearable-instrumented t-shirt is shown. The used accelerometer is the low-power LIS3LV02DL commercialized by STMicroelectronics. It is a three-axis digital output linear accelerometer composed by an inertial system and an IC interface to provide the measured acceleration signals from the sensing element to the external world through a SPI interface. The acceleration data are composed of 6 bytes and are stored in a circular buffer of size 4 kB created in the internal RAM

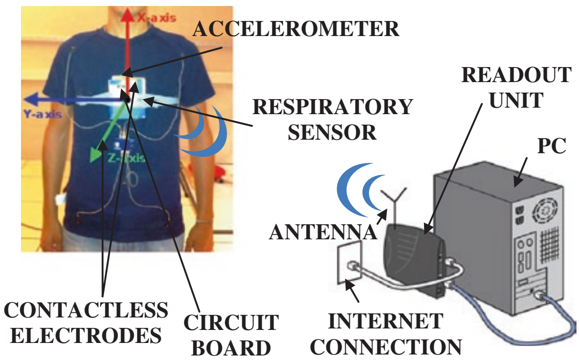

Fig. 5 Overall architecture of the system

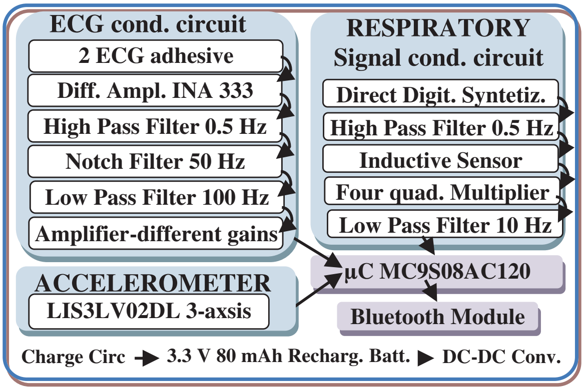

Fig. 6 Block diagram of wearable data acquisition hardware

of the microcontroller. These data have been sent to the Bluetooth module using the SPI digital interface with a baud rate of 41.66 kHz. In the proposed application, a measurement range FS of ±2 g and an output data rate of 40 Hz are used. With this configuration, the accelerometer resolution is 1.0 mg and the sensitivity is 1024 LSBs/g, about 1 mg. In Fig. 6, the block diagram of the wearable data acquisition hardware is described. The system consists of various processing blocks of the signals coming from the sensors and from a low-power microcontroller for the signal digitization and the transmission to the wireless module. Different preliminary experimental results were obtained. Figure 7 shows the acceleration outputs during sit-down and stand-up to/from a chair. Whereas, the angles are calculated using the three acceleration values by the classical equations [15] using the inertial measurement unit theory. To validate the data obtained by the accelerometer, an optical measurement system was used, the Codamotion's 3D Motion Capture. Figure 8 shows the comparison of thee antro-posterior angle obtained from the accelerometer and compared with the angle obtained from the 3D system. In this way, it is possible to know the movements and the positions of the patient in trouble guaranteeing faster intervention of specialized medical staff.

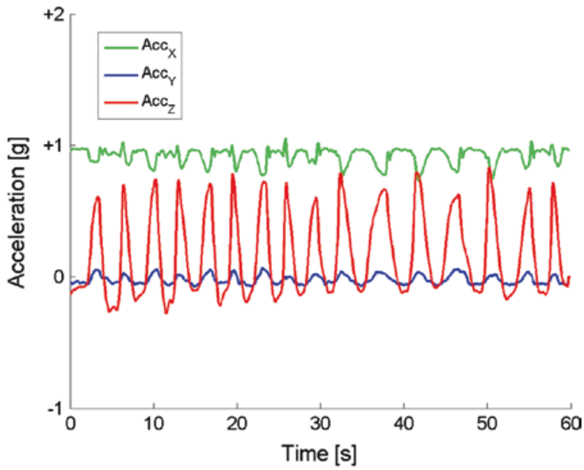

Fig. 7 Acceleration during stand-up activity

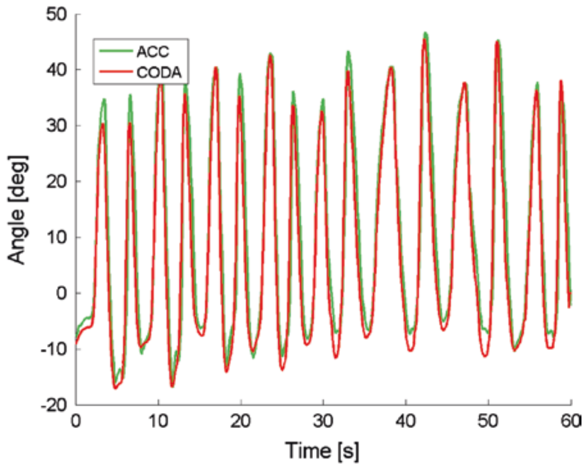

Fig. 8 The antro-posterior angle (*green trend*) compared with the angles (*red trends*) calculated with the Codamotion data when the patient sits-down and stand-up on/from a chair

2.3 Instrumented T-Shirt for Posture Monitoring

The analysis of posture is usually performed to measure the kinematic variables of the anatomical segments using specific devices as electrogoniometers [16], inertial sensors [17], electromagnetic sensors [18] or optical sensors [19]. In the analyzed cases, the main drawbacks are their weight, the rigidity of the structures that support them, size, and other properties that make them uncomfortable for the patient and therefore hardly acceptable if worn continuously throughout the day. Moreover, inertial sensors such as accelerometers and gyroscopes can present problems of offset due to the method of measurement. Another limitation is that many systems are not able to provide immediate feedback, while the patient performs the exercise. Based on this therapeutic approach, a monitoring system has

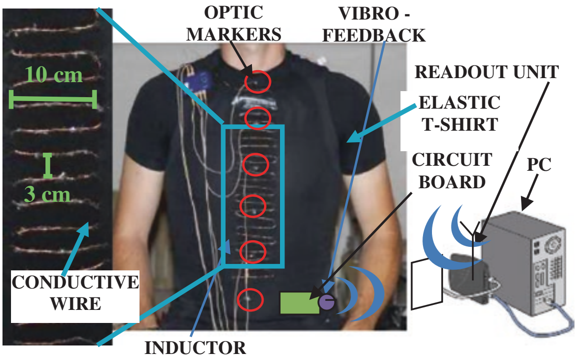

Fig. 9 Image of the wearable system with attached markers for a comparison activity with an optical measurement system

been developed by [20] to manage patients with scoliosis. The system was used to monitor the posture of the spine and to provide feedback signals to the patient to correct posture. However, the device asks you to fix with adhesive tape the sensor cable directly to the skin back and this makes it difficult to apply without the aid of another person. In [21], sensor-busts are used for patients with lumbar scoliosis, patients with low back pain for the elderly and osteoporotic vertebral fracture. However, the use of these resources is limited by external factors such as invasiveness, disorder, physical restraint, and then low level of acceptance. In [22], the research is centered on the development and implementation of a T-shirt able to detect posture and movement of the human body using an innovative inductive sensor. These inductive sensors can be used in biomechanical analysis to realize wearable interfaces able to detect posture and movement of the human body. The system tries to meet the clinical and psychological needs, such as patient comfort, ease of use and non-invasiveness. The electronics can process the data directly on the T-shirt and then create a feedback system that can provide information about the patient posture. The data may be available for immediate presentation and analysis, or sent via Internet. Figure 9 shows an image of the T-shirt instrumented for posture measurement. The proposed system can be divided in two parts: the sensorized T-shirt and the readout unit. The instrumented T-shirt is constituted by an inductive sensor, a conditioning and transmission electronics and feedback system to the patient (vibro-feedback). Two identically inductive sensors connected serially were sewed to the T-shirt, one front and the other back. Figure 9 shows an image of the inductive sensor. The sensing technique is simple: a change in posture causes a change in the geometry, generating a variation of impedance across the terminals of the inductive sensor. The circuit board linked to the T-shirt allows to measure the change in impedance of the sensor and to transmit wirelessly the data to the readout unit connected to a PC or directly via LAN cable. The block diagram of the wearable board is reported in Fig. 10. Repeated tests were performed to evaluate the performance of the proposed measuring system. A strengthening exercise for the back, performed with the subject seated, was monitored with the proposed system and the optical measurement system (Codamotion's 3D Motion Capture). In Fig. 11, the different impedance moduli are reported for six

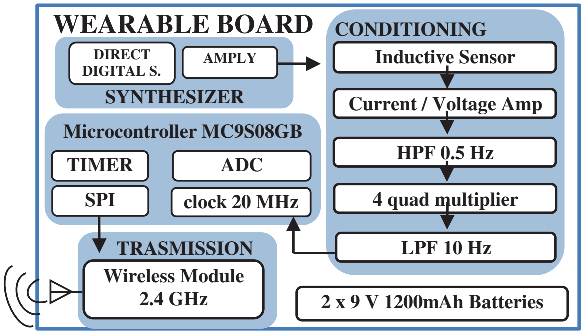

Fig. 10 Block diagram of the wearable board

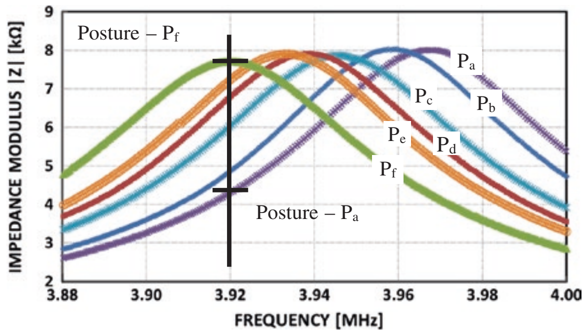

Fig. 11 Impedance measurement at different postures

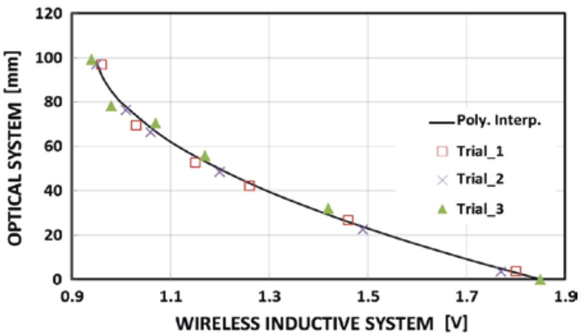

Fig. 12 Lengthening characterization obtained with the optical system versus the designed conditioning electronics

different postures. As it can be seen from Fig. 11, the posture changing from Pa (slump) to Pf (hyper-extended) generates a lowering of the resonant frequency due to an increasing of the sensor inductance. A single frequency is monitored with the designed conditioning circuit and, considering the results reported in Fig. 11, the maximum resonant frequency obtained with the back at its maximum lengthening was considered as reference. According to the data, the frequency of 3.92 MHz has been considered as reference frequency for the conditioning circuit. Fixed the frequency, Fig. 11 gives an idea of the magnitude of variation of the impedance that can be measured at the selected frequency. Figure 12 shows the lengthening values of the back obtained with the optical system and compared with the values obtained with the dedicated conditioning circuit. The exercise was executed three times and the marker positions were monitored and registered using the optical system. In the same time, the signal of the inductive sensors was sampled and recorded by the proposed system.

3 Discussions and Conclusions

The potential benefits of a remote monitoring system based on wearable sensors are obvious, but there are significant challenges before such a system can be used on a large scale. As we have seen, the integration of physiological monitoring in a wearable system often requires ingenious designs and intelligent positions of the sensors. For example, the wrist can be an ideal place for tremor associated with Parkinson's disease monitoring, but it is not considered sufficient to study patterns of locomotion [23]; in this respect, other points of application are used: trunk, head, back, and pelvis. The wrist is not recommended to be a good location, since there are many movements of dynamic acceleration that would increase the number of false positives. The positioning on the wrist is more acceptable from the point of view of the user, since this option is well suited to a belt and is closer to the center of gravity of the body. A sensor on the head gives an excellent possibility to detect a potential impact, but the hardware must be small and lightweight. These two characteristics are necessary to ensure its usability, with the aim to wear the sensor continuously. There are many other places, such as the armpit, thigh or trunk, depending on the type of measurement. Sometimes, the sensors are embedded in clothes, for example jackets, or accessories such as watches or necklaces, this allows greatly increasing its acceptability. In fact, the position and integration in general cloths strongly influences the acceptability. Therefore, the ideal system should be based on a single sensor with small form, possibly placed in a comfortable place. However, the measurement of one specific parameter is not always compatible with a measurement on a simple place such as a belt. For example, this position could complicate the posture detection. Furthermore, there are various challenges that must be taken into consideration during the design, such as, guarantee the use of the device by the patient also unsupervised, provide feedback to the patient in order to increase his/her clinical outcomes, guarantee sampling, conditioning and transmission in real-time with the aim to identify alarm situations. These challenges also include the removal of technological barriers such as reducing the weight and increasing the life of the batteries, besides the removal of cultural barriers as the acceptance by the patient of the use of medical devices for the clinical monitoring at home. Among the items listed, definitely the power supply using batteries is a strong element of criticality. The power consumption must be low in order to extend the battery life. This calls for careful management of radio communications (the task with the highest consumption of energy), signal conditioning, data acquisition and processing. To support the clinical requirements, the battery life is a big concern; the minimum duration of the battery should be at least a day, to prevent the activities of charging and changing the battery. In fact, the more the battery life is increased, the more the continuity and effectiveness of the system increases. A viable solution could be the adoption of power harvesting systems that could harvest energy from the human body in order to obtain battery-less devices [24]. In addition, further research is needed in order to solve a number of issues and enable the use of these systems in an environment without human supervision and long term. Finally, another important aspect is that the techniques of data processing and analysis are now an integral part of the design and development of systems for remote monitoring based on wearable technologies. These techniques can help in the proper attenuation of movement artifacts. The increasing attention of the scientific world to the wearable sensors aiming to develop comprehensive systems, which allow remote monitoring and interaction with the surrounding environment, will bring at systems that can operate autonomously or in cooperation with the help of robotic systems.

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A Near Field Communication-Based Platform for Mobile Ambient Assisted Living Applications

Alessandro Leone, Gabriele Rescio and Pietro Siciliano

Abstract This paper presents an open platform for continuous monitoring of clinical signs through a smart and non-invasive wearable device. In order to accomplish a communication in proximity, the Near Field Communication wireless technology is used, providing a fast link between the device and the host, avoiding the pairing (as typically occurs for Bluetooth protocol) and limiting the power consumption. The Arduino ecosystem has been used for prototyping since it allows an easy and open integration of ad-hoc functionalities. The first release of the platform has been customized for human body temperature measurement, although other kind of clinical signs could be handled with a low-level effort.

1 Introduction

In recent years the healthcare costs for aged population are rising, so that new welfare models have been defined in order to permit homecare monitoring through ICT infrastructures. The health status monitoring of aged people becomes a priority in order to improve the wellbeing and the autonomy level. The interest of research and market is not limited to dangerous events detection (as falls)

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but also on the physical condition evaluation [1]. Wearable devices might contribute to improve the quality of life of elderly, promoting healthy behavior and health awareness. Wearable systems for health monitoring may include several kinds of miniaturized/implantable sensors. Normally, they are able to measure relevant clinical parameters as heart-rate, blood pressure, body temperature, etc., providing an useful tool in self-care activities supporting healthcare specialists with elaborated and customized information. In order to guarantee a wide diffusion of wearable devices for clinical monitoring, an easy-to-use, comfortable, robust and maintenance-free technology is required [2]. Moreover, an important constraint about the usage of them is the lifetime of battery that should allow a long-term monitoring to reduce the intervention of the end-users or caregivers. Several wearable commercial devices for healthcare applications are often limited in terms of usability and feasibility due to the high power consumption (and then limited battery lifetime), especially when wireless modules are activated for data transmission. A more recent technology for radio transmission is the Near Field Communication (NFC) that assures a very short-range link (up to 10 cm) through inductive coupling. According to the TouchMe paradigm [3], NFC is easy-to-use and low-power, presenting a short latency compared to the Bluetooth protocol. Several consumer mobile devices integrate NFC, so they can be used as gateway in homecare medical services, by transmitting clinical parameters/measurements from the point-of-care to remote servers [1, 3–6]. A NFC-based architecture for Ambient Assisted Living (AAL) scenarios is described in the following. The first prototype realized integrates a biomedical chip thermistor for body temperature measurements. It allows a continuous monitoring of the thermal balance, even in presence of critical diseases, during medical treatment or everyday life. Moreover, an open source Arduino ecosystem is used [7], allowing the integration of different kind of sensors for clinical signs monitoring with low-level effort during tuning and adjusting activities.

2 Near Field Communication Technology in Healthcare

The market NFC devices is growing more and more in both active and passive form. It has been estimated that the amount of smartphones adopting NFC will increase to more than 800 million by 2015 [8]. NFC technology is a short-range half-duplex wireless communication protocol, which enables an easy, fast and secure communication between two devices in proximity. The communication occurs with 13.56 MHz operating frequency [9] providing a high-level safety than other well-known wireless technologies as Bluetooth. Since NFC reaches a maximum transfer speeds of 424 kbps, the power consumption is lower than the other aforementioned wireless protocol. However, the time to establish a connection through NFC is lower than 0.1 s., whereas Bluetooth normally takes up to 6 s. For pairing (see Table 1 for technical details about NFC and Bluetooth).

Table 1 Comparison between NFC and Bluetooth technologies

Features	NFC	Bluetooth
Network standard	ISO 13157 etc.	IEEE802.15.1
Network type	Point to point	WPAN
Range (m)	<0.2 m	10–100 m
Frequency	13.56 MHz	2.4–2.5 GHz
Set-up time	<0.1 s	6 s
Bit rate	<424 kbit/s	<2.1 Mbit/s
Power consumption	<1 mA	>15 mA

In healthcare domain, the need for a secure communication is very important. NFC enables a connection only if two devices are close, so that the data exchange is less prone to hacking by a third. Moreover several encryption techniques and security system has been developed and other new security schemes are important topics of research [10]. Furthermore, the data size generated by medical devices is usually within the capability of NFC to transmit without any undue delay. The wearable/implanted devices or long-term monitoring medical devices should have highly energy efficient and save as much power as possible. NFC protocol is well suited for such applications, as the reader can activate the RFID tag only when necessary and can also transfer power wirelessly. NFC is also more intuitive and easily understandable than other wireless technologies for elderly patients. Since NFC, in its passive form, acts just like any other RFID tag, it can be used to keep tabs on pill boxes, blisters and other drug dispensing solutions.

3 Hardware Architecture for Clinical Signs Measurement

Arduino is an open-source electronics prototyping platform, based on easy-to-use hardware and software. Arduino has developed many boards Atmel AVR-based processor since their compact size, useful peripherals and low-power sleep modes. The main features of the Arduino boards are reported in Table 2.

Table 2 Key features of Arduino boards

Supported microcontrollers	CPU speed (MHz)	Analog input	Digital I/O	EEPROM (KB)	Serial output
ATMega328 ATMega1280 ATMega2560 ATMega32U4 SAM3X	8 16	Up to 12	Up to 54	Up to 4	SPI I2C UART

A USB slave connector is used both to program the board and to provide power (otherwise a separate regulator can be used). Arduino software is implemented by using a simple Integrated Development Environment (IDE): the system accepts simplified and compiled C/C++ codes in a standard GNU tool-chain, and a simple boot-loader to automatically upload code to the processor. In this work, the first release of the platform has been customized for body temperature measurement. The Arduino NANO board (43 mm × 18 mm) [11] has been considered for the integration of a commercial thermometer since the expected workload is compatible with the integrated microcontroller (8-bit Atmel Atmega328p). The main features of the board are reported in Table 3.

For the final prototyping, the Arduino board has been replaced with a full custom designed board, by integrating the same microcontroller and the circuit blocks shown in Fig. 1. The dimensions of the overall system are lower (and then compatible with the mobile application), an accurate power management of each electronic module has been made and a full compatibility with Arduino open-source software platform has been guaranteed.

The proposed platform integrates (a) the MA300GG103A NTC thermistor [12] for human body temperature measurement, (b) an interface circuit for the

Table 3 Main features of Arduino NANO board

	Microcontroller	Atmega328p
	Voltage input (V)	7–12
	Digital I/O	14
	Analog input	8
	Output current	40 mA
	FLASH	32 kB
	SRAM	2 kB
	EEPROM	1 kB
	Operation frequency	16 MHz
	Serial output	SPI, I2C, UART

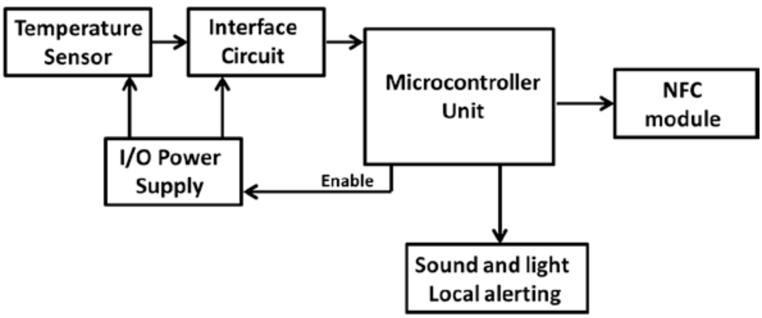

Fig. 1 Block diagram of the platform for temperature measurement

temperature sensor, (c) the SonyFelica NFC Dynamic Tag [13] module for NFC wireless communication (up to 10 cm range, up to 212 kbps speed communication) and (d) a speaker and a low power led for the local alerting. The microcontroller receives and processes data coming from the temperature sensor. The platform also provides one I2C input and five analog inputs to add other micro-sensors and textile sensors for the measurement of biometric parameters. The temperature sensing part has a low-power consumption with a resolution of 0.1 °C in the range of 35–43 °C.

The Atmega328p microcontroller is connected to NFC module through the SPI link. The NFC Dynamic Tag can emulate an NFC Forum Type 3 Tag if the data from the host microcontroller (in response to any commands sent by the reader/writer) follows the specifications of the NFC Forum [14]. Moreover, the NFC Dynamic Tag includes a function able to detect the magnetic field generated by the reader/writer allowing appropriate information to the host Microcontroller Unit (MCU). In this way the biometric parameters can be read by the user in "on demand" mode, approaching the smartphone to the device. The temperature sensor conditioning circuit has been designed according to a well-known Wheatstone bridge-based interface circuit (Fig. 2).

The platform can be set to work up to 16 MIPS and frequency up to 16 MHz. A good trade-off between MIPS and power consumption for the acquisition, real-time computing and data transmission has been found for 4 MHz operating frequency. In this configuration, the maximum total current consumption of the system is lower than 20 mA and MIPS is 4. The system is supplied by two micro-power Low-DropOut (LDO) CMOS voltage regulator with a low temperature dependence. When it is set to shutdown mode (via a logic disable signal), the power consumption of LDO and related circuits are reduced to almost zero watt (only few nA of current consumption). As shown in Table 4, the power consumption is dominated by the local alerting circuit, but it is activated (in intermittent mode) only when a critical situation is detected (a simple threshold approach). Through an intelligent and proper management of every electronic components, a long battery life is provided.

The final discrete prototype circuit is shown in Fig. 3.

The developed platform is suitable to be integrated in a wearable device. In Fig. 4b it is shown a first prototype of a customized package (as a watchstrap),

(a)

(b)

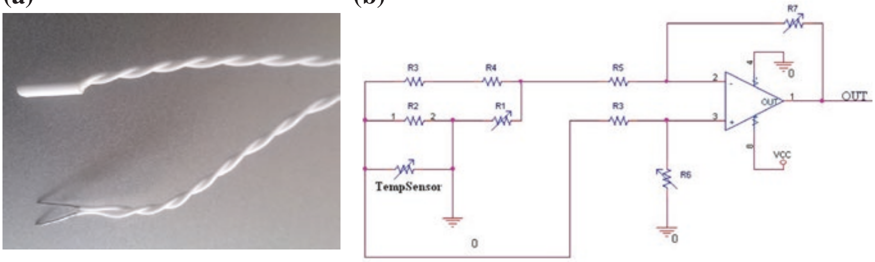

Fig. 2 NTC temperature sensor (**a**) and read-out interface circuit (**b**) for temperature acquisition by NTC thermistor

Table 4 Current consumption of each logical part of the platform

Block unit	Current consumption	
	Active mode (mA)	Sleep down (mA)
Temperature sensor	0.15	<0.001
Interface circuit	0.60	<0.010
Microcontroller unit	2.80	<0.010
Sound and light local alerting	12.00	<0.001
NFC transmission	0.80	<0.001
Power supply	0.05	<0.001
Total	16.40	<0.030

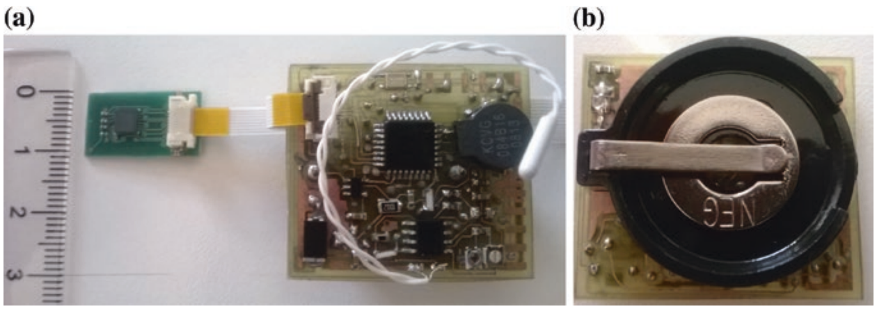

Fig. 3 *Bottom* (**a**) and *top* (**b**) layers of the final platform

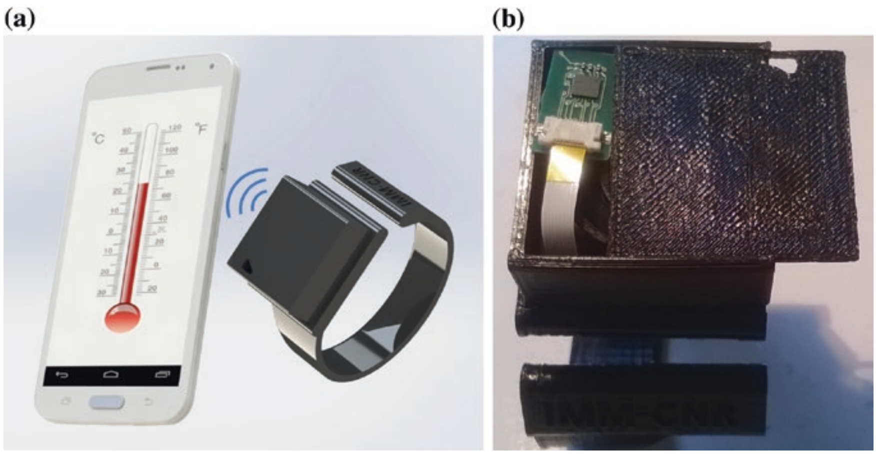

Fig. 4 Application example (**a**) and picture of the first package (**b**) integrating the platform

made in Polylactic Acid (PLA) by a BQ Witbox 3D printer [15]. The layout of prototype presented can be optimized and the dimension reduced. An example of application that can be developed for NFC-equipped smartphone is reported in Fig. 4a. Approaching the smartphone to the wearable device, the values of body temperature can be read instantly and automatically by the users. Furthermore the temperature data can be sent to a caregiver for home healthcare services (HCS), by using the smartphone as gateway.

4 Open-Based Firmware for Temperature Monitoring

The firmware for Atmega328p has been developed by using the Arduino IDE and the related open source libraries. The first step of the code considers the initialization of the peripheral I/O ports and the NFC parameters set up. Afterwards, the device is ready to measure the human body temperature and to send the data by NFC. In order to guarantee stability of the measurement, and according to the functional principle of the commercial temperature measurement devices, the time required to calculate the temperature is about 30 s. The system is able to record on the on-board EEPROM up to 500 body temperature values, allowing to evaluate the trend of body temperature along the days. During the temperature measurement phase, the maximum current consumption is about 4 mA (temperature sensor, interface circuit, microcontroller unit and power supply are activated). Moreover, by considering the NFC hardware module, the total current consumption is less than 5 mA. In Fig. 5 the duration of battery at varying of the daily measurements cycles is shown. By analyzing Fig. 5, it is apparent that it is possible to calculate and transmit the temperature measurements 100 times a day for 2 months. The local sound and light alerting is activated (in intermittent mode) only when a critical situation is detected (a simple threshold-based approach). To manage the NFC SonyFelica tag the free libraries for Arduino has been considered.

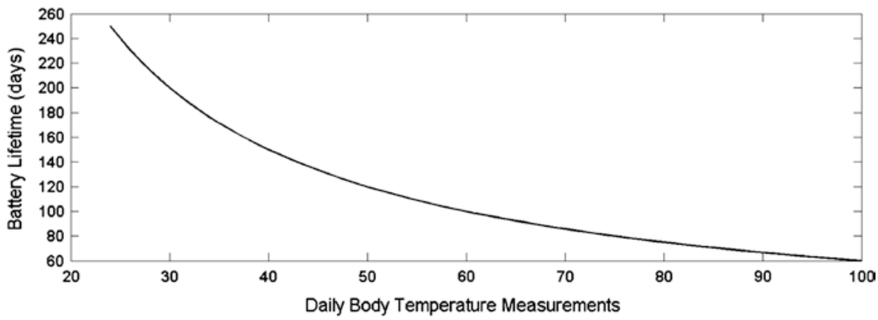

Fig. 5 Battery lifetime versus daily body temperature measurements

5 Conclusion

An open and low-power platform based on Arduino ecosystem for mobile clinical signs monitoring has been developed. To reduce the power consumption and to obtain a user-friendly system, the NFC technology has been chosen as wireless protocol in proximity. The first prototype of the platform integrates a NTC thermometer for temperature acquisition. The dimensions and weight of the 3D printed package are compatible with the considered application scenario, though the dimension of the device can be further optimized. The architecture is based on Arduino libraries permitting an easy integration of other customized functionalities. Through the free SonyFelica SDK for healthcare, cost-effective applications for smartphones or mobile devices can be realized in order to read and handle data coming from the presented platform.

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Domestic Monitoring of Respiration and Movement by an Electromagnetic Sensor

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Abstract The aim of this paper is to investigate the capabilities of a novel electromagnetic technique designed for contactless monitoring of breathing activity in Ambient Assisted Living applications. The method is based on the transmission of a frequency sweep and the measurement of the reflection coefficient to determine the respiration rate of a subject. To date, the method is under optimization, but it has already shown interesting capabilities of calculating not only the respiration rate, but also additional features, as the position of the subject inside a room and his/her movements. After a brief mathematical description of the algorithm, some preliminary tests will be described concerning the monitoring of a human target inside a room. These first results clearly show the capability of the method to detect the subject, his breathing rate, position and physical activity. Of course further signal processing is required in order to distinguish between different types of movements and to classify them.

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1 Introduction

The respiration rate is one of the physiological signals (also known as vital signs) that are generally monitored in daily patient observation, in intensive care monitoring or for remote control of the physiological status of subjects in indoor environments, as in modern Ambient Assisted Living (AAL) applications, because it is considered an important predictive parameter for many pathologies.

In general, the traditional procedures to gather vital signs from human body require the use of one or more transducers, electrodes, cables to be connected to the patient or, for what concerns respiration monitoring, chest belts to be applied around patient thorax under the supervision of medical personnel. In the context of AAL monitoring of elders living at their homes and then out of specialized clinical environments, it should be convenient to monitor patients without any contact with the body to ensure subject's comfort, but most importantly, to reduce the level of collaboration required by the subject himself.

In this background, the monitoring of respiration activity using electromagnetic (EM) sensing has become an interesting solution [1–5] due to the possibility of non-contact measurements at significant distances (even 2 or 3 m), and most importantly, through tissues (bed sheets, blankets, clothes), because common fabrics are generally transparent to EM waves. This aspect may represent a clear advantage for both the monitoring of non-collaborative or burnt patients, and the remote monitoring in indoor environments. In fact an EM system may be easily installed inside hospital rooms or even at home without the need of a direct view of the target, the intervention of medical personnel or of the subject and without privacy issues.

First studies related to the EM monitoring of respiration activities [4, 5] considered an EM signal launched by a double ridge horn antenna fed by a Vector Network Analyzer (VNA), which measured the antenna reflection coefficient, S_{11}, defined as the ratio of the phasors of the reflected and the emitted wave. The set-up, based on Continuous Wave (CW) microwave reflectometric radar technique at 6 GHz, explored the dependence of amplitude, phase and quality (signal-to-noise ratio) of the signal on the distance between sensor and patient and on the posture of the subject. In particular, it has been demonstrated that the variation of the distance l between the antenna and the subject's thorax due to the inspiration/expiration acts, produce variation on the phase of S_{11} [4, 5].

To date, a novel EM measurement method based on the transmission of a frequency sweep rather than on a CW technique is under investigation. The measurement chain is similar to the one used in [4, 5]: the same double ridge horn antenna is fed by a portable VNA used to generate a frequency sweep from 1 to 6 GHz. In few words, the method allows to perform several CW analyses in parallel (obtaining a measurement matrix whose rows represent the complex spectrum of the backscattered signal), and then, average the measures, to obtain a more robust estimation of the harmonic content of subject's thorax movements.

In this paper it will be shown that the proposed method allows the correct measurement of the respiration rate of the subject and that the same matrix can be also used to calculate additional features, as the position of the subject inside a room (distance from the EM antenna), a useful information for AAL application. Moreover from the time sequence obtained, a spectrogram can be generated in order to evaluate the variation of the power spectrum density (PSD) over time. The investigation of distribution of such variations can provide additional information: a localized intensity is synonym of a periodical movement, like breathing, while a spread spectrum indicates some sort of activity, like arms movements or walking.

2 The Frequency Sweep Technique

The theory is based on a reflectometric approach, using the data collected from the portable VNA which measures the S_{11} between the wave backscattered from an obstacle placed at a distance l and the incident one:

$$S_{11}(F) \triangleq \frac{E_{refl}}{E_{inc}} = \Gamma e^{-2j\beta l} \tag{1}$$

being Γ (a function of the EM frequency F) the complex reflection coefficient evaluated at the reflecting surface and $\beta = 2\pi/\lambda$ the wavenumber.

Selecting a range of frequencies, F_{min}–F_{max}, the instrument automatically returns an array of measurements performed at N uniformly spaced points in the chosen range.

Moreover, using the time domain technique implemented in commercial VNAs to determine fault locations in cables, it is possible to handle the measured array of reflection coefficients, as the portion (from F_{min} to F_{max}) of the discrete spectrum of a certain time signal. At this point, it is only required to add, at the head of the vector, the data referring to the part of the spectrum from DC to F_{min} with the same uniform spacing, and then to extend its content by doubling the vector length with complex conjugate data symmetrically taken for negative frequencies. The resulting array can be inversely transformed using a well-known IFFT algorithm to obtain a real valued time sequence, which is related to the position of the reflection source(s) in front of the antenna. In order to simplify the implementation of the algorithm, a suitable number of zeroes has been added at the beginning of the vector instead of extrapolating the S_{11} values for the unmeasured frequencies (0–F_{min}). This is equivalent to say that at those frequencies any obstacle is transparent to the incident wave, thus no reflection occurs.

The distance sequence is then computed as:

$$d[n] = IFFT\left[\overleftrightarrow{h^*}\,|0,\ 0,\ldots 0|h\right] \tag{2}$$

where the argument is a concatenation of h, the $1 \times N$ vector returned by the VNA, and $\overleftrightarrow{h}^*$, the horizontally flipped and conjugate vector. The resulting sequence is then the sampling of a continuous time function $d(t)$ evaluated, in time, in $t = n/(2F_{max})$ or, equivalently, in space at $x = (c/2) \cdot t = cn/(4F_{max})$, where $c/2$ is considered because of the double distance from/to the reflecting object.

Connecting the VNA to a PC which stores the time evolution of the reflection coefficient array over time, it is possible to obtain a matrix H of complex values $h_{i,j}$ where the jth index refers to a particular frequency in the chosen range, and i is a sample time index. Operating the IFFT of each row of the matrix a distance-vs-time positioning matrix D is obtained and the placement of the main reflecting objects can be determined, in a radar-like representation.

Furthermore it is possible to evaluate the harmonic content of a suitably chosen moving window using the discrete time Short-Time Fourier Transform (STFT). The window size is as usual a tradeoff between frequency resolution and time resolution/delay (Fig. 1).

To avoid sensitivity issues related to certain columns (that may result in noisy PSD) instead of focusing on the transform at a single EM frequency, the contribution in magnitude of all of them has been considered by taking the sum of all Fourier Transforms:

$$M(f) = \sum_{j=1}^{N} \left| STFT_j(f) \right| \tag{3}$$

being j the column index (i.e. EM frequency) and f the low frequency (range 0.1–1 Hz) at which the body motion is evaluated for spectral density. For example, a still body, which is only breathing, shows a peak at a frequency equal to the respiration rate, while a moving subject yields a composite magnitude spectrum as the result of several contributions. This leads to a spectrogram able to correctly

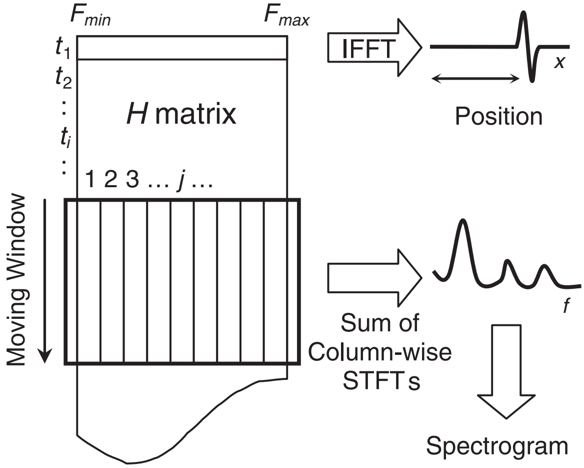

Fig. 1 Depiction of data handling to determine both position and spectrogram

differentiate a still subject who is just breathing (only the fundamental harmonic of the moving chest is detected) from a scenario where the subject is walking or making physical activities.

Therefore, by cross-matching both positioning and spectrogram, the same array of measurements will reveal if the subject is still (constant positioning, narrow spectrogram), if he is not walking but making some activity (constant positioning, spread spectrum) or if he is walking (variable positioning, spread spectrum).

3 Respiration Rate and Movement Non-contact Detection

In order to validate the theoretical approach described in previous section, some experimental tests have been carried out in our laboratory. The experimental set up used for tests is composed by:

- Agilent FieldFox VNA N9928A (VNA), [6] set up to perform a sweep scan from $F_{min} = 1$ GHz to $F_{max} = 6$ GHz, in $N = 176$ points, with an output power of 0 dBm;
- A.H. Systems SAS-571 Double Ridge Guide Horn Antenna (HA), as transmitting/receiving antenna hanging to a dielectric support;
- A laser Doppler vibrometer (LDV) and a respiration belt [7] for the detection of the reference respiration signal;
- One volunteer (target);
- A PC for real-time data acquisition and offline data processing (PC).

All the measurements have been conducted in an anechoic angle delimitated by pyramidal absorbers (Emerson & Cuming ECCOSORB VHP-18-NRL) to avoid unwanted reflections. In Fig. 2, the experimental set-up used for the test is schematically reported.

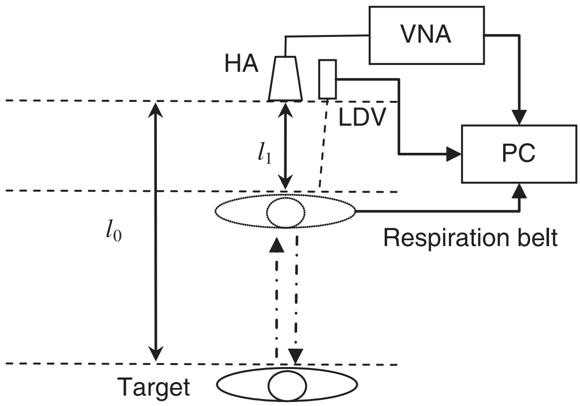

Fig. 2 Schematic view of the experimental set-up used for the tests

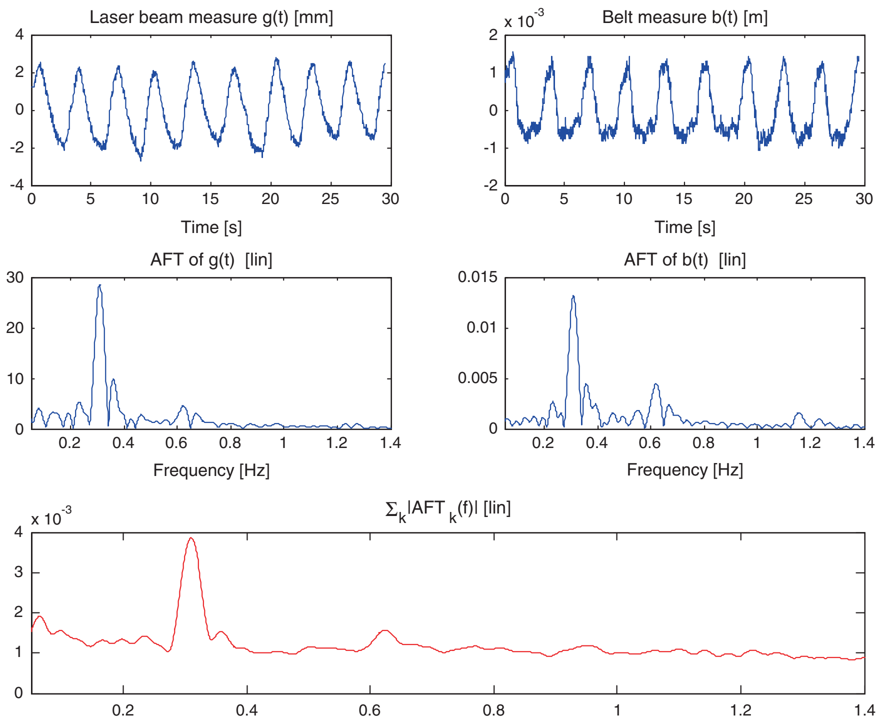

Fig. 3 Time signals from the LDV and respiration belt (*top*); power spectra of the previous signals (*center*); cumulative power spectrum of the EM system (*bottom*)

In Fig. 3, we report an example of the time signal and the relative power spectra of the two reference instruments (LDV and respiration belt) and the cumulative power spectrum measured by the EM system at all the 176 frequencies.

In our tests, the difference between the value of the frequency peak measured by the EM system and the LDV system was <0.3 % (mean over 12 tests), while using the respiration belt as reference the difference <0.5 % (mean over 12 tests). While each frequency sweep has a duration of 100 ms, the delay due to the communication protocol leads to a final sampling frequency of 3 Hz. A software code has been realized for real-time calculation of the direct Fourier Transform (measurement of the respiratory rate) and inverse Fourier Transform (measurement of the distance). Spectrograms are computed using offline data, but it would be possible to visualize them at runtime on the same software as well. The measurement range is: 0.5–3.5 m.

In Fig. 4, we report the EM system signal measured while the volunteer (target) stood still at a distance of $l_0 = 3$ m for about 10 s, then he started walking towards the antenna up to a distance of $l_1 = 1.5$ m; subsequently he walked backward to the initial position l_0; this sequence of movements was repeated four times. Finally

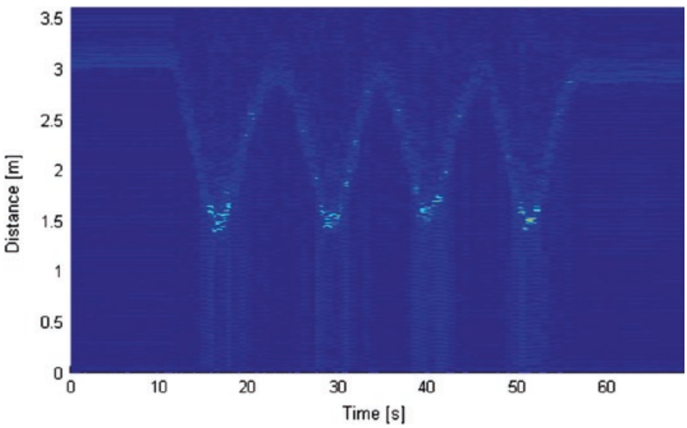

Fig. 4 Graphic representation of *D* matrix, for position detection of a human target

(last 10 s), the subject stood still again. It is clear how the system correctly locates the target: the light blue line represents the position (in m) detected during the whole experiment.

These results can be useful for AAL application, representing a first step toward the monitoring of patient's activity, providing, for example on a daily basis, an estimate of the amount of physical activity of the subject.

In order to further investigate the system capability, another test has been conducted (Fig. 5). In this test, the subject, placed at a fixed distance of about 2.2 m from the antenna, stood still for the first 30 s. Then he performed a light physical activity in two parts: arms side lateral rise for 30 s and arms front rise for the last 30 s.

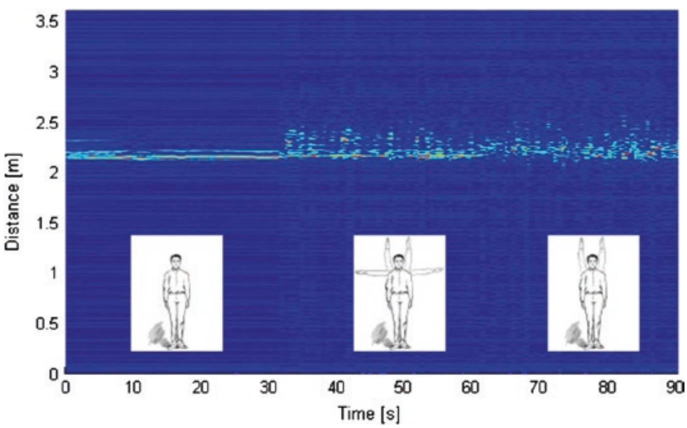

Fig. 5 Example of position detection (*D* matrix) of a human target when stands still (*left*), raises the arms laterally (*middle*) and frontally (*right*)

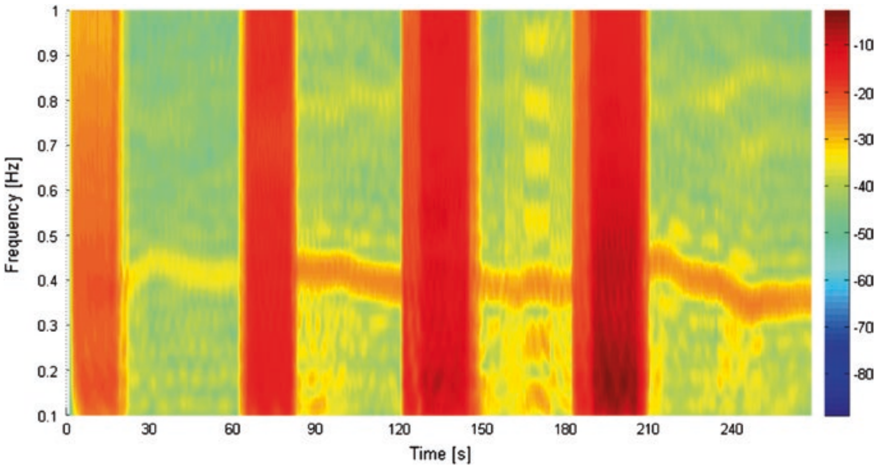

Fig. 6 Spectrogram of the signal measured during a dynamic test

Finally in Fig. 6, we report the spectrogram for the case of the subject who moves and sits in 4 different positions in the room (also out of the anechoic angle).

In detail the subject was asked to sit in front of the EM system and breath regularly at a distance of 3 m (first 60 s), then he moves toward the antenna and sits at 1.8 m for more 60 s (up to $t = 120$ s in Fig. 6). After that he moves out of the anechoic angle at a distance of 2.5 m for another minute (up to $t = 180$ s) and finally he moves to a distance of 2 m with his back leaning against a high reflective surface (metal plane) till the end of the experiment. Observing the related signal spectrogram (Fig. 6), it is possible to note that when the target is stationary the breathing fundamental harmonic is clearly detected (horizontal line at about 0.4 Hz) while during the movement it is not possible to detect a single frequency. The last portion of measurement shown in Fig. 6 also reveal that the presence of a highly reflective surface (behind the subject) does not blind the system and still allows the measurement of the respiration rate.

4 Discussion and Conclusion

The EM system proposed has been designed to monitor the respiration rate with no contact with the target, at a distance of few meters and without requiring the collaboration of the subject. Nevertheless, the preliminary studies shown in Sect. 3 have demonstrated that using a suitable signal processing, it is possible to use the same sensor to calculate additional features concerning human position inside a room and his/her physical activities, as for example arms or legs movements. The proposed system has the capability to see through tissues like clothes and blankets and other non-conductive obstacles, like wood or plastic panels. The algorithm for respiratory rate detection removes static clutter caused by other reflecting surfaces in the antenna range by subtracting the average component, thus specifically enhancing the detection of harmonic content of the moving parts of the body. The inverse transform for subject positioning is also obtained as a result of a subtraction with a reference measurement taken at time zero and updated at regular time intervals, to account for any change in the surrounding environment (i.e. a chair moved from one place to another in the observation room).

Therefore, the system proposed paves the way for a future generation of unobtrusive remote monitoring of physical parameters and activity, with the aim of increasing patients' well being and personal independence. For example it may be interesting to record patient's physical activity over a day in order to elaborate a report with the amount of estimated activity of the subject (to be compared with the daily schedule prescribed by the doctor) or detect sudden changes in activity levels which may indicate illness or injury. Furthermore, the possibility of distinguishing and monitoring more than one subject is under investigation. The last step will be the study of a suitable mathematical algorithm, for example based on pattern recognition techniques like dynamic neural networks or on the cross correlation between data received from more EM sensors conveniently located inside a room, to distinguish among different types of activity: walking, washing dishes, dressing and others.

The preliminary tests carried out considering a human target inside a room have demonstrated the possibility of:

(1) monitoring breathing rate;
(2) tracking target position;
(3) distinguishing if the subject stands still or if he is making some type of physical activity, like moving arms or legs.

All this functions can be very interesting in the fields of AAL to remotely control the physiological status of subjects (for example elders) in indoor environments, like their homes or hospital rooms, in order to elaborate a daily report or to detect changes in the activity levels and hence the presence of injuries.

Acknowledgment This work was partially supported by the regional project HDOMO 2.0 (*Smart House for an independent and active longevity of the elderly*).

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Part III
Assistive Devices

An AAL Adaptive User Interface to Support Frail People in Manufacturing

Margherita Peruzzini, Matteo Iualè and Michele Germani

Abstract Ambient Assisted Living (AAL) is one of the most strategic research fields of research due to the increasing aging of the world population and the developments of assistive technologies, which enable people with specific demands to live longer and better by providing specific care. It has been demonstrated that AAL technologies provide effective support to frail people and their application is increasing in home and medical contexts with positive effects on costs reduction. However, such models have been rarely applied outside the domestic context. This paper describes the application of AAL concepts to manufacturing in order to support frail people to properly handle machine tools and complex systems. It presents an industrial case study focusing on machine tool operators: under these circumstances frailty assumes a broad sense as people have to carry out highly specialized jobs and also mild deficiencies can represent a frailty (i.e. slight reduction in sight, hands that are not perfectly steady, slightly reduced mobility or human force). The case study in particular aims at designing an adaptive user interface based on AAL principles and user-centered approach to support frail operators to work better and more safely.

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1 Introduction

Ambient Assisted Living (AAL) is one of the most important research areas in Human-Machine Interaction (HMI) field and ICT-based system interfaces. It generally aims at supporting people with specific demands (e.g., disabled or elderly) to execute complex tasks and live in a better way in a specific environment, by increasing their autonomy and self-confidence, monitoring people behaviors or supporting the human-machine interaction in a intuitive way [1].

In this context the present research addresses AAL topics by facing a novel field of application: manufacturing. Indeed, in manufacturing environments usability and assistive technologies assume a fundamental role due to two main factors: on one hand growing system complexity, which requires high-precision movements and cognitive abilities, and on the other hand the increasing aging of technical operators, due to the aging of the global population [2]. Therefore people working in manufacturing firms, especially those involved in production and operative roles, are becoming older and companies rarely have young people with equal experience and elevated competencies; furthermore, the recent economic crisis has progressively discouraged assuming young people. Contemporarily machines are more and more complex, digitalized and technologically advanced so they required elevated manual and mental abilities, while aging inevitably affects human faculties [3]. In order to control or use such systems, also mild deficiencies like small low vision, minimal reduction in human force or lower concentration ability, can affect the executed tasks and risk to compromise the use of advanced interfaces and complex systems. In particular, through User-Centered Design (UCD), it is possible to analyze the users' characteristics and collect information to guide the technological development in order to optimize the human-machine interaction achieved [4].

For these purposes, the research aims at realizing an AAL manufacturing technology (TAALM—Technology for Ambient Assisted Living Manufacturing) able to support people with deficiency to work properly in manufacturing contexts. Such a research was carried out within an Italian research projects funded by the Marche Region in the context of "Promotion of industrial research in technological production chains" (POR MARCHE FERS 2007–2013 INTERVENTO 1.1.1.04.02). The project scope is realizing an assisted environment to support frail people working on complex machine tools by using innovative technologies and AAL concepts, which are already known in literature but have never been applied to working spaces or devices. The final TAALM environment will be composed by four main components: a highly usable machine tool, a monitoring system, an adaptive user interface and a knowledge-based system to dynamically configure the interface. The present research focuses on the last two points and aims at creating an Adaptive User Interface (AUI) to support frail elderly people in manufacturing operations; it adopts UCD principles and a QFD-based approach to configure the interface according to the specific user needs and tasks.

Section 2 describes the state of art of assistive technologies for AAL purposes in manufacturing; Sect. 3 presents the research methodology; Sect. 4 describes the industrial case study from the TAALM project and the main results achieved so far; finally Sect. 5 deals with conclusions ad future works.

2 Research Background

Frailty is the most problematic expression of population ageing. It has been defined as a "state of physiological and/or physical vulnerability associated with aging due to an alteration of the capacity of homeostatic reserve and a reduced ability of the body to cope with stress, such as acute diseases" [5]. The definition is generic and refers to disabilities associated with an advanced age or unstable health condition and other factors that cause the deterioration of health and functional status. In technological-oriented sectors and manufacturing for instance, frailty assumes a broad sense since also mild deficiencies can affect the usual performance of operators: reduction in sight, reduced mobility or ability to lift weights, memory reduction or anxiety can seriously decrease the working performance.

However, the increasing use of Internet and communicating technologies in all the technological sectors by the progressive introduction of sensors to create Smart Objects and collect data and improve the interaction with the operators [6], is creating numerous opportunities and challenges for both workers and companies. As a consequence, mechanisms delivering information to all potential users have, therefore, increased significantly. They pave the way also to the introduction of assistive technologies in manufacturing to support operators in their everyday tasks by improving Human-Machine Interaction (HMI). HMI is a complex process, both in case of abled users and frail users, describing the dialogue established between the user and the machine/system through the interface, which is the communication channel that puts "in contact". In this context usability principles and cognitive psychology help to build a proper dialogue that conveys the right information to the user and simplify the machine understanding and use. Indeed, only using right models of communication allows predict and support the human behaviors and assist the users' actions [7]. In particular, the so-called information design allows defining the best way to present the right information in order to realize an intuitive communication and support the user in his/her actions by affordances. Mapping is one of the basic principles to adopt: it consists of creating a set of logic relations to easily apply mental models to the real world. A good mapping provides exactly what the users are expecting when they are expecting in a familiar way.

In manufacturing contexts the adoption of AAL to create highly usable and assistive interfaces can be achieved firstly by transferring past experiences in other fields like home care and web-based services, which refer to the concepts od adaptable and adaptive interface. Indeed, as far as interfaces are concerned, the biggest problem of standard products is that they do not take account the users' special needs. Such limitations are usually not inherent to the technology, which is characterized by an enormous flexibility, but paradoxically from the absence of requests made to the technology itself.

In order to improve HMI, interfaces can be *adaptive* and *adaptable*. Being adaptive means that the system is able to automatically adapt its features to the user in a transparent way; being adaptable means to allow the user to modify the interface in a conscious way [8]. In our context we focused on Adaptive User Interfaces (AUI). The relevant literature offers numerous examples illustrating tools for constructing adaptive interaction and case studies in which adaptive interface technology has improved, or has the potential to improve, the usability of an interactive system. In all cases the basic and distinctive characteristic of an AUI is its capability to dynamically tailor itself to the abilities, skills, requirements and preferences of the users, to the different contexts of use, as well as to the changing characteristics of users, as they interact with the system [9]. In order to be adaptive, the interface has to support the various "special" input and output data and dynamically reconfigure its main elements:

- *layout* (colors, fonts, graphical compositions in general);
- *contents* (information and data provided and managed at different levels of detail);
- *feedback* (interaction way to provide alerts and notifications).

3 The Research Methodology for AUI

The present research adopts a user-centered design approach that starts from the identification of the target users and the analysis of their frailties in order to identify their specific needs on the basis of the tasks they are asked to carry out. Subsequently, it adopts a Quality Functional Deployment (QFD) methodology [10] to correlate the users' frailties with the interaction elements to properly configure the features of the system interface, which will be an AUI. The best configuration is achieved by the adaptation of the interface items and features according to AAL principles and mapping between the specific users' needs and the adaptation rules for AAL interface configuration.

The precondition is identifying the target users to be supported; after that, the research approach, shown in Fig. 1, can be summed into five main steps:

Step 1. Analysis and classification of the users' frailties;
Step 2. Identification of the user's needs in terms of actions and tasks to be performed;
Step 3. Analysis of the interface features (items) and external events affecting the human-machine interaction;
Step 4. Correlation between the user's frailties and interface elements;
Step 5. Definition of a set of adaptation rules to configure the interface elements according to the required actions and the occurring events. It allows supporting the specific user in executing his/her tasks by the adaptation of the interface elements and their features to his/her specific frailties.

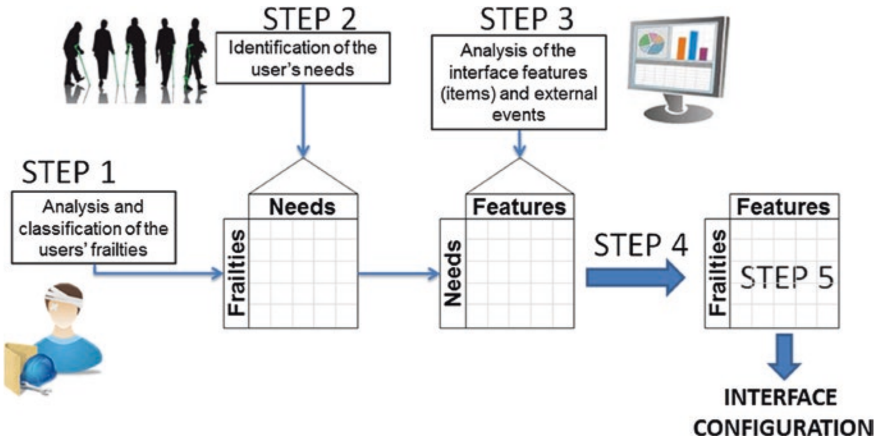

Fig. 1 The research methodology for AUI

The rules identified in Step 5 are logical relations that can be easily traduced in algorithms to be implemented for interface configuration. In this case, when a specific user is going to execute a certain tasks, the system infers which items of the interface will be used and intelligently reconfigures them to be used properly. Configuration rules are defined by considering the specific frailties affecting the user, external conditions and interface items' characteristics and "degrees of freedom" (e.g. colors, dimensions, shapes, position, audio feedback).

4 The Industrial Case Study

4.1 The TAALM Project

The TAALM (Technology for Ambient Assisted Living Manufacturing) project aims at realizing an AAL environment to support users in manufacturing context by an AUI, which enables an knowledge-based configuration of the interface elements in order to support a certain user in executing his/her tasks according to his/her specific needs and frailties. In particular, it is oriented to the woodworking machine sectors, where machine are becoming more and more advanced (like in mechanics or automotive), while the age of key figures is increasing due to the lack of new generations involved as it has a very traditional sector. So that operators are frequently over 55–60 and are affected by minor frailties; even although such frailties cannot affect their personal living way, however they can affect some tasks during their job and decrease their efficiency. In this context introducing assistive technology can really bring advantages to both operators and companies.

The conceptual model to realize such AAL adaptive interface is based on two main items:

1. The AAL machine with ergonomic features and an embedded monitoring system, which provide information about the external events and conditions to which the interface will have to adapt. In particular the AAL machine provides data about:
   (a) the user, identified by its role and personal characteristics;
   (b) the process, described by its status, typology, processing operation, type of processed piece of wood, production constraints, time, etc.);
   (c) the surrounding environment (level of dust and noise, presence of elements like people, trolleys, etc.).
2. The adaptive interface that is accessible locally or remotely by a mobile device. It is composed by:
   (a) the adaptive interface that is simplified and highly usable to support users to visualize the necessary information in the best way for the specific user taking into account his/her specific frailties, control the machine status and any critical events; and monitor the process status and the actions required (loading, unloading, etc.) according to the user's frailties;
   (b) the configuration system that is the knowledge-based application able to configure the interface elements according to the user's needs and external events.

Target users are identified as the operators responsible for the machine programming, progress control and maintenance actions. Three kinds of operators have been identified for the research purposes: they differ from their skills, level of expertise and tasks to be executed.

Op1. He/she is a regular operator, which has to control the machine status and processes. Op1 does not access detailed information and in case of specific alert is not authorized to intervene. He/she is responsible for the following tasks: loading/unloading parts to/from the machine and place the loading/unloading by simply activating the Start button; monitoring the progress and status of the machine; cleaning the machine at the end of turn; and performing normal supplies (e.g. staples, materials for labeling).

Op2. He/she is a specialized operator and usually represents the typical operator able to carry out not only the basic activities such as Op1, but also to work on the machine and restore it when needed. In addition Op2 takes care of restoring the operating conditions after interruption of work processes to jam stapling, changing tools or power failure; managing all the main operations on the machine; and intervening in case of a warning within the limits of its functions.

Op3. He/she is a skilled expert operator, which is able to carry out all the activities on the machine but also program the working cycles in addition to the above-mentioned tasks. He/she handles a variety of advanced features and delicate operations. He/she is also responsible for equipping the machine with new tools; checking the tool paths for new projects; and refining the processing parameters.

4.2 Method Application in Machine Tool Sector

The application of the proposed method to the TAALM project allowed identifying the main correlations to create an AUI for manufacturing applications by adopting the AAL paradigm and to finally define the system architecture as shown in Fig. 2.

4.2.1 User Frailty Classification and Needs Identification

The first step consists of the identification of the user frailties; in particular, they have been classified according to the three operator categories according to their tasks. In particular, among the general frailties we considered the most affecting ones belonging to four frailty classes (vision, auditory, motor, cognitive). Such classification is based on literature [5] and experimental evidence in the specific industrial sector analyzed carried out by focus groups with the company managers. Table 1 shows the frailty classification considered for this study. After classifying the frailties, the user needs have been defined according to the three operator typologies and their role. As a result, a list of tasks for each operator (Op1, Op2 and Op3) is outlined (Table 2).

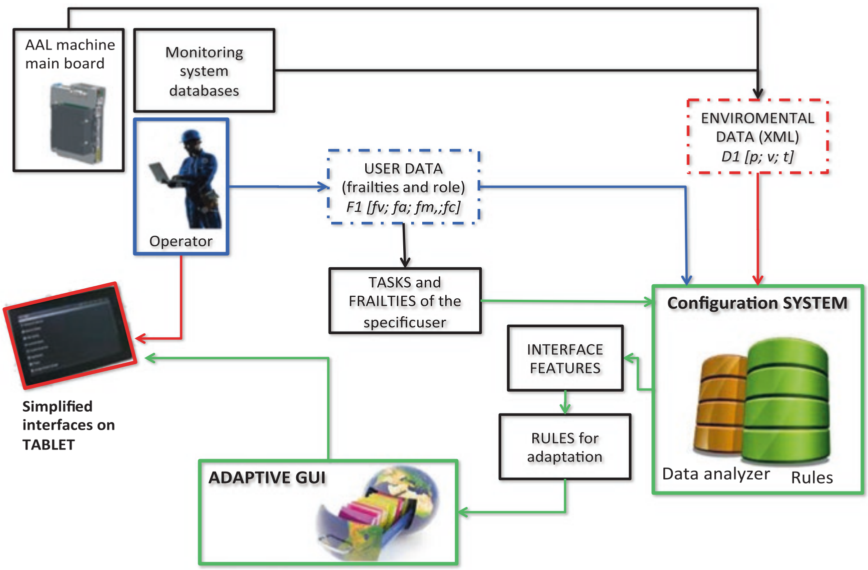

Fig. 2 System architecture for the AUI for the TAALM project

Table 1 Frailty analysis and classification

Frailty classes			
Visual	Auditory	Motor	Cognitive
Long-sightedness	Minor hearing loss (26–40 dB)	Minor reduced mobility of legs	Anxiety disorders
Short-sightedness	Medium hearing loss (41–55 dB)	Medium-High reduced mobility of legs	Memory problems
Far-sightedness & Astigmatism	Medium-High hearing loss (56–70 dB)	Minor reduced weight lift (<25 kg)	Difficulties in concentrating and processing large amounts of information
Contrast Sensitivity	High hearing loss (71–90 dB)	Medium reduced weight lift (<15 kg)	
Colour-blindness	Sever hearing loss (>90 dB)	Highly reduced weight lift (<6 kg)	

Table 2 User needs identification (expressed as tasks)

	Op 1	**Op 2**	**Op 3**
T1. Read the status of the environment	x	x	x
T2. Read the status of the machine	x	x	x
T3. Load/unload the parts to/from the machine	x		
T4. Read the next part to be loaded	x	x	x
T5. Read the weight of the next part to be loaded/unloaded	x	x	x
T6. Read the volume of the next part to be loaded/unloaded	x	x	x
T7. Read the execution time of the leading program	x	x	x
T8. Read the label to be inserted on the part after unloading	x	x	x
T9. Visualize the Load/Unload button	x	x	x
T10. Check the manual loading	x	x	x
T11. Check the automatic machine loading	x	x	x
T12. Check the internal movements of the machine	x	x	x
T13. Check the external parts of the locking clamps	x	x	x
T14. Restore failures during manual loading		x	x
T15. Restore failures during automatic loading		x	x
T16. Restore failures on internal machine movements		x	x
T17. Supply staples and labels	x	x	x
T18. Recognize an alert and its typology	x	x	x
T19. Visualize level of dusts/vibrations/noise/pollution by diagrams		x	x
T20. Visualize the multi-level schema		x	x
T21. Organize the workflow			x
T22. Restore the machine downtime		x	x
T23. Restore the cell		x	x
T24. Check new tool paths			x

4.2.2 QFD-Based Correlation for Interface Adaptation

The interface features to be adapted to the users' needs have been defined on the basis of users' deficiencies, tasks to be performed and external events (Table 3). Such features have been properly organized in different pages with different layouts according to the supported tasks in order to create an intuitive navigation path for the specific user and actions that can be executed easily. According to the

Table 3 Interface features to be adapted

Page and section	Interface features
Header (common to all pages)	F1. Multicolour status bar for environmental parameters
	F2. Multicolour status bar for machine parameters
Load/Unload main page	F3. Loading minutes
	F4. Information about the part processed
	F5. Part volume
	F6. Part weight
	F7. Load button
	F8. Unload button
	F9. Information about parts that have been already loaded
	F10. Label to be put on the part processed
Detailed information page	F11. Information about parts to be loaded next
	F12. Information about running process
Video control panel page	F13. Video about Manual lading information
	F14. Video about Automatic lading information
	F15. Video about machine internal movements
	F16. Video about machine external locking clamps
Detailed diagram pages	F17. Diagram of dusts
	F18. Diagram of steams/fumes
	F19. Diagram of sound pressure
	F20. Diagram of vibrations
	F21. Diagram of internal noises
	F22. Combined graphs
Multi-level pages	F23. Multi-level information
Alert (common to all pages)	F24. Alert and warning messages

Table 4 Adaptation rules description

Adaptation rules	
R1. Larger font	R7. Point out the weight text
R2. Larger chart	R8. Point out the weight text and send an alert
R3. Colors with strong contrast	R9. Full-screen viewing of the stream video
R4. Notable font	R10. Alert report
R5. Font with more contrast	R11. Insert summary page
R6. Chart lines thicker	

RULES FRAILTIES - FEATURES	F1	F2	F3	F4	F5	F6	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	F22	F23	F24
Long-sightedness			R1	R1	R1	R1	R1	R1	R1	R1					R2	R2	R2	R2	R2	R2		R1
Contrast Sensivity	R3	R3	R4	R4	R4	R4	R5	R5	R5	R5					R6	R6	R6	R6	R6	R6		R4
Medium rediced weight lift (<15 Kg)					R7	R8																
Difficulties in concentrating and processing large amounts of information											R9	R9	R9	R9	R10	R10	R10	R10	R10	R10	R11	R10

Fig. 3 Adaptation rules adopted to configure users frailties with interface items

(a)

Frailties / Tasks	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24
Long-sightedness	3	3		9	9	9	9	9	3									9	9	9		3	3	9
Short-sightedness	9	9		3	3	3	3	3	3	9	9	9	9	3	3	3	3	3	3	3		3	3	9
Far-sightedness & Astigmatism	3	3		3	3	3	3	3										3	3	3		3	3	3
Contrast Sensitivity	9	9		3	3	3	3	3		3	3	3	3						9	9				
Colour-blindness	9	9							9										9	3				
Minor hearing loss														3	3	3	3	3				3	3	3
Medium hearing loss														9	9	9	9	3				3	3	3
Medium-High learing loss														9	9	9	9	9				9	9	9
High hearing loss														9	9	9	9	9				9	9	9
Sever hearing loss														9	9	9	9	9				9	9	9
Minor reduced mobility of legs			3											3	3	3	3					3	3	3
Medium-High reduced mobility of legs			3											9	9	9	9					9	9	3
Minor reduced weight lift (<25kg)			9											3	3	3	3					3	3	
Medium reduced weight lift (<15kg)			9											3	3	3	3					9	9	
Highly reduced weight lift (<6kg)			9											9	9	9	9					9	9	
Anxiety disorders				3			3	9	3					9	9	9	9	9			9	3	3	3
Memory problems			3	9	3	3	3	9	3					9	9	9	9	9			9	3	3	3
Difficulties in concentrating and processing large amounts of information				3	3	3	3	3		9	9	9	9	3	3	3	3	9	9	9	9	3	3	9

(b)

Features Tasks	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24
F1	x																	x						
F2		x																x						
F3			x				x																	
F4			x		x	x	x	x																
F5			x			x																		
F6			x		x																			
F7			x						x															
F8			x						x															
F9			x																					
F10			x					x																
F11			x	x																				
F12			x	x																				
F13										x				x										
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F15												x				x						x	x	
F16													x									x		
F17											x	x	x					x	x					
F18											x	x	x					x	x					
F19																		x	x					
F20											x	x	x					x	x					
F21											x	x						x	x					
F22											x	x	x					x	x		x			
F23										x	x	x	x	x	x	x				x	x	x	x	x
F24																	x	x						

Fig. 4 Correlation between frailties and tasks (**a**) and features and tasks (**b**)

QFD approach, the identified frailties have been correlated with the selected tasks by 0-3-9 point correlation: this value indicated how much each frailty affects the execution of each specific task; after that, tasks have been mapped with the interfaces features: this correlation expresses which features will be used by operators to carry out a certain task.

For each task, a configuration rule (e.g. font regulations, colors variation, contrast regulation, resizing of some features and/or hiding of some features, providing alerts when needed, sending messages) has been identified to properly adapt a certain interface feature to the users' needs before task execution. The specific rule changes according to the correlation severity (0-3-9).

Four case studies have been identified. For each of them, a set of adaptation rules (Table 4) have been implemented in order to correlate specific frailties affecting the user with interface items of the AUI pages (Fig. 3).

Figure 4a, b shows the correlation between frailties and tasks considered in the case study.

4.2.3 The AUI Prototype

A first prototype of the AUI for the TAALM project has been realized by adopting ASP.NET and Microsoft Ajax technologies. In particular, the ASP.NET technology is used to create the interface main AUI items and controls, while the Ajax technologies allows adding to each page dynamic contents that can be loaded independently from the page structure and the other items. Furthermore, it allows mixing dynamic content with standard controls in the same page easily. Such framework

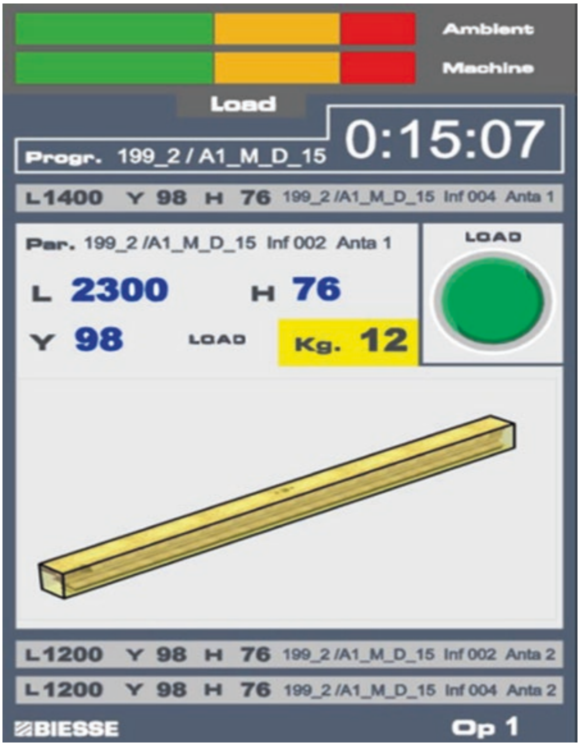

Fig. 5 The AUI page containing the different interest areas

makes also the AUI totally generic and accessible from any web-based devices, being independent from the platform used (i.e. Android, iOS, Windows phone) since the pages are reached via Internet as a generic web page. The only prerequisite is having a web browser installed, as the majority of devices do.

As a consequence, the AUI pages (Fig. 5) have a predefined layout with fix position of the interest areas, whose content can change easily and in an adaptive way; the main page has three sections respectively concerning (1) a control panel at the top of the page, representing the machine and environment status by control bars, (2) a display section about the on-going process with details about the processed piece and its data (e.g. weight, time to finish, right positioning, 3D view), and (3) a managing section indicating the process advance and the next pieces to be processed. The footer contains information about the specific operator (e.g. name, code, role). In specific pages the first and third sections remain unchanged while the second section is replace by dynamic contents varying displayed data or diagrams, according to the specific purposes.

5 Conclusions

The present research proposed a methodology to define an AUI by exploiting the AAL concepts, and described its first prototype. It allows supporting operators in manufacturing contexts by dynamically configuring the interface features according to the specific users' needs. Method application allowed defining a general architecture to create such adaptive system for realizing an AUI to support frail users working on machine tools. The case study demonstrated the method validity and provided a preliminary idea of the power of its application. The system implementation is actually on going and a prototypal system will be ready soon. Future works will focus on a better analysis of the adaptation rules and further testing on other experimental cases.

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Electromagnetic Technologies as Travel Aids for Visually Impaired Subjects

G. Cerri, A. De Leo, V. Di Mattia, G. Manfredi, V. Mariani Primiani, V. Petrini, M. Pieralisi, P. Russo and L. Scalise

Abstract The aim of this paper is to present the electromagnetic (EM) technology as possible assistive technology for the mobility tasks of visually impaired subjects. The paper will present their characteristics, discussing pros and cons of their use with respect to the existing traditional technologies and electronic travel aids, in terms of performances, miniaturization and wearing comfort. In particular, two applications of EM technologies will be presented more in detail: a first example consists in the design and realization of a laboratory prototype of an EM system able to detect the presence of obstacles along the walking path of visually impaired users and hence to assist them during their mobility tasks, possibly allowing them to walk safely and independently. The second example is the theoretical and experimental study of feasibility of an EM system specifically addressed to visually impaired runners. In conclusion, some hints for discussion will be presented; the user interaction with the sensing system, the signal analysis and possible features extraction will be reviewed addressing issues requiring a multidisciplinary approach.

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1 Introduction

Globally, 285 million people are estimated to be visually impaired: 39 million are blind and 246 have low vision [1]. Outdoor mobility tasks are the main issues for visually impaired subjects, influencing their social and professional life [2, 3].

Main assistive devices for these subjects are: sighted guides, white or long canes and dog guides [4, 5]. In particular, the most diffused is the cane, which can only provide alerts for obstacles found in front of the user's feet (<1 m), without any protection against obstacles on the upper part of the body and without information regarding their speed, volume and distances [5]. In order to overcome such limitations, specific electronic travel devices have been proposed, named Electronic Travel Aids (ETAs) [6, 7], devised for detection of objects along the user's pathway. The international guidelines for ETAs [6] require the following:

(1) detection of obstacles in the travel path from ground level to head height for the full body width;
(2) travel surface information including textures and discontinuities;
(3) detection of objects bordering the travel path for shore lining and projection;
(4) distant object and cardinal direction information for projection of a straight line;
(5) landmark location and identification information;
(6) information enabling self-familiarization and mental mapping of an environment.

Today, there is a wide range of navigation systems and tools available for visually impaired individuals [7, 8]. Most of the proposed ETAs are based on the transmission of an energy wave and the detection of echoes from objects present on the user pathway and a great number of them use ultrasonic emitter/receiver transducers [7, 8].

There are also some commercial products available on the market for the mobility of the blind and visually impaired (ultrasonic sonars, laser range sensors; infrared and photodiodes sensors, etc.). They have been proposed with the aim to solve the problem of individuate shoulder-width openings [9].

All of these systems require a mental effort to identify the obstacle with respect to the user's position and/or direction. Despite recent improvements, these devices still present some drawbacks such as restricted functionalities, relatively high cost, and limited acceptability by the users. In general, the recognized limitations of the actual ETAs (commercial systems or prototypes) based on ultrasonic are the following [6–10]: limited useful range, difficulties of operating on highly reflective surfaces (smooth surfaces) with a low incidence angle (<40°), and when detecting small openings due to the aperture of the emission cone of ultrasonic waves. Optical ETAs, which do not suffer from these limitations due to their shorter wavelength, however suffer other difficulties such as high sensitivity to ambient natural light or dependence on the optical characteristics of the obstacle surface (transparency or mirror-like reflection). It is generally agreed that, currently, no available ETA incorporates all the required features to a satisfactory extent [6–10].

It is interesting to note that, in the literature, there is a lack of studies that consider electromagnetic (EM) radiation as the physical quantity able to deliver information on obstacle presence for visually impaired users.

The main aim of this paper is to present the characteristics of EM assistive technologies for visually impaired users and present some works carried out by the authors mainly addressed to investigate the capability of novel EM systems designed to support visually impaired and blind user mobility.

At first an obstacle detection system was proposed and set up to carry out a preliminary experimental analysis to investigate the possibility of adopting EM waves for ETAs and to provide useful information for the design of an EM sensor to aid visually impaired users during mobility tasks, possibly allowing them to walk safely and independently [11].

On the base of the encouraging results obtained in the preliminary study [11], an innovative sensing method, based on EM pulses, was designed and will be presented together in the following with some experimental results achieved in obstacles detection. The proposed approach accomplishes most of the operative requirements of ETAs for visually impaired subjects and can provide additional information (height form the ground, distance and position of the obstacle) on obstacles respect to the available assistive technologies currently used.

The third example can be considered an indirect and unexpected result of the experimental activity concerning the "EM cane" previously mentioned. The blind person that we involved in our activity to test the system is a world champion of marathon for disabled people. For this reason, the idea was designing a system able to make the athlete free of running independently from his guide, at least during training sessions.

In this contribution, the authors want to underline that the satisfactory results obtained demonstrate how EM technology is capable of providing some helpful aids for visually impaired people. Nevertheless, the full development of a device to insert on the market at reasonable costs requires the joint effort of different scientific expertise and a multidisciplinary approach deeply involving the visually impaired user community. Therefore, the paper finally presents some hints for discussion to the automatic control community.

2 A Preliminary Experimental Study

The aim of any obstacle detection system is to allow a visually impaired person to speed up mobility mainly by getting information on the surrounding complex environment. Our system will explore a defined volume in front of the partially sighted user. The scenario we refer to is a 3-D region in front of a walking person, where there may be some obstacles at different heights, which can be very dangerous for blind people [6]. In a realistic context, several kinds of situations can be a serious threat, e.g., open windows, public telephones (that are large but attached to a slender pole), low branches, or rears of trucks, and for these cases, the cane is not able to help the person; some examples of possibly dangerous obstacles are shown in Fig. 1.

The system has to give information on the presence, location, and, possibly, the nature of the obstacles immediately in front of the subject, exploring in elevation a region from ground-to-head level and in azimuth an area corresponding to the

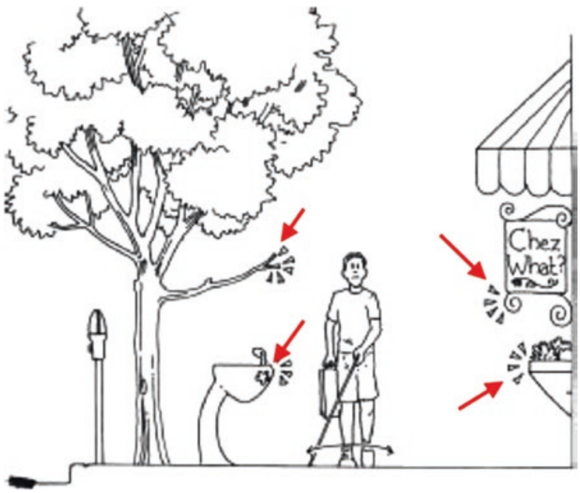

Fig. 1 Examples of obstacles potentially dangerous for visually impaired mobility not detectable by the cane

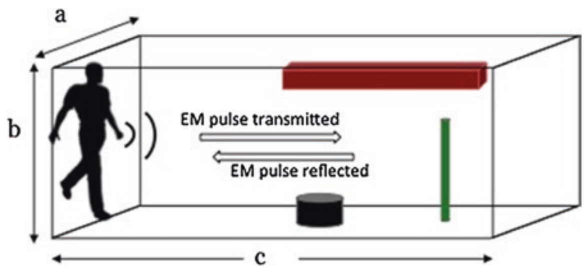

Fig. 2 Volume explored by the proposed system

subject's body; this explored volume has also been determined as significant for blind users in [11]. The minimum distance or range over which this information is needed is a comfortable stopping distance at normal walking speed [6–10, 12]. The volume explored in this study is a parallelepiped in front of the subject of 3 m of length, 1.5 m of width, and 2 m of height (Fig. 2).

Such dimensions are a compromise between the necessity, in a real system, to give sufficient information to the user and the need to limit meaningless alarms. For a quick identification of obstacle location, we have considered three different sub volumes of the scenario:

(1) leg zone: volume in front of the subject in contact with the walking surface;
(2) trunk zone: volume in front of the subject's trunk;
(3) head zone: volume in front of the subject's head.

The system was realized using laboratory instrumentation and some tests were performed considering dangerous obstacles similar to those reported in Fig. 1 [11]. Figure 3, where the horizontal axis has been converted in distance, clearly shows how the EM pulse is able to detect, discriminate different obstacles and even locate their position at the right distance.

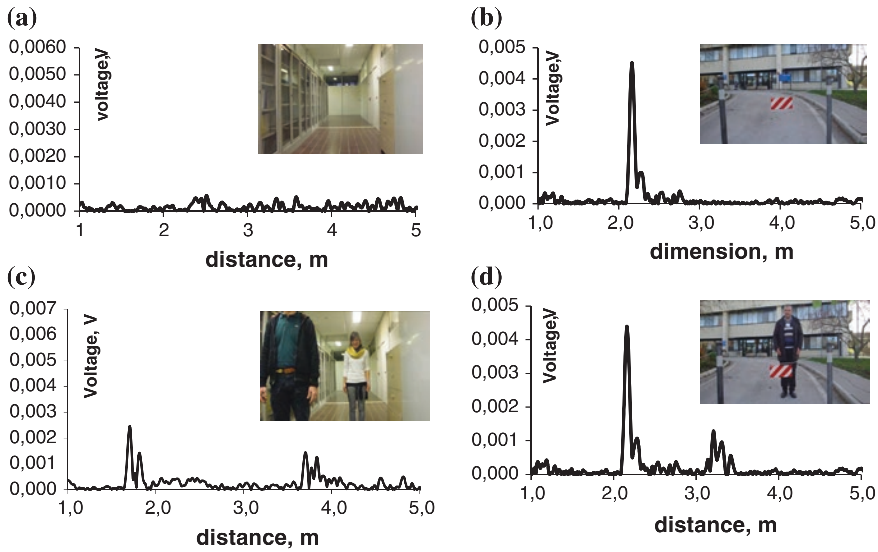

Fig. 3 Signals measured in cluttered scenarios. **a** Indoor corridor without obstacles and **c** the same corridor with the obstacles. **b** Outdoor scenario with metal poles and chain and **d** same as **b** with a subject behind

3 The Electromagnetic Cane

The experimental set-up realizing the EM obstacle monitoring system is described in detail in [11]. The EM system consists of a control unit, a Tx/Rx unit and a radiating element. Each part has to be set up and/or properly designed according to the requirements of the scenario. The radiated signal is a short pulse whose echo will be used to extract information of the object. In detail, the obstacle is illuminated using an antenna and a Vectorial Network Analyzer (VNA) has been used to measure the reflection coefficient at the antenna input. The VNA provides a time domain pulse with duration of 0.4 ns (calculated at 50 % of the pulse amplitude), corresponding to 12 cm spatial resolution. Actually the pulse is reconstructed from the VNA that generates a continuous wave signal with a frequency sweeping from 1 to 6 GHz as explained in [11]. The system is intrinsically immune to the external disturbances, because in our system, the reflected and transmitted signal are always synchronized.

Figure 4 shows the portable prototype of the EM obstacle detection system realized with a homemade helical antenna (matched from 4 to 6 GHz; half power beam of about 35.9° in the plane $\varphi = 0°$ and 36.9° in the plane $\varphi = 90°$, realizing a suitable beam able to scan the volume depicted in Fig. 2), a portable VNA and a laptop for signal processing and acoustic warning. After a first stage of laboratory measurements to optimize the set-up parameters, different tests have been carried out asking to a blind volunteer to walk toward a sound source using the EM prototype

Fig. 4 Photos of the EM obstacle detection sensor. The homemade antenna and the VNA (*left*) the system in use (*right*)

and holding the antenna connected to the VNA in one hand and wearing a back-pack containing the laptop [13]. The test carried out confirmed the effectiveness of the system and highlighted important suggestions for future developments [14].

4 Athlete Guiding System for Marathon Race

Although the view plays an extremely important rule in almost every sport, many people with visual disabilities participate in high performance, competitive and/or recreational sports, but no electronic devices have been conceived yet to improve their autonomy during sports. In fact, looking at the marathon race, the most widely used technique by blind athletes is to run linked to a sighted guide by means of a non-stretchable tether tied around the wrists or held between fingers. For these reasons, the a different EM system has been thought to support and guide blind athletes while training or running a marathon race [15].

As an overview, the system has to draw an invisible track that should be followed by the runner by means of the generation of two “EM walls” due to the radiation patterns of high directional transmitting antennas, as depicted in Fig. 5. To make sure that the athlete always remains inside the virtual hallway, it is necessary to generate a warning whenever he is getting closer to the borderlines so as to encourage the runner to move toward the central position. To this aim, the whole system proposed consists of transmitting and receiving subsystems. The transmitting subsystem, to be placed on a trolley or a vehicle running in front of the user, includes: two radiating elements that generate the two EM walls and two amplitude (AM) modulators at two different frequencies in order to discriminate between left and right boundary. On the other side, the receiving system, to be worn by the user, is composed of a receiving antenna, an AM demodulator, two band-pass filters, a Micro Controller Unit for thresholds settings and further signal processing and two vibration transducers to communicate a warning signal to the blind athlete.

An important issue is the design of the transmitting and receiving antennas, working at about 10.4 GHz. Since to generate an EM wall the radiation pattern

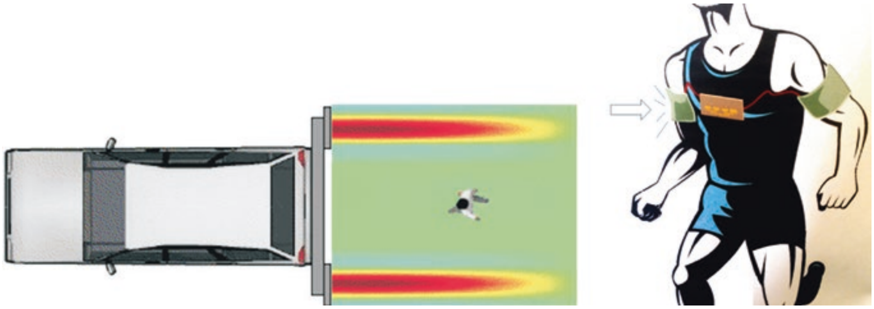

Fig. 5 Transmitting system placed on a car and representation of the virtual hallway (*left*); image of the receiving unit worn by the athlete (*right*)

should be narrow on the horizontal plane and wide on the vertical one (fan-shaped), a slot antenna has been chosen as radiating element.

As concerns the receiving antenna, it has been designed in order to have a lightweight and wearable device with a radiation characteristic similar (but less restrictive) to those of the transmitting antennas. A microstrip array antenna of four elements has been designed and realized. The combination of the transmitting and receiving radiation patterns leads to different levels of the demodulated signal. As the position of the runner changes with regard to the transmitting antennas, the magnitude of the received signal changes accordingly and it can be used to drive the warning signals.

5 Discussions

The encouraging results reported in this paper and mentioned above seem to be potentially useful for the scope of assisting visually impaired users in their daily life.

The EM obstacle detection as well as the EM system for runners can contribute to reduce the daily limitations that visually impaired users have to undergo, improving their quality of life. Nevertheless, it is worth noting that they still are laboratory prototypes and consequently far to be ready for the market. To reach this aim, a series of improvements of the existing prototypes are necessary in order to address the following aspects: portability, communication with the user (user-interface), real-time data processing, etc. These aspects, common to all ETAs [6], are requiring the joint effort of different expertise and the very important contribution from the visually impaired user-community.

An important aspect that needs to be addressed is the realization of a computationally efficient algorithm for a real-time inversion of radar data in order to greatly improve the knowledge of the surrounding. A lot of information is stored into the reflected echo signal, but a powerful signal-processing algorithm is necessary to be integrated within traditional radar techniques in order to extract significant parameters in real time. More specifically, from the radar signal, suitable parameters related to the geometrical and physical characteristics of obstacles could be obtained and inverted to determine distance, velocity, dielectric properties and dimensions of the detected objects.

Another important issue to be addressed is the user interface that allows the visually impaired user to control the system and to receive information about the detected obstacles according to strategies meeting the needs of visual impairments. Pushbuttons/mini joysticks could be integrated in the cane or in a device worn or held in one hand; by means of them, the user would be able to control the system activating functioning modalities (enabling/disabling obstacle detection, disabling vibration feedback, getting information about the battery status, etc.). The output user interface could be based on vibration feedback, audio messages and sound alerts, and could operate according to proper strategies to avoid overcharging the sense of hearing, widely used by visually impaired people to get information on environments. The possibility of interconnection between the user interface device and a smart-phone could offer new capability to the user. It is worthwhile to underline the importance of using the experience of visually impaired users for this issue.

Finally, portability aspects have been recently been addressed for what concern the possibility to miniaturize the radiating element in order to easily install it on the VI user cane. Further improvement of the system portability could be obtained substituting the PC with an embedded electronic board providing the data processing and output signals for the user.

Many other opportunities may arise joining EM technology and assistive robotics. Autonomous mobile robots can be adapted to work as assistive robots, because their capabilities to navigate in unstructured environments and react to changes in it [16]. Now it is an easy task mounting a radio beacon on the robot with the aim of realizing an automated system able to guide a visually impaired subject in a complex and indoor environment as an airport, a station or a hospital. A small and lightweight device could receive the beacon signal providing in real time direction and distance of the robot, allowing the user to follow the robot along the desired path.

6 Conclusions

The capability of EM devices working in the radio frequency range to be used in the realization of ETAs for visually impaired people has been highlighted. Two practical examples, an EM cane for obstacle detection to warrant a safe walking and a system for autonomous running of a marathon athlete, have been shown and realized using laboratory instrumentations.

However, the main aim of this contribution is to provide hints for discussion, because technology is mature enough to allow design of small, lightweight, and cheap devices, but the reliability of the system depends on the joint interdisciplinary work of scientist with different expertise.

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Evacuation Aid for Elderly in Care Homes and Hospitals: An Interactive System for Reducing Pre-movement Time in Case of Fire

Marco D'Orazio, Gabriele Bernardini, Sauro Longhi and Paolo Olivetti

Abstract Population aging phenomena are increasing the attention to safety aspects for Elderly in care homes and hospitals: individuals that can autonomously evacuate should be helped during the evacuation by providing specific devices to them. Our activities are aimed by the design of "guidance" system for these categories, and to inquiry their impact on people motion. One of the most important evacuation steps is represented by the pre-movement phase: after the fire alarm sound, individuals continue to spend time in activities not directly connected to the evacuation. This phase could be very long. This work proposes an interactive system for the pre-movement time based on an experimental analysis of pre-movement time behaviors. The system is composed of an individual wearable device: the Zig-Bee-based localization module identifies people's positions after the alarm and understands whether they are motionless; the interactive module gives a personal stimulus to the latecomers. Technical requirements are evaluated. The effectiveness of the system is investigated through simulations: up to 30 % reduction in total evacuation time can be obtained.

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1 Introduction

The population aging provokes an increasing request of accommodations for Elderly in healthcare homes [1]: for this reason, their safety, especially in case of an evacuation, becomes an essential aspect. Current regulations adopt a schematic approach in building layout and in characteristics of healthcare assistance. In case of evacuation, patients have to be directly carried out by health assistants: as such, a constant presence of a large staff is needed. In addiction, the assistance staff is not usually adequate in the real cases; in any case, a high evacuation times is connected to the transportation of each patient. On the contrary, guests with motion autonomy could exit the building by themselves: they do not need the intervention of a healthcare operator, but they can be simply helped by a series of evacuation facilities, such as "guidance" systems. Both initial and motion phases must be inquired. Our research is intended to design interactive system that can help similar individuals during the whole evacuation procedure. Two issues are needed: understanding human evacuation behaviors; designing the "guidance" system, including experimental studies on their technological requirements and their influence in space perceptions and motion.

The first issue involves the behavioral investigation of evacuations for different structures [2, 3], including healthcare structures [2, 4]. The fundamental influence of the first evacuation phase on the whole procedure is evidenced. The "pre-movement" phase [2, 3] starts after the evacuation causes detection (fire, earthquake, flood) and the occupants alert. In this phase, people spend time in different activities before moving out [5]: interpreting any information about dangers, interacting with other neighbor individuals [6], waiting for other people ("attachment to people") [6] and collecting their belongings ("attachment to things") [7]. Pre-movement time duration depends on the type of building and activities in which people are engaged [2, 4]. A significant delay in evacuation start can lead to numerous losses of life [8], especially when people are involved in carrying out other activities or are in not familiar spaces. Efficient systems that are capable to help people during the evacuation can reduce the egress time in both pre-movement and motion phases [3]. Wearable personal devices can be used [9, 10] in order to define the individual's position, recognize his eventual time-wasting behaviors and interact with him. Then, localization data can be analyzed and simple information or direct stimuli can be addressed to the evacuating pedestrian through an interactive module placed on the worn device itself [11, 12]. One of the most significant real-time building monitoring technologies concerns sensor units and communication network based on wireless Zig-Bee [13], also in evacuation conditions [10, 14]. A limited number of works adopts a similar approach; only few of them propose an interactive system. The interaction with people during the pre-movement phase including a strict relation to time-wasting behaviors is not investigated. This work provides an interactive system for pre-movement time reduction and so evacuation aiding. A wearable system that takes advantage of a wireless network by using Zig-Bee technology is offered. System requirements are experimentally analyzed in relation to localization error and response time. The system effectiveness in terms of evacuation time reduction is evaluated by using an Elderly evacuation simulator [15]. Our system could be used as an evacuation support tool for autonomous elderly people in healthcare structures: individuals can be continually monitored (also with health monitoring sensors systems) and a direct stimulus can be simply addressed to him in emergency situations.

2 Phases, System Architecture and Evaluation

2.1 Phases

The work is organized in four phases:

- summary of noticed pre-movement behaviors;
- design of the system for pre-movement time reduction;
- evaluation of technological requirements;
- system evaluation in terms of evacuation time reduction by using a simulator.

Firstly, experimental results of previous works are organized in order to define a list of time-wasting behaviors performed by individuals during the pre-movement phase; "attachment to things" phenomenon is included [7]. Secondly, the interactive system, including composing modules characterization, is defined. Technological requirements are analyzed in relation to localization error and system response time. Finally, our system effectiveness investigation adopts the use of an evacuation simulation software in a hypothetical case study. We actually do not assemble a series of real devices: as such, computer simulations are used for the tests.

2.2 System Architecture and Evaluation

Our interactive system architecture is designed in order to recognize the "wrong" pre-movement behaviors that are experimentally noticed, and to address a direct and personal stimulus to individuals. For this reason, we adopts a wearable device composed of a localization module for determining the individual's positions, and an interactive module with a vibration motor for stimulating the latecomers. The CC2431DK hardware platform produced by Chipcon is used [16]: this platform uses a wireless network based on the ZigBee-2006 standard [13]. The CC2431 location detection module can be used in nodes with unknown location (blind nodes, on the devices) to receive signals from nodes with known location (reference node). The location engine estimates the blind node position by using the value of Received Signal Strength Indicator (RSSI) [16]. This system could also simultaneously evaluate other environment and individual's quantities (CO_2 levels,

Table 1 Please write your caption table here

Setup	Type of test	Height of blind node (m)	Number of sample
1	Still test	0.5	7705
2	Motion test (1.5 m/s)	1.0	2502

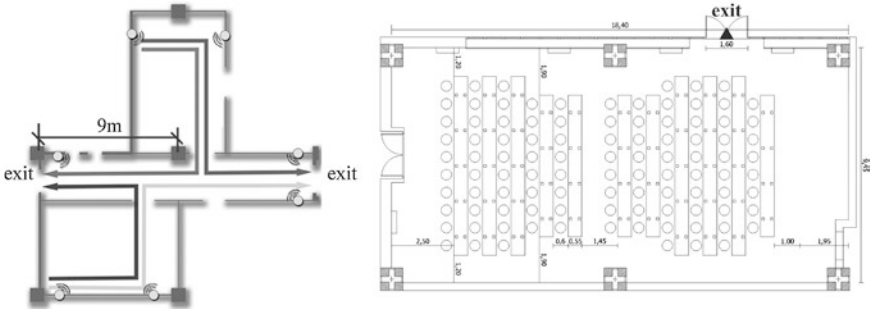

Fig. 1 Setups and simulation environment. **a** (*left*) Setups environment; reference nodes (*grey circles*) and paths for motion tests (*grey arrows*) are evidenced. **b** (right) Simulation environment (refectory)

air temperatures, people's body movements). The included vibration motor can produce a direct stimulus. Technological requirements are investigated through an experimental analysis by using the SmartRF04 EB of the CC2431DK as monitoring system for collecting data on a laptop. Tests are conducted in various rooms of the main building of "Università Politecnica delle Marche", Ancona, Italy. Firstly, the localization module analysis (localization error E (m)) concerns the possible interferences with other wireless devices present and the estimation of the localization distance error. Table 1 and Fig. 1a characterize still and motion experimental tests. Wi-Fi devices could potentially interfere with ZigBee communication when their carrier frequencies overlap [17]. In motion tests, the blind node is moved, for 20 times, along the evacuation routes with a speed of 1.5 m/s; activities were repeated for each route. E is considered as the distance between the real position and the calculation result of the blind node which is recorded every 0.5 s.

Secondly, the system response time R_{time} is investigate in order to understand the system activation time. Equation 1 proposes the R_{time} value needed for detecting a wrong behavior and to transmit the stimulus:

$$R_{time} = 2 \cdot E/V + T_s + 2.0\,\text{s} + 2.5\,\text{s} + 3.5\,\text{s} \tag{1}$$

where E (m) is the localization error threshold value, V (m/s) is the average walking speed, T_s (s) is the time needed for the sit-to-walk activity [18]. In Eq. 1, we consider: 2.0 s for standing up, 2.5 s for acquiring the 5 new locations, 3.5 s for giving a direct stimulus. A *latecomer* is individuated if his pre-movement time is higher than R_{time}: the system will so interact with him through the personal stimulus. Finally, a multi-agent simulator for evacuation of care homes and hospitals for

Elderly [15] is used for the first system evaluation. The simulator is used to evaluate the influence of the interactive system in the case-study. The room in Fig. 1b, organized as a refectory, is chosen as hypothetical evacuation environment; input values concerning number (62 individuals) and positions of people are constant, while elderly parameters (pre-movement time, walking speed) are based on literature values [2]. In simulations, we consider that not all the *latecomers* would positively respond to the stimulus: variations in the percentage of the positive *latecomers*' reactions are considered, from 0 % (equivalent to an absence of the system) to 100 %; stimulated *latecomers* are randomly chosen. In scenarios, in case of positive response to the stimulus, an individual reaction time equal to R_{time} is considered. The random choice of *latecomers* with positive response implies *latecomers* with a negative response (with a high pre-movement time and, consequently, a high total evacuation time): as such, the pedestrian flow rate at the door is analyzed at the 54th individual in each simulation.

3 Results

3.1 Noticed Pre-movement Time Behaviors

Table 2 summarizes a list of noticed pre-movement behaviors, also according to results of previous analyses on real events in emergency conditions and experimental evacuation [3, 4, 7, 19]. Keywords and main references, short description and direct

Table 2 Noticed behaviors

Behavior keywords [main references]	Short description	Consequences
information exchanges [7, 15]	communicating with other neighbors, deciding if it is necessary to evacuate, confirming emergency conditions	increasing collective pre-movement time
attachment to belongings [7, 19]	collecting belongings and then going to the exit	queue phenomena block of evacuation path high individual pre-movement time
"Herd Behavior" [15]	dependency of own motion and velocity from the neighbors' ones	group motion
attachment to people [6, 7]	waiting for other people and then go to the exit	queue phenomena group motion increasing collective pre-movement time
coming-and-going [7]	apparently starting of evacuation, but rapidly returning to the initial point to collect belongings; then going to the exit	queue phenomena counterflow motion high individual pre-movement time

visible consequences are evidenced for each behavior. Concerning pre-movement time in health care homes and hospitals, a general average value of 48.0 s is suggested, while the speed in horizontal paths is equal to 1.04 m/s for elderly, and to 0.95 m/s for individuals with partial motion disability and no aid [2].

3.2 Design of the Interactive System

Table 2 confirms how pre-movement behaviors involve a large series of time-wasting effects. Although *latecomers* mainly spend time in individual behaviors (*attachment to belongings, coming-and going*) and not in group phenomena, they cause a general evacuation delay, especially due to queue phenomena. As such, our system is designed for interacting with these *latecomers*, using personal stimuli, with the aim to reduce their pre-movement time and so to improve the whole evacuation process. Table 3 summarizes our system interactive components. Our system is composed of a wearable device for each person in the environment. Each device includes two main modules: the *localization module* and the *interactive module*. Figure 2 graphically shows the system operations. The *localization module* detects the person's position during both the fire alarm and the evacuation process (continuous calculus of the position and record of the last 5

Table 3 Characterization of system components

Components	Main issue	Main requirements
Reference node	interaction in the radio range with the blind node; known position	more than one for each room
Blind node	interaction in the radio range with the reference node	one for device
Location module	estimation of blind node position (by using the RSSI value) and records it	one for device
Interaction module	detection of individual's motion and eventual vibration motor activation	one for device
Vibration motor	direct and personal stimulus to the *latecomer*	one for device; activated in a certain time after the alarm start

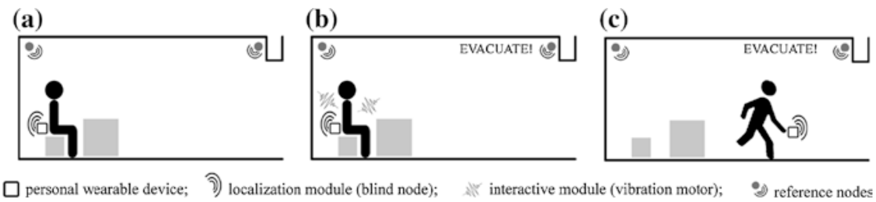

Fig. 2 Graphical representation of the three main operating phases of the system

positions) by using the blind node-reference nodes communication in the wireless network based on ZigBee-2006 standard (Fig. 2a). When the alarm sounds, the *location module* starts recording 5 locations and gives the time to the elderly to stand up and to tread a distance that is equal to $2E$ (Fig. 2b). Then, 5 new locations are recorded and compared whit the previous ones: in this way, the module understands if people is effectively moving toward exits or if they are spending time around the same position. If the *latecomer*'s positions are close (e.g. distance $\leq 0.5E$), the *interactive module* considers that the *latecomer* is not moving: then, it addresses to him a personal stimulus through the vibration motor. The vibration is chosen because it is direct and personal; it lasts for about 3.5 s. The system has to detect the behavior and interact with the *latecomer* in a short time, in order to be really efficient. A limit time could be inferior than the experimental average pre-movement time for the application environment [2]. Finally, the *localization module* control the rest of the individual's motion, and additional stimuli could be given in case of other stops in evacuation (Fig. 2c).

3.3 Technological Requirements Evaluation

An average location error E value of about 3.2 m is retrieved for setup 1, with a maximum value of 13.4 m. Setup 2 shows similar values: in a movement test, and average E value of 3.4 m is retrieved, with a maximum of 13.9 m. A common minimum of 0.1 m is offered for both setups. When Wi-Fi network activities in the building and the related interferences are present [17], the average E is higher than 2 m, also according to previous work [20]. A E threshold of 5 m implicates a probability to correctly detect the 83 % of positions of people in motion. Equation 2 shows the R_{time} calculus according to Eq. 1:

$$R_{time} = 2 \cdot (5\,\text{m})/(0.95\,\text{m/s}) + 1.82\,\text{s} + 2.0\,\text{s} + 2.5\,\text{s} + 3.5\,\text{s} \approx 20\,\text{s} \qquad (2)$$

where $E = 5$ m according to the experimental threshold value, $V = 0.95$ m/s [2], $T_s = 1.82$ s [18]. The *localization module* operates in 12 s, the *interaction module* in 8 s.

3.4 Evaluation of Evacuation Time Reduction

Figure 3 shows the simulations results referring to the pedestrian flow rate at the doors considering the egress time of the 54th evacuating individual: this flow depends on the different percentages of individuals with a positive response to the vibration stimulus. The time for flow calculus include both pre-movement and movement time.

The response time in case of positive response is equal to 20 s, according to R_{time} in Eq. 2: this represents the best evacuation condition about individuals'

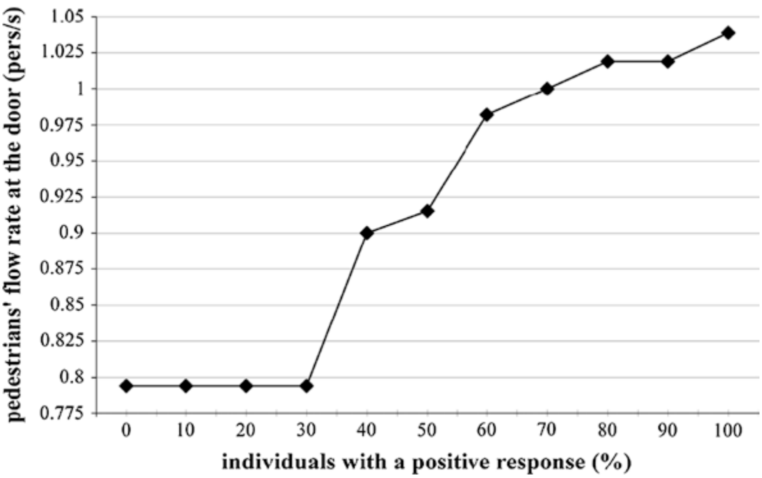

Fig. 3 Pedestrians' flow at the 54th student in 10 percentages of latecomers' reaction to the stimulus

response. Every setup considers a different percentage of positive reaction of the *latecomers* to the stimulus, starting from a null percentage (0 %) of positive responses to stimulus (equivalent to an evacuation without devices) to the simulation with a full percentage (100 %). Our system needs a percentage of positive reaction to the stimulus above 30 % in order to have an evacuation benefit. It is possible to increase the pedestrians' flow up to 30 %: in this condition, the total evacuation time decreases from 81.6 to 57.00 s, with 24.6 s of benefit.

4 Conclusions

After the alarm sound, people carry out activities not connected with evacuation and that lead a high evacuation time and queuing phenomenon due to the block of some evacuation routes. Reducing this pre-movement time is very important especially in Elderly safety: a possible solution is introducing interactive systems for identifying *latecomers* and giving them a personal evacuation stimulus. This work proposes a system for pre-movement time reduction based on interactive wearable devices. Time-wasting behaviors activated in the pre-movement phase are summarized. Then, the system is defined. The *localization module* determines the person's position by using the Zig-Bee network, in order to understand if he is evacuating: in negative case, a personal stimulus is addressed to him through the included vibration motor (*interactive module*). Technological requirements are evaluated. Individuals' localization can be influenced by other Wi-Fi networks: an error of 5 m in assigning people's positions is estimated. The *response time* (identifying the latecomer and interacting with him) is equal to 20 s: as such, the system effectively operates if the individual's pre-movement time is $\leq$20 s. A hypothetical case study is inquired with the purpose to evaluate the system effectiveness by means of a simulation method: a reduction up to 30 % in total evacuation time is retrieved by using our system.

The physical creation of a series of evacuation devices is needed in order to provide a series of real experiments, and to evaluate out system reliability in presence of Wi-Fi networks in a deeper way. Experiments would also determine the effective requirements for the type of stimulus to be given by the interactive module, by considering the final user (elderly). The device could be also inserted in wearable objects (e.g.: badges) and simply integrated to health monitoring systems for health care homes application: in case of problems, assistance staff will be advised. Various localization systems could be compared in order to detect the most efficient system with the lowest interference level. This work is one of the activities of our research group. Our goal is defining and designing a series of evacuation facilities ("guidance" systems, interactive building components) that allow people with in particular conditions (elderly, people with partial disabilities in motion) to properly evacuate in an autonomous way, with a reduction of the healthcare operators interventions to the really needed cases.

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RESIMA—An Assistive System for Visual Impaired in Indoor Environment

Bruno Andò, Salvatore Baglio, Cristian O. Lombardo and Vincenzo Marletta

Abstract This paper presents results achieved during the RESIMA project aimed to develop a remote monitoring system to assist weak people to safely exploit unknown environments. The system consists of a wireless sensors network distributed within the environment and intelligent paradigms able to acquire awareness on the environment, the user's location and his/her posture. Exploiting such piece of information allows the system to properly manage the user-environment interaction (UEI) and to contextualize the user within the environmental status (UEC). Information generated by UEI and UEC paradigms allow for guaranteeing a real-time and continuous form of assistance for the user tailored to his/her specific needs.

1 Introduction

The scientific community is focusing on enabling technologies to improve the life quality of weak people such as elderly and persons with sensory disabilities [1–8].

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A system for navigation for the visual impaired using the ultrasonic signal to detect obstacles is presented in [9]. Other devices use vision systems to transmit information to the user on the surrounding environment [10, 11].

Solutions able to detect the user in proximity of reference sensing nodes are addressed in [12]. Such solutions suffer from the discontinuity form of information on the user position thus compromising the possibility to estimate and manage his/her interaction with the environment.

Solution proposed in [13] uses a CANBUS sensor network (Controller Area Network Bus) and it represents a preliminary attempt to achieve a real time awareness on the user/environment relationship and to continuously provide him/her with a continuous form of assistance. An improvement of the CANBUS system based on a Wireless Sensor Network is prosed in [14].

The RESIMA system is aimed to fix above mentioned drawbacks of assistive systems oriented to weak people exploiting indoor environments. In particular, the proposed methodology relies on a real time and continuous user localization task, while a decision making system assists the end user by assessing the User-Environment Interaction and the User-Environment Contextualization [15, 16].

2 A System Overview

The RESIMA architecture is shown in Fig. 1. The system consists of a Wireless Sensor Network (WSN) composed by a user node (embedding navigation and positioning sensors) and distributed nodes for the monitoring of the environmental status and the user position. A synch node acts as the collector for wireless nodes.

The WSN has been realized by Crossbow Iris XM2110 modules exploiting a ZigBee protocol. The user module is realized by a Iris module for wireless communication, an ultrasound transmitter, an electronic compass and a inertial monitoring unit (9DOF sensor stick). The generic network node is equipped with environmental sensors for gas detection (Figaro LPM2610) and smoke detection (FR209), temperature measurement (LM35) and a ultrasound receiver for the sake of user localization.

The user's position estimation is based on the continuous interaction between the user module and the environmental nodes which perform a ultrasound trilateration and advanced paradigms to perform a very accurate user localization. Information provided by the WSN are exploited by the User-Environment-Interaction (UEI) and User-Environment-Contextualization (UEC) tools, to assess meaningful events for the user such as the presence of obstacles and/or services, environmental risks and anomalous user posture.

A dedicated software environment has been developed in LabVIEW™ to implement signal processing and to provide a dedicated Graphical User Interface (GUI) for the system supervisor or the caregivers.

UEI algorithm exploits a priori knowledge of the local map in terms of fixed objects and services, and the knowledge of the user position in order to estimate

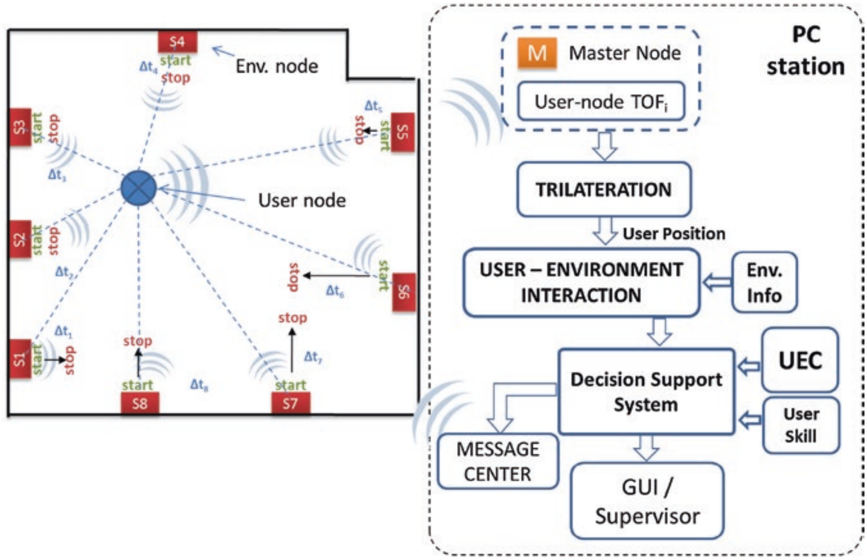

Fig. 1 Schematization of the RESIMA system

the degree of user interaction with the environment by identifying possible obstacles and highlighting the possibility to use services close to the user. Each event detected by the UEI tool generates a candidate message with an assigned priority. The algorithm UEC instead correlates the posture of the user with information about the environment status and generates candidate messages with a priority.

Outputs of the UEI and UEC tools are then used to properly assist the user for a safe and efficient exploitation of the environment. In particular, the Decision Support System, DSS, manages the priority of candidate messages and the user feedback modality taking into account his/her ability. In case of specific needs, the DSS uses routing algorithms to guide users towards emergency or requested location. The following sections will describe the functionality of the UEI, UEC and routing algorithms.

3 The UEI and UEC Tools: Implementation and Experimental Assessment

A description UEI working mode is shown in Fig. 2. The system performs two checks in order to determine if an obstacle or a service is close to the user and in the direction of his/her motion. As first the interaction of the two safety areas around the user, defined by R_{user}, and the obstacles/services, defined by $R_{obst/serv}$, is verified.

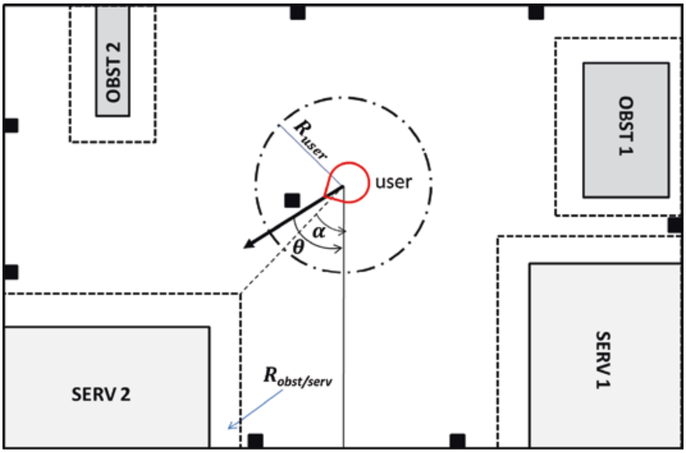

Fig. 2 Schematization of the environment used for UEI functionality assessment

If these two areas are overlapped a second check is performed to verify if the obstacle is located along the user path direction. If both checks are successful a message related to the presence of obstacle/service is provided to DSS.

Two types of tests were carried out for different values of R_{user}, with different normal sighted users (bandaged) which were asked to move within the test environment. The first set of experiments is designed to test the ability of the system to properly warn the user about the presence of obstacles, by considering the number of obstacles intentionally avoided (True Positive, TP), and the number of collisions (False Negative, FN).

Results related to this tests are presented in Table 1 which demonstrates that the number of failures increases by decreasing the notification distance (the distance at which the user is informed about the obstacle presence). The second class of tests was aimed to assess the system performances in terms of service exploitation. Results for this test are presented in Table 2, which evidences that, also in this case, an optimal notification distance can be defined.

Table 1 Results of the collision avoidance performances of the UEI algorithm

	Distance from the obstacle [m]			
	0.10	0.25	0.50	0.75
TP	29	48	76	86
FN	71	52	24	14

Table 2 Results of the service exploitation performances of the UEI algorithm

	Distance from the service [m]			
	0.10	0.25	0.50	0.75
TP	29	48	76	86
FN	71	52	24	14

For the sake of completeness Fig. 3 reports the sensitivity in performing the two analyzed tasks estimated as:

$$Sensitivity = \frac{TP}{TP + FN} \tag{1}$$

where true positives (TP) correspond to successfully accomplished tasks, while false negatives (FN) count failures.

Regarding the UEC tool it has to be observed that the user module is equipped with inertial sensors suitable for the measurement of the user posture. The basic postures identified by the algorithm are: erect (ER), bowed (BO), sitting (SI), lying prone (LP), lying supine (LS), lying lateral (LL). The algorithm also detects and properly manages four different indeterminate conditions: erect/bowed (ERBO), erect/sitting (ERSI), sitting/lying (SILD) and bowed/lying (BOLD) in order to avoid false identification of the user postures.

The tests on such system were carried out by 10 users with different physical characteristics. Each basic position was repeated 100 times. The tests results are reported in Table 3.

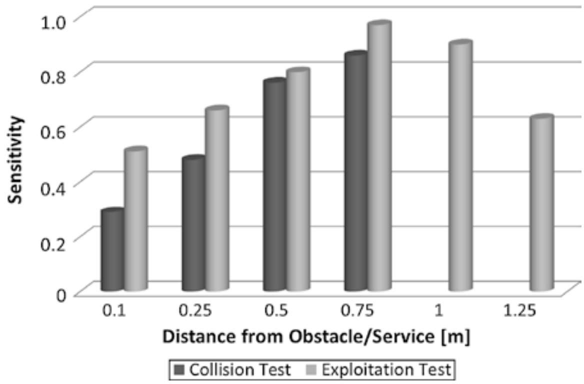

Fig. 3 Sensitivity of the UEI algorithm

Table 3 Experimental results of the user posture tool

		Posture measured									
		ER	*BO*	*SI*	*LP*	*LS*	*LL*	*ERBO*	*ERSI*	*SILD*	*BOLD*
Posture expected	*ER*	289	2	0	0	0	1	7	1	0	0
	BO	2	273	0	0	0	0	25	0	0	0
	SI	17	0	234	0	0	0	0	45	0	4
	LP	0	0	0	225	0	75	0	0	0	0
	LS	0	0	0	0	207	48	0	0	0	45
	LL	8	0	2	0	1	285	0	3	0	1

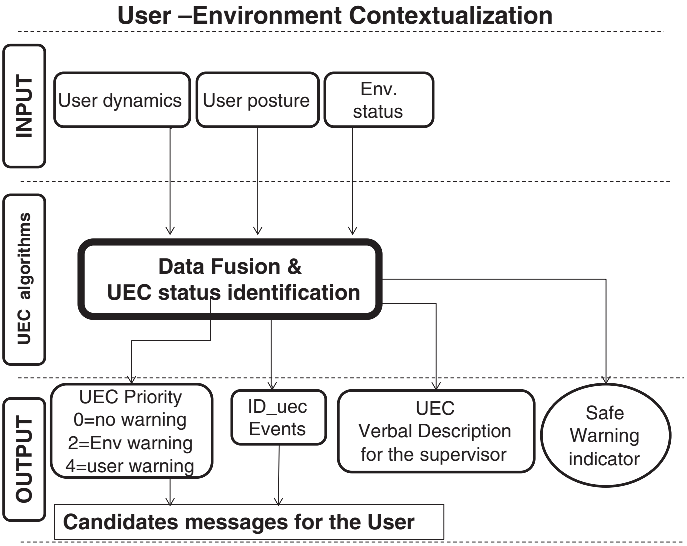

Fig. 4 Data flow representation of UEC algorithm

The UEC algorithm combines information on the user posture with the environmental status and generates messages candidates for the user with a priority assigned according to the scheme outlined in Fig. 4. The kind of generated messages is sketched in Table 4.

4 Routing Algorithm

As already evidenced, the assistive system exploits routing features to provide the user with indication on how to reach an emergency/requested target location.

The routing algorithm has to provide the user with navigation information which guarantee the location target with obstacles avoidance.

In particular, routing functionality for AAL applications requires 1fast path elaboration and minimal orientation changes of the path.

The algorithm chosen is the Basic-θ*, which discretizes the environment map in cells, calculates the routing path in accordance with issues above outlined, provides the user with simple route generated by using the map cells called waypoints.

Figure 5 shows waypoints to be provided to the user to reach the final target by straight path without obstacles.

Table 4 UEC outputs in terms of user messages and indications for the supervisor

		Environmental status					
		Safe		Gas leakage		Fire detection	
		User message	Supervisor message	User message	Supervisor message	User message	Supervisor message
User posture	Erect	0	0	Instructions to drive the user to the emergency exit	Call fire department for gas leakage	Instructions to drive the user to the emergency exit	Call fire department for fire
	Bowed	Courtesy message	Send assistance to the user	Courtesy message	Call fire department for gas leakage. Send assistance to the user	Courtesy message	Call fire department for fire. Send assistance to the user
	Sitting	0	0	Instructions to drive the user to the emergency exit	Call fire department for gas leakage	Instructions to drive the user to the emergency exit	Call fire department for fire
	Lie down	Courtesy message	Call ambulance. Send assistance to the user	Courtesy message	Call fire department for gas leakage. Call ambulance. Send assistance to the user	Courtesy message	Call fire department for fire. Call ambulance. send assistance to the user

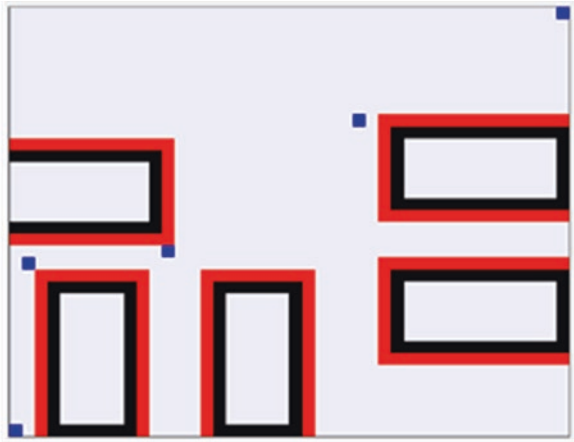

Fig. 5 Routing path identified with the Basic-θ*algorithm. Path is obtained by connecting waypoints

5 Conclusion

This paper deals with description of the general architecture of the RESIMA system, aimed to monitor and to assist people with visual impairment in indoor environments. In particular algorithms are devoted to analyze the functional relationships between the users status, in terms of position, posture and skills, and the environment status, in terms of obstacles/services location and hazard events. Actions implemented by the system in order to assure a safe and efficient exploitation of the environment have been also addressed.

Performances of the system developed are satisfactory and encourage the development of assistance systems based on the paradigms described.

Future developments will extend the RESIMA functionality in order to embed the management of evolving environments.

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An Electronic Cane with a Haptic Interface for Mobility Tasks

Bruno Andò, Salvatore Baglio, Cristian Orazio Lombardo, Vincenzo Marletta, E.A. Pergolizzi, Antonio Pistorio and Angelo Emanuele Valastro

Abstract There are numerous electronic solutions to help visually impaired in mobility tasks in everyday life. Although many of these systems correctly detect obstacles and locate services, thus improving the life of visually impaired people, generally the information provided by these systems is codified arbitrarily, thus requiring a learning phase and therefore discourages their use. This paper proposes an haptic approach to provide information about the presence of obstacles along the walking path that can be easily understood by the users. The aim of the proposed system is to reproduce the feeling provided by a traditional white cane, but using a short cane equipped with a smart system of sensors and actuators.

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1 Introduction

This document is intended to deepen the technologies dedicated to help visually impaired people during daily mobility activities. In literature many reputable reviews of the state of the art [1–6] can be found and several Electronic Travel Aids (ETA) have been proposed [7–14].

In spite of appreciable performances of above mentioned systems in environment perception, the arbitrary form of information conveyed to the user itself and, above all, the form of information can represent serious drawbacks leading to the user diffidence in the use of electronics aids. A wrong way to convey the information can cause masking of natural echoes and the need for hard trainings. So the presentation of information in a simple and easily understandable way is the key aspect in the implementation of these systems. An haptic user interface may be the best approach to provide information to visually impaired people. Haptic was defined by Gibson (1966) as "The sensibility of the individual to the world adjacent to his body by use of his body". Thus, in the last years, there has been a growing interest in haptic interfaces. A survey is available in [15] while a comprehensive review and classification of haptic methods for data visualization is given in [16].

Interesting approaches to assist visually impaired users in mobility tasks include the "Haptic based walking stick for visually impaired people" [17], developed using a traditional white cane. This system employs a group of ultrasonic sensors positioned near the end of the stick and a set of vibrating actuators in the handle of the cane, the vibration intensity of the actuators is proportional to the distance of the obstacle.

Conversely, the approach proposed in this paper is based on the stimulation paradigm developed to reproduce on the user palm a sensation similar to the one produced by a white cane.

Another device is the GuideCane [18, 19] developed at the University of Michigan. The GuideCane comprises a steerable sensor head mounted at the distal of a white cane. Ultrasonic sensors mounted on the sensor head detect obstacles and steer the device around it. Although the idea is very interesting and the feedback to the user is intuitive, the system is heavier than the proposed haptic cane and the use of the GuideCane across a rough terrain or in the stairs may be very difficult.

The research team of the Sensor Lab at the DIEEI in Catania—Italy is concerned with smart multi-sensor systems for AAL [20–22]. This paper presents a study on a haptic user interface concept to provide the user with information on incoming obstacles in a natural and easily understandable way. The proposed solution consist of a smart multi-sensor system embedded in a short cane equipped with an active handle. The smart multi-sensor system implements the natural haptic codification strategy which conveys to the user's palm a sensation similar to the one provided by a traditional white cane. The advantage of the proposed solution resides in the possibility to convey the user with a natural form of codification of the detected obstacle position instead of an arbitrary form of codification. Provide the user with natural information by miming the perception of objects known by the user, may improves the confidence in the device effectiveness and reduces training efforts.

The Haptic Cane is a valuable example of such possibility which shows the suitability of natural perception codification as compared to artificial codification forms. Moreover, the proposed methodology presents important social outcomes: it enhances the autonomy of visually impaired people and avoids inconvenient interactions with obstacles or people. The small size of the haptic cane makes its use more discreet than the traditional white cane, thus representing an advantage for users who refuse the use of the traditional long white cane.

Moreover, the white cane is one of the most popular aid for visually impaired people, accordingly an electronic equipment of the cane, improving the performance and the functionality, could represent an important evolution of the aid for blind people.

2 The Developed Prototype

This section describes the development of the proposed haptic cane. The aim of the latter is to reproduce the same sensation that the user would perceive using a traditional long white cane, but avoiding the physical interaction with objects and other people.

A simple representation of the solution is shown in Fig. 1. When the multi-sensor cane's head detects an object in front of the user, a group of actuators generate a vibration on the cane handle reproducing the sensation given by the bumping of a real white cane into an obstacle. A first prototype of the system was proposed in [23]. In the following some aspects of the new prototype are presented. The obstacles detection is based on a couple of ultrasonic sensor, Devantech SRF08, placed on the tip of the stick to evaluate the obstacle distance, *D1* and *D2*. To identify

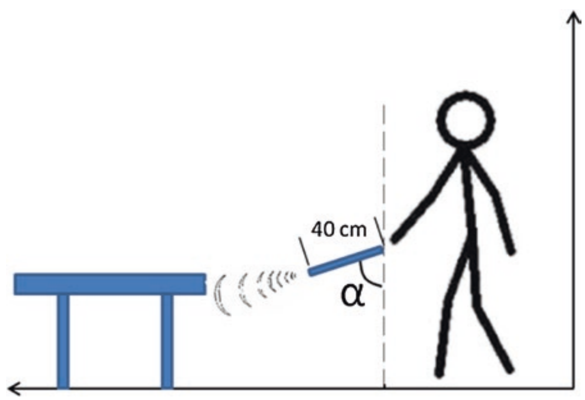

Fig. 1 Schematization of the proposed solution

the position of the obstacle (left, center, right), the ultrasound sensor have been installed in such a way to have a partial overlapping of the conical beam of the two modules. If one or both the two measured distances is lower than the detection distance (minimum distance between the obstacle and the sensor head) *Ddist*, the algorithm running on a microcontroller detects the presence of an obstacle. Information on which module (left/right) detects the obstacle is used for the obstacle position estimation: in case both the distance measures are lower than the threshold distance value, the obstacle is detected in center position.

It must be observed that the sensing solution provides the user with awareness of the obstacle position (left, center, right) without the need for sweeping the cane from left to right and vice versa as in the case of a traditional white cane.

A low-power 3-axis accelerometer ADXL335 has been used to evaluate the cane inclination.

The device has been designed for slow walking users; in this condition walking speed effects on the tilt estimation do not seriously compromise the system operation, as will be demonstrated by experimental results.

A matrix of 12 vibrating actuators Solarbotics VPM2, was installed on the cane handle, as shown in Fig. 2, with the aim of conveying on the user's palm a sensation similar to that provided by a conventional white cane.

The actuators are controlled by the digital ports of the microcontroller. Each actuator installed on the cane handle has been univocally identified by a numeric

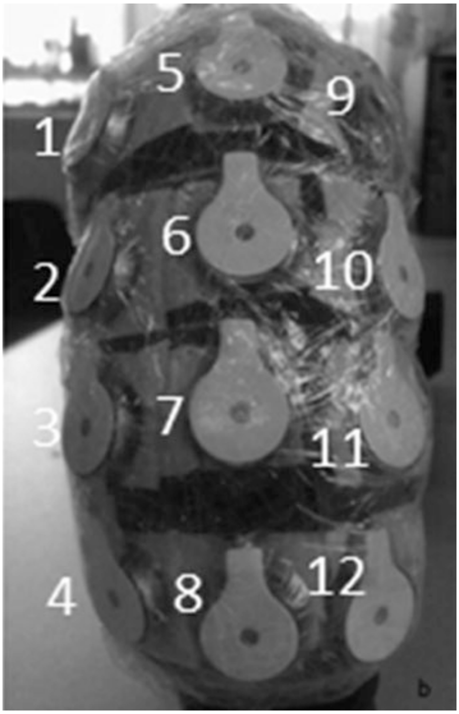

Fig. 2 The vibrating actuators installed on the cane handle

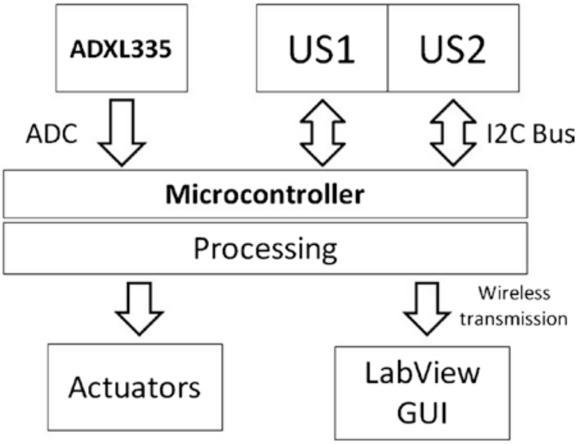

Fig. 3 Schematization of the electronic installed on the contactless cane

identifier as shown in Fig. 2. Data from the sensors are acquired and processed by a Droids Multi Interface Board (MuIn) microcontroller unit equipped with a PIC18F2520 Microchip running at 40 MHz. The sensor head and the processing node is fully battery operated.

A schematization of the electronics is given in Fig. 3.

To monitor the operation of the system during the development phase, data provided by the multisensor architecture were transferred by a wireless transmission protocol (IEEE 802.15.4) to a dedicated PC station. The wireless link was implemented through a XBee-PRO module by MaxStream, Inc., which supports the ZigBee communication protocol in the ISM 2.4 GHz frequency band. A XBee-USB board connected to the PC station was used to receive and supply data to a LabVIEW VI.

It must be highlighted that the device responsiveness is constrained by the acquisition/processing cycle duration which, in the worst case, is 1 s. Such dynamics are compatible with the users' needs and would not compromise the performance of the proposed solution. Of course, the haptic cane developed is a prototype aimed at the proof of concept of the methodology proposed. The dimensions of all the system components can be drastically reduced along with its weight.

3 The Detection/Stimulation Paradigm

The sensations generated by a traditional white cane have been thoroughly studied in [23]. The main idea of such study was monitoring the user palm using an array of strain gauges installed over the cane handle. Figure 4 shows the zones stimulated by the white cane bumping into obstacles [23].

The obstacles have been classified as "Low" if the inclination of the white cane was in the range [0°–30°], "Medium" in case the inclination was in the range

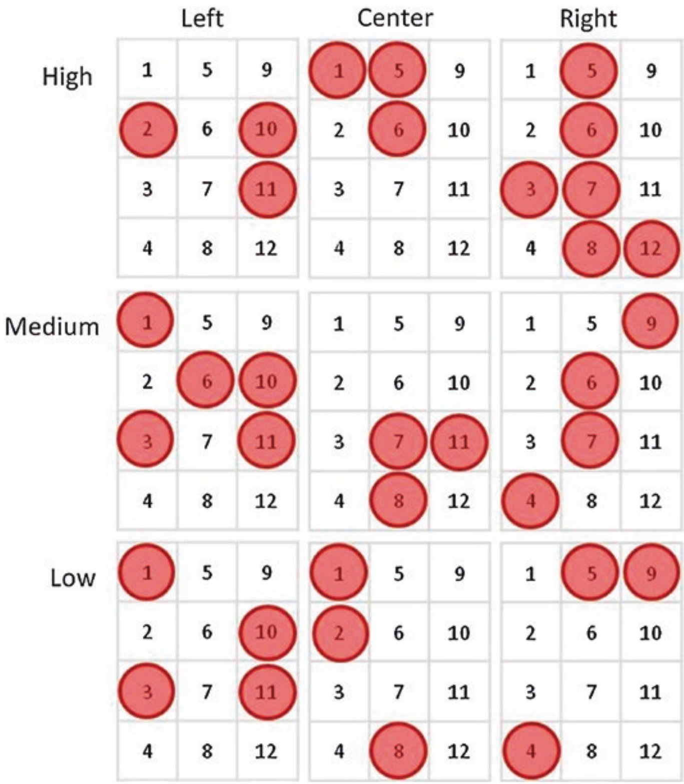

Fig. 4 Results of the characterization surveys oriented to estimate the relationship between obstacle locations and stimulated hand palm zones. Dark cells correspond to the stimulated zones of the palm [23]. Results obtained are related to the right-hand side use of the device

[30°–60°] and "High" in case the range was [60°–90°]. The different positions of the obstacles generated a different solicitation over the hand's palm. The solicitation maps were used to properly drive the actuators installed in the cane handle in order to reproduce on the user palm a sensation similar to the one produced by a white cane bumping into obstacles. The activation times for each set of actuators have been fixed on the basis of experimental observations [23].

A dedicated algorithm has been developed to implement the mapping between the information collected through the multi-sensor probe (obstacle position) and the set of actuators to be activated.

The first task of the algorithm was to properly locate the detected obstacle in the space in front of the user. Successively, a look up table, implementing the correspondence maps in Fig. 4, was used to properly activate the actuators embedded in the cane handle. The overall effect produced by the paradigm was the stimulation of the user palm zones, thus mimicking the real sensation provided by a traditional white cane bumping into an (detected) obstacle. In order to avoid false alarms in obstacle detection due to the cane-floor interaction, an adaptive operation mode of the obstacle detection strategy has been implemented. Considering the length of the haptic cane developed (40 cm, see Fig. 1) and the standard length of a white cane (120 cm), in cases of Medium and High obstacles the detection distance, *Ddist*, (minimum distance between the obstacle and the sensor head) has been fixed to 80 cm, in order to mimic the operating range of a traditional white cane. In case of the cane tilt, α, belonging to the range [0°–10°], the information provided by the ultrasound distance sensors is ignored, while for cane tilt in the range [10°–30°] the detection distance is defined as a function of α (see Fig. 1). Another quantity to be introduced is the Offset Distance, D_{OS}, between the cane in vertical position (α = 0) and the floor. By fixing the following constraints:

$$D_{dist}|_{\alpha=0^\circ} = D_{OS} \tag{1}$$

$$D_{dist}|_{\alpha=30^\circ} = 80\,\text{cm} \tag{2}$$

the following interpolation model has been used to estimate the detection distance as a function of the tilt α:

$$D_{dist} = D_{OS} + \alpha \frac{80 - D_{OS}}{30} \quad [\text{cm}] \tag{3}$$

A flow diagram of the Detection-Stimulation algorithm is shown in Fig. 5, where numbers in the circles are the identifiers of the activated actuators (as shown in Fig. 2).

4 Experimental Tests

In order to assess the performances of the haptic cane, a set of dedicated experiments has been performed. In particular, the tests involved 10 right-handed users with different height and weight in good health and 24–40 years old, with a mean of 31.1 years and a standard deviation (STD) of 6.32 years. Table 1 summarizes the characteristics of the users involved in the tests. Users were blindfolded and requested to move inside an environment where obstacles have been randomly positioned. An example of a typical scenario is shown in Fig. 6.

The aim of the tests was to assess the system capability to produce on the user the right feeling of an obstacle positioned on the right, left, center position as respect to his/her walking path. Since users involved in the experimental session are normally sighted people, they were briefly trained to feel the presence of obstacles by means of a traditional white cane, in order to perceive the sensation produced on the palm by the cane when bumping against right, left, or central obstacles.

Moreover, exploiting the already mentioned feature of the haptic cane to detect left and right positioned obstacles while maintaining the cane positioned along the walking direction, without sweeping movement, users have been requested

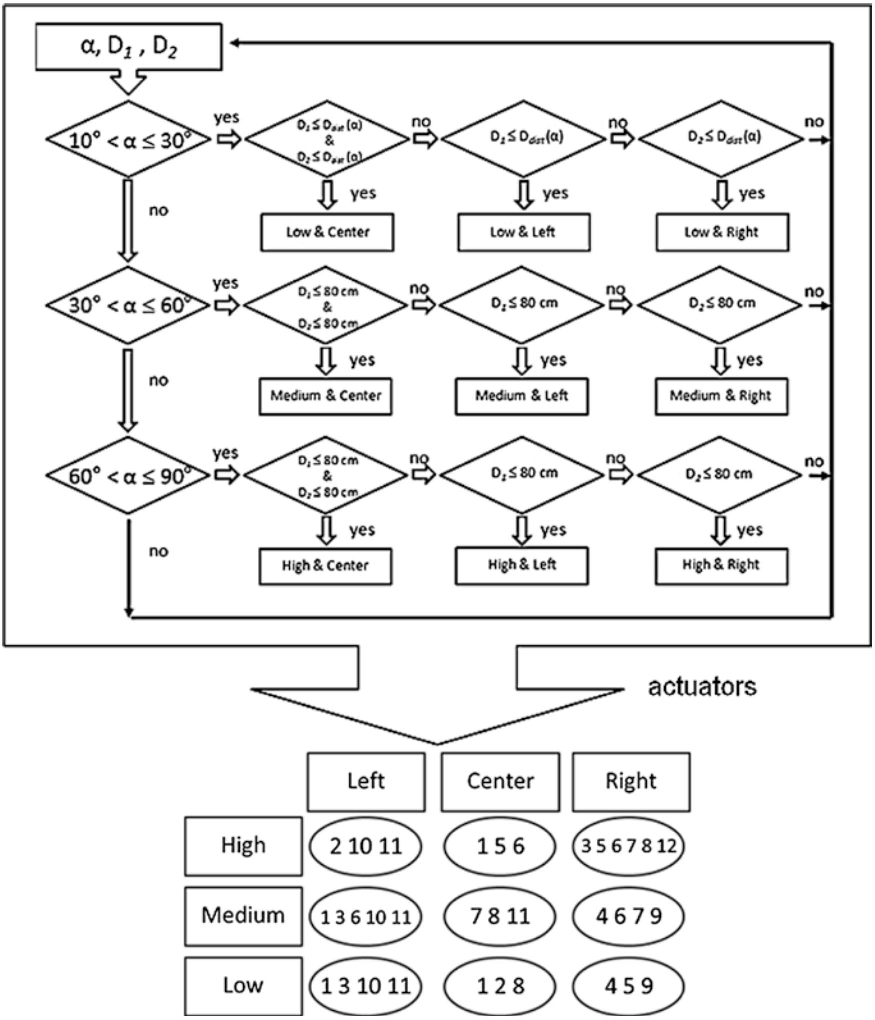

Fig. 5 Flow diagram of the algorithm used to determine both the position of the obstacle on the user path and the combination of actuators to be activated. D1 and D2 stand for the estimated obstacle distance by the two ultrasound sensors, respectively, while **α** is the cane tilt

to assume such an operating rule. The blindfolded user was randomly positioned inside the environment and free to move until 10 obstacles were identified.

Results obtained during the experimental sessions are presented in Table 2, in terms of sensitivity, R, and specificity, S, in detecting Left, Center and Right obstacles, defined as following:

$$R_{LRC} = \frac{TP_{L,R,C}}{TP_{L,R,C} + FN_{L,R,C}} \tag{4}$$

Table 1 Characteristics of the users involved in the tests

User	Gender	Stature [cm]	Weight [kg]	Age [years]
1	m	175	95	38
2	m	170	80	25
3	m	190	90	35
4	m	170	85	24
5	m	170	80	33
6	m	170	84	24
7	m	180	87	32
8	m	180	90	36
9	m	180	95	40
10	m	175	80	24

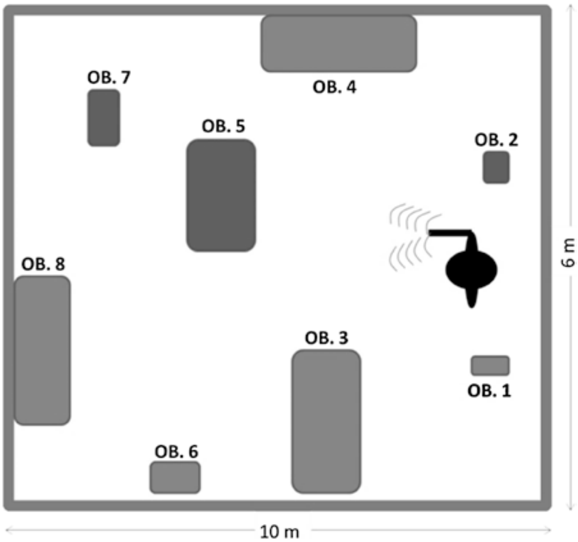

Fig. 6 A typical scenario

$$S_L = \frac{TP_R + TP_C}{TP_R + TP_C + FP_L},\ S_R = \frac{TP_L + TP_C}{TP_L + TP_C + FP_R},\ S_C = \frac{TP_R + TP_L}{TP_R + TP_L + FP_C} \quad (5)$$

where:
$TP_{L,R,C}$ correspond to successfully detected Left, Right, Center obstacles;
$FP_{L,R,C}$ correspond to erroneously detected Left, Right and Center obstacles.

The experiments were performed in supervised mode. Supervisors were able to detect eventual failures of the UltraSound system (obstacle detection along with their position) by a Graphical User Interface in order to abort such experiments. Note that, during the tests performed (by 10 users detecting up to 10 obstacles), the supervisors were never notified of ultrasound system failures.

Table 2 Results obtained with blindfolded users

Users	R_L	R_R	R_C	S_L	S_R	S_C
1	1.00	0.67	0.67	0.67	1.00	1.00
2	1.00	0.80	0.50	0.75	0.75	1.00
3	1.00	1.00	0.67	0.83	0.88	1.00
4	1.00	0.86	1.00	1.00	1.00	0.88
5	0.50	1.00	1.00	1.00	1.00	0.67
6	1.00	0.00	0.80	0.80	0.88	0.75
7	0.50	1.00	1.00	1.00	0.89	1.00
8	1.00	0.75	1.00	0.88	1.00	1.00
9	0.50	0.50	0.75	0.83	0.80	0.60
10	1.00	0.67	0.67	0.67	1.00	1.00
OverAll	0.88	0.71	0.82	0.86	0.92	0.90

As can be observed, the tests showed good performances of the developed prototype both in terms of sensitivity in detecting incoming obstacles and specificity in correctly classifying the obstacle positions. The OverAll (OA) behavior, shown in the last row of Table 2, has been estimated for the whole set of users (i = 1,..,10) as follows:

$$R_{LRC}^{OA} = \frac{\sum_{i=1}^{10} TP_{L,R,C}^{i}}{\sum_{i=1}^{10} \left(TP_{L,R,C}^{i} + FN_{L,R,C}^{i}\right)} \tag{6}$$

$$S_L^{OA} = \frac{\sum_{i=1}^{10} \left(TP_R^i + TP_C^i\right)}{\sum_{i=1}^{10} \left(TP_R^i + TP_C^i + FP_L^i\right)} \quad S_R^{OA} = \frac{\sum_{i=1}^{10} \left(TP_L^i + TP_C^i\right)}{\sum_{i=1}^{10} \left(TP_L^i + TP_C^i + FP_R^i\right)}$$
$$S_C^{OA} = \frac{\sum_{i=1}^{10} \left(TP_R^i + TP_L^i\right)}{\sum_{i=1}^{10} \left(TP_R^i + TP_L^i + FP_C^i\right)} \tag{7}$$

The obtained values demonstrated the system robustness against different user characteristics. The values of sensitivity reported in Table 2, demonstrate that, by using the proposed haptic cane, users were able to properly recognize Right, Left and Center obstacles. The values of specificity reported in Table 2, demonstrate that the users did not misrecognized positions of obstacles thus highlighting the system reliability in providing the correct haptic feedback.

The higher values of R_L with respect to other sensitivities, as arising from Table 2, can be justified by the non optimal distribution of actuators in the cane handle for the prototype developed, with respect to the palm receptive area. Future efforts will be dedicated to improve the haptic system geometry.

5 Conclusions

This paper investigates the possibility of combining the concept of "natural pathway sensing" and the use of a short multisensor cane to implement an electronic aid to assist visually impaired people in obstacle avoidance.

Besides the possibility of obstacle detection without any physical interaction with the environment and providing the user awareness on obstacle presence by means of a natural form of codification, the proposed solution exploits the most widely accepted aid by blind people, the cane. Moreover, avoiding artificial auditory or tactile codification of surroundings events is strategic for the user in order to receive a stimulus from the environment itself. Finally, the sensing architecture allows for obstacle detection without the need for sweeping the cane from left to right and vice versa as in the case of a traditional white cane.

It must be emphasized that this work demonstrates the possibility to convey environmental perception to the user by using a natural codification rather than an arbitrary form of codification. The developed haptic cane is an example of such a possibility which shows the suitability of natural perception codification as respect to artificial codification forms. The results obtained by tests performed with blindfolded normally sighted users encourage further efforts to develop the proposed methodology. Future actions will be dedicated to optimize the active handle (also for left-handed users), and to include new sensors extending the system functionality in terms of environment perception and tilt estimation (e.g. by a gyroscope). Moreover, tests with real end users will be performed; of course, such experiments require safety conditions which will be assured.

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A System to Promote Walking for the Elderly and Empower Tourism: The Sweet Mobility Project

Gianfranco Borrelli, Massimo Pistoia, Benedetta Fruttarol and Casacci Paolo

Abstract Sweet Mobility—"System to promote Walking for Elderly Empowering Tourism and improve MOBILITY" is a project co-funded by the European Union and the Tuscany Region, whose purpose is to spur cultural-tourist activities and thus mobility also by the elderly and frail users. The project aims at developing a technological system through a smartphone based on a simple and user-friendly interface and a non-invasive wearable device specifically designed in order to detect vital parameters to be monitored during physical effort resulting from simple activities, such as a walking. This system allows to provide the elderly or frail users with a safe guide throughout specific chosen walking paths or tourist places, by pointing out, in the meanwhile, all of the difficult parts of the pathway, the possible presence of unevenness, architectural barriers, resting facilities areas or points of particular and unique landscape relevance. It will be able to detect and signal hazardous situations in the distance as well and to provide prompt, remote or on-site, intervention. This project aims therefore at fostering mobility for the elderly, by removing physical obstacles and barriers that often prevent them to allow themselves recreational and tourist activities. The project and its goals, the development methodology and the planned experimentation stages are here in detail introduced.

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1 Introduction

Miscellaneous surveys and research studies underline the importance of physical activity practice during the ageing process in delaying the onset of impairments and frailties both in physical and in cognitive terms and improving the quality of life of the elderly as well [3]. The current increase in the number of the elderly originating from the progressive phenomenon of the prolongation of life expectancy [4] suggests then a rise in neurodegenerative diseases affecting older people in the near future. One of the most significant issues related to life expectancy increase is precisely the one concerning mobility.

Maintaining an adequate level of physical activity is considered, indeed, a key factor for a healthy and active aging process, since it allows the elderly to carry out an independent and dynamic life as long as possible [6]. The higher the level of mobility, the greater the potential for independent living expectations, with a higher sociability as well and ability to keep on maintaining an active role in the local community. Psychophysical well-being as a whole is therefore associated with mobility, even moderate. When this last one is impaired or subject to limitations, the consequences for the individual can also be significant: in many cases, this can lead to isolation, sense of depression and frustration or an increase in propensity to diseases [2]. Mobility, indeed, is an important factor of social integration and self-perception by the individuals of a good quality of life during the ageing process.

The Second World Assembly on Ageing promoted by the United Nations and held in Madrid in 2002 underlines, for instance, that worldwide, people aged 60 or over-60 are going to double by 2050. Mobility-related issues are becoming then more and more relevant in social and global terms [4].

SWEET MOBILITY, a project co-funded by the European Union and the Tuscany Region in the context of the POR CREO-FESR 2007-2013, has its roots in these considerations and intends to properly meet the needs of the elderly or users affected by frailty conditions, but longing to maintain at the same time a good level of mobility during their ageing stage.

Although most of the elderly, indeed, enjoys good health conditions and are able to benefit from an adequate level of physical activity, they often have to cope with obstacles and barriers, both in physical and psychological terms, which limit their will and opportunity to practice physical, cultural or tourist activities such as going for a walk in a historic, tourist or naturalistic site. Most of the times it follows also the fear of not knowing if a destination may fit or not one's physical conditions and abilities or if it is possible or not to find resting spaces in the surroundings, not being familiar enough with the characteristics of a tourist pathway or even getting lost in a place. In the case of extra-urban locations, such as in a mountain environment, then, these difficulties are further amplified along with the fear of not being able to communicate with someone, if dangerous situations immediately occur.

The goal of the SWEET MOBILITY project is therefore to overcome the various barriers by the means of advanced ICT and user-friendly technological tools [5] specifically designed to encourage a planned-mobility and sufficiently supported by adequate information on places to visit, their characteristics or possible physical requirements.

Experimentation stages and validation are going to take place over the months to come in order to test each feature proposed and proceed with the system integration.

2 The System Architecture and Its Features

The SWEET MOBILITY system provides the end-user with a mobile device, such as a smartphone, with large touchscreen, an integrated GPS receiver, Internet access and a specific software application with an easy-to-use interface specifically designed to meets the elderly needs and abilities. This device will be able to guide in safe conditions the elderly through a chosen pathway, by pointing the parts characterized by unevenness, architectural barriers, resting spots, facilities etc. A graphical scheme of the whole system architecture is shown in Fig. 1.

By the means of a sensors-equipped wearable and non-invasive device such as a wrist band, then, the system will allow to detect and monitor some vital parameters, such as heart rate and breathing, in real-time.

On the basis of the data collected, the SWEET MOBILITY platform will be able to formulate suggestions and advice for the user or send alert messages to the remote central server which also contains all of the information concerning the possible destinations, the differentiated pathways along with the user's profile. In case of specific diseases, other particular parameters may also be detected and on request sent to the user's GP.

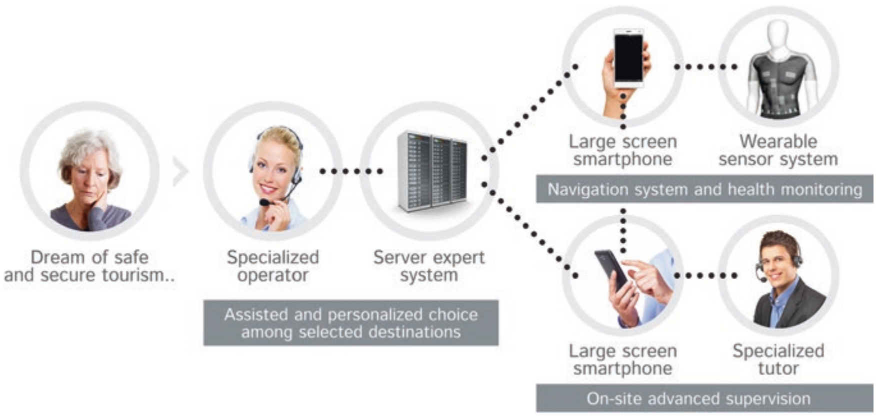

Fig. 1 A graphical representation of the system architecture

Since the smartphone and so the other integrated devices constantly communicates with the central server, data detected will be monitored in real-time by a remote operator able to guide the user throughout the walking path or the tourist activity and to provide information, if requested, and rapid intervention, if necessary.

The kit of tools supplied constantly monitors, indeed, the psychophysical user's health status, collecting and processing, in this regard, the data detected by the sensors and then sent to the central server for remote control. The smartphone, instead, gives the user information about the correct directions or the characteristics of the chosen pathway in terms of practicability through a match between the user's profile and the features of the chosen activity.

Moreover, it shows the user the possible resting spots in the nearby or suggests, on the basis of the detected vital signs, to take, for instance, a short rest if he/she hasn't done it yet. In addition to that, it is able to give the elderly also information about possible alternative paths or suggestions during the performance of physical effort on the basis of the monitored collected data.

Furthermore, the system enables to use the GPS receiver feature through a web application accessible via mobiles devices in order to locate the user, its position and that of all the other users associated to a group leader, who can be represented by a member of a service association, a friend, a relative etc. The mobile device, indeed, uses this information along with the user's vital parameters detected by the means of the wearable vest and the information concerning the chosen destination and stored in the remote server in order to assist in real-time the end-user throughout the activity.

Finally, the simplicity and intuitiveness of the user-friendly interface of this system allow even users who do not have particular knowledge or abilities in managing technological devices to use it and benefit from its services.

This particular set of features can only give the elderly an enhanced sense of protection which will broaden possibilities and occasions of mobility for them, allowing a greater level of autonomy and satisfaction with the activities undertaken.

The SWEET MOBILITY system is not only then expected to spur socialization and recreational tourist activities in unfamiliar places to the user, allowing him/her to perform physical exercise as well, but it will also give tourist organizations and travel agencies a promising opportunity to open up a new market sector, not yet properly covered by the current services.

2.1 Development Methodology

The entire development of the SWEET MOBILITY platform follows the so-called *User Centered Design* (UCD) approach [1]. It's a process which contemplates the involvement of the end-user of the product throughout the conception, design and development cycle in order to allow the user to fulfill his/her needs resorting to the minimum effort and the maximum efficiency.

This approach strongly takes into consideration the end-user's needs, limits, expectations and requirements in order to optimize the end-product around these kinds of considerations.

The UCD methodology tries to focus on the users' needs by adopting a systematic and structured approach able to detect and collect all of the information relating to their habits and requirements and to involve them during all of the stages of the life cycle of the product. It resorts to quantitative and qualitative measures concerning on the usage characteristics of the product and implements an iterative-design based on the "first design—testing stages—second design" development pattern, to be applied throughout the whole process.

The SWEET MOBILITY project has been then implemented by taking strongly into consideration these features and focusing so in meeting the end-user's needs as much as possible, in terms of product usability, acceptability and efficiency.

2.2 Scenarios

It is possible to identify at least two possible scenarios in relation to the use of the SWEET MOBILITY system and the services it is able to offer.

1. The first scenario concerns the assisted organization of tourist and cultural activities:
    a. The elderly decides to take a trip/journey and he/she contacts the local service association. He may choose destination, duration and if he/she wants to be part of an organized group, with a relative/caregiver or alone.
    b. The operator asks for the necessary data and information in order to set and define the user's profile on the server. At this point, the server generates a list of possible destinations in accordance with the elderly's profile, needs and requirements.
    c. The user receives then a kit consisting of a wearable wrist band containing the sensors and a portable device. This kit aims at detecting data concerning the user's vital parameters in order to constantly monitor the psychophysical health status of the elderly, by collecting and processing then via the server all of the data detected by the sensors.
    d. If the heart rate, for instance, is too high or the user has not stopped for a long period yet, the mobile device may display an alert message in order to suggest the elderly to take a rest. If there is a bar, restroom facilities, a fountain or any other point of interest in the surroundings of the user, he/she can be alerted as well by the means of the smartphone.

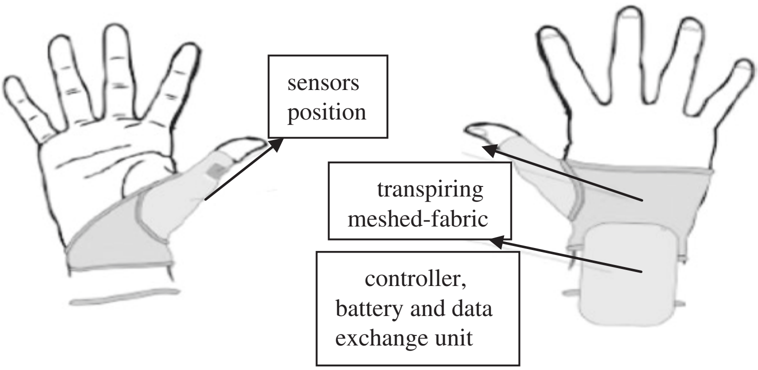

Fig. 2 An example of a sensors-equipped wristband

2. A second scenario concerns, instead, the monitoring service offered to the user throughout the tourist-recreational activities:
   a. The user wears a sensors-equipped wristband able to detect vital signs related to his/her physical health status and then it sends the data collected to the mobile device, which in turn communicates with the central server, by means of a wireless connection. A graphical representation of the wearable wristband containing the sensor devices is shown in Fig. 2.
   b. This information, in combination with location data and those taken from the server, are used to guide and/or inform the user during the walking.
   c. The supervisor, then, may have, at any time, information on the physical health status and the position of each elderly assigned to him either by using the smartphone or accessing the server application via Web
   d. The supervisor may also reach the elderly on-site, if needed, or remotely interact with him and give him assistance, if necessary.

3 State of the Art

A the moment, there is not such a solution on the market aiming at fostering mobility for the elderly, by creating specific tourist paths, offering at the same time a continuous monitoring service of vital parameters in real time, allowing remote assistance throughout the whole recreational activity as well and thus comparing the one proposed through the SWEET MOBILITY project.

It is possible to find, instead, non-integrated solutions and services only partially offering these typologies of features.

Concerning the management of situations outside the home environment there are, for instance, electronic tracking devices which enable to control the geographical position of the elderly in real-time and to send and alert message to relatives in case of danger. However, these ones can be considered only as restricted tools, since they contemplates that the elderly are always able to use the emergency button of the device and they are often ineffective in case of stroke with loss of consciousness.

Concerning the possibility of vital parameters monitoring, then, there are miscellaneous devices specifically designed to work in outdoor conditions, but they are often designed for sport purposes and to meet the athletes' needs and thus not always suitable to detect situations and parameters which may be considered critical, instead, for the elderly. Besides, data are not sent to any service center.

For what concerns the existing telemedicine systems, towards which during the last decade there has been a crescendo in terms of interest and in regard to their potential features, they are specifically designed for organizational and social purposes in order to remotely monitor the frail patients, but in their living environment.

In relation to the touristic organizations and travel agencies, then, they are usually focused on issues concerning attractiveness, costs and popularity of a place when offering and planning destinations and activities to customers. They rarely take into account the physical limits or the specific needs of some target groups, such as the elderly or the frail individuals who often end up so in being discouraged from undertaking a touristic or recreational activity in unfamiliar places to them.

SWEET MOBILITY tries, instead, to cope with these kinds of considerations and to integrate thus all of the proposed features and services into one integrated-solution able to foster mobility for the elderly and to break down some of the most common psychophysical barriers which usually prevent them to leave their home environment and to allow a trip or a walking outside.

4 Planned Experimentation Stages

The experimentation activities, aimed at testing each components of the proposed technology and at integrating then the system as a whole, are going to take place over the months to come.

A first phase of the experimentation stage will be held in Abbadia San Salvatore, a small town in Tuscany. In its old town center and then in a small wood nearby, the researchers involved in the project will be testing the smartphone with its GPS feature aimed at locating and assisting the user throughout the tourist recreational activity, as a walking for instance. During the testing stage, it will be verified the ability of the GPS feature to locate the user and to guide him/her through a chosen path, by showing the sightseeing, indicating information about the places, the possible presence of unevenness or restrooms in the nearby and giving suggestion on the basis of a match between the user's profile that is on the server and the information relating to the chosen path, as well.

It will be also tested the sensors-equipped wristband in order to check its reliability to detect the required vital parameters and to send them properly to the central server in real time. The collected data originating from the smartphone and the sensors will be then processed and analyzed to verify their correspondence to the reality.

During this testing stages, different alert situations will be also monitored or suitably simulated in order to assess the recognition degree of such events by the system.

Moreover, during the analysis stages different and relevant focus groups have been implemented. They were attended by both the end-users and experts in the field and were particularly useful in order to collect the different points of view about the technologies involved, the solutions proposed, the state of the art and the end-users' expectations and requirements on the development of the interface of the mobile device. They also were of great importance in order to lead to the development of a system with a high level of acceptability, able to meet so as much as possible the end-users' needs.

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IR-UWB for Ambient Assisted Living Applications

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Abstract Wireless technology has been developing fast for years and it is spreading to new areas of everyday life. One of the newest areas is healthcare and welfare sector where it can be a significant way to save costs and improve existing procedures. The coming years are going to be challenging as the population, in the developed countries especially, is ageing fast and more patients are going to need treatments. Wireless sensor network (WSN) is an emerging in wireless technology for short range indoor used for health monitoring. On the other hand, the Impulse radio ultra-wideband (IR-UWB) defined by IEEE 802.15.4a standard, comes with a number of desirable features at the physical layer for wireless communications, for example, low RF power emission, ranging, accurate position location, imaging sensing radar. In this work, the potential strengths of IEEE 802.15.4a for Ambient Assisted Living Applications (AALs) has been showed. Subsequently, an IEEE 802.15.4a RF Front-End, resilient to interferers, in 65 nm CMOS for AALs has been proposed. It consists of low noise amplifier (LNA), mixer, frequency synthesizer (LO).

1 Introduction

For ambient-assisted living (AAL) and elderly care applications, accurate location of people in indoor and domestic environments is one of the most important requirements. The location information can be accomplished by the use of Low

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Data Rate Wireless Sensor Network (LDR-WSN) that can be used for multiple purposes, e.g., to track electroencephalography (EEG), electrocardiography (ECG), electromyography (EMG), to monitor the daily activities and observe the tendencies of people, to alert caretakers and doctors in case of abnormal behaviour of events, etc.

Indoor location has received considerable attention in recent years from the research community, and different systems and sensing technologies have been applied in the context of AAL.

In a LDR-WSN system [1], very stringent requirements have been placed on the sensor node. The sensor nodes should be small, consume extremely low power and reliable. Therefore, it is very important to minimize the power consumption of a sensor node.

There exist several possible technologies for LDR-WSNs, i.e., ZigBee, Bluetooth and UWB, each with advantages and disadvantages. ZigBee offers low power consumption but with restricted data rate. Bluetooth is mature and cheap technology with fairly high power consumption. Ultra-wide band (UWB) is an attractive wireless technology for medical monitoring systems and more importantly it has not an EMI risk to other narrow band systems and medical equipments in healthcare environment since its transmitter power is quite low and the frequencies used are at very high frequencies (>3.1 GHz). Nonetheless UWB features anti-multipath capabilities.

Impulse-radio ultra-wide bandwidth (IR-UWB) technology applied to AAL systems has gained great popularity.

It is defined by IEEE 802.15.4a standard. The potential strength of IR-UWB system lies in its use of extremely low-power transmitter, low radio frequency (RF) and electromagnetic interference (EMI) effects in medical environment, small size antenna, and ultra wide bandwidth, which results in many interesting properties, e.g., high transmission rate and accurate position location [2].

The IEEE standard 802.15.4a PHY [3] supports three independent bands of operation: the sub-gigahertz band, which consists of a single channel (channel 0) and occupies the spectrum from 249.6 to 749.6 MHz; the low band, which consists of four channels [1:4] and occupies the spectrum from 3.1 to 4.8 GHz, and the high band, which consists of 11 channels [5:15] located within the 5.8–10.6 GHz band. A compliant device has to implement support for at least one of the mandatory channels (these are channels 0, 3, and 9 for sub-gigahertz, low, and high band, respectively).

For the indoor and hand held IR-UWB users, the IR-UWB frequency band of 3.1–10.6 GHz may be interfered by other existing radio signals (e.g. WLAN, PCS/GSM). These interferers generate unwanted second-order and third-order intermodulation products equal to the wanted RF input signal desensitising the IR-UWB receiver. Reducing this type of interference is considered as a crucial issue in designing RF transceivers.

In this work, a low power IEEE 802.15.4a compliant zero-IF RF front-end, in 65 nm CMOS is presented [4–6]. It operates at 4492.8 and 7987.2 MHz center frequency with a bandwidth larger than 499.2 MHz and consists of a dual-band balun low noise amplifier (LNA), a highly linear mixer. The matching input network is a double-peak single notch network exhibiting a dual band input matching and notch filter for IEEE 802.11a interferes removing the 5–6 GHz WLAN dedicated filtering at the antenna reducing costs.

This IR-UWB front-end will be used for enabling LDR-WSN systems, accurate ranging according to IEEE 802.15.4a. Furthermore, the same hardware can be used as radar imaging sensors by exploiting the large channel bandwidth.

2 Exploiting IR-UWB for AAL

Existing wireless standards have difficulty in meeting low power and low complexity requirements for short-range communication systems. The required power consumption for LDR-WSN devices is much lower than that of any existing standard including ZigBee systems. Typical transmission energy efficiency of the LDR-WSN system is 10 n Joule per bit (nJ/bit) while the ZigBee system easily exceeds 100 nJ/bit. Depending on the transceiver architecture and data rate, the energy efficiency less than 1 nJ/bit can be achieved. In addition to ultra-low power, many applications occupy similar frequency band of 2.4–2.5 GHz, facing RF interference problems and making it difficult to have reliable transceiver performance. For the LDR-WSN and biomedical applications, following features are demanded or considered desirable:

- Low power with high energy efficiency;
- Coexistence with other wireless standards;
- Robust to multi-path interference;
- Low radiated RF power (less harmful to human body);
- Precise location;

The UWB technology has received great attention in recent short-range communication systems and been considered one of the potential candidates for IEEE 802.15.6 LDR-WSN. The main features that makes this technology attractive are reported in the following.

2.1 Accurate Ranging and Positioning

The use of few nanosecond duration UWB pulses with hundred of MHz of bandwidth offers the unique possibility of distinguishing the different multipath components which compose the received signal and of accurately estimating its Time of Arrival (TOA), which contains the relevant information for positioning. In this way, 10 cm accuracy can be achieved, even in multipath rich indoor environments.

Ranging, i.e., the estimation of distance between two wireless devices has been proposed by the IEEE 802.15.4a standard as a physical layer standard. As the ranging via IR-UWB is based on time of arrival measurement, it is more robust against multipath fading which can be very strong in indoor environment. On the contrary the most common strategy for geolocation using ZigBee signals is based on the Received Signal Strength (RSS) of communication signals which is quite less robust with respect to multipath fading. However, the achievable accuracy of RSS-based ZigBee positioning systems is usually in the order of magnitude of 1 m (Fig. 1). In IR-UWB LDR-WSN, positioning is accomplished based on ranging [7]. The analyzed indoor system consists of a central device, which plays the role of a Base Station (BS), a tag and some sensors. The BS will receive the ranging information of the sensors and will determine (x, y, z) coordinates of the tag. The user will wear the tag, which must be located. The sensors communicate using IR-UWB signals and are able to estimate the distance to the tag. The sensors will be placed in specific positions of the house in order to be a reference when locating the user worn tag. Time based positioning techniques rely on the measurement of the travel time of the signal propagating from the transmitter to the receiver. In the conceptually most simple situation in which two nodes have a common clock, the receiver node can determine the Time of Arrival (TOA) of the incoming signal and directly calculate its distance from the transmitter, by multiplying the estimated TOA (after subtracting the known time of transmission); in this way, the estimated range allows to draw a circle (in 2-dimensions) with the reference node in its center and radius equal to the estimated range. By collecting at least three measurements between the node with unknown position and some reference nodes with known position, and by intersecting the defined circles, it is possible (in the absence of noise and inconsistencies) to univocally determine the position of the node, as depicted in Fig. 2. This is equivalent to solving a system of three non-linear equations in two unknowns, the Cartesian coordinates of the node to be positioned. The problem which is addressed here is to determine the unknown position of a target with respect to the known position of a network of dedicated reference nodes.

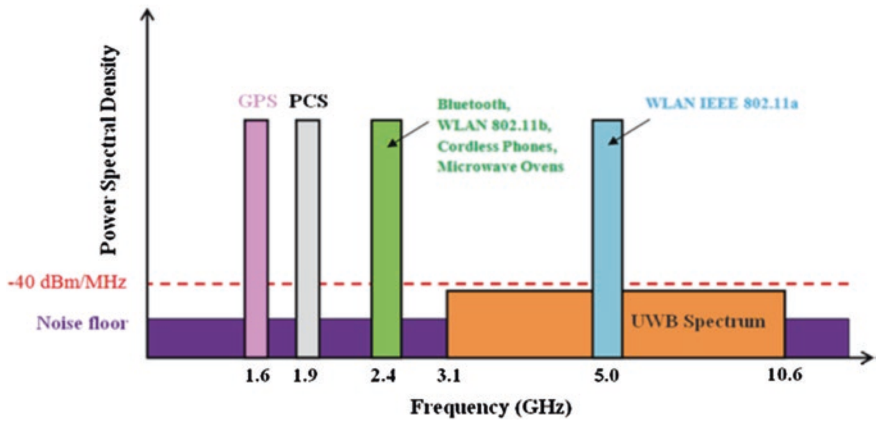
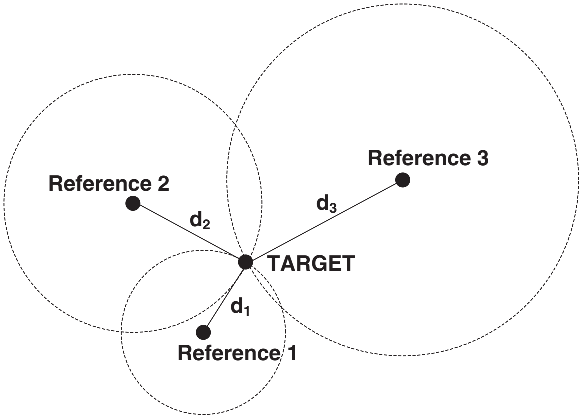


Fig. 1 UWB power spectral density (PSD) versus other radio communication systems

Fig. 2 Position estimation via ranging



2.2 Low Energy Consumed and Low RF Power Radiation

Since IR-UWB uses very short pulses for radio transmission and very careful design of signal and architecture, the transmitter could be designed simple and allows extreme low energy consumption, which also enables the usage of long-life battery-operated devices. These features are quite similar with the LDR-WSN nodes which must work under extreme condition and require very strict power control mechanism and high power efficiency [8]. E.g., [9, 10] show 0.24 and 0.32 nJ/bit transmission energy respectively. The inherent noise-like behaviour of UWB systems make it highly possible to deploy medical sensor with UWB since the signal is hard to detect and also excel in jamming resistance. LDR-WSNs for surveillance of human body can be deployed due to this feature. For instance, in Fig. 3, the using of UWB in monitoring the patient in intensive care unit could avoid usage of too many wires around the patient. Low electromagnetic radiation less than −41.3 dBm/MHz (Fig. 1) is safe for human tissue exposure and makes it suitable for hospital and home applications.

Fig. 3 Intensive care unit monitoring using UWB

2.3 Radar Imaging

The same standard compliant IR-UWB radios can be used for radar imaging, extending its functionality further the typical LDR-WSN nodes implementation. Thanks to its to the wide channel and impulse modulation, IR-UWB is very suitable for the application of medical monitoring. These monitoring applications could be patient motion monitoring, wireless vital signs monitoring of human body, and the medicine storage monitoring. Because of high temporal and spatial resolution of radar sensors, their compatibility to existing narrow-band systems, the low integral power of the probing signals and their ability to penetrate objects are exploited for this purpose. Especially the last one is the very property which makes UWB radar so attractive for medical applications.

Ultra-wideband electromagnetic pulses (spectral bandwidth up to 10 GHz) generated by an UWB radar and transmitted by an antenna are able to probe the human body with low integral power (~1 mW), because electromagnetic waves can propagate through the body and are reflected at interfaces between materials with different dielectric properties (Fig. 4). This monitoring function could be applied in intensive care units, emergency rooms, home health care, paediatric clinics (to alert for the Sudden Infant Death Syndrome, SIDS), rescue operations (to look for some heart beating under ruins, or soil, or snow). Impulse radio UWB technology can propose radar applications such as: Non-Invasive Heart and Respiration Rate Monitoring; Detection of Cardiac Arrhythmias; Detection of Pathological Respiratory Patterns, particularly in Sleep Apnea; Multi-Patient Monitoring; Detection and Non-Invasive Imaging of Breast Tumours [11, 12].

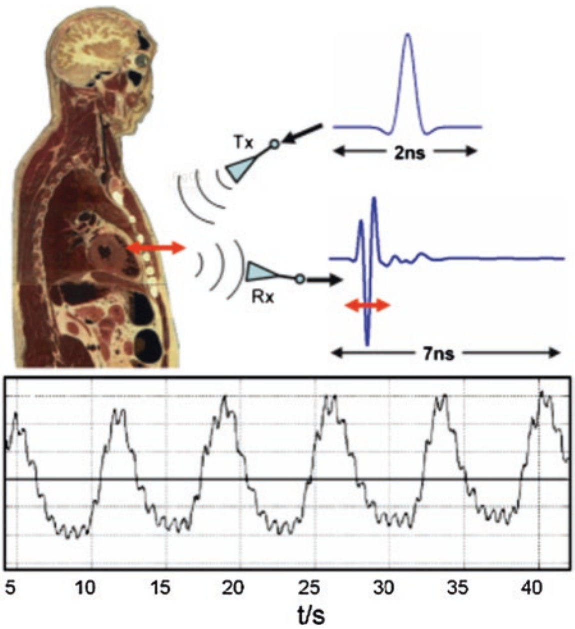


Fig. 4 Probing the human body with broadband electromagnetic pulses. *Top* Transmitted pulse and received pulse (impulse response function, IRF) modulated by physiological processes. *Bottom* Reconstructed physiological signature, breathing with superimposed heartbeat, reconstructed from ultra-wideband radar data

3 IR-UWB Front-End Design

3.1 IR-UWB: Interferers Scenario

The IEEE 802.15.4a standard specifies mandatory channels #3 and #9 at 4492.8 and 7987.2 MHz center frequency respectively. The bandwidth of each channel has to be larger than 499.2 MHz.

As described in Sect. 1, interferers like WLAN (IEEE 802.11.a/b/g) but also PCS/GSM (1900 MHz), generate intermodulation products (e.g. Fig. 5) at a frequency equal to the frequency of the wanted signal that cannot be separated from the signal resulting in a desensitisation of the entire receiver [13].

For the above reason, a receiver designed for this standard should have an LNA with sufficiently high out-of-band IIP2 ($IIP2_{OB}$) and out-of-band IIP3 ($IIP3_{OB}$) in order to handle strong interferers. The required intercept points depend strongly on the assumed interferers scenario and the assumed amount of pre-filtering of the interfering signals.

3.2 Low Nosie Amplifier Design

The proposed LNA is a LC-tuned balun-LNA based on the CG-CS topology [5]. It consists of three building blocks: the input network for matching purposes, the CG-CS and LC-load for channel #3 and channel #9 selective gain. The WLAN interferers are strongly reduced thanks to high transmission loss due to input unmatching condition and to attenuation for 5–6 GHz frequency range of the gain stage.

3.3 Mixer Design

The mixer is designed to be embedded in a IR-UWB IEEE802.15.4a receiver. It consists of a Gilbert cell with passive output load, operating in IEEE 802.15.4a #3

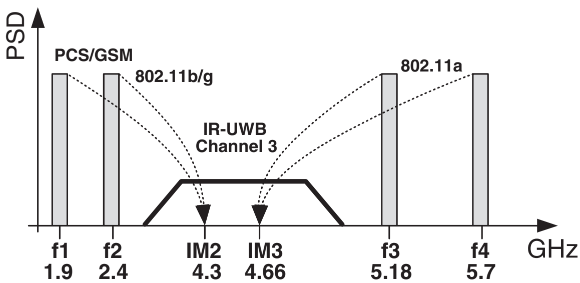


Fig. 5 Intermodulation products for channel #3

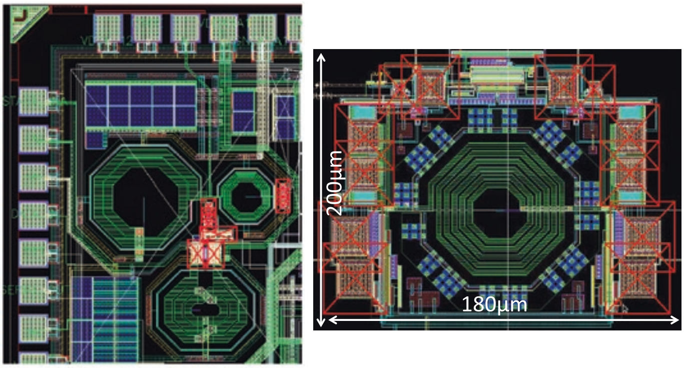


Fig. 6 LNA layout (400 μm × 600 μm) and Mixer layout (180 μm × 200 μm)

and #9 mandatory channels at 4492.8 and 7987.2 MHz center frequency respectively (with 499.2 MHz bandwidth), and in channel #11 at 7987.2 MHz (with 1331.2 MHz bandwidth) [6]. The mixer layout is shown in Fig. 6 and occupy 180 μ × 200 μm silicon area. Most room occupation is due to inductor L1 which is 1.94 nH with a 12.15 Q factor. Its occupation area is 46 % of total occupation area. The proposed mixer has been designed in 65 nm CMOS technology.

3.4 PLL-Based Frequency Synthesizer Design

The local oscillator (LO) requirements are not too stringent [14] allowing a low-power implementation. Since the synthesizer is not intended for frequency selectivity as is the case in more traditional narrowband communication, but rather as a template for wideband signals, a fairly high level of phase noise can be tolerated. High-level system simulations did not show any significant performance degradation for levels up to −90 dBc at 1 MHz offset.

The architecture of the synthesizer is depicted in Fig. 7. A charge-pump structure, with passive loop filter, voltage controlled oscillator (VCO) and integer-N divider, was chosen. The choice of the integer-N synthesizer architecture relies on the synthesized output frequency resolution (f_{OUT}) that is a multiple of 38.4 MHz temperature compensated crystal oscillators (TCXO) used as reference (f_{ref}):

$$f_{OUT} = N \times f_{ref} \; (13 \le N \le 60). \quad (1)$$

The multi-band carrier generation is accomplished by using the VCO followed by a set of high speed dividers. The VCO provides the 9, 11, 12, 14 IR-UWB channels (Fig. 7). It also drives a current mode logic (CML) divider-by-2, followed by a CML to CMOS generating 2/4 and 3 output bands. Then, the mandatory sub-GHz channel (499.2 MHz) is provided by CMOS divider-by-8. A 2 bit

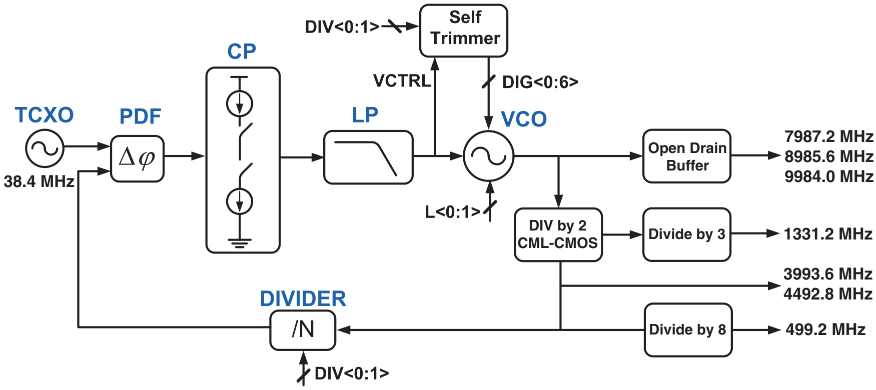


Fig. 7 Schematic view of the PLL-based frequency synthesizer

Table 1 IEEE 802.15.4a synthesized carriers

Channel	f_c (MHz)	Bandwidth (MHz)	Mandatory/Optional
0	499.2	499.2	Mandatory below 1 GHz
2/4	3993.6	499.2/1331.2	Optional
3	4492.8	499.2	Mandatory in low band
9	7987.2	499.2	Mandatory in high band
11	7987.2	1331.2	Optional
12	8985.6	499.2	Optional
14	9984.0	499.2	Optional

programmable CMOS divider, with nominal division factors ranging from 104 to 130, is then used to provide the feedback signal that feeds the PFD. Additionally, 1331.2 MHz carrier has been synthesized (Fig. 7). The 499.2 and 1331.2 MHz generated frequencies are employed as clock signal of 6 bit analog-to-digital converter (ADC) in zero-IF UWB receivers. In order not to worsen the signal-to-noise ratio (SNR) of the ADC, the jitter must be less than 3 ps [15] (Table 1).

4 Conclusion

In this paper the IEEE 802.15.4a standard for ambient assisted living has been presented. It comes with a number of desirable features at the physical layer for wireless communications, for example, low RF power emission, ranging, accurate position location, imaging sensing radar. Subsequently, the design of IEEE 802.15.4a RF Front-End, resilient to interferers, in 65 nm CMOS for AALs has been proposed. It consists of low noise amplifier (LNA) and mixer.

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Adaptive Reminders in an Ambient Assisted Living Environment

Riccardo De Benedictis, Amedeo Cesta, Luca Coraci, Gabriella Cortellessa and Andrea Orlandini

Abstract The GiraffPlus home environment represents a complete AAL system that gathers environmental and physiological measures from distributed sensors for continuous monitoring of an older person. A key point of innovation in the project is the synthesis of reasoning services on the gathered data. Among those services the personalisation of feedback messages to users according to both individual's needs and continuous data analysis represents an open challenge. This paper paves the way with respect to this challenge by presenting a user-adaptive reminding services endowed with the ability to trigger heterogeneous messages over time. The messages can simply remind to take a medication, can warn that a physiological value is deteriorating, or even offer regular suggestions on "good quality of life behaviour" triggered by some observation on individual users data.

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1 Introduction

The GiraffPlus project[1] [7] is an Ambient Assisted Living (AAL) system which main aim is to collect elderly daily behavioral and physiological measurements from a network of sensors deployed in the living environment. Gathered information is organized so as to provide monitoring services through a visualization service customizable for both primary and secondary users.

The need to provide personalized services has soon been mentioned as a key aspect in elder care and highlighted during the project user requirement analysis. An additional aspect worth mentioning is the need to reach an agreement with the elderly on which information is to be shown, and who can access them, is a critic issue to consider. More specifically, relatives are not supposed to know everything about older users life since elderly, understandably, may not want to easily renounce to their privacy [3, 9]. Furthermore, to provide too detailed information to non-professional users may cause confusion in the data interpretation with possible unwanted consequences, such as exaggerated fright reactions, that can undermine the quality of life of fragile elderly users. In this respect, data presented to users should be customized according to which kind of information is needed depending on both the involved users and the specific needs of the moment.

This paper describes an attempt to introduce more complex forms of automated reasoning within AAL environments. Specifically, this paper extends the work in [4] presenting a user adapted reminding service. In the following we will provide first an introduction on state-of-the-art reminding systems. Then Sect. 3 contains an outline of the GiraffPlus project providing a description of the interactive and personalization services provided by the system. Finally, Sect. 4 describes the proactive reminding system we have developed for the GiraffPlus system. A concluding section ends the paper.

2 Related Works

Although following different paths and techniques, most of the AAL projects are concerned to acquire data from the environment and from the users taking advantage of the many sensors provided by the available technologies. Subsequently, the acquired data undergo some more or less complex elaboration that clean them up and propose them in an high level format to final users. In other words, semantic information is generally inferred from raw sensorial data collected in an ambient intelligence environment. Proactive interactions towards users have always been restricted to simple reminding services having the task to remind users to perform important repetitive tasks such as taking medicines. The use of artificial intelligence to automatically support rehabilitation processes, therapies, or other possible forms of assistance, has

[1] http://www.giraffplus.eu.

often been relegated to the analysis of data, preserving for healthcare professionals the responsibility for carrying out tasks often boring and repetitive.

While these services are mainly devoted to support caregivers, and thus provide only an indirect support to the elderlies, the reminding systems are examples of direct interfaces towards elderly. Most of the current reminding tools [1, 11, 13] have been developed mainly for reminding users for taking medicines as well as for providing time management assistance supporting users in their daily activities. Periodically, these systems send a signal to the user, not worrying about his/her current status or possible changes that may have occurred since the service configuration. These systems become, in the long term, repetitive and tedious, with the risk for the user to ignore or, even, to abandon them. An intelligent service should verify the actual taking of medicines, decreasing with time the intensity of reminders and reintensifying them in case of need.

Literature presents many attempts to overcome these difficulties [12, 14, 15, 18]. These context aware reminding systems slightly adapt to the current status of the user avoiding annoying situations (e.g., when the user is in bed or at the phone) and/or choosing the most appropriate device for prompting (e.g., the closest one to the user). Predictably, these approaches are more successful than simple time based reminders keeping the user affiliated to the system.

The Autominder system [19] is an intelligent cognitive orthotic system for supporting people with memory impairment. This system plans the interactions with the user and adapts the generated plans to a temporal model of the user representing his/her habits. The COACH system [2] provides an example of an instructional cueing device assisting people suffering from dementia in washing hands. This system uses some reasoning techniques to ensure that the reminders are adapted to the specific tasks the user is performing issuing reminders if important steps such as using soap are skipped or performed inappropriately.

Even though the domain is slightly different, given their adaptability capabilities, it is worth mentioning some works in the context of software assistance for the office domain. The CybreMinder project [10], for example, provides a Context Toolkit for the definition of arbitrary complex situations describing the context that would trigger the reminder. By doing so, the system is able to manage the timing of a reminder based on a user's context. Still related to the workplace domain, yet very prolific from the point of view of the reminding systems, the CALO project [16] is intended to support a busy knowledge worker with problems of information and task overload. The CALO system is able to provide proactive behaviour automatically initiating reminders for future tasks by applying BDI reasoning [17] and/or by reasoning on digital to-do lists [6].

Unlike the above-mentioned approaches, the GiraffPlus system maintains a dynamic model of the user taking into account his/her mutable psychophysiological state. In other words, our system is able to adapt to the possible changes of the state of the user and to pro-actively produce new messages when relevant changes occur. We are able to identify risky situations and to produce simple recommendations for the elders inside their homes as well as alerting messages for the caregivers following the elder.

3 The GiraffPlus Concept

The general idea behind the project is given in Fig. 1. The figure offers a conceptual schematization of the components of the system and allows to identify some key concepts relevant in our work and for the current paper.

First of all we can identify the human actors which are the target of the service given by the intelligent environment: (a) the *primary user* is the older adult living at home, mostly alone, that the system is supposed to actively support; (b) the *secondary users* are a network of people who participate in the support of the older adult from outside his/her home. Such users can be formal caregivers (a doctor, the nurse, etc.), informal caregivers (a son, generic relatives, etc.) or simply friends that want to maintain a contact with the old person.

The GiraffPlus system is basically composed by 4 parts: (1) a network of sensors deployed in the home that continuously gathers data; (2) a data management infrastructure that guarantees data gathering in a permanent data store or directly to some external user in real time; (3) a telepresence robot (the Giraff) that guarantees communication between people outside the house and the primary user inside the house, enriching the dialogue with the possibility of moving in the home environment and performing visual monitoring through a camera connected to the robot [5]; (4) a personalizable interaction front-end that allows to visualize data from the house and, also, to call the robot from outside the house.

Given these ingredients, a key aspect for creating a useful tool for real people are the services that the complete system can deliver to the different users. More specifically, it is important to highlight that there are two paths which are relevant: from inside the house to outside, and viceversa.

If we consider the *from-inside-to-outside* path we can say that we are mainly: (a) exporting data for a long term data analysis (storing them first in a data storage service). Notice that the secondary users usually are heterogeneous people having different "social goals" toward the old person, hence a doctor may be interested in physiological data and general information on the daily activities connected to health, an informal caregiver may be interested in a daily summary that says "everything is OK", "the windows were left open", etc. (b) exporting data for a real time use (hence, for example, for issuing alarms). In fact, the system can rise alarms and/or send warnings, for instance, in case of falls or in case of abnormal physiological parameters. Here a problem exists of delivering them timely and to the right person.

On the other hand, if we explore the *from-outside-to-inside* path we can say that: (c) the communication through the telepresence robot is the basic media for social communication from outside into the house; additionally (d) having such a general set up, the system offers now a channel from secondary to the primary for messages and reminders created through the visualisation front-end and delivered on the robot screen (also other media are possible but here we are focusing on the basic GiraffPlus components). This information exchange is stored by the data storage service for subsequent analysis.

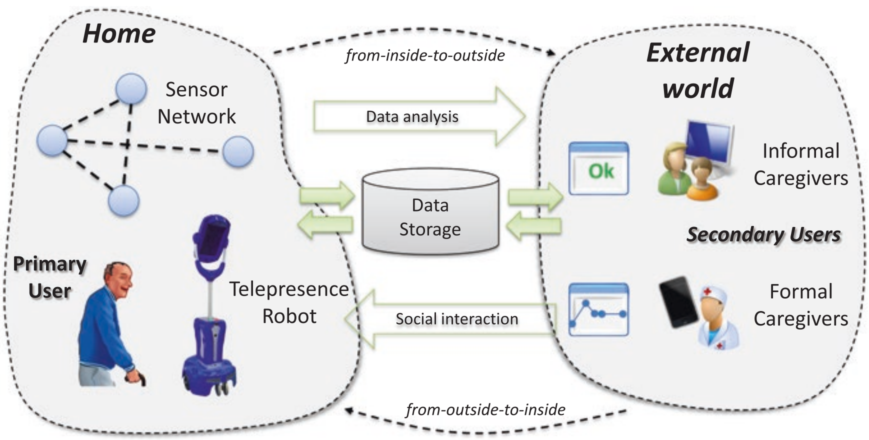

Fig. 1 The GiraffPlus project sketchy idea

In addition, it is worth underscoring how there are also other services that are possible given the infrastructure in Fig. 1: (e) long term data from the home sensor network are available in the data storage and can be also shown, with some attention, to the primary user; (f) having the home sensor network and a communication media in the home through the robot screen opens up the possibility of reasoning on those data and synthesize different messages (for the moment we assume precompiled messages) triggered by such a reasoning (for example, to react to some information contained in the data). Let us make a simple example here: if the primary likes the window shut by 9:00 p.m. and 1 day the balcony windows are still open at 9:30 p.m. we could exploit the robot to deliver a message "do not forget to close the balcony windows, they are still open".

The messages and the information open up an interesting spectrum of possibilities that should be coordinated by some possibility of personalization because different people would like different delivery of the information to each of the human actors connected to the dialogue with the GiraffPlus system.

4 An Adaptive Reminder for GiraffPlus

As we have just mentioned, an important aspect of the GiraffPlus system is the idea to provide personalized and proactive interaction services. The personalization back end is indeed responsible for preparing the "personalized information to the users" and for offering support for different types of services like *reminders*, *reports*, *proactive suggestions warnings* and *alarms*. This section gives an example of a reasoning service provided by the GiraffPlus infrastructure that can be considered as an example of the personalized services for the users. By reasoning on updated features of the primary user we pursue a “proactive reminding” service modulated by the user model information. The broad idea is to create a proactive service at home, by reasoning on user personal data and modulating system messages, directed to primary users.

The monitored features are a combination of: (a) a *static user profile*, considered immutable during the care process, describing not only general data (e.g., his/her age), medical condition (a chronic disease), bust also his/her attitude toward interaction and toward technology (these are used for example to avoid flooding a person with undesired information or recommendations he/she is not willing to accept); (b) a *dynamic user profile*, with a higher rate of change with respect to the static parameters, whose components are extracted from the physiological monitoring and other continuous data flows. (c) an *internal status* which, acting on such information, determines the user internal status by performing a classification process and triggers the planning of stimuli toward the involved users.

This classification, for example, is used to generate a brief and immediate information on the status of elderlies in terms of three main indicators (i.e., Alarms, Physiological and Social) providing an immediate feedback to the caregiver with a judgement on the level of each indicator (we will see soon how to compute these values): *green* = *good*; *yellow* = *warning*; *red* = *risk*. The status of such indicators a trigger to a strategy to decide which messages and which frequency of messages to select for the users. For example observing value transitions (es., when the physiological status change from good to warning) we can send simple questions like “have you taken your daily pill?”, or issuing dietary suggestions like “avoid salt while cooking”. These alerting messages can be sent, more or less often, both inside the house, to reassure or advise the primary user through the telepresence robot, and outside the house, to send an alerting message to a designated care person, etc.

This kind of behaviour is obtained by adapting a representation from temporal planning, known as timeline-based (we will adapt terminology from [8]), and a classifier system as described in the following.

4.1 User Modelling and Timelines

A *timeline* is, in generic terms, a function of time over a finite domain. Events on timelines are called *tokens* and represent information units over temporal intervals. For this purpose, tokens are represented through predicates extended with extra arguments belonging to the Time domain $\mathbb{T}$ (either real or discrete).

Definition 1 A *token* is an expression of the form:

$$n(x_0, \ldots, x_k)@[s, e, \delta]$$

where n is a predicate name, $x_0, \ldots, x_k$ are constants, numeric variables or object variables, s and e are temporal variables belonging to $\mathbb{T}$ such that $s \leq e$ and δ is a numeric variable such that $\delta = e - s$. A *token* $n(x_0, \ldots, x_k)@[s, e, \delta]$ asserts that $\forall t$ such that $s \leq t \leq e$, the relation $n(x_0, \ldots, x_k)$ holds at the time t.

Given the mutable nature of the user dynamic information and of their classifications in time, we have addressed the user modeling problem by making use of several timelines for each primary user that represent, respectively, their static and dynamic information as well as their current internal status classification.

Figure 2 shows a subset of the personalization timelines required for the physiological classification. In particular, in the sketched example we have used: (a) three predicates $Age(int\ age)$ $CC(enum\ cc)$ and $PT(enum\ pt)$ to represent the user static profile (characterized by *age*, *chronic condition* and *personality trait*). Such features are constant in time hence its timeline never change value, (b) three predicates $SBP(int\ sbp)@[s, e, \delta]$, $DBP(int\ dbp)@[s, e, \delta]$ and $HR(int\ hr)@[s, e, \delta]$ to represent dynamic features (characterized by *systolic blood pressure*, *diastolic blood pressure* and *heart rate*, each lasting δ from time s to time e) and (c) three predicates $AS(enum\ as)@[s, e, \delta]$, $PS(int\ ps)@[s, e, \delta]$ and $SS(int\ ss)@[s, e, \delta]$ to represent the user classification (characterized by *alarm status*, *physiological status* and *social status* lasting δ from time s to time e).

Following the representation in Fig. 2 it is possible to notice how the changing of the user's dynamic information, in particular his/her blood pressure, is associated to a change in his/her physiological status that results in a transition from *good* to *warning*, first, and from *warning* to *risk* later. This transitions can automatically trigger messages to the primary users such like "did you take the blood pill today?", just as we were mentioning before. In general, these state transitions can make the system recognize dangerous situations requiring a more significant intervention sending, for example, a reassurance message for the primary user together with an alert for the associated caregiver describing the current state of the elder.

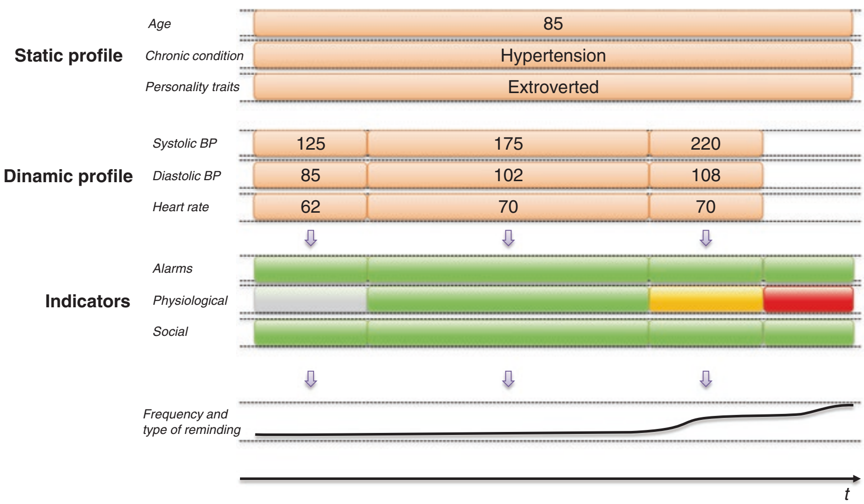

Fig. 2 User modeling through timelines

This kind of "rules of behaviour" are generalized in a concept usually called *compatibility* (the causal knowledge in temporal planning).

Definition 2 A *compatibility* is a tuple $c = (name(c), R(c))$, where:

- $name(c)$ is the *master* (or *reference*) predicate and is an expression of the form $n(x_0 \dots x_k)$, where n is a unique predicate symbol with respect to a timeline (i.e., no two compatibilities in a given timeline can have the same predicate symbol), and $x_0 \dots x_k$ are its associated variable symbols.
- $R(c)$ is a *requirement*, i.e. either a *slave* (or *target*) predicate, a constraint among predicates or a conjunction of requirements.

Compatibilities define causal relations that tokens should comply to in order to be valid. It is worth underscoring that the compatibilities may often involve predicates defined on different timelines, thus allowing to synchronize concurrent values on different domain components.

In our case, we use compatibilities to define both type and frequencies of reminders, considering the latter as the causal consequence of the current psychophysiological state of the user. By changing the psychophysiological state of the users, indeed, the underlying planning technologies applies different compatibilities adapting de facto the planned reminders to the current state of the users.

An example of constraint among predicates that is worth describing is the one that links static parameters and dynamic parameters with the status of the user. In order to achieve this elicitation, the current implementation makes use of *naive Bayes classifiers*[2] for extracting different features of the user profile. We have seen that this kind of classifier performs quite well with the training data set currently provided by caregivers. Furthermore these classifiers, with some adaptation, can handle numeric parameters thus allowing us to include temporal aspects inside the classification (e.g., the social status could make a transition from "good" to "warning" in case the social interaction with the primary user does not occur for a long time). Although the collection of this data is still an ongoing process, we have been able to gather different training sets for the different classifications (i.e., alarm, physiological and social).

As an example, in order to clarify this aspect, physiological classification has a schema like $\langle age, cc, ms, bphour, sbp, dbp, hr, class \rangle$ associating the parameters *age*, *chronic condition*, *taken medicines*, *blood pressure measurement hour*, *systolic blood pressure*, *diastolic blood pressure* and *heart rate* to a *class* having values among "good", "warning" and "risk".[3]

By exploiting the compatibility concept, the timeline-based technology allows, for example, the generation of stimuli in the future that foster the system to

[2]Simple probabilistic classifier based on applying Bayes' theorem with strong (naive) independence assumptions.

[3]An instance of training data, corresponding to the "risk" state of Fig. 2, is ⟨85, "*Hypertension*", "*Diuretics*", "14:30", 190, 110, 80, "*risk*"⟩. A similar instance would produce an alarm for the caregiver.

automatically follow the rehabilitation process associated with the therapy established by the caregiver. In particular we could describe rehabilitation therapies through predicates having specific stimuli as compatibility requirement. The timeline-based technology will be responsible for placing these stimuli in time and for dispatching them when the moment comes.

4.2 Modulating Reminders

A step by step example clarifies the underlying reasoning processes. Let us suppose we are taking care of an 85 years old elder suffering from slight hypertension and, for this reason, taking some diuretics (this situation is the one described in Fig. 2). Since the elder is forgetful, the caregiver has activated on the GiraffPlus system a daily reminder for remembering him/her to take the diuretic pill (GiraffPlus allows this by creating a token having an associated compatibility whose requirements represent a reminder for each of the days the therapy lasts). The resolution process analyzes the new incoming token applying the associated compatibility and thus producing the reminders and placing them in time. As long as the situation remains stable, the caregiver can skip the visit to the old person reducing his/her required effort in carrying out daily activities.

A first example. Now suppose the primary user measures his/her blood pressure obtaining dangerous levels like 190 for systolic blood pressure and 110 for diastolic blood pressure. A change in the dynamic parameters of the person is assessed and a new token for the planing process, requiring the application of a new compatibility, is generated. Now, the compatibility, associated to this state change, takes the values from static parameters, together with the values from the dynamic parameters, and gives them as input to the Bayes classifier which concludes the user is in a risky state. Again, a “risk” token is added to the system requiring the application of a new compatibility producing a reassurance message to the elder (e.g., “You’re fatiguing too much, rest a little”), sent by the telepresence robot, as well as an alerting message to the caregiver, describing the current state of the elder and fostering the user to take some action. At this point, it is up to the doctor to take the right (and prompt) decision. Supported by historical data of the elder provided by GiraffPlus, the caregiver could change the therapy associated to the elder, maybe, prescribing some beta-blockers. It is worth noting how the whole service is based on the other layers of the intelligent environment that are currently deployed and a combination of reasoning techniques that allow to create a new reminding service that goes beyond the simple “message for pill” which is part of all the AAL systems. This stimuli modulation technique is quite general and can be used in various active ageing scenarios.

A second example. Since the GiraffPlus system is highly customizable it allows us to explore several different possibilities. When no relevant activity is triggering any planning process, a periodic timer updates the current status of the user generating statistics on common activities that can be analyzed and used to foster different forms of reasoning. This process allows the extrapolation of information on the user's social state and/or information about deviations in the daily behaviour of the monitored person. Suppose, for example, that the primary user usually tends to be extroverted and thus socially active. Suppose also that the telepresence robot usage statistics show a reduced use of robot during the last days. This fact highlights an anomalous deviation from the default behavior that could be a symptom of some underlying problem and which, at least, should be further investigated by caregivers. Just like in the previous example, this statistical data constitute input for a "social" classifier. Since a reduction in the social activity of the elder may very well be linked to temporary minor problems, the system classifies the internal status as a social warning, resulting in a new goal for the planner. The replanning process is than triggered and a new compatibility is applied which, in turn, generates a support message to the elder by the telepresence robot (e.g., "Did you called your grandchildren today?"). With a similar reasoning, if the isolation of the elderly continues to persist even after several days, the system could classify the person as socially risky, exhorting the elderly to communicate with relatives and/or friends on a daily basis through daily reminders and, possibly, will also send a warning message to the caregivers, describing the current state of the elder.

5 Conclusions

This paper presents recent work to introduce Artificial Intelligence service in GiraffPlus. In particular, a proactive and user-adaptive reminding system has been integrated within an Ambient Assisted Living environment. The high-level interpretation of raw data provided by the sensors, carried out thanks to machine learning algorithms, combined with the ability to generate new stimuli, put into practice by the timeline-based infrastructure, enables to model complex interaction elements required by an AAL system like the one in this project. The interaction of these two aspects allows the GiraffPlus system to have an accurate understanding of the environment in which the intelligent system acts and, simultaneously, to produce a plan of interaction with users, reacting (or adapting) to changes in the environment.

Thanks to the described techniques the system is able to synthesise more effective and appropriate messages and dynamically adapt them according to the user status. This feature cope with the issue of maintaining the technology less invasive, avoiding to the user the boring effect of "over communication". It is also worth saying that the system is able to intervene when risky situations are detected by sending warning messages to the appropriate persons and/or modulating reminders toward primary users.

It is worth underscoring how the secondary user still remains the ultimate responsible for the care of the elderly person. Nevertheless, thanks to the support of intelligent techniques, he/she takes advantage from a decreased workload.

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Part IV
Smart Housing

Advanced Solutions to Support Daily Life of People Affected by the Down Syndrome

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Abstract Recent technologies applied or explicitly developed for assisting people with physical disabilities or weaker individuals needing particular attention, are becoming an emerging research topic. In this paper we focus on ambient care systems and we present an overall architecture that aims to provide multiple interfaces between a *smart house* and its guests. In particular we describe the results applied in the project Casa + , a smart house that is addressed to people with Down syndrome; it offers functionalities for monitoring the environment and its guests, giving indication signals, audio messages or even alarms in case of incorrect actions. Through exploitation of the most recent technologies, keeping in mind the trade off with costs, we developed the following functionalities: security, time management, assistance for daily activities, monitoring and remote control, outdoor tracking.

Keywords Ambient assisted living · Wireless sensor networks · Multimedia communication · Indoor localization · Outdoor tracking

1 Introduction

In the last decade there has been an increasing interest in how technology can help disability, which has been demonstrated in the behalf of the Sixth Framework Program, FP6 [1]. An interesting branch of this research is related to the aspects of Ambient Assisted Living which is however mainly focused on physical disability, [2]

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and Reports therein. For instance [3] proposes the use of digital cameras for fall detection of elderly or disable people and alarm generation through an SMS. In [4] the authors propose the integration of visual systems with low level sensors in order to obtain more precise results and to increase the reliability of the system. Most of the literature is focused on safety aspects for physically disabled people, that do not need to be followed by educators. Instead, while concerning with mental disability, personal awareness and social rehabilitation are the main requirements. We particularly focus on people affected by the Down syndrome, with the aim of helping them to improve their mental and physical growth, in order to integrate and have an active participation in the social context, [5, 6]. Basing on data collected in [7] individuals with Down syndrome can easily face daily activities such as "eating" and "drinking", respectively the 84.4 % and the 78.3 %, followed by the capacity of "undressing" (the 65.3 %) and "using toilet facilities" (the 60.2 %). Less individuals can wear and take care of their personal hygiene (respectively the 51.4 % and the 40 %). The latter activity is the one causing major problems to interviewees. Also the use of public transportation is enjoyed by only the 14.4 %, even if there is a percentage of them admitting a low or medium difficulty (the 18.2 %), while the 50.3 % state to not be able at all. Domestic activities are achieved without difficulties by the 18.8 %, "cooking" a simple dish is an easy action for the 10.2 % and is completely impossible for the 45.5 % of the interviewees. Furthermore while teachers and scholastic operators are the most important persons for individuals with Down syndrome in school age, parents association become the only reference points for people aged between 20 and 30, [7]. It is thus important to reduce the dependency from relatives and to make these persons facing and solving the daily problems, in order to guarantee a future to their own lives and been recognized as adults, [8]. The project presented has also been pushed by the critical social environment of the town of L'Aquila, Italy, that after the destructive earthquake of 2009 is missing in infrastructures for disables and their families, both in terms of socio-educational and physiologic aspects. This is due to the lack of public structures, which causes difficulties in displacements and absence of reference meeting points, thus generating a destabilizing scenario particularly for people belonging to the weakest section of the population to which people affected by the Down syndrome belong. In this framework, technology for daily life appears to be again an important aid for educational processes and individuals skills improvements. For this reason the project is called Casa + , [9], (where Casa means *home*) referring mainly to a smart apartment, where disables have the opportunity of spending a few days each month and interacting with their friends while learning from the domotic facilities which gradually reduce the intervention of educators. Figure 1 represents some technological aids introduced in the apartment as an aid to the proper educative process, by strengthening and continuously providing the educative action itself.

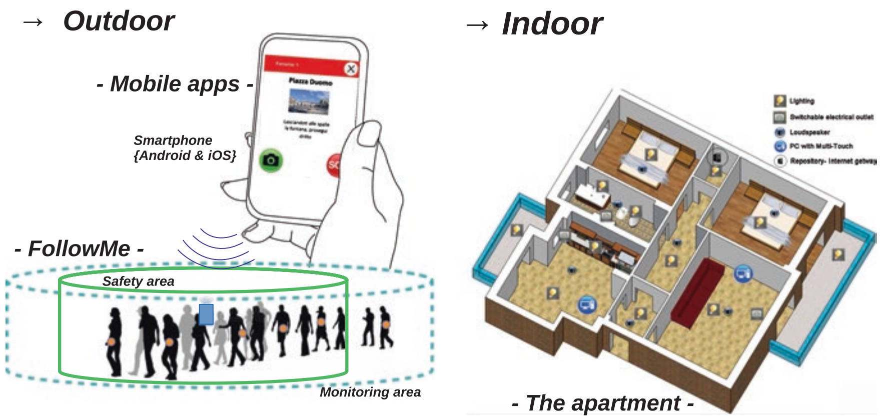

Fig. 1 Casa + technological aids

2 Casa + Project Overview

2.1 Casa + Facilities

In this section we briefly present a list of issues for the project.

Domestic safety—The apartment is equipped with specific units in charge of verifying the presence of people inside each room for a double aim: control and authentication. In particular authentication devices have to be hidden inside a device (e.g. a watch), which is able to communicate in a wireless fashion to another device collecting all data.

Time management—is a critical aspect for people affected by the Down syndrome because they often take too much time to carry on daily actions. In order to efficiently organize and schedule these actions we introduced duration indicators helping Casa + guests to become aware of the passing time. Indicators can be of various types: tactile, auditive, visual or a combination of them. The basic idea is to progressively remove these devices while guests improve their sense of the time flow.

Daily actions assistance—The aided daily actions are: preparing food, taking care of the house, doing the groceries etc. In particular audio/video devices are used to send data and suggestions with the primary aim of progressively reducing their presence.

Remote monitoring and control—The process of increasing awareness on potentialities and capabilities is a procedure that has to involve also the families. With this objective in mind and in order to provide for personal safety, we equipped the apartment with remote monitoring and control devices. Some data are thus remotely accessible; furthermore educators can use these devices to send messages to guests, and parents can convince themselves of potentialities and capabilities of their sons.

Communication infrastructure from and to the outside—We provided for a communication infrastructure to guarantee described monitoring and control functionalities and to send messages to the guests. Various communication protocols and an alternative power supply are assumed to avoid absence of service.

Tracking—The geographic position survey is an essential element to guarantee mobility support to a person affected by the Down syndrome. We exploited the use of a small and simple device allowing the tracking of position data. This allows the educators to supervise these data depending on the level of autonomy of each person as well as his/her improvements due to the increasing experience. *Follow-me* is a service for monitoring and supporting guests in outdoor experiences, e.g. short trips, when educators would like to receive an alarm message in case someone move far from the rest of the group.

2.2 Casa + Technology

We faced previously presented problems by committing a technological apartment intended for guests, relatives and educators. These functionalities also allow to develop a case study for setting up and evaluating the educational method.

As first requirement we analysed the possibility of providing a robust *indoor localization service*; this service partially fulfils the requirement of security, since, without excessively invading the privacy of the guests, it can still allow a control on the occupation of the spaces, on the interaction between users and the system, and between the users themselves. It can also bring benefits to the goal of time management, as it is possible to control excessive stops and trigger an alarm at the precise point of the fault. We focused on localization techniques using RF sensors, since the benefits brought by a WSN become evident in other requirements satisfaction. A wearable TI Chronos watch [10], that is equipped with a built-in radio transceiver, a microprocessor and a tri-axial accelerometer, is used for localization purposes. The watch represents a proper trade-off between technological requirements and Casa + guests acceptance since it is a common and daily device that is also useful from the educational point of view on time passing. By the use of the watch as a mobile node within the scope of a WSN, we aimed to obtain location information about Casa + guests. We introduced also passive infra-red (PIR) sensors in order to point out the presence of foreign persons or non-collaborative guests inside the rooms. A WSN comes as a natural solution for *environmental parameters* such as temperature and humidity, but also for interfacing with sensors to control the use of the water in rooms like kitchen or toilet. For security purposes WSN nodes can also be connected to gas sensors. All data collected from localization service or monitoring service can feed a statistical database to keep track of the evolution of an educational path or can be used real time to signal anomalies, Fig. 2.

The main channel for signalling and human communication toward guests is a *service to broadcast preloaded audio messages*; in this way it is possible to record messages with familiar voices and use them for specific purposes, guests or

Fig. 2 Indoor localization

locations, letting the system play them when a particular situation occurs. When the use of systems is not correct, basing on the presence of people and/or the time spent, for instance, inside the toilet, a proper audio message is played concerning the incorrect situation. The audio system is also exploited to help users for the proper management of the flow of time. Indeed it provides time messages for: wake-up, shopping, lunch preparation, dishes washing, as well as personalized messages for individual persons which are in charge of doing something in particular. The presence of these functionalities inside the apartment implies the need of exploiting a *gateway for indoor services*, that is responsible of offering an interface also outside the system.

Another developed indoor functionality is a component for the Joomla! CMS that implements some simplified web applications accessible with multi-touch capabilities. The choice of using a CMS as base system of our applications, relays in the possibility to easily install, configure, move and export the whole system through a web interface; moreover user management and access control features are managed by the CMS itself.

The developed applications are described in the following.

Store cupboard. It is a representation of the real store cupboard whose content is continuously updated. After shopping, each element has to be organized in a specific shelf, pointed out by the application. In this way the guests are facilitated in organizing the store cupboard, finding the ingredients to cook, understanding what is missing to fill out the shopping list.

Shopping list. With this application, guests can build up a shopping list in a very easy way just tapping on a set of products on the screen. The produced list can be directly sent to a printer. Each product has a text description and an image, in this way also people that are not able to read can use this application.

Money index book. The aim is to increase guests' knowledge of coins and money. The application presents a set of images of coins and euro bills, tapping on an item, a list of products, purchasable with that amount of money, is presented.

Cookbook. This application is a simplified version of an interactive cookbook through which the guests are supported in the choice of proper meals basing on available ingredients, or in choice of ingredients basing on their wishes (that have eventually to be added to the shopping list) as well as in the steps to be followed to prepare their meals.

Moreover we introduced an *outdoor localization system* through the use of GPS in smartphones for safety also outside the apartment area, as well as helping the user to make the proper actions (choosing a direction, using the proper bus etc.) in outdoor activities. Concerning outdoor facilities, the guests of Casa + are encouraged to autonomously go out from the house and enjoy a walk in the main meeting points of the town. Their behaviour outside is supervised by an application, whose parameters are established by the educators depending on the level of autonomy of

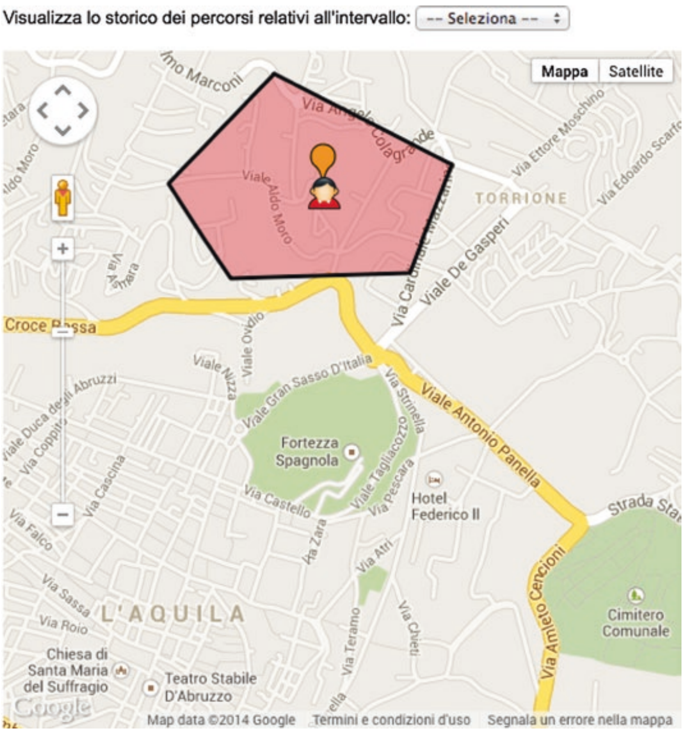

Fig. 3 Outdoor localization

each person as well as his/her improvements due to the increasing experience. The outdoor localization application has two main working mode:

- *Free walk* with geo-fencing capabilities in order to guarantee the safety of the user; educators can define a safe zone, where the person can move without generating any remote warning by using a simple web interface, Fig. 3.
- Paths, ordinary and safe (e.g. from house to workplace, or to the supermarket): each one with its own travelling time. If the user gets out of path or takes too much time to reach the destination, a warning will be generated and sent both to the user and the educator. While working in Path mode the mobile application will guide the user towards his/her destination by consecutive steps made by Point of interest (POI) well known to the users (e.g. reach the church than go left toward the bridge.), Fig. 1; POI can be easily defined by educators using the web interface; furthermore a picture, for example taken by the smartphones, can be bind to each POI.

Different alarms can be triggered if position is lost (weak GPS signal) or if the phone, or the user, does not respond to solicitation messages.

3 System Architecture

In the process of mapping systems and devices to an effective technology, in order to satisfy requirements and solve problems of previous section, we defined the architecture as shown in Fig. 4.

Automation System—The home automation is realized by using the UNA System by Master divisione Elettrica [11]. The overall architecture is presented in Fig. 5. The Eva board is the core of the system, it manages all the lighting system, controlled loads (such as ovens, washing machines etc.) and the heating system. There are 5 Eva boards in the apartment each one connected to a subset of controlled items. All Eva boards are connected together through a bus that ends up to a Vesta Board. Vesta is the webserver of the automation system and allows controlling everything through an intuitive and easy web interface. It also coordinates all Eva boards allowing them to exchange messages in a custom protocol. Eva is also capable of managing events, for example if someone leaves a room and it appears to be empty, Vesta will turn off the lights, it can also preform some action at given time during the day such as switching on outside lights at the sunset. Vesta is connected to Gateway2 and we developed some software that allows web application and WSN to communicate with the automation system without using the previously mentioned custom protocol, for example the CooKBookApp will make a kitchen light blink when a cooking time ends.

Wireless Sensor Network—Most of the previously presented functionalities and services can be easily implemented through the use of a WSN. As mentioned in previous section, a critical point was the choice of a node or device that could be wearable, but also reasonable as trade-off between requirements, costs

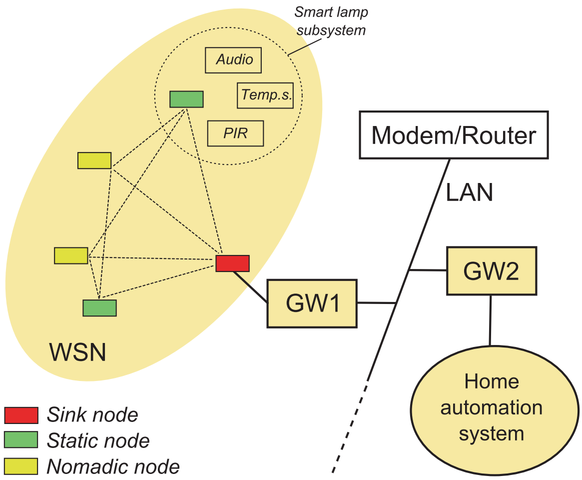

Fig. 4 System architecture

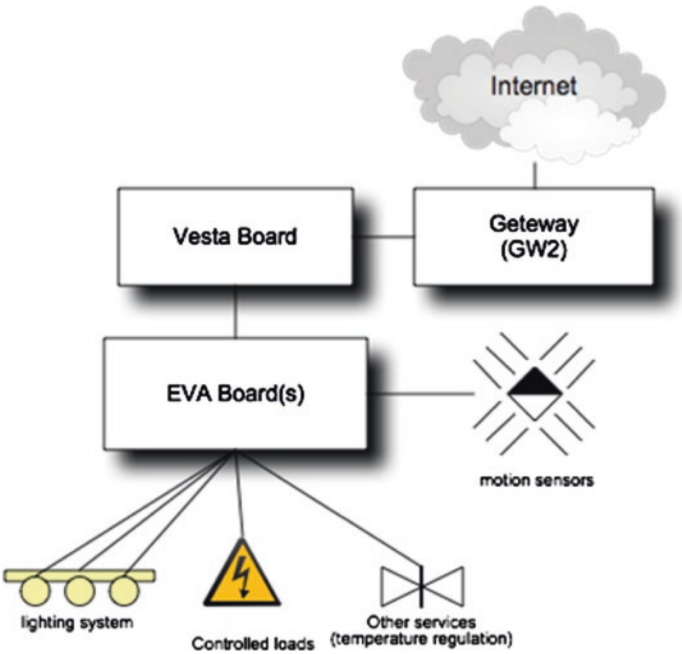

Fig. 5 Home automation architecture

and potentialities; we found a good solution in Texas Instruments SoC CC430, which combines an MSP430 micro-controller and an integrated CC1101 wireless transceiver [12], which can operate in the European ISM band of 868 MHz. Our network is made up of a multitude of nodes that are distinguished as *static* and *nomadic* nodes, basing on mobility. *Static nodes* occupy fixed positions and are masked within the environment and its furniture. They have been used as anchor nodes in the first prototype of the localization system inside the apartment; in particular we integrated different COTS boards and devices, hiding all the hardware in a ceiling lamp (a sketch in Fig. 6). Our *smart lamp* comprises an SD memory player card for storing and playing pre-recorded messages, an audio front-end/amplifier with stereo loudspeakers, a temperature sensor, a PIR sensor and a battery backup power supply. The CC430 in the *smart lamp* is responsible of controlling power-on and power-off of other hardware, as of sending proper commands to the audio board for playing messages, loudness regulation and eventually new messages uploading. Other fixed nodes are those connected to the hydraulic system for monitoring water usage due to the previously described time management problem, or the one interfaced with carbon monoxide (CO) and methane (CH_4) sensor gas for signalling gas leak in the kitchen, a cooker forgotten open or a malfunction in the heating system. A special static node is the *sink node*, that acts as the coordinator for the network. The sink node receives, from the other network nodes, data concerning environmental monitoring or localization service information. On the other side, it sends commands and messages or data packets, for instance related to a new audio file. We want to remind that different messages can be managed on different smart lamps.

Nomadic nodes are in charge of user's monitoring and are mainly given by the previously described watches. They are used for monitoring the activity of the users and the messages sent to the network encapsulate data from accelerometers and temperature sensors. These messages are used to feed the localization algorithm as well, through the Received Signal Strength (RSS) level measurements, Fig. 2. It has to be noticed that localization is mainly used to underline too long permanence times in a room. This implies that a strict precision is not necessary, while stability, reliability and low complexity are all properties required for the correct functioning of the system. This is perfectly achieved by the proposed algorithm.

Gateways—In our architecture gateway functional requirements are split on two different hardware devices, according to service level. The gateway GW1 is responsible for the interaction with WSN at a lower level; the gateway GW2, instead,

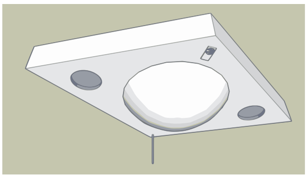

Fig. 6 A sketch of *smart lamp*

behaves as an access point to internet for all the higher level services and applications offered. It should be noted that all the lower level system, i.e. the whole WSN and the GW1, is independent from the home main power supply, since it is battery backuped and can run in case of emergency, when for instance a black-out occurs.

GW1 is directly connected to the sink node of the WSN and it has to guarantee the following functional requirements:

- interaction with nodes belonging to the WSN and memorization supports;
- execution of complex computations (e.g. the ones required by the localization algorithm);
- forward of commands and messages for the audio players;
- notifying the verification of certain events (e.g. opening of the shower water, temperature over some threshold, etc.).

GW2 is responsible for offering services at a higher level for direct human interaction. It hosts various application among which: the one for the interaction with home automation system; a back-end application for the educators for setting up system parameters or managing audio messages; a simplified web server for web applications mentioned in Sect. 2.2; a graphical interface for localization service. It mainly uses and exposes services from GW1 and from home automation system, representing data and exposing functionalities in a user friendly mode, either inside and outside Casa + . GW2 is connected to the LAN and its applications are accessible through two personal computers with multitouch capabilities.

Mobile app and follow-me—We also developed a Mobile application both for iOS and Android, that offers all the features of the web applications optimized for smartphones and tablets and can receive push notification from Casa + system for example when the shopping list has changed, Fig. 7. The follow-me service is an integration between the mobile apps and the WSN; the smartphone is the gateway of the sensor network constituted by the previously describe watches that are worn by the guests. The app reports information on the watches wearing and the distance from the educator and the guests.

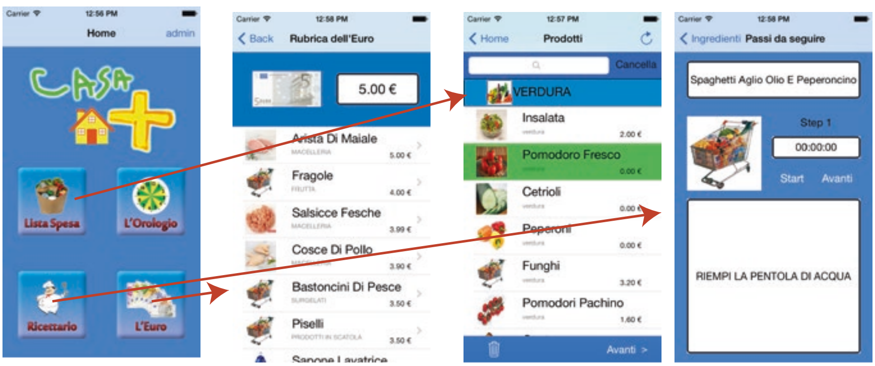

Fig. 7 Mobile apps screenshots

4 Results

The overall technological system has been set up in an apartment located in L'Aquila. This is used by an association for people affected by the Down syndrome in order to allow them to make autonomous residential experiences. In particular the guests are all adults and they join the experience in small groups of four people. The first attempts have been carried on during weekends under the supervision of two educators that are in charge of allowing the guests to act as autonomously as possible. Although the project is just at the beginning, the tests results, so far, are very positive for everyone. Indeed the educators expressed their satisfaction in seeing the guests becoming very friendly with technological facilities and guests, on their side, are very enthusiastic. Concerning the technological aspects improvements and variations are introduced every time this is required by educators basing on guests responses.

5 Conclusions

In this paper we presented the Casa + project. This is addressed to people affected by the Down syndrome with the aim of helping them to increase awareness of their potentialities and independence. We described the equipped apartment for autonomous residential experience and went through technological facilities providing for security systems, time management, assistance for daily activities, monitoring and remote control, outdoor tracking. It has to be stressed that technology can not be useful if a proper education path is not followed, together with the introduction of technological aids. Moreover it is important for the users to positively perceive the innovative supply, which is the first step to be reached in order to increase confidence in their potentialities as well as maintaining individuals' freedom. The project is not yet concluded and although we achieved good results basing on educators experience, we think that Casa + will be successful only when its users will be able to reduce the use of technological aids due to their increased awareness and independence. We are currently moving the focus from the web to the mobile world, by redesigning applications for smartphones and tablets to take advantages from all the capabilities of those devices, with the aim of providing each user with a personal and customized smartdevice.

Acknowledgment This work is partially supported by Vodafone Foundation. We would like to remark the irreplaceable help and sustain we gathered by educators and responsible persons of AIPD (Italian Association for People affected by the Down syndrome) of L'Aquila that represented the fundamental interface to understand the need of people affected by the Down syndrome, to guide the technological choices and to adapt to continuously arising needs.

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Localization and Identification of a Person in an Indoor Environment Using a Low-Cost ZigBee Based Gateway System

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Abstract The European population is becoming older and older, causing AT and AAL topics to become more and more important. A ZigBee based low-cost home automation system named CARDEA has been developed at the University of Parma, with the aim to permit elderly people to live their lives autonomously and independently. In this paper is presented a new feature: a gateway monitoring system which allows to detect crossing of a doorway or a predefined gateway and, if the person is carrying a wearable ZigBee sensor, to identify he/she. This technology could be helpful to control movements of a not completely self-sufficient person, to supervise the access to a particular location or to keep track of the person's habits to possibly relate them to his/her health state.

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1 Introduction

The ageing of the population is one of the most relevant phenomenon in the 21st century, leading to major consequences in multiple aspects of our society and in everyday life [1]. It is mandatory to consider the demographic change that is taking place, finding a way to let older adult remain a resource for the society for as long as possible, and also ensuring them to be autonomous and independent.

This may be achieved only by the combination of state of the art ICT (Information Communication Technology) in the context of AT (Assistive Technology) and AAL (Ambient Assisted Living), that can help to support a non completely self-sufficient person and can offer to elderly people a way to be an active part of the society and to improve their well-being at home.

DoTALab, the Domotics and Assistive Technology Laboratory of the Information Engineering Department of the University of Parma, has developed CARDEA, a powerful and low cost home automation system [2] to which it is possible to connect MuSA (Multi Sensor Assistant) [3], a small wearable ZigBee device developed at DoTALab as well.

An indoor localization system is very useful in a assistive context for the possibility of immediately locate a person in case of emergency and also in everyday life, for example to check when somebody reaches a zone of the house where he needs more help or where he can put himself into danger. It also has a major importance in order to execute a long term analysis on the health state of a person: it is possible to gather information from different sensors (related both to certain conditions of the person itself, like the blood pressure or the heart rate, or conditions of the environment, like the usage of lights or the temperature of the rooms) to build a sort of long term profile of the person's health, in order to find in advance any kind of signs that could lead to prevent the appearing of diseases or of any kind of health-related issues. In this context it would be very important to keep track of the movements of the person inside the house, to link the information from the sensors to the circumstances in which they were received and also because the movements themselves can give a lot of hints about the health state of a person. This kind of study is actually under research at DoTaLab [4].

MuSA presents on board an accelerometer, a gyro and a magnetometer that can be used to implement an indoor localization system [5]. This solution is cheap and accurate in the short term, but errors tend to stockpile over time, due for example to integration needed to compute velocity and then the position, and a sort of reset system is needed [6].

In this paper is presented a low cost ZigBee-based gateway monitoring system, which allows to detect the crossing of a door or a predefined gateway by a person and to identify he/she. This can have a double aim: to check when somebody reaches a zone of particular interest (for example, as mentioned before, because that person could need particular help in that situation) and to work as a reset for the inertial localization system [5]: in this case, once the person who crossed the gateway is identified, his location is placed in the nearby of the gateway and the inertial tracking is reset, canceling the errors accumulated to that point. The gateway system has the basic functionality of any "line-of-sight" sensor (e.g., infrared barriers), detecting any person crossing the gateway line (regardless of him wearing a MuSA device), however posing much less stringent constraints in terms of placement, alignment, maintenance and cost. If the user wears a MuSA further "active" interaction modes with the passing user are enabled, allowing for user's identification and for zeroing the drift error in inertial navigation. This system is completely ZigBee-based and can be perfectly integrated with MuSA, CARDEA or any ZigBee-based system without the need of ad hoc hardware solutions.

2 The Gateway System

As mentioned before, a gateway system aims to detect every time a person crosses a doorway or a predefined gateway, and to identify that person. To define a gateway a couple of devices are needed, named G_a and G_b in this paper, which have to frequently communicate with each other over time. The communication is based on the ZigBee protocol due to his versatility, low-power consumption and possibility of easily communicate to CARDEA and MuSA. The couple can be mounted on the two sides of a door to look for the passages across the doorway, but can also be placed on any relevant place that needs to be monitored (as for example an armchair or a fridge to infer a sort of behavioral analysis). In order for a person to be identified he has to wear a MuSA device, that simply replies to the messages sent by G_a and G_b as will be discussed later in details.

The gateway system works thanks to the absorption of the radio signals caused by the human body: if a person walks between two devices, he absorbs part of the power of the signals they are transmitting to each other [7]. The gateway is able to detect the passage by calculating the RSSI (Received Signal Strength Index, an index of the power of the received signal [8]) of every signal the devices receive: if there is a sudden loss in the RSSI, it probably means that a person just walked across the gateway, and the passage is detected. Because of this, an initial phase of training (that lasts just a small amount of seconds) is needed, in which let the two devices of each gateway calculate the RSSI value in quiet conditions (when no person passes between them). After that, the system is ready to operate and a passage is detected when the gateway RSSI is below a predefined threshold value. The threshold is determined experimentally: a series of trials have been conducted spacing the gateway devices at 1 m and then at 2 m. A person had to walk across them, and the threshold was defined as the value that maximizes the detection rate.

The gateway devices are part of a ZigBee network and are configured as Router: the Coordinator of the network is presently connected to a computer via USB port, in order to send the data to the pc which elaborates them and displays the results on the monitor.

For identification purposes, when a passage is detected the two devices of the gateway send an identification request to each MuSA in the network, then they

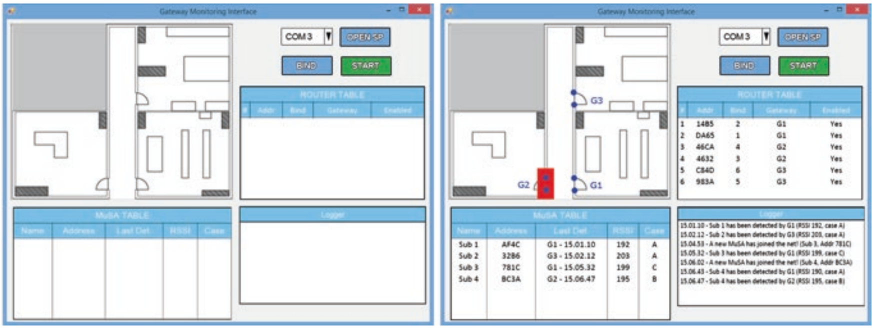

Fig. 1 The gateway monitoring user interface

calculate the RSSI of the replies and send them to the coordinator. The coordinator simply passes the data to the pc, that shows on a friendly UI (User Interface) which MuSA is crossing the particular gateway. The UI has been developed using Visual Basic on Microsoft Visual Studio 2010, and it is showed in Fig. 1.

The map represents the floor of the Information Engineering Department in which DoTALab is located. The lower part of the UI contains the information about the last passages detected: time and place of detection and the identification of the person who crossed. The blue dots on the map represent the location of the gateways: once a passage is detected, the corresponding dots are highlighted in red, making it easier to understand where the passage just happened. The Router table contains information about the gateway devices deployed in the network.

3 Detection Experiments

First of all, the initial idea of using the shadowing effect caused by the human body to detect a passage needed to be validated. A single gateway was set up in the middle of a room in order to avoid interferences with the furniture, with G_a and G_b at a high of 1 m and spaced 1 m: a person walked across it, slowly at first and then quickly for 32 and 48 times respectively. The results were positive and the 100 % of the passages were correctly detected.

After this initial test, a more accurate characterization was carried out in order to evaluate some important features: the variation of the detection rate with the distance between G_a and G_b, the influence of the crossing position (in the middle of the gate or closer to one of the two devices) on the detection rate, and the rate of false detections caused by a person walking close to the gateway but not across it. Six different distances between G_a and G_b were considered (from 0.5 to 3 m with 0.5 m steps), and for each distance four tests were made: crossing the gateway in the middle (Test 1), crossing it close to G_a or G_b (Test 2), walking parallel to the gateway and perpendicular to the normal pathway (Test 3) and walking on

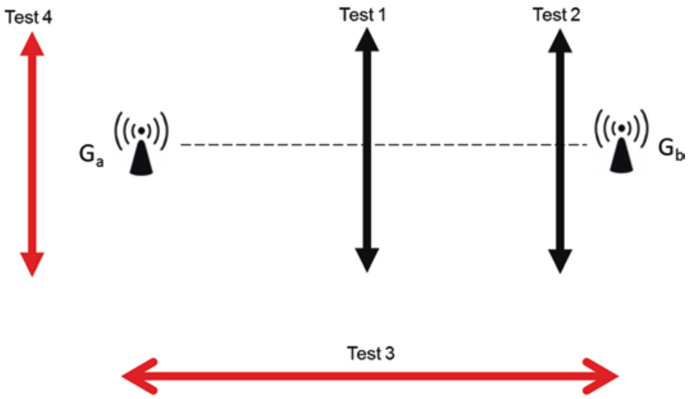

Fig. 2 A sketch explaining the test performed

the outer side of the gateway and parallel to the normal pathway (at a distance of about 0.5 m) (Test 4). In Fig. 2, a sketch of the tests is depicted: the arrows represent the direction in which the person was walking. The first two tests were conceived to check the detection rate, while the other two were made to evaluate the percentage of false positives. For each test, 50 tries were made.

In the first and second test, the 100 % of the passages was correctly detected in each of the six different distances between G_a and G_b. An important behavior noticed was that the passage was detected while the person was actually crossing the imaginary optical line between the antennas of G_a and G_b when they were placed at a small distance, while as the distance increased the passage was detected also when the person was a little bit behind or a little bit above the line-of-sight. As expected, the distance between G_a and G_b affects the signal path, but not the detection rate, at least in the range used in these tests.

The aim of the third test was to find the lower distance from the gateway that could give false positives. This resulted to be pretty hard to find accurately, since the human body doesn't have a regular shape, and it is difficult, for a person, to walk on a perfect straight line. However, a rough evaluation has been attempted: the limit range grows with the distance between G_a and G_b, at 0.5 m it is between 15–20 cm, while at 3.0 m it is above 60 cm. This is consistent with the changes in the signal path observed during the first two tests.

The results of the fourth test show that walking in the outer side of the gateway does not lead to false positive independently from the distance of the two devices.

After that, a gateway was installed on an actual door (110 cm wide) to see if the success rate was affected by the real scenario, and also on this case the 100 % of the passages were correctly detected. Subsequently, the third test was replied in the real scenario and the limit distance to have a false positive resulted to be about 0.4 m. These experiments proved that the system is efficiently capable of recognize the crossing of the gateway without generating many false positives. Consequently, the following step was to test the identification algorithm.

4 Identification Experiments

As mentioned before, a person has to carry a MuSA device in order to be identified. Since MuSA is a battery-operated device using a sleep-awake cycles to reduce power consumption (as specified in the ZigBee protocol), it is impossible to communicate with it using a 1-hop message: the messages sent are stored in its parent (the router/coordinator allowing MuSA to join the network) until it is ready to receive them (the sleep period can be programmed accordingly to the user's need). Taking this into account, the following procedure has been implemented: once a passage is detected by a gateway, G_a and G_b send to each MuSA in the network a message. The MuSAs reply in 1-hop mode. Then G_a and G_b send to the coordinator the RSSIs calculated and the ID of the MuSAs replying, which passes the information to a PC. Ultimately, the PC individuates the gateway detecting the passage and identifies the MuSA.

A first test has been executed: a person was walking across the gateway wearing a MuSA (M_1) and another person, with a second MuSA (M_2), was standing at a distance of about 3 m. The same test was repeated inverting the role of the people, so that M_2 was the device crossing the gateway and M_1 was the one standing at some distance. For each situation, 14 tries were made. Figure 3 shows the results: the dark and light blue bars represent the RSSIs from M_1, and the dark and light yellow bars represent the RSSIs from M_2.

Considering this results a simple decider has been implemented, which selects the MuSA that replied with the greatest RSSI as the one crossing the gateway.

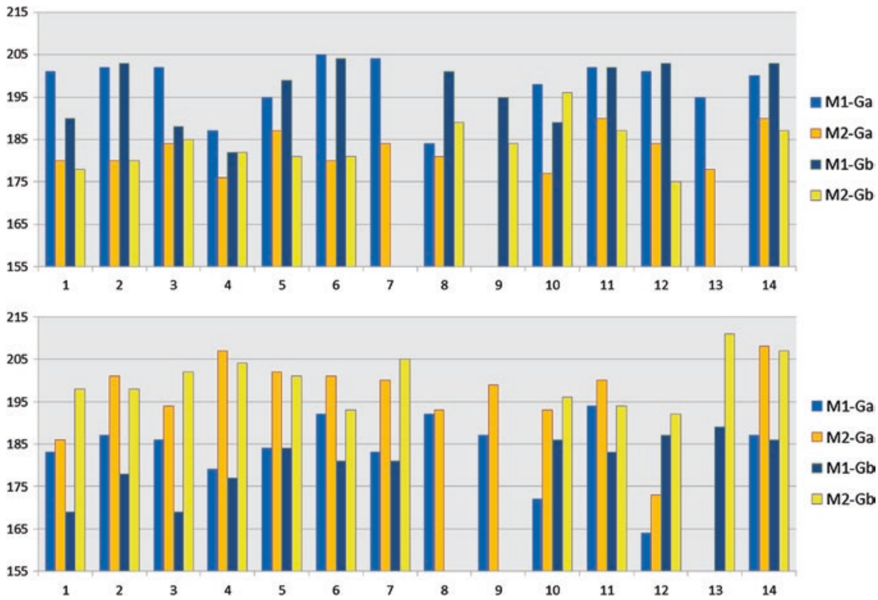

Fig. 3 Identification process results

This may lead to three possible cases: G_a and G_b agree in identifying the same device, G_a and G_b make two different decisions, since they receive the higher RSSI from different MuSA, or only one between G_a and G_b detects the passage. In the second case the decider selects the device with the overall greatest RSSI.

The previous experiment was then repeated to test the decider, but this time the person who was not crossing the gateway was standing at a distance of 3 m. A rate of success above 97 % has been obtained, since only one error (i.e. choosing M_2 instead of M_1 as the one crossing the gateway) has been made on 44 tries.

5 Multiple Gateways Experiments

A final test has been conducted, in which three different gateways (G_1, G_2, G_3) were placed on three actual doors. Four subjects were involved, each one of them wearing a different MuSA: they had to walk through a path in which they had to enter and exit from rooms where the gateways were placed, so that on each try six passages should have been detected, two for every gateway. In Fig. 4 a map with gateway placement and one with the itinerary are shown.

The starting point was inside the room where G_1 was placed, so a perfect path would have been signaled by G_1-G_2-G_2-G_3-G_3-G_1. The other three people that were waiting for their turn were sitting at a desk about two meters inside the room where G_1 was placed: this was made to monitor the possible interferences between different MuSA, i.e. to check again the success rate of the decider.

A success rate of 87.5 % has been obtained (21 out of 24 tries). Out of the three errors, one of them was caused by an undetected passage, while the other two were caused by a wrong decision taken by the decider, i.e. the MuSA which replied with the strongest RSSI was not the one supposed to.

This is a positive result, taking into account the simplicity of the decider, the setup conditions and the context this system is conceived for. The integration with

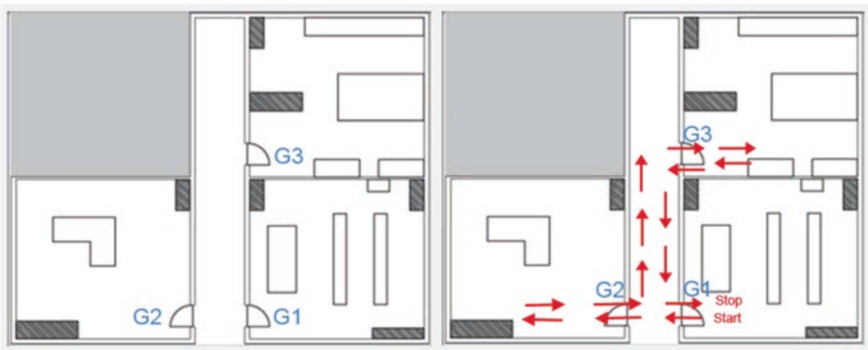

Fig. 4 Gateway placement and itinerary of the experiment

a tracking system and the use of a more accurate decider, that may for example consider the history of the movements of the person, will probably lead to a strong increase in the success rate.

6 Conclusions

In this paper a ZigBee-based gateway system has been presented, which allows to detect the passage of a person across a predefined gateway and to identify that person if he is carrying a ZigBee device. This system is highly innovative since it allows the detection and the identification using the same technology without the need of ad hoc hardware, leading to a very low cost, maintaining high reliability.

A gateway system may be very helpful in a assistive context, for example to detect when a not self-sufficient person reaches a place where he needs help or should not go for his safety.

In this paper a first implementation of the gateway system is shown. A success rate above 97 % is obtained, both in terms of detecting a passage and identifying the correct person between two of them.

Future works will lead to improve the decider (the algorithm to identify the correct person), the threshold calculation (for example using a dynamic threshold according to the spacing of the gateway or other environmental conditions) and the signal transmission process between the devices, in order to improve the reliability even in crowded or more complex areas.

The final goal to be achieved is to merge this system to a tracking system based on inertial sensors, to create an accurate low-cost indoor positioning system.

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An Ontology Designed for Supporting an AAL Experience in the Framework of the FOOD Project

Monica Mordonini, Guido Matrella, Mirko Mancin and Michele Pesci

Abstract This work focuses on the design and the implementation of an ontology devised to extract knowledge from an Ambient Assisted Living environment, equipped with an Home Automation System. In particular, the design of the ontology is been carried out taking as reference the experience of the FOOD project [1], funded in the framework of the European AAL Joint Programme [2]. In the pilot installations of the FOOD project, a set of sensors was installed in the kitchen of the users in order to monitor the behavior of the persons, aiming to recording their feeding habits. The main part of the performed activity is the design of the ontology itself and, in particular: the identification of most important conceptual classes, the way to describe the concept of time within the ontology, and the development of a relational database that enables the interfacing between the ontology and the actual data provided by the sensors and collected by the Home Automation System.

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1 Introduction

In recent years, the use of ontologies in the field of knowledge-based systems is an activity in strong growth. Develop ‘ad hoc’ ontologies for specific application contexts (or domains) allows the design of relational databases that enables for the implementation of more sophisticated artificial reasoning. The main purpose of implementing ontologies-based description is the deduction of non-trivial information, closely related to the context. This work aims to provide an ontology, specifically designed for an Ambient Assisted Living environment, in order to improve the knowledge of the behaviors of users, with particular interest towards the use of the kitchen and feeding habits.

The starting point of this work was the FOOD Project [3], in which the kitchen becomes a smart environment that, exploiting smart kitchen appliances, wireless sensors network, and a technical infrastructure and end-user’s interfaces, enables services dedicated at increasing safety, at providing help and guidance in food preparation, at fostering social and cultural implication of feeding.

In the context of the project FOOD, more than twenty users, belonging to three different countries (Italy, the Netherlands and Romania), have installed in their kitchen a pilot version of the FOOD system.

The inspiration for the developed ontology was the typical pilot installation of the FOOD project. In these actual experiences, the users kitchen was equipped with an hardware/software infrastructure, in which each smart devices was connected by a ZigBee wireless network; the main part of the hardware provided in the pilot installations consists of a smart oven (produced by Indesit Inc.), and a wireless sensors network (provided by Department of Information Engineering of University of Parma).

The set of ZigBee wireless sensors is composed of:

- a movement sensor (called PIR, Passive Infra-Red) for detecting the presence of a person inside the kitchen;
- a magnetic contact for detecting the opening/closing of a drawer/door (for example, the cutlery drawer or the door of the pantry);
- a smart fridge-box (with sensors of temperature, light and humidity) for detecting the opening of the fridge and others parameters;
- an hob sensor for monitoring the cooking activity;
- a sensor of smoke/gas presence, and a flooding sensor.

Each smart sensor is connected, by the means of a ZigBee wireless network, to a Central Unit (a server PC) and provides information that are stored in a database which contains the history of the system, similarly to a data logger. The database is accessible for implementing behavioral analysis algorithms useful for the FOOD project purposes.

Even drawing inspiration from a particular application, the work has been developed with the main methodology issues identified in the literature.

Publications dealing with the issue of the integration between Ambient Intelligence and Ontologies domain, have been considered: in [4] an ontological model is used only to personalize the environment and not to detect behaviors, while in [5] the behavior of inhabitants in smart homes are taken in account but with unsupervised learning methods. The research and the definition of ontologies have been examined in various fields of Ambient Assisted Living and Ambient Intelligence. They range from ontologies that support the coordination of domestic network infrastructures (that often are heterogeneous networks, built up over time) [6], to an actual control framework of an AAL [7]. In these cases only an ontological model of the AAL environments is presented while other researches have also investigated the possibility of discovering some behaviors on the basis of the observation of the data coming from the sensors such as in [8]. The proposed modeling process could be used in e-health system to anticipate possible health hazards before emergency situations arise, but not to track complex situations in order to recognize not only the danger but also a "bad" behavior or suspicion of an aggravation of pathology.

The work presented in this paper focuses on the development of an ontology that is flexible, scalable, standards-based and, moreover, that enables to an efficiently database interfacing. From this point of view, the most comprehensive work is the BONSAI project [9], conducted by the University Hellenic International; in this case, all the ontology files, descripted in the standard OWL format, are available on the web. It is a good starting point for this work also because it includes concepts for functionality (e.g., hardware, services), environment, users, context and it is compatible with top-down descriptions (upper ontologies, OWL-S standard) and can import bottom-up characterizations (e.g., SAWSDL).

In the next sections, the activity dedicated to the specification and the design of a domain ontology is illustrated; the objectives to be achieved are presented; the designed ontology and the used tools are descripted with more details; conclusions and future developments conclude the paper.

2 The GOALS of the Ontology Design

The database used by FOOD system is not designed according to an ontology scheme. In that approach, data provided from the smart devices installed in the kitchen were stored as a simple collection of records, without a structure suitable for semantic reasoning.

Thus, in the development of the ontology, a constraint was to map the available information into an entity-relationship scheme, in order obtain a more efficient data collection.

The use of ontologies is often regarded as both a useful tool to support decisions both as an operational tool to better management the task: from the planning phase, the run-time management, to the evaluation phase. In fact, the ontology can be seen as an abstract and simplified model of reality and it is able to highlight the correct contest exchanges of information for the achievement of the system objectives.

The use of graphical tools allows the understanding of knowledge to all players regardless of their skills (such as an engineer or a physician).

To facilitate the development of heterogeneous software services that can be developed in different times and circumstances, the storage and querying of ontologies are made through the adoption of standard languages and models.

Finally, the use of tools shared by the scientific community allows the use of well-tested reasoners that help to achieve and maintain a consistent and coherent ontology.

2.1 Tools for the Design of Ontologies

Firstly, the discussion was on a directed graph which summarizes the ontology.

A graphical representation of an ontology allows all users that contribute to its development to identify the relevant information and to easily explore the structure.

Suitable software tools are needed to explain in more detail the relationships among classes and to perceive (and solve) possible conflicts.

The Protégé editor has been used for the creation of the ontology: it is an open source software and it is the most popular tool for creating and editing ontologies. Developed by Stanford University, is supported by a large number of developers and researchers. This software is written in Java and several plugins to extend its functionality are available on the web. The tool allows the advanced development of ontologies, via a graphical environment, ant it supports their creation in OWL (Ontology Web Language, a standard for Semantic Web applications) format.

3 The Designed Ontology

The ontology was built exploiting specific competences on the particular domain, starting from a preliminary classification of the main concepts and gradually refining the taxonomy, introducing the relations between the classes and their properties. In Fig. 1 the final scheme of ontology is shown.

The purpose of this ontology is to provide a tool to extract knowledge from sensory data that in order to extrapolate the usual behaviors of the user.

After an analysis of the problem, the following main classes have been identified:

- *Hardware*
- *Parameters*

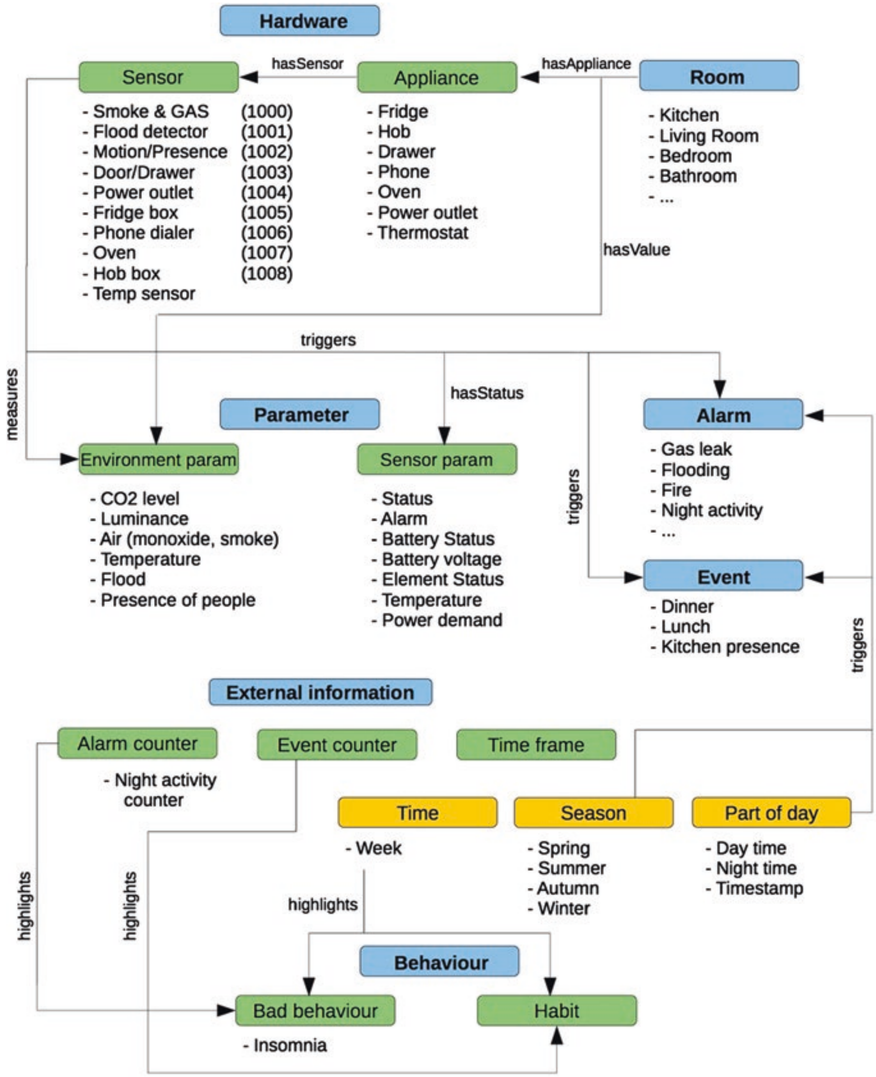

Fig. 1 The ontology graph

- *Room*
- *External Information*
- *Alarm*
- *Behavior*

The *Room* class represents any environment of the home. In the current situation it is present a single individual in the *Kitchen* subclass.

The classes of *Sensor* and *Appliance* have been grouped under the *Hardware* class: in the *Sensor* class there are the sensors that are installed in the environment; the *Appliance* class collects the information on the appliances that are present in the room.

Then, it was decided to introduce a *Parameters* class with two subclasses: *Sensor parameters* and *Environment parameters*: they include the information about the parameters of the sensors and of the environment, respectively. These parameters provide information about the state of the sensors, including the charge of the integrated battery, the sensor value, internal errors and alarms. In the developed ontology, only the sensor actually installed in the pilot sites have been shaped.

Within the *Alarm* class, a series of alarms that the provided sensors could detect have been suggested.

For example, an alarm of nocturnal activity has been hypothesized. It can be triggered on the basis of this rule: "it is night", and the presence of someone inside the kitchen is detected, and the opening of the refrigerator is detected and/or, some cooking activities are detected, etc.

When an alarm is triggered, it will be necessary to keep track of this fact outside of the ontology: it is not an ontology task to trace every single event, but only

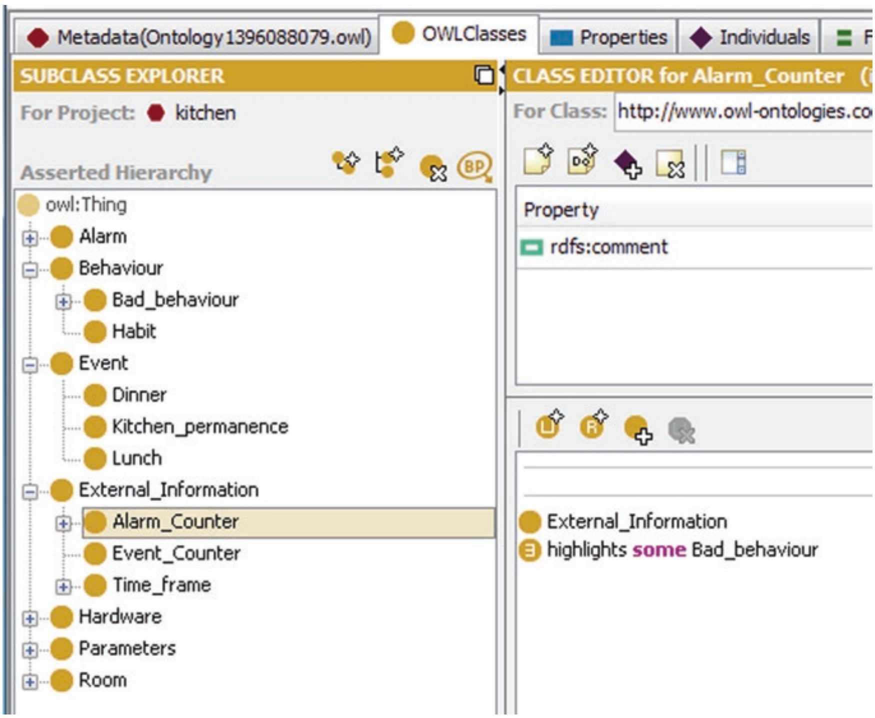

Fig. 2 A screenshot of the ontology in Protégé

to detect its occurrence; and this can be performed by using a semantic reasoner. Outside the ontology, it is possible to track an alarm by writing each occurrence of it on the database.

The *Event* class collects information about particular situations that arise from the detection of specific sensory data. The nature of this class is similar to that of *Alarm*, but it has no negative connotation about the detected events. For example, cooking activities (using the oven or the hob), the opening of the refrigerator and the presence of people in the kitchen or the opening of the cutlery drawer, can determine the event "lunch" or "dinner", depending on the time. Also for these events there is the necessity to keep track of their occurrences.

An *External Information* class was provided in order to gather all the information necessary for the functioning of the ontology. In this class there is the *Alarm-counter* subclass that is populated by many individuals as there are instances of an alarm in corresponding table of the database. In analogous way the occurrences of events are handled in *Event-counter* subclass.

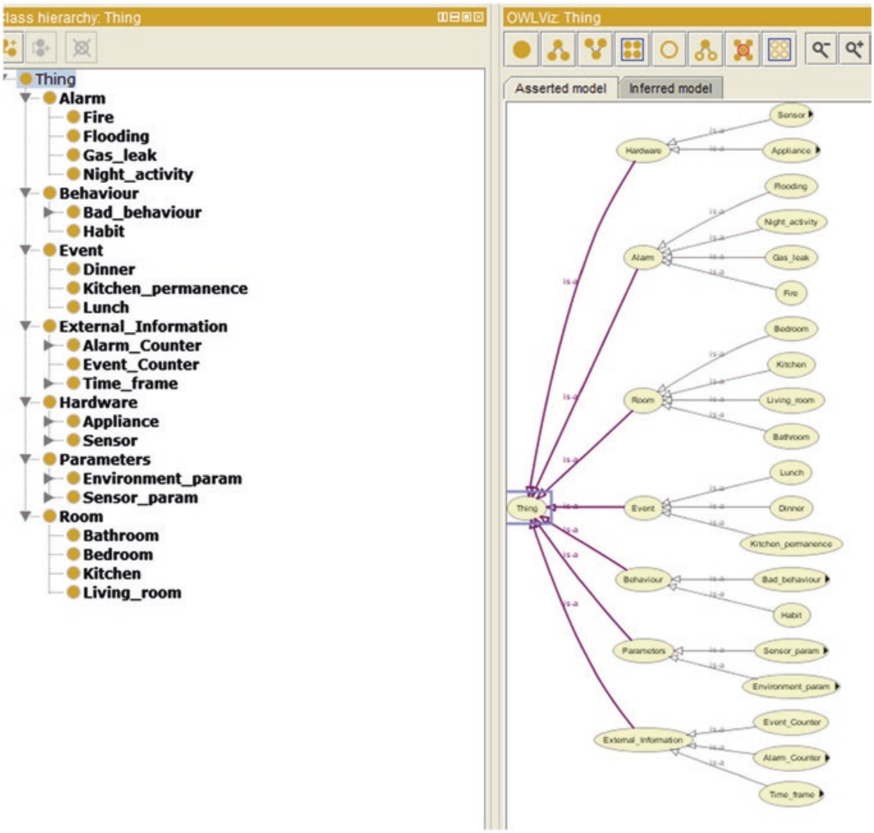

Fig. 3 The classes tree of the ontology

Moreover, a class called *Time Frame* was introduces: it collects all the temporal information that are necessary to take into account the flow of time within the ontology. A subclass of *Time Frame* is the *Time* class. This class can manage the passing of the weeks by the using of a software link with an external data structure. The *Season* class follows the operation of *Time* class with respect to the passing of the seasons, as well as the *Part of Day* subclass for the part of a day.

Finally, the concept of repeatability of an alarm or an event was modelled by introducing the *Behavio*r class and its subclasses of *Bad Behavio*r and *Habit*.

In Figs. 2 and 3, screenshots of the ontology edited in Protégé are reported.

4 Results: From Ontology to Database

Starting from concepts and relations of the ontology a relational database was built in which the data coming from the case study are stored.

In general, if the switch from a relational database to an ontology is possible by the using of some specific tools, the inverse is a non-trivial operation.

To do this, some queries in SPARQL language can be made and they return the equivalent tables. In this way it is possible the definition of a relational database which is consistent with the planned ontology. So the necessary information for a proper interaction between the data of the sensors and the ontology can be saved and made available to an intelligent agent which will be responsible for the reasoning.

The E-R diagram of the resulting database is shown in Fig. 4.

In the kitchen, that it will be used as a test, there are the following sensors:

- Smoke and Gas Sensors
- Flooding Sensor
- Presence Sensor
- Sensor that detects the opening of the door and the drawers
- Electric socket
- Ambient light sensor placed in the refrigerator
- Phone Dialer
- Temperature and Lighting Sensors inside the Oven
- Temperature Sensor for the Cooker
- Environmental Temperature Sensor.

In this situation it was possible to hypothesize some rules to determine alarms, behaviors and habits.

At the snap of an alarm, the system has to keep track of the event by writing it into the database associated with the ontology. Then the system is able to read the number of occurrences of the alarm and to put it into the *Alarm counter*, subclass of *External Parameters*. The number of occurrences of the alarm and the elapsed time (in the example of nocturnal activity, more or less of 1 week, that is an instance in the class *Week*) determine the conditions for the creation of an

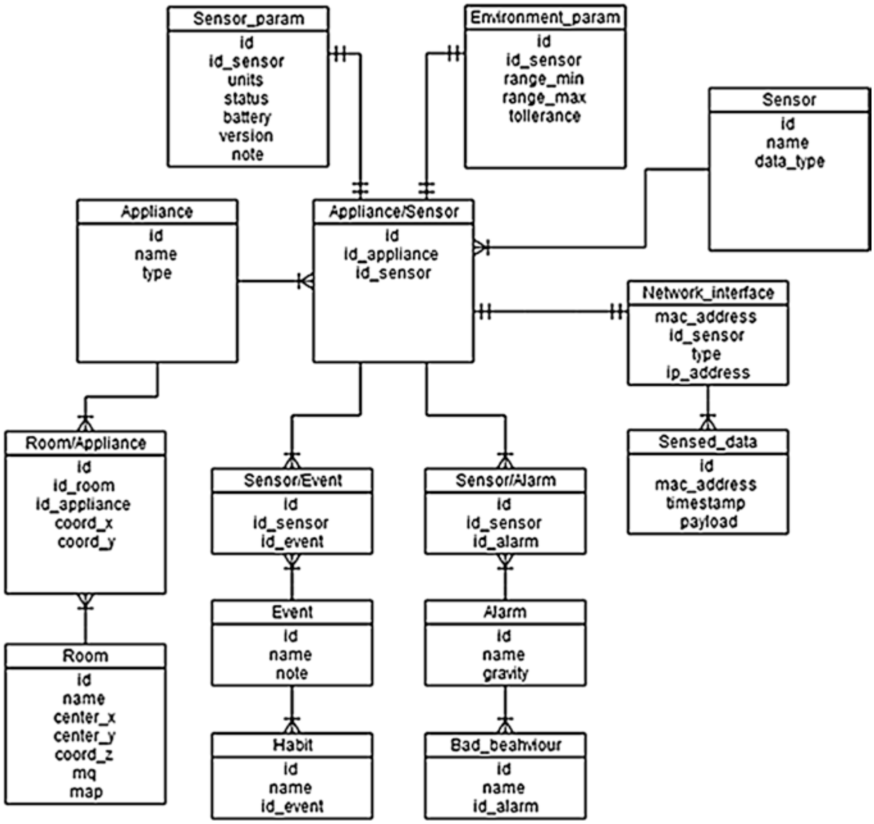

Fig. 4 The entity-relationship schema of the database

individual in the class of *Bad Behaviors*, namely to make explicit a bad behavior of the user.

In a similar way, a set of rules able to manage single or multiple alarms were specified. Through this work used together to the number of occurrence of the event and the passing of time, the system is be able to find the conditions to deduct a bad habit.

5 Conclusion and Discussion

In this work, an ontology is designed for an AAL environment by thinking it as an useful tool both in the design phase and in the operational one. The use of an upper-level model makes simple the personalization of the model itself on the basis of the user and his context. Moreover the employment of an abstract model of sensors facilitates the integration, also in different times, in the environment of heterogeneous sensors and/or “smart” sensors that can be the results of machine learning algorithms applied to the raw data to solve a specific task in a reliable way. Finally, the close interaction with a database allows the ontology to be a valuable support in the decision phase.

The carried out activities have shown the importance of the participation of many actors (the experts of the involved domains: hardware, software, human behaviors) in the design of an ontology. This is a critical task of the approach: on the one hand it allows a full understanding of the system to all the players, on the other hand, the system needs an explicit description of the experience on the domain to operate correctly.

Another drawback is the lack of simple tools to deal with incomplete, partial or uncertain knowledge, but it could be solved by the analysis of the researches about the introduction in OWL of Bayesian networks or Fuzzy logic.

The experience gained during this work showed that in order to extract knowledge from a database, the definition of the latter and the design of the ontology must be pursued together. In this case, the initial database was produced exclusively for data storage. It was therefore necessary to devise a new database that is able to interface effectively the data with the created ontology in order to have a successful integration of the two instruments.

Furthermore, the use of an ontology in the design phase of the system is shown as a valuable help to formulate and reshape the conceptual schemes and their implementations in software objects. In this phase of the work, one of the major difficulties was to find a valid definition of the tree classes in order to properly cover all areas of the semantic context in examination. It was also necessary to solve the problem of how to integrate the concept of time with an OWL-based ontology. In fact OWL is based on a description logic theory, which is not suitable to treat the flow of time.

The next step of this work is the implementation of a software agent able to query both the relational database and the developed ontology, to provide reporting alarms and behaviors and, finally, manage these events. From this point of view, in the next months, a significant contribution will come from the FOOD project in order to test our approach, by providing actual data with which to populate the developed database.

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An Integrated Approach to the Well-Being of the Elderly People at Home

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Abstract The paper presents the outline and the preliminary developments of NINFA (iNtelligent Integrated Network For Aged people), a project for the well-being of the elderly people at home. This architecture is based on a service platform suited for elder people called the Virtual Village Network, whose user interface allows to deliver different services at home, namely: user supervision, communication and interaction among users for social inclusion, exergame delivering, monitoring of the wellness status. After the discussion of some results of the investigation on the acceptability issues of the ICT technologies related to the project, the User Interface (UI) and the novel Human Computer Interface (HCI)

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have been developed. The HCI is particularly suited for elderly people and motor impaired patients because the interaction is managed only by finger/hand gestures and by vocal control through simple commands. A set of preliminary exergames developed for the user training and monitoring are presented. During the exergame execution, the user interface allows the real-time acquisition of a set of motor, linguistic and cognitive parameters related to the user performance. The analysis of the verbal production of each subject is used to observe its language evolution and to detect the onset of any cognitive deficit. The relationship between some parameters and the neurological/wellness status of the user is discussed.

Keywords ICT platform · Wellness network services · 3D movement analysis · Linguistic and cognitive analysis · Exergames · “At-home” technologies

1 Introduction

Currently about 20 % of the EU28 population is aged 65 or over. According to the baseline projection of Eurostat[1], this percentage will almost arrive to more than 29 % in the year 2050 and there will be more than 41 million people 80 and over with various needs for care. Many elderly people feel pushed to the margins by the generational shift and suffer from loss of identity and hence they lose motivation, recognition and self-esteem: they are often considered to be no longer capable of performing any service. The individual becomes just a consumer of services, unfit for, and excluded from, the productive part of the community. Solitude and fear are common among the elderly, and tend to increase the risks of physical and mental health.

However, to minimize these “threats” and perhaps improve these people’s quality of life, action can be taken in the care for elderly people such as involving the social network and reducing the need of help with activities of daily living. Specifically designed ICT based assistive technologies can be of great benefit to older people that are increasingly at risk of having functional difficulties in areas such as mobility, vision, hearing and in some aspects of cognitive performance. Many solutions for smart housing, independent living and gerontechnology have been created to fulfill these expectations and to provide a better life for older people and to be able to reduce health costs [10]. Unfortunately assistive technology is often not accepted by old users. This may be due to an incorrect prescription of technology or to a too great burden imposed by its usage. Often, however, the stigma plugged to an assistive product could be an important reason for the rejection. Since 2008, the EC funded specific activities for elderly people within the

[1]Source: Commission Services (DG ECFIN), Eurostat (EUROPOP2010), EPC (AWG). available at: http://europa.eu/epc/pdf/2012_ageing_report_en.pdf.

Ambient Assisted Living Joint Programme (AAL JP). The aim of this call for project was the enhancement of the quality of life of older people and the strengths of the need to let the elderly people to stay home as longer as possible through the use of ICT. The Horizon 2020 EC workprogramme 2014–2015 contains many topics related to active and healthy ageing with ICT. Since 2012 the Italian National Research Council (CNR) founded the project 'Ageing: technological and molecular innovations for improving the health of the elderly people'.

In this framework the NINFA[2] architecture aims to promote the maintenance of health, physical and cognitive capabilities and the identification of new architectures and instruments to improve the elderly's autonomy in the home environment, their quality of life and the prevention of critical events. A Virtual Village Network (VVN) connects a group of elder users, or "*virtual neighbours*", allowing the access to AAL solutions at home is proposed. The VVN architecture have been inspired by social life organization in the old Italian village. In the past, within these villages, a physical social network of personal relationships allowed even lonely old people to be integrated in the area where they were living. They could live and take advantage of different kindness and communications from familiar and friend environment. If an old peasant had some problem, the village community could noticed it (i.e. because he did not go to chat at dusk on the door step) and could check for the causes giving an indirect surveillance. This ICT approach allows the monitoring and the automatic objective evaluation of the wellness status [8] and the effectiveness of the rehabilitation therapies undertaken at home [4], with a minimum impact on the user. The archiving and management of this info in a secure repository allows the access and the evaluation by specialized medical staff able to promptly act in presence of an alteration of the motor/cognitive activities, either caused by the worsening of chronic diseases or due to the effects of physiological aging.

The VVN architecture is organized on 3 levels:

- a Domotic Health Network (DHN), a domotic network that delivers specific "at home" services (e.g. as motor/cognitive rehabilitation exercises, social networking, gaming, remote assistance, critical life events prevention);
- a Virtual Service Centre (VSC) that, through a proper home interface, can carry out the support, monitoring, prevention and social facilitation.
- a Dynamical Village Network, (DVN) a network of "virtual neighbours" with a series of relationships able to have a positive influence on the interactive abilities and self-image of the elderly, and to prevent or overcome solitude and isolation, and the effects of these on the elderly person's overall quality of life and health.

In the following the preliminary work done in the context of the NINFA project is presented. Acceptability issues of ICT technologies are investigated on statistical basis by elder people interviews. The linguistic parameters related to the

[2]NINFA (iNtelligent Integrated Network For Aged people) Project is a sub-project founded within the CNR Project on Aging 2012-2014.

wellness status are discussed. A low-cost acceptable HCI suited both to manage the UI and to collect kinematic and cognitive parameter is presented. Language, hand/finger trajectories and logic choices of the user are analysed during the execution of exergames delivered by the UI software. The relationship between the wellness status and kinematic, linguistic and cognitive parameters produced by the analysis is investigated.

The relevant information produced is stored both locally and in a remote repository for the archiving of the subject performances. This allows both the remote supervision by clinicians and the tracking of the wellness status evolution during time.

2 ICT Tool Acceptability

Studies conducted on elderly people usage of ICT technologies (PC, mobile phones, Internet, etc.) demonstrate how the reluctance of adopting communication technologies is not only due to a lack of skills but, also, to the absence of perceived advantages and benefits. Acceptance of ICT is a complex and multifaceted issue. One of the primary goals of the VVN architecture is to turn technology into something "familiar", i.e. interfaces that are perceived as belonging to our own world, that fit into our daily practices, and that can be interpreted and used exploiting common and practical knowledge acquired through experience.

However, awareness of the importance of these aspects must be coupled with the acknowledgment of the importance of the compensatory processes that older people develop to adapt to the changes, and by the crucial role played by motivation, affection, and experience in supporting them. To address the acceptability of new ICT technologies, within the NINFA Project a questionnaire on interfaces acceptability has been submitted to 300 elderly people aging from 65 to 83 years living at home. Age distribution of the investigated sample is shown in Table 1.

The questionnaire where completely anonymous. After some questions used to evaluate the technological competence of the interviewed, each participant was asked to rate (from 1-low to 5-high) the acceptability of many different ICT tools described verbally or through picture. In Tables 2 and 3 some answers are summarized.

In Table 2 we can see that the best accepted interface is the videoconference interface that allows a visual contact with other human people is followed by the augmented reality games. While a robot can still be considered as acceptable as tool for assistance, the presence of a camera in each room is often considered too intrusive.

Table 1 Age distribution of the investigated sample

Age range	65–70	71–79	80 and over
Sample percentage (%)	46	31	23

Table 2 Examples of acceptability rates for some ICT tools/interfaces for AAL

Rate	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)
Videoconferencing (Skype-like)	0	0	0	13	87
Augmented reality games	0	1	10	40	49
Robot	3	13	22	29	34
Surveillance camera	37	37	21	4	1

Table 3 Example of acceptability rates for robot types

Rate	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)
Service robot	0	0	1	27	71
Pet robot	0	0	1	39	60
Robot toy	0	3	21	55	21
Humanoid robot	24	27	41	8	0

The acceptability of a robot look has been investigated to design of a mobile assistive robot that can work collaboratively with the DHN and the VSC. The NINFA project architecture indeed proposes the usage of a robot to better support older people living at home, with special regard to ‘critical events’ (i.e. when an expected user activity is missed).

In Table 3 preliminary results for this investigation are shown. The pet robot is the most liked, while, contrarily to expectations, the humanoid robot seem to be the worse acceptable. Here we can foreshadow the uncanny valley effect [8].

3 Monitoring and Evaluation of Wellness Status

Aging is characterized by a gradual worsening of the motor and cognitive functions and by an increased risk of trauma, strokes or other neurological diseases which can produce cognitive and linguistic disorders. In this preliminary phase of the investigation the aim is to assess if specific sets of kinematic, linguistic and cognitive parameters proved to be useful to assess the neurological disease status [2, 3, 5, 11] are significant also to assess the wellness status of healthy elders.

To use assessment tools not invasive and well acceptable for elders, a set of simple exergames in an extended reality interface is delivered to users by the UI software. User gesture and vocal inputs control the interface during the execution of exergames,, thus avoiding less suited devices such as mouse or keyboard. Sets of kinematic, linguistic and cognitive parameters are extracted during exergame execution, thanks both to the HMI capability to track finger and hand trajectories in three-dimensional (3D) space and to the UI capability to record video, speech, and user choices. These parameters acquired for every exergame session are used to characterize the specific users by a "*personal wellness signature*" which is used to monitor the wellness status evolution. All these data are stored both locally and in a remote repository to create an historical archive of the subject performances available to medical supervision.

3.1 Natural Language Processing and Cognitive Impairment

Due to the increasing life expectancy, dementia is emerging as a major health problem. Since neural degeneration of dementia begins many years before clinical signs appear, and an early diagnose is important to get the right treatments, there is a need for cognitive screening tools, low-cost and easy to use. Discourse and conversation analysis is applied to explore verbal behavior of people affected by different types of disorders: aphasia, traumatic brain injury, dementia, right hemisphere dysfunction [7]. In the last decade, language has been increasingly recognized as a marker for distinguishing various dementias. Many initiatives have been undertaken aimed at enhancing performance of the cognitive impairment detection by using Natural Language Processing (NLP) techniques. An example is the application of NLP techniques to measure syntactic complexity of spoken language samples from healthy and cognitive impaired subjects [11], where audio of retelling narratives of healthy and Mild Cognitive Impairment (MCI) are recorded and subsequently transcribed. The study results have shown that NLP techniques can automatically derive measures useful to discriminate between healthy people and subjects affected by MCI.

One of the specific goals of the NINFA project is to monitoring verbal behavior of aged people over the time by means of the NLP techniques. Pathological subjects and controls will be recorded whilst talking about different stimuli (a picture, a working day or a personal dream). Their transcribed discourses will be submitted to a computational analysis by using NLP techniques. The analysis of language production by people elicited by the same set of stimulus over the time, can be is useful to characterize the evolution of possible diseases and to apply adequate rehabilitation strategies.

Preliminary audio recordings of Parkinsonian subjects, have been used to evaluate audio transcription problems and text annotation strategies. The annotation apparatus have been designed focusing on phenomena defined as relevant in literature [11], as shown in Table 4.

A repository of spoken language of both healthy and affected by Alzheimer and Parkinson disease subjects has been designed. Each person is required to perform one or more of the following tasks: autobiographical tale, fairy tale, description of situational picture (Cookie Theft), reading of a list of words. Subsequent test should take place at least 6 month after the previous one, then annotated corpus of anonymous transcription will be created.

Table 4 Example of relevant phenomena

Semi-lexical linguistic phenomena	Truncated forms, pronunciation errors, interjections, etc.	Vanno a *in* a intaccaree
Non-lexical verbal phenomena	Hesitation, full and empty pauses, etc.	
Non-verbal phenomena	Laughing, sneezing, sighing, etc.	
Comments of the transcriber on the linguistic content	Forms or sequences unintelligible, dialects, etc.	…sonooo *maquilmm* sono una signora…

3.2 The Motor/Cognitive Analysis

Tracking the user movements is important for the assessment of several types of neurological disease (e.g. Parkinson's, Multiple sclerosis) and their worsening. Specific kinematic parameters have been demonstrating to be useful to classify neurological status of patients (e.g. [3, 5]).

To track user movements and behaviour, several technologies have been explored (e.g. mobile and wearable sensor networks, smart homes, passive and active vision systems, robotics, etc.) [10, 14]. In this context, the number of approaches based on active vision systems (e.g. RGB-D cameras) is rapidly increasing because of the recent availability of low cost device (e.g. Kinect®) and supporting software tools for three-dimensional (3D) body motion capture (OpenNI®). Some examples based on RGB-D cameras are seen in gait analysis for the risk of fall in elder people [6, 12, 13], or in exergame for rehabilitation of motor [9] or of cognitive [4] or of neurological diseases (e.g. Parkinson's) [1].

In NINFA we investigate the extension of this approach to healthy elderly. Further, we investigate how to assess at the same time also cognitive and linguistic aspects. The solution we propose is the delivery of specifically designed exergames by a user friendly HCI suitable for elder people or motor impaired patients, where interaction is managed by finger/hand gestures and vocal control. A set of simple, user adaptable exergames were designed to monitor specific kinematic parameters of the hand/finger trajectories that we found discriminative of the neurological patient status. At the same time, cognitive and linguistic aspect are monitored thanks to the recording of the user choices and timing of the games, and of the user speech, which is required to answer to some question.

The HCI is based on a RGB-Depth camera (Kinect®) and light gloves with colour markers and it is able to track hand/finger of the user during exergame execution [3] (See. Fig. 1). Respect to other approaches based on sensorized gloves and wearable sensor, the solution is less invasive, and results in a good compromise between accuracy and costs. Kinect device provides synchronized RGB/DEPTH streams to a PC or notebook via USB port. The silk gloves are soft and light, suited for movement-impaired subjects. Each marker is in correspondence with a

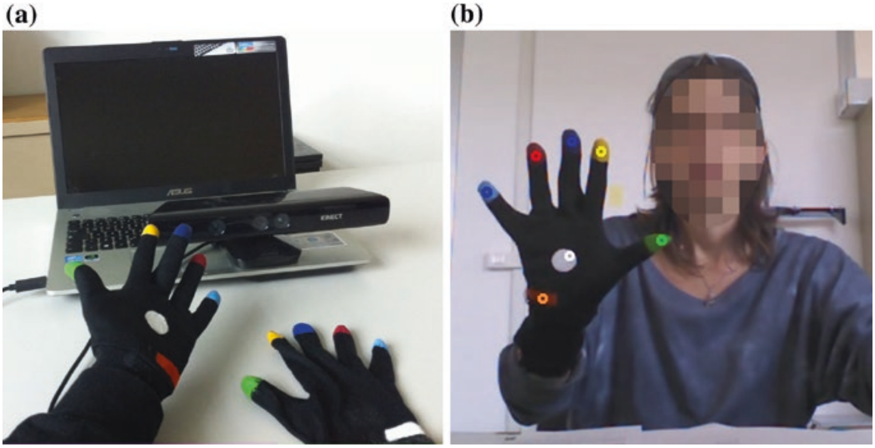

Fig. 1 **a** Human computer interface (PC, Kinect® and gloves). **b** Detected hand reference points on gloves for 3D tracking (markers trajectories)

reference point of the hand (e.g. fingertips) to allow the tracking of its 3D trajectory, or to perform specific system functionality (e.g. calibration for lighting, or menu selection). The colour, shape and position of the markers are designed to be easily tracked in different environmental lighting conditions thanks to light intensity and colour compensation algorithms.

The positions of colour blobs in 2D images are fused with the corresponding depth info to track the 3D marker trajectories (See [3] for details).

An example of the proposed exergames is “Follow the square”. First the user selects the exercise by her/his hand (Fig. 2a), then she/he is required to point by finger movements a colored square showed on the screen (Fig. 2b), whose position and color change during the time. The white irregular line (Fig. 2b) is the user visual feedback of her/his finger movements. A typical run of the 3D trajectories recorded by the UI is shown as a 2D projection in Fig. 2c. The 3D trajectories are used for the 3D movement analysis and the kinematic parameter estimation.

In this preliminary phase, wellness parameters are defined based on an heuristic integration of different measured contributions: neurologically relevant kinematic parameters, linguistic ability parameters and game logic errors and timing performance in game accomplishment.

In the next phase a machine learning approach based on classifiers trained on geriatrician and neurologist scores will be used to improve the assessment of the wellness status.

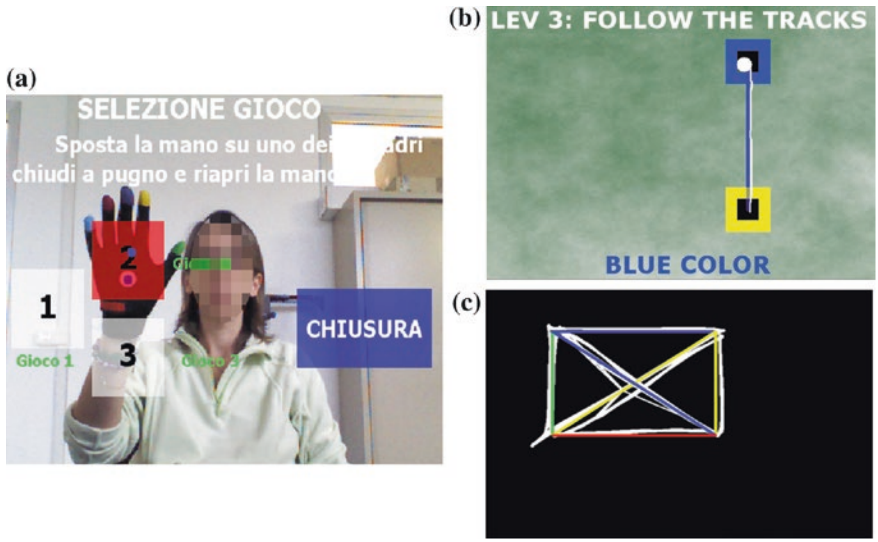

Fig. 2 **a** Game selection: hand is moved and closed on the "game selection" squares. **b** Example of the "Follow the square" exergame with the visual feedback (the white track of the finger trajectory). **c** Game completion trajectories: the shorter ones (*colored*) versus the tracked ones

4 Conclusions an Further Work

The preliminary outcomes of the NINFA architecture implementation t are presented and the preliminary results are encouraging. Further work will address these goals: the improvements in the definition of a "personal wellness signature" by a better comprehension of "wellness status" for healthy elderly people by the contributions of linguists, neurologists, geriatricians and psychiatrists. Better kinematic, linguistic and cognitive parameters suitable to capture this signature and its time evolution will be investigated. Specific exergames able to capture these parameters will be designed following the user's acceptability evaluations. To implement the automatic assessment of the "wellness status" a machine learning approach will be used. Finally, an acceptable robot with regard to critical event will be specified and designed.

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Smart Object and Smart House for Ambient Assisted Living: Design Concept

Giuseppe Losco, Andrea Lupacchini and Luca Bradini

Abstract This project is the second phase of the research already presented in Foritaal 2013. The project consists of two specific parts: (1) The presentation of a Green Smart House System model made up of assisted living environments according to different levels of complexity, defined by its architectural and technological components, as well as furniture and everyday objects. (2) The presentation of case studies that propose projects for systems, components, technology elements, furnishings and objects of use for users with varying degrees of physical ability. The objective of this project was to identify the design elements essential to support new systems and methods of assistance, in the context of their own discipline of design, and to help users with different degrees of ability and/or disabling diseases. The project is based on the integration of the components of design products with innovative digital technology (ITC, AAL, home automation) in order to define new housing systems that are both integrated and interactive. This research project uses the definition of spaces, objects and components as its points of reference, designed in an inclusive (*For All*) and sustainable way that are technologically implemented with digital systems to assist in the daily activities of the user. The expected result consists of a series of concepts that can be developed and proposed as a progression of the current components available for this type of housing context.

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1 Introduction

The role of design in the Ambient Assisted Living Facility is to combine the different elements of innovative technology necessary to produce elements, components and tools for users with specific ergonomic and adaptable physical features.

The aim of this project is to propose effective tools for user activities, assistance and environmental control of living areas, inspired by a formal language that enhance these qualities and at the same time inspire a new emotional quality that will stimulate the user. The home environment is considered an integrated system of elements, comprised of the shell of the building and its components, as well as furnishings, down to the individual items. These must be able to interact with each other in a coordinated manner, managed by an intelligent platform able to provide substantial support to domestic life for users with varying degrees of ability.

The expected results of these research activities aim to determine practical systems that meet the diverse needs for end users, as well as being useful for everyone involved in the welfare activities referred to, providing two scenarios of research; design and technological digital innovation.

The design in this scenario, as well as combining the actual innovative physical elements, plays a key role in providing new ways of constructing components and innovative products, which for their functional purpose and use, play a communicative and emotional role currently extremely compromised by the operating purposes for which these systems are intended.

The research aims to identify a system of complex elements (1) (project concept) that make up both the overall shell and the individual components at different scales.

The main elements of reference, coordinated by an integrated control system, are scaled in terms of the following:

1. The building enclosure in its home environment configuration characterised by the following filters:
    - Access and use;
    - Adaptability and integration;
    - Sustainability and environmental well-being.
2. Furniture and everyday objects for users with different physical abilities characterised by the following filters:
    - Usability and interface;
    - Physical and digital integration;
    - Functionality.

2 Green Smart House Design System

The concept of Green Smart House System connects an innovative approach to the design of the home environment, also applied to the principles of Ambient Assisted Living (AAL), where the manufactured housing and all its components are organised and managed in a unified way.

The design is based on the combined interaction of:

- Home systems and technologies;
- advanced ICT systems;
- experimenting with innovative materials and processes with low environmental impact and a high degree of eco-sustainability;
- low production costs;
- control and optimisation of energy consumption;
- applying the principles of User Centred Design;
- achieving the highest levels of comfort and efficiency according to the modern principles of the DFA.

The major systems that create the conceptual model presented are applied and applicable to different types of households, targeting three different levels of intervention:

1. Non-invasive interventions on existing buildings that foresee the adjustment of implementation systems for the AAL in existing domestic contexts, with integrations that do not change the domestic structure and avoid invasive or irreversible interventions on the building. Positioning of wireless sensors, replacement of doors or the addition of furniture components or low maintenance installations.
2. Medium-level interventions on the existing building, with possible substantial invasive work. These interventions tend to be significant transformations and changes of the home environment and are irreversible.
3. New solutions, planned as an overall redevelopment of the home environment through an integrated and completely innovative design.

The SAD research group (School of Architecture and Design "E. Vittoria"—University of Camerino) has developed a typological model that addressed the potential of the above mentioned levels with a series of configuration options.

The basic principles of the model for the first level are:

- Integration—with building enclosure components that can be easily modified.
- Implementation—furniture items and everyday objects.

The basic principles of the model for the second and third levels are:

- Flexibility and convertibility (multi-functionality) of the spaces relative to the current conditions of the rooms and the different physical abilities of the users.
- Organisation of integrated implementation systems for the management, control and monitoring of the environment, components, everyday objects and the user.
- Sustainable approach of the product foreseeing an intervention that aims to have both self-supplied energy and the systematic use of zero impact products, especially at the level of new interventions.

If at the first level the key elements are mainly intelligent everyday objects and furniture items (see next chapter), for the second and third levels, elements consist mainly of a principle of spatial flexibility organised and managed for an 'on-time' change of the possible configurations with the help of its platform management (Fig. 1).

Fig. 1 Spatial variations diagram

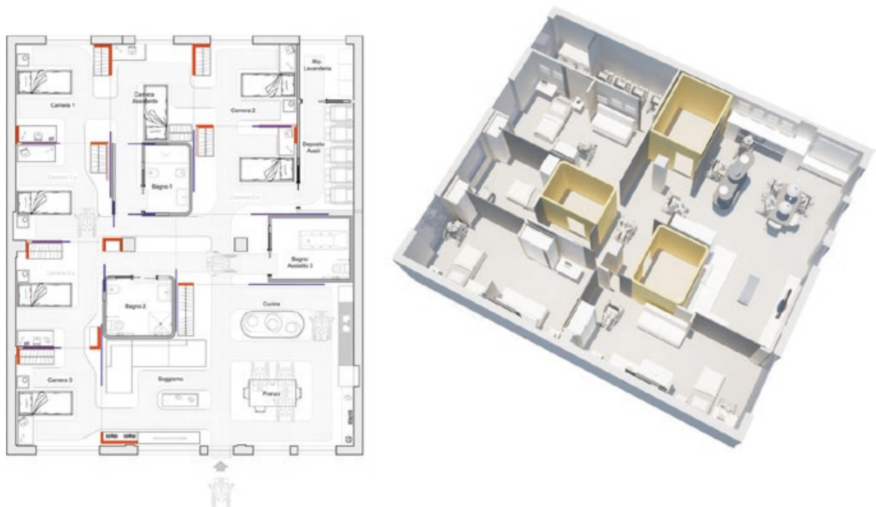

Fig. 2 Bluprint of the studied model

As the core element is the generator, the moving key elements (walls/doors/furniture) are responsible for the transformation of the space, allowing ergonomic flow adapted to the needs of the user, both daily and for long periods of time.

The typological model was that of a simulated new intervention for the creation of a collective domestic environment for long stay users developed according to the PaSS project (Fig. 2).

3 Smart Object: Design Concept

This project takes into consideration the international standard ISO 9999, which was approved in 1998 as the European standard EN ISO 9999 and defines 'aid' as "any product, tool, equipment or technological system of specialised or commercial production, for use by a disabled person to prevent, compensate, alleviate or eliminate an impairment, disability or handicap."

Specifically, the research into smart objects has helped identify several case studies related to supporting principles and the corresponding creation of baseline concepts.

Taking the plan of requirements as a reference with the following inputs:

- Wide range of scenarios of usage.
- Prevent danger.
- Adaptability and flexibility (range of needs of "habitability" and "usability" with the advancement of ageing).
- Automated domestic solutions and tele-assistance directly related to the smart-object.
- Implementation of smart-objects with medical functions (allowing the user to measure vital signs).
- Support of the total coverage of specific needs (care profiles), according to an expanded model, as one unique reference cannot be used.
- Requirement for customisation and adaptability of solutions.
- Accessibility according to lifestyle, socio-economic level, cultural level, family composition etc.
- Easy communication with the outside world, enabling a wide range of people with different roles and responsibilities to contribute to the welfare of the elderly. This includes the health care system, the welfare system, the voluntary sector, research centres and in general anyone who contributes to improving the quality of life of older people and their families.
- Reversibility or adaptability of the interventions to be carried out, both for possible variations of the needs of the elderly and for the possibility of a different arrangement being required due to the worsening of an existing condition.

- Reduction of long term hospital stays, in favour of trying to strengthen home care and to encourage rehabilitative care in their own homes.
- "Sense of normalcy" for the user to live and move in a controlled environment without it becoming a controlled centre.
- Multisensory and multimodal interaction through the use of the senses of touch (touch screen), voice (voice recognition, gestures) in user-friendly interfaces in everyday life, integration of innovative technologies that help to remember information (augmented memory) and to increase the vision of the surrounding world (augmented reality).
- Use of smart or functional materials, which are able to perform certain sensitive functions, i.e. be reactive, active or interactive to external stimuli.
- Flexibility of some smart-objects that are characterised by non-intrusive elements such as mobility and wearability and are versatile such as tele-medical assistance.
- Ease of use of smart-objects placed in the home environment, characterised by a low level of functions, ease of use and interaction.

Examples of different types of concepts (Figs. 3, 4, 5, 6 and 7):

The developed concepts have tried to overcome the functional problem in order to avoid that the user is confronted with the equipment and tools, in a manner that is decontextualized from daily living. This involves the problem of social inclusion, since these tools that are incorporated into domestic environments may highlight the "difference" and "disability" of users, which could result in resistance to accept them.

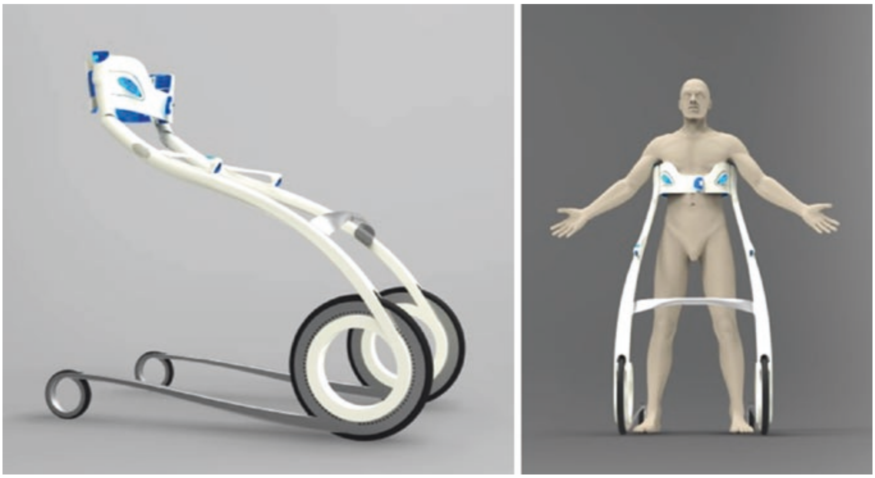

Fig. 3 Smart axillary walker_ A. Garaguso

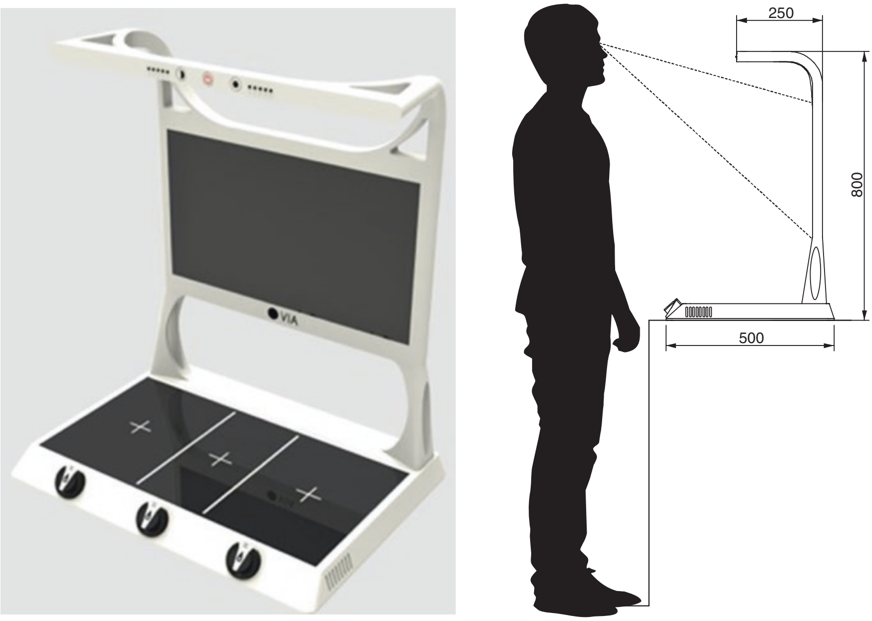

Fig. 4 Food prepartaione aid system for visually impaired users_ A. Petrucci

Fig. 5 Obstacle recognition glove for visually impaired users_ C. Norscini

4 Green Smart House System and Smart Objects: Implementation of Integrated Systems for Control

The relationship between the system implementation, the architecture of components and the design aspects, concerns the positioning of the sensors and the relationship with the user in relation to the interaction and integration with the components of the building enclosure, furniture and objects of everyday use.

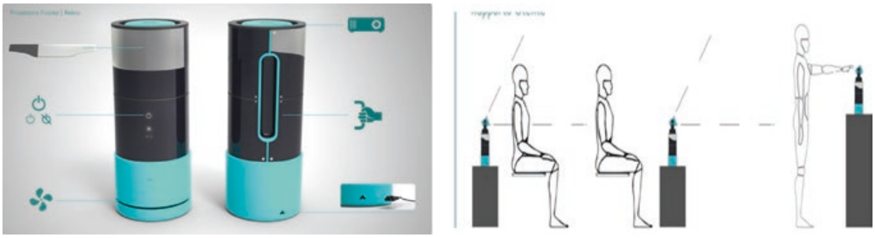

Fig. 6 Sound recognition and translator for users affected by loss of hearing _ F. Rizzo

Fig. 7 Bed with easy access system _ F. Rizzo

Current systems are based on a collection of inputs which mainly follow two types of surveys for the collection of data:

Passive:

- Environmental sensors or detection systems;
- User sensors or tracking systems.

Active:

- Environmental management interfaces;
- Mechanical or voice commands or activations.

These instruments are positioned according to five criteria of proximity relationship with users:

Environments. Placed in strategic points of the home to ensure complete view of the surroundings with the least amount of equipment.

Components. Placed on the elements that constitute the building enclosure, such as doors, walls, furniture and windows of the house.

Furnishings. Placed on furnishings that allow for action and reaction, in relation to a larger system. Using touch or mechanical controls, either power assisted or manual, aimed at resolving problems of handling.

Everyday objects. These have an active role in day-to-day activities and direct monitoring, where the technological implementation system is integrated with a specific interface.

Wearable accessories. Placed on clothing or accessories that can be “worn” by the user. To date they are used for types of reading and detection primarily in the medical and measurement fields.

There still remain objects that are not integrated into everyday objects, but which are used for specific functions and with active intervention by the user.

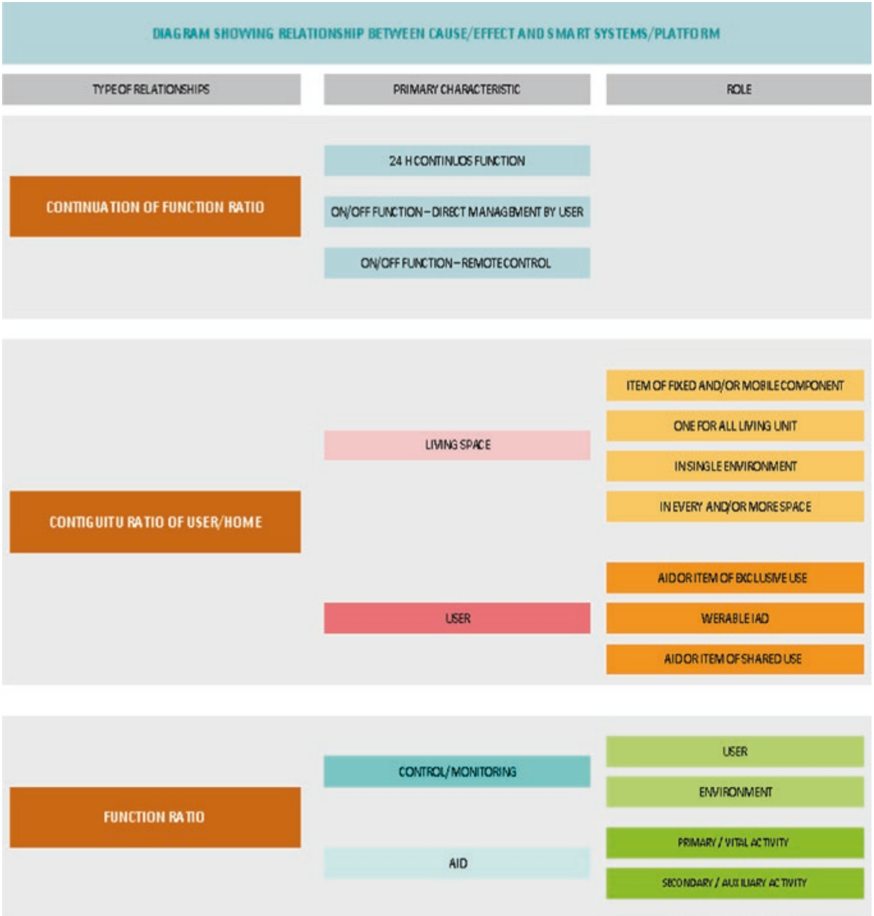

Fig. 8 Table Showing ration between control system and functions

The management platform provides a reference system (diagram of cause/effect) of three main principles:

Continuity ratio: based on the activation throughout time.
Contiguity ratio: based on the user's level of ownership.
Function ratio: based on the role of monitoring or aid of the item or component.

The chart shown below summarises the different relations systems managed by the platform (Fig. 8).

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Part V
Elderly People Monitoring

ADL Detection for the Active Ageing of Elderly People

Bruno Andò, Salvatore Baglio, Cristian O. Lombardo, Vincenzo Marletta, Elisa A. Pergolizzi, Antonio Pistorio and Angelo Valastro

Abstract The correct identification of Activities of Daily Living (ADL) is a fundamental task to implement an effective remote monitoring of weak users with particular regards to elderlies. In this paper a comparison of the performances of two different algorithms for the classification of ADL, developed by the authors, is presented. The first algorithm exploits a threshold mechanism while the other one is based on Principal Component Analysis (PCA). The threshold based algorithm provides reasonable performances in performing classifications between different ADL. Moreover the threshold definition mechanism implemented is flexible and adaptable to several different application contexts due to the use of Receiver Operating Characteristic (ROC) theory which allows to properly define thresholds

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values on the basis of constraints on the system sensibility and specificity. Advantage of the PCA approach resides in the possibility to improve the system specificity in classifying different kind of ADL and a reduction of the classification problem complexity. The developed strategy allows for ADL classification with sensibility and specificity features in line with real applications in Ambient Assisted Living (AAL) context.

1 Introduction

Poor invasive and user-friendly devices would really change the way of implement reliable monitoring of ADL of weak users, with particular regards to elderlies, achieving awareness on the user status thus reducing times for the implementation of emergency activities. Different approaches have been proposed in literature to develop systems for ADL detection in the Ambient Assisted Living contexts. Among these, customized devices [1, 2] and smartphone based platforms [3–10] represent two main proposed solutions. Customized solutions generally present sounding performances but they could provoke users diffidence and discomfort due to body positioning and difficult to use. Fully smartphone based solutions for ADL detection, exploiting smartphone sensing and processing facilities but do not requiring user interaction, could represent a promising way to monitor weak users involved in common daily activities.

Researchers at DIEEI of the University of Catania are investigating novel methodologies and solutions providing useful and reliable information for the efficient implementation of a reliable remote elderly monitoring with particular attention to falls and ADL detection [11–15].

The assistive system developed are aimed to provide effective solutions for ADL detection in AAL contexts. The main task of these assistive system is to acquire awareness of common ADL such as falls, stair negotiation and sitting, in order to provide weak users with a suitable degree of assistance. In particular in [13] authors discussed a system based on a smartphone positioned at the pelvis and exploiting embedded sensors and advanced signal processing paradigms to detect ADL basically considering the moving average of the magnitude of the three acceleration components and event polarized cross-correlation analysis which make the system robust against external influences. The platform developed could be exploited both for indoor and outdoor contexts, such as homes, museums, hospitals, public sites but also as monitoring of patients recently discharged by the hospital.

In any case, independently from the hardware solution, a reliable detection and classification of the ADL is mandatory. In this paper authors present a comparison of the performances of two different algorithms for the classification of ADL.

The first algorithm exploits a threshold mechanism to perform classification between different class of ADL. The threshold definition mechanism implemented is flexible and adaptable to several different application contexts due to the use of ROC curves theory which allows to properly define thresholds values on the basis of constraints on the system sensibility and specificity.

The other algorithm is based on the Principal Component Analysis (PCA) approach whose advantages reside in the possibility to improve the system specificity in classifying different kind of ADL and a reduction of the classification problem complexity.

In the following the two algorithms are discussed and a comparison of their performances in performing classification task of ADL is presented.

2 The Developed Classification Algorithms

The two developed algorithms exploit the acceleration magnitude to perform detection and classification of ADL. The main idea underpinning both the two algorithms is that each observed event is characterized by a typical signature of the acceleration magnitude signal. The signature of the observed events is then used to perform detection and classification of the ADL. The first task was then represented by the identification of a suitable set of signatures.

2.1 Signature Extraction Procedure

The two algorithms exploit the same signature extraction methodology schematized in Fig. 1.

Different users with different height, weight and gender have been required to generate repeated actions belonging to each class of monitored events. Accelerations on the three axis have been acquired by using the accelerometer embedded into a smartphone placed at the pelvis of the user.

With reference to Fig. 1, after a pre-processing of the three acceleration components implemented by a moving average filter, computed acceleration magnitudes are aligned and averaged. Once trends for each class of event considered have been obtained, a dedicated normalization procedure has been implemented to fit signals in the range [−1,1] thus preserving signals dynamics while leading to a signature generalization. Class of performed actions are: stair negotiation (step up 'SU', step down 'SD') and sitting down (SI). The algorithms also identify and classify falls events. Performances in accomplishing task of distinguish between different kind of falls and ADL have been already discussed in [13].

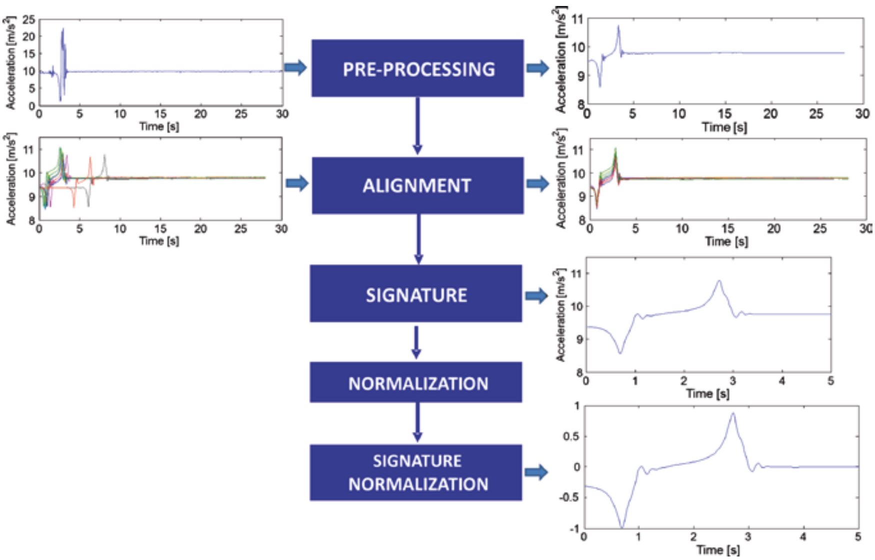

Fig. 1 Schematization of the procedure adopted for extraction of signatures related to the set of event of interest

2.2 *The Classification Methodology*

The flow diagram of the classification approach is sketched in Fig. 2.

As it can be observed the first step consists in performing a moving average filtering of the acceleration module followed by the normalization procedure above described. The cross-correlation between sliding windows of 5 s of the obtained signal and the set of signatures of candidate class of events are then calculated. The cross-correlation maximum values are used as features for the classification procedure.

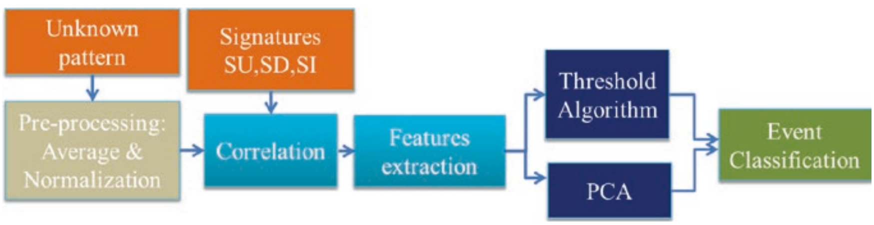

Fig. 2 Flow diagram of the classification algorithms

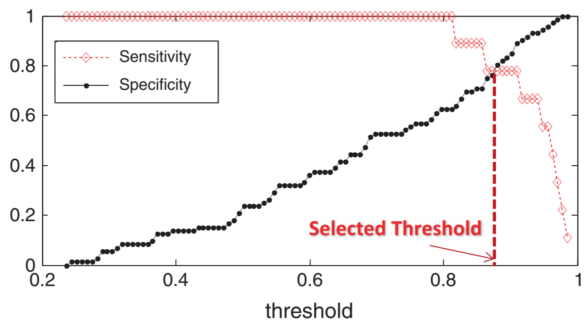

Fig. 3 Example of sensibility and specificity behavior as function of the threshold value

2.3 The Threshold Based Classification Algorithm

The first classification approach exploits a threshold based algorithm which compares extracted features to threshold values defined for each class of events. In this case the last step of the classification algorithm schematized in Fig. 2, consists in comparing extracted features to threshold values in order to define the potential class or classes to which the unknown target belongs.

Thresholds have been defined by using the ROC curves theory looking for a good compromise between sensitivity and specificity. The intersection value between the curves of specificity and sensitivity has been taken into account. Figure 3 shows an example of observed curves as a function of the threshold value and the threshold value selected for the sake of classification. Actually, the classifier sensitivity and specificity have been estimated as a function of the threshold value for each class of events. Sensitivity and specificity have been computed on the basis of the following relationships [14]:

$$Sensitivity = \frac{TP}{TP + FN} \quad (1)$$

$$Specificity = \frac{TN}{TN + FP} \quad (2)$$

where

TP True Positives
FN False Negatives
TN True Negatives
FP False Positives

2.4 The PCA Based Classification Algorithm

The second classification approach is based on Principal Component Analysis (PCA). PCA algorithm provides orthogonal transformation of the input dataset of observations into a new set of values of linearly uncorrelated and orthogonal variables called principal components. First principal component has the largest variance in the data.

Input dataset of correlated variables provided to the PCA algorithm is composed by features computed as discussed above.

An example of a map correlating Feature1 (maximum value of the correlation between the signature FF1and unknown patterns) and Feature2 (maximum value of the correlation between the signature FF2 and unknown patterns) is shown in Fig. 4a. As it can be observed different events are not separable, among these, the SD and SU events. Similar results have been obtained by different features combinations.

By applying the PCA algorithm to the considered data set, the results shown in Fig. 4b, have been obtained. After application of the algorithm, the SD and SU events became separable. Results demonstrate the classification performances of this clustering methodology.

Expected advantages of this solution as respect to the threshold based approach is an improvement of sensitivity and selectivity features due to the peculiarity of this method to create a new data set with an optimized degree of information. Results obtained by the PCA tool are discussed in the next section .

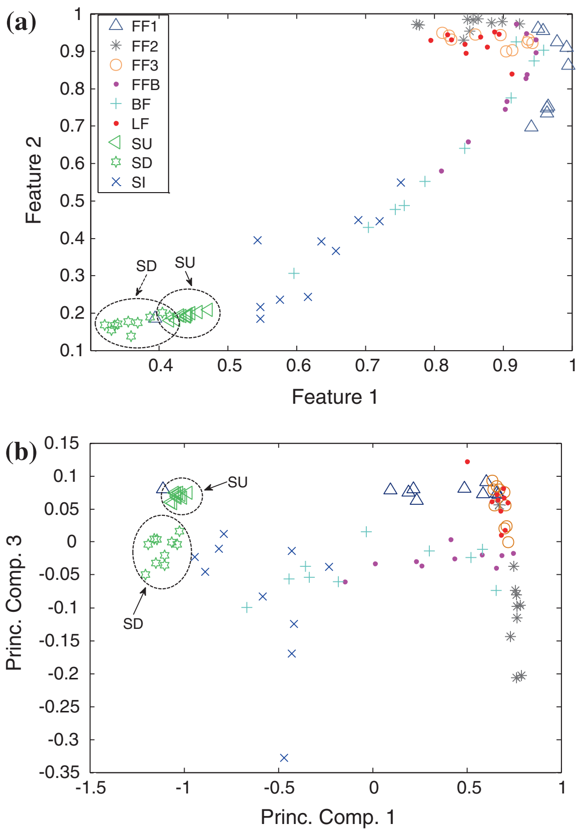

Fig. 4 **a** An example of a classification map obtained through combining rough features. **b** An example of a classification map obtained through PCA

Table 1 Performances of classification paradigms in terms of sensitivity and specificity

Events	Sensitivity of threshold algorithm	Sensitivity of PCA algorithm	Specificity of threshold algorithm	Specificity of PCA algorithm
FF1	1	1	0.94	1
FF2	1	1	0.79	1
FF3	1	1	0.92	0.96
FBW	0.78	1	0.92	1
BF	0.78	1	0.86	1
LF	0.89	1	0.87	0.96
SU	1	1	1	1
SD	1	1	1	1
SI	0.89	1	0.68	1

3 Conclusions

In order to test the algorithms, simulated intentional actions were performed by healthy subjects. The subjects were asked to wear the smartphone on their right hip and to perform a sequence of tasks. Each action has been repeated nine times.

Obtained results in terms of sensitivity and responsivity are given in Table 1 where all the monitored events (included the falls events) have been reported for the sake of completeness. As it can be observed, performances of PCA based approach are definitively better than the threshold based classification solution and as respect to the State Of The Art.

In conclusion, results obtained encourage the development of this kind of assistive systems exploiting performances of these processing algorithms.

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Comparison of RGB-D Mapping Solutions for Application to Food Intake Monitoring

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Abstract Food intake behaviours are strictly correlated to health, especially for elderly people. Dietary habits monitoring is one of the most challenging activity for researchers in AAL scenario. RGB-D sensors, such as Kinect, provide multiple useful data to perform behavioural analysis in an unobtrusive way. Unfortunately, when using the Kinect sensor, depth and RGB data are not available with the same point of view, and a mapping algorithm is required in order to associate a 3D point to the same pixel in both the RGB and depth frames. In this paper, some techniques for RGB-D mapping of Kinect sensor data are compared, and a proposed implementation is described. Some experimental results in specific conditions are finally provided.

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1 Introduction

Within the Seventh Framework Programme scenario, the European Union has promoted the integration of research infrastructures to correlate food intake behaviors and human health [7]. The aim of these studies is the development of guidelines to raise population's awareness on nutrition-related problems, as promoted by the U.S. Department of Health and Human Services campaign [25]. The obesity problem is directly correlated to the food intake behaviors, as confirmed in [24] by the analysis of quantity and frequency of meals. On the other hand, the amount of water that a person should drink is one of the key elements that have to be considered in a correct diet. In [22], the authors state that an adequate fluid intake should be between 1500 and 2500 ml/day. When these quantities are not respected, the risk for fatal coronary heart disease could increase. A concrete study of this relationship is obtained from the evaluation of 8,280 male and 12,017 female subjects aged between 38–100 years [4]. A related risk of 0.46 in men and 0.59 in women were identified when low daily intakes of water were compared with high ones. Particular attention is given to the elderly, since their ability to sense thirst decreases with age, as described in [3]. In hospitals or other similar structures, accurate fluid balance charts are used to monitor the patients' hydration status. These tables must be frequently updated by the nursing-qualified staffs. Missing notes could occur and the results depend by the capacity of the person that assesses the patient [20].

When surveys require many information, technology can improve the data gathering process. However, the subjectivity problem is not completely covered, i.e. in [26] the patient has to provide his data. As a consequence, a cost-efficient solution that provides a support to the healthcare professionals for continuous assistance to the elderly is needed.

A diet monitoring system may overcome the previously described limitations for self-assessment and fluid balance check. In [17] the authors designed an algorithm to process the bites-taken information provided by an accelerometer placed in the wrist of a volunteer during a meal. When the intake food rate is too fast, the person is informed by an alert sent through Bluetooth from the wearable system to an Android mobile application. Recently, vision-based solutions have become a valid option, in order to resolve the acceptability and invasiveness that affect wearable devices. In [16], a RGB camera in ceiling configuration constantly monitors the table to catch and analyze the best representative picture of the patient's meal. The authors declare that the captured frame will be exploited in the future by another algorithm to extract the dietary behaviors of the patient. The weak aspect of this approach is the susceptibility of the RGB sensor to light changes in the room and the lack of a behavioural monitoring to recognize the food effectively eaten.

A depth information may overcome this limitation and represents an alternative solution to resolve the automatic meal analysis problem. Kinect integrates a depth sensor together with a classic RGB camera in the same low-cost device. It raised large interest in the AAL field thanks to the possibility of environmental monitoring using distance and video informations [9]. There are several tools [13] [19] [18] that allow data retrieving from depth and RGB cameras. In [15] the depth sensor is exploited to identify objects grasping. The device is in ceiling configuration and hands are recognized and tracked using a gradient kernel descriptor and a linear SVM classifier. The solution proposed in [15] has a significant computational complexity and unfortunately it does not run in real-time. A similar approach is proposed in [23] based on three different machine learning algorithms (generic classifier, SVM and K-nearest-neighbor). The solution can identify different actions correlated to meal preparation activities. On the other hand, [1] is finalized to the automatic pursuit of fluid intake actions. Kinect is placed in the standard configuration with the person in front of it. The system is trained by Naive Bayes Classifier to catch the relevant activities. The authors state that the performances of the algorithm decrease when the person shows the side-part of the body and occlusions may partially affect the fluid intake recognition.

It is quite easy to use depth or RGB data from Kinect sensor separately, but it might be not so easy to use both information jointly. Cameras have different fields of view and different reference systems, so a specific area in the depth-frame does not correspond to the same area inside the RGB frame. Some libraries [13], [19] provide built-in methods for coordinates mapping between video and depth-frames but usually they are not very accurate. The aim of this work is the evaluation of different methods that allow RGB-D mapping of Kinect sensor. The built-in methods provided by Microsoft SDK and OpenNI are compared against a calibration-based solution realized by RGBDemo [21] using [27].

The paper is organized as follows: Sect. 2 discusses different RGB-D mapping techniques for Kinect sensor data; the performances obtainable are tested and discussed in Sect. 3. In Sect. 4, one of the algorithms tested is selected and applied in a ceiling configuration. Finally, Sect. 5 summarizes the conclusions of the work.

2 Mapping Solutions

Depth (D) and RGB sensors, both integrated in Kinect device, do not have the same origin of frame coordinates. There is the need to calibrate both cameras in order to use the information jointly. A stereovision system features the following parameters, that can be computed by a calibration procedure:

- *intrinsic parameters*: coefficients that allow conversion between image coordinates and 3D coordinates, and depend on camera lens;
- *distortion coefficients*: parameters that depend on lens distortion;
- *extrinsic parameters*: coefficients required to convert coordinates systems of different cameras, depending on cameras mutual position.

For example, starting from a pixel in the D frame, the following steps need to be implemented to obtain the corresponding pixel in the RGB frame:

- transformation between D frame coordinates system $\left[x_d\ y_d\ 1\right]^T$ and 3D depth camera coordinates system $[X_d\ Y_d\ Z_d]^T$ (by using intrinsic parameters of depth camera);
- conversion between 3D depth camera coordinates system and 3D RGB camera coordinates system $\left[X_{rgb}\ Y_{rgb}\ Z_{rgb}\right]^T$ (by using extrinsic parameters of both cameras);
- conversion between 3D RGB camera coordinates system and 2D RGB image coordinates system $\left[x_d\ y_d\ 1\right]^T$ (by using intrinsic parameters of RGB camera);
- lens distortion removal (by using distortion coefficients).

The relationship between the camera and the image coordinates systems is defined by [10]:

$$\begin{bmatrix} x_d \\ y_d \\ 1 \end{bmatrix} = K_d \begin{bmatrix} X_d \\ Y_d \\ Z_d \end{bmatrix} \tag{1}$$

where K_d is the matrix that contains the intrinsic parameters of IR camera:

$$K_d = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \tag{2}$$

f is the focal length, $f_x = a_x f$ and $f_y = a_y f$ are used to differentiate the focal length along both the directions. The parameters c_x and c_y account for the translation between the coordinates $[X_d\ Y_d\ Z_d]^T$ and $\left[x_d\ y_d\ 1\right]^T$. The conversion between the D camera coordinates $[X_d\ Y_d\ Z_d]^T$ and RGB camera coordinates $\left[X_{rgb}\ Y_{rgb}\ Z_{rgb}\right]^T$ needs a rotation matrix R and a translation vector $t = [t_1\ t_2\ t_3]^T$, which define the mutual positions of both systems:

$$\begin{bmatrix} X_{rgb} \\ Y_{rgb} \\ Z_{rgb} \end{bmatrix} = R \begin{bmatrix} X_d \\ Y_d \\ Z_d \end{bmatrix} + \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} \tag{3}$$

Finally, the coordinates in the RGB frame, can be retrieved with the same principle of Eq. (1), by using the intrinsic parameters of RGB camera:

$$\begin{bmatrix} x_{rgb} \\ y_{rgb} \\ 1 \end{bmatrix} = K_{rgb} \begin{bmatrix} X_{rgb} \\ Y_{rgb} \\ Z_{rgb} \end{bmatrix} \tag{4}$$

The pixel coordinates $\left[x_{rgb}\ y_{rgb}\right]^T$ inside the RGB frame corresponds to the pixel $\left[x_d\ y_d\right]^T$ inside the D frame.

The image distortion introduced by the lenses can be removed by using distortion coefficients, as defined in [11]. For example, considering the RGB camera, coordinates normalization is the first step of the processing:

$$[X_n \quad Y_n]^T = \left[X_{rgb}/Z_{rgb} \quad Y_{rgb}/Z_{rgb}\right]^T \tag{5}$$

Let $k = [k_1\ k_2\ k_3\ k_4\ k_5\ ]^T$ be the vector of distortion coefficients computed in the calibration phase; the distortion-compensated coordinates are:

$$\begin{bmatrix} X_k \\ Y_k \end{bmatrix} = \left(1 + k_1 r^2 + k_2 r^4 + k_5 r^6\right) \begin{bmatrix} X_n \\ Y_n \end{bmatrix} + \begin{bmatrix} 2k_3 X_n Y_n + k_4(r^2 + 2X_n^2) \\ k_3(r^2 + 2Y_n^2) + 2k_4 X_n Y_n \end{bmatrix} \tag{6}$$

where

$$r^2 = X_n^2 + Y_n^2 \tag{7}$$

Finally, the pixel coordinates in the undistorted RGB frame are:

$$\begin{bmatrix} x_{rgb\_und} \\ y_{rgb\_und} \end{bmatrix} = \begin{bmatrix} f_x & 0 \\ 0 & f_y \end{bmatrix} \begin{bmatrix} X_k \\ Y_k \end{bmatrix} + \begin{bmatrix} c_x \\ c_y \end{bmatrix} \tag{8}$$

Although specific distortion models have been proposed for Kinect sensor D camera, the same distortion model of RGB can be also applied to the depth frame.

2.1 Kinect RGB-D Mapping Tools

There are some solutions, specific for Kinect sensor, that can be used to perform mapping between RGB and depth frames. Some of them are embedded inside the libraries that allow communication with the device. For example the official Microsoft SDK and the OpenNI SDK provide methods that receive as an input the coordinates of a pixel in the depth frame and output the corresponding coordinates of the pixel in the RGB frame that represents the same 3D point. The mentioned solutions do not require any calibration procedure and can be used very quickly. RGBDemo is another tool that allows retrieving and processing data from Kinect sensor, and also provides a tool for RGB-D mapping. RGBDemo, differently from Microsoft and OpenNI SDKs, requires the calibration parameters of the device and provides solutions devoted to compute them. The algorithms implemented in RGBDemo exploit some OpenCV primitives [2], based on the theory briefly shown in the previous paragraph.

The solution herein proposed derives from the pinhole model theory and follows the same approach of RGBDemo, but does not require any additional library, so it can be integrated in other applications. The calibration parameters are evaluated using the same tool provided by RGBDemo: in fact, each Kinect device has its own lenses, so its own intrisic/extrinsic parameters but they do not depend on position or setup configuration, therefore calibration is needed only once.

The calibration phase needs the identification of the same points by both cameras. A simple way to obtain such points is capturing the same pattern, as the one given by a chessboard. The corners represent easily identifiable points that can be correlated. Obviously the corners are on the same plane, so they cannot be distinguished in the depth map. Nevertheless, the depth estimation algorithm uses an IR camera and the IR frame can be retrieved from the sensor. Usually 30 RGB and IR frames are enough to perform a good calibration, with an average reprojection error lower than 1 pixel.

Microsoft SDK provides two methods for RGB-D mapping, the former called *NuiImageGetColorPixelCoordinatesFromDepthPixelAtResolution* integrated in the SDK 1.5 and later, the latter *NuiImageGetColorPixelCoordinateFrameFrom DepthPixelFrameAtResolution* available since version 1.6. The OpenNI SDK 2.1 defines a class for coordinates conversion, called *CoordinateConverter*, with a method that computes a punctual mapping: *convertDepthToColor*. The other solutions evaluated need a calibration procedure and are represented by RGBDemo algorithm, and the proposed implementation.

3 Performances Evaluation

In order to evaluate the different mapping solutions, some tests have been performed. The simplest way to assess performances of mapping functions is the computation of edge misalignment in a regular object. The target is represented by a wood block of dimensions 39.6 × 35.1 × 1 cm, located at a distance of 1, 2 and 3 m from the sensor, at two possible directions, centre and side. The former direction is considered when the wood block is positioned in the centre with respect to the frames, while the latter is when the target is near to the right bound. The Kinect sensor is elevated at 92 cm from the ground, while the block is at an height of 87.4 cm. RGB and D frames considered have a resolution of 640 × 480 pixels.

3.1 Comparison Algorithm

With the aim of providing an objective method to compare the mapping solutions, some algorithms for error assessment applied to edge identification have been developed. The idea is to evaluate the mismatch in the detection of the target edges in the RGB frames, against the same edges in the D frames. The first step is the computation of borders in both images, by using the Canny algorithm for the RGB frame and the Sobel algorithm for the D frame. Results are shown in Fig. 1.

The comparison algorithm takes the edge frames as inputs and evaluates the difference between the pixel of a vertical edge (right) and a horizontal edge (top)

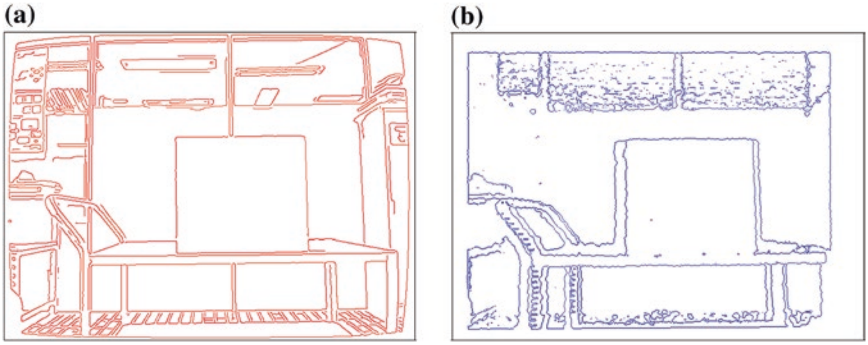

Fig. 1 Edges in **a** RGB and **b** D frames when the target object is positioned at a distance of 1 m, in the centre configuration

of the target in RGB frame and the corresponding edges in the D frame, for each mapping solution. A mean error is obtained and used to represent the goodness of the examined mapping solution. The lower the mismatch error, the better the performance of the mapping algorithm.

3.2 Results Analysis

The evaluation of the considered mapping solutions has been performed by capturing the data in the same setup and computing the mismatch error as explained above. Table 1 shows mismatch errors in top and right edges when the target is aligned with the Kinect sensor. Table 2 shows the same errors when the target is in the side view, near to the right bound of the frame. Microsoft SDK mapping solutions are labeled as SDK 1.5 (*NuiImageGetColorPixelCoordinatesFromDepthPixelAtResolution*) and SDK 1.6 (*NuiImageGetColorPixelCoordinateFrameFromDepthPixelFrameAtResolution*) respectively. In Tables 1 and 2, minimum error values are marked bold, while maximum values are underlined.

Table 1 Mismatch errors in top and right edges in *Central* configuration

Central config.	Right edge				Top edge			
	1 m	2 m	3 m	*Average*	1 m	2 m	3 m	*Average*
SDK 1.5	2.39	<u>9.68</u>	<u>11.07</u>	<u>7.71</u>	**1.08**	**0.54**	<u>3.16</u>	1.59
SDK 1.6	<u>4.89</u>	2.04	4.07	3.67	1.12	0.81	1.30	**1.08**
OpenNI	1.09	7.94	9.05	6.03	1.12	0.74	3.07	1.64
RGBDemo	**0.67**	1.31	0.42	0.8	<u>1.95</u>	1.14	1.93	<u>1.67</u>
Proposed	0.96	**0.71**	**0.66**	**0.78**	1.58	<u>1.24</u>	**1.23**	1.35

Table 2 Mismatch errors in top and right edges in *Side* configuration

Side config.	Right edge				Top edge			
	1 m	2 m	3 m	*Average*	1 m	2 m	3 m	*Average*
SDK 1.5	1.75	6.90	8.49	5.71	0.89	1.04	2.65	1.53
SDK 1.6	7.69	**0.84**	**1.17**	3.23	1.37	1.31	2.85	1.84
OpenNI	2.56	4.77	6.45	4.59	0.87	0.96	2.68	1.5
RGBDemo	2.44	1.86	3.16	2.49	1.16	0.82	**0.63**	0.87
Proposed	**1.16**	1.19	2.28	**1.54**	**0.86**	**0.71**	0.83	**0.8**

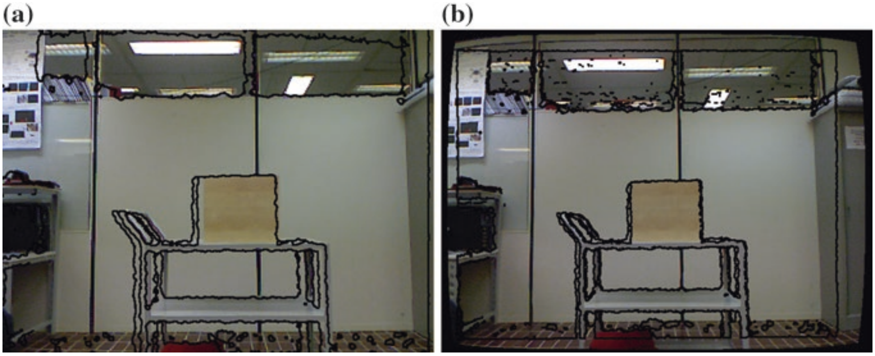

Fig. 2 Overlay of mapped D edges on mapped RGB frames in **a** SDK 1.5 and **b** Proposed implementation

The proposed implementation shows better performances in many analyzed configurations but not in all the setups. On the other hand, it shows a mismatch error that is always below a certain threshold, near to 2.3 pixels in the worst case. Solutions that do not need calibration show errors that can exceed 11 pixels, also when the target is close to the sensor.

Columns labeled as *Average* in Tables 1 and 2 show average error values for each algorithm and edge. The proposed implementation reaches better average performances in three out of four analyzed setups. Only in the top edge in *Central* configuration, the proposed implementation is outperformed by SDK 1.6 but the gap is less than 1 pixel.

Figure 2 shows a visual comparison between mapping performances provided by SDK 1.5 and the proposed implementation, in the same setup configuration (2 m—*Central*). This images are obtained by computing edges in the mapped D frames and superimposing them (in bold black color) to the mapped RGB frame.

4 Application to Food Intake

The automatic food intake analysis requires both the sensors integrated in the Kinect device: RGB and D. In this work, the Kinect is located on the ceiling at a distance of 3 m from the floor. The development of an algorithm that exploits only one data stream reduces the potentialities of the sensor and can lead to a more complicated solution. In fact, dishes and glasses are too much thin to be recognized by the depth sensor because their thickness is comparable with the depth resolution, which is 1.2 cm at the distance that exists between the sensor and the table [5].

To the aim of monitoring the area where the person eats, the algorithm needs first to recognize which pixels belong to the table. More in detail, the intrinsic parameters are applied to the D frame, in order to obtain a point cloud (PC) of the scene captured by Kinect. In this coordinates system, ad hoc solutions are exploited to recognize particular objects. For example, the RANSAC [8] algorithm is designed to find plane surfaces in PC, such as the table. The Hough transform [6] has been used to identify the round objects exploiting RGB information, since dishes and glasses are usually circular. The distance between device and table has been used to tune the parameters that the Hough algorithm takes as inputs, such as the objects dimensions. A machine learning solution [14] could be used to estimate the skeleton joints of the person, which model the upper part of the body. The food intake action may be recognized by tracking the joints of the hands and monitoring their interactions with dishes and glasses on the table.

Figure 3a, b show the result of the SDK 1.5 mapping solution and the proposed implementation, respectively, applied only to the area of the depth frame identified as table. The data fusion procedure is more difficult in the first approach than in the second one, as confirmed by the mismatching in the interested area. In Fig. 3b the dashed square encloses the identified glass while the continuous square denotes the dish, both of them identified by a computationally efficient implementation of Hough algorithm [12].

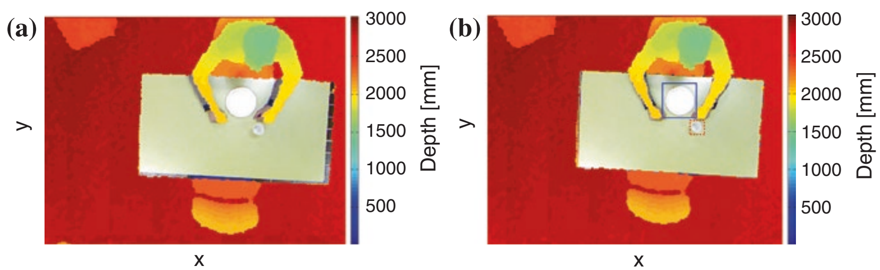

Fig. 3 Comparison of **a** SDK 1.5 and **b** Proposed mapping solutions in ceiling configuration

5 Conclusion

RGB-D mapping solutions can be used in AAL applications when individual streams are not sufficient to extract information, for example in a food intake monitoring system. This paper presented different mapping algorithms that allow to jointly use depth and RGB information provided by Kinect sensor. Specific tests showed that calibration-based solutions reach better performances in terms of edge identification in RGB and depth frames. Current research is focused on further validation of table and dishes recognition techniques and, as the interaction between hands and dishes on the table denotes a food intake activity, the next step is the person identification for hands tracking.

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Care@Home: Methodology, Goals and Project Experimentation Activities

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Abstract The Care@Home project, funded by the Apulia Region, aims at developing an integrated system able to monitor and collect continuously vital parameters of the elderly or frail users in order to allow patients who require specific therapies or rehabilitation activities to perform them at home. By the means of ICT technologies and mobile devices simple to be used, such as smart phones or Tablet PCs able to carry out the monitoring activity noninvasively and assess the patient's health status at the same time, it will be therefore possible to allow frail users to live as long as possible in their own home environment and to receive assistance in remote as well. Miscellaneous testing and experimentation activities and stages are going to be undertaken over the months to come in order to develop a first prototype consisting of a solution to monitor frail person and an electronic medical record accessible via the Internet from any remote location. Project objectives and initial results concerning the experimentation stage are here introduced.

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1 Introduction

One of the key-points of a mature and structured welfare system is the efficient and correct evaluation of the self-sufficiency degree and health status of its citizens, with particular regard to frail and elderly individuals. Although the majority of patients are usually affected by conditions of general frailty or functional decline, also related to chronic conditions caused by rare diseases, they are nevertheless endowed with a potential good level of self-sufficiency, if supported by proper remote assistance and monitoring systems able to assess continuously their health status. If the hospitalization may be central in the early stages of a disease, for what concerns the diagnostic and therapeutic aspects, hospitals, instead, are not

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able to provide in the aftermath appropriate responses to patients' needs which are then entrusted to caregivers, family networks and local health care facilities.

In this context, the Care@Home [3] project—funded by the Apulia Region in the framework of the Apulian Living Labs [1]—aims at developing an integrated information system for the management of the continuity of the treatment of frail patients through advanced ICT home care solutions [2].

The services which are meant to be proposed through this project aims thus at the development of a remote monitoring and assistance system able to assess the end-users' health status, by detecting critical events such as fall-risk or alteration of vital signs and fostering as well the communication with caregivers and family networks, in order to operate a coordination of the miscellaneous therapy or rehabilitation activities.

It will be used a mobile device in order to detect the user's vital parameters at the user's premises, whereas, the collected data will be stored—by using appropriate security protocols—in the central server of a database which can be accessed by all of the previously authorized stakeholders.

The system will allow then to represent the individual patients' summary data and the detail ones, highlighting significant changes and reporting through appropriate algorithms the need for intervention.

Besides, the system considers the development of an electronic medical record accessible by each operator on the basis of his competence, enabling so a multilevel communication frame work.

2 Development Methodology and Main System Features

The conceptual development methodology of the Care@Home system is based on the UCD—*User Centered Design* [4–7] approach. The core of this process—which considers the involvement of the end-user of the product throughout the whole conception, design and development cycle—can be described as "the practice of designing products so as to allow the user to carry out his duties with minimum stress and maximum efficiency". The purpose of this approach is to tailor then the system around the user's needs, expectations and limits, employing a co-design procedure, which implies that designers, technicians and providers have to necessarily work in direct and close contact with end-users in each of the design phases.

The user is therefore placed at the center of each step of the development process in order to maximize the usability and acceptance of the product, optimizing it around the needs of the users. The UCD methodology is characterized by a multi-level co-design and problem solving process which requires designers not only to analyze and foresee how the user will utilize the final product, but to test and validate at the same time their assumptions by strongly taking into consideration the end-user's behavior during the usability and accessibility tests into the real world. This methodology enables so the creation of the final product through an interactive process that provides the development of a first prototype and a following test and assessment stage on the basis of which to proceed with the development of the next prototype.

Therefore, each cycle leads to the creation of a product that is closest to the real and practical needs of the user. On the basis of the feedback collected after each stage of experimentation activities, indeed, it will be implemented a more precise prototype up to the one that most meets the needs of the end-user and the purposes of the project. In compliance with the principles of the UCD methodology, each experimentation phase influences the development of the next prototype, thus leading to a product which is more and more refined and tailored on the end-user's needs and requirements. In particular, two are the planned cycles of experimentation activities for this project which have just started and will lead to the implementation of the next prototypes.

The system provides for the involvement of the following stakeholders:

1. Patients in need of care and rehabilitation activities;
2. Family networks and caregivers;
3. Medical operators;
4. ICT Companies (eResult, Sabacom, AserNet)
5. Scientific Partners (e.g. CNR-IMM, IRCCS Casa Sollievo dalla Sofferenza; Università di Bari, MATRIX S.p.A., CETMA)

On the basis of a match between the users' needs and expectations in terms of self-sufficiency in their own living environment and the information provided by the medical providers concerning healthcare treatments and rehabilitations activities the patient has to undergo, a technological platform of services and solutions has been developed.

2.1 The ICT Platform

The system makes use of an ICT platform which integrates on the one hand the OMNIACARE platform [6] developed by eResult and on the other hand the management software developed by Sabacom SRL for what concerns the implementation of an electronic medical record.

OMNIACARE is a system specifically designed for the social welfare and healthcare sector and provides tools to both operators providing assistance and the patients. To promote the independence of frail users and to help them to carry out an independent life as long as possible in their own home environment, the platform makes use of advanced technologies that allow to perform a continuous remote monitoring of the health status of the patients.

The system is composed of a hi-tech kit which includes a mobile device such as a smart phone, a Central Server able to store data collected from smart sensors that detect vital and environmental parameters such as degree of humidity, temperature, ECG, RR interval, body heat, body posture, heart rate etc. An Integration Module (developed by the Research Lab CETMA) allows then data exchange through a wireless connection.

Once stored in the Server, data are accessible via the Care@Home website (in Fig. 1 an example of the architecture of the system is detailed).

Besides, the system is configured with the user's profile which contains information about its needs, habits, limits, impairments, therapies etc. The mobile device will support the user during daily life activities allowing him/her to live in his home environment and to receive remote assistance by caregivers or medical providers. In case of detection of critical situations, indeed, the system is able to generate an automatic message or alarm to alert a caregiver.

Sabacon S.r.l., contributed with the development of a new software application to record medical and diagnostic data of patient with special focus on cardiopatic patient in strict collaboration with IRCCS. Together they have also developed a module for the Multidimensional Prognostic Index test (MPI test) which can help doctors to elaborate a patient anamnesis on his social and health status at the time of hospitalization and it is maintained together with the clinical record. Finally, they implemented a software module for the management of healthcare operator connected to the clinical record of a patient.

Data exchange process is performed by Integration Module, that gets Smart Sensors' data through Multi-Protocol Gateway (developed by the Research Lab Matrix), as the Fig. 2 shows.

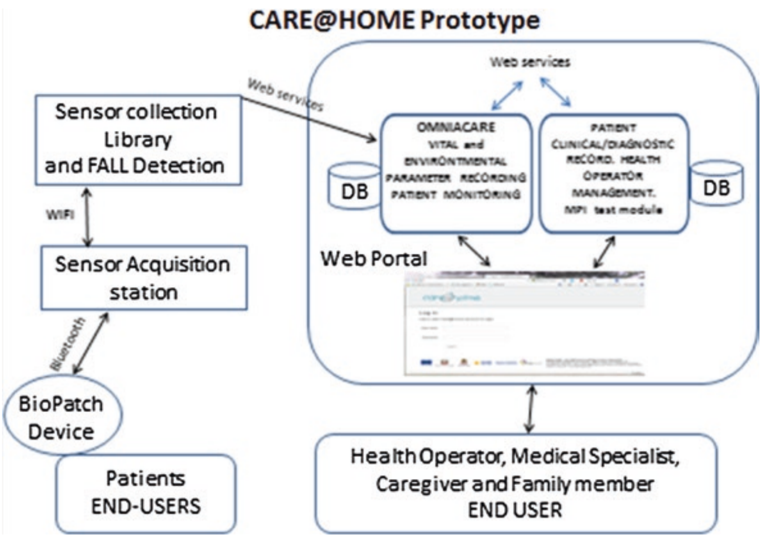


Fig. 1 System architecture structure

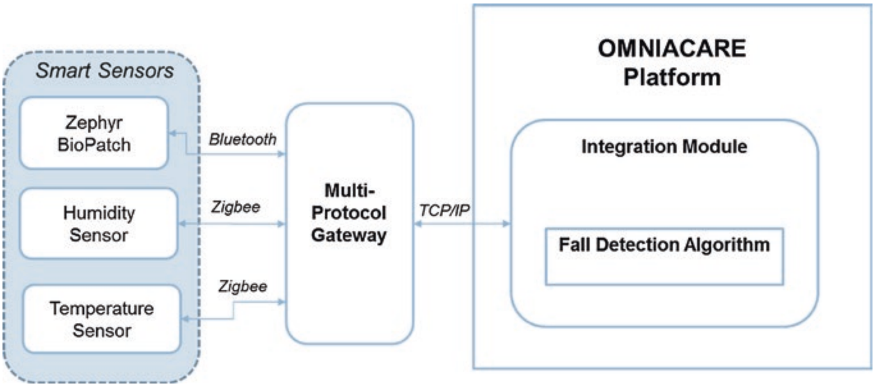


Fig. 2 Data exchange process

Integration Module has the following tasks:

- managing vital parameters: the module gets data packets from Zephyr BioPatch device, through Multi-Protocol Gateway (Bluetooth-TCP/IP communication) and processes them;
- managing environmental parameters: the module gets humidity and temperature data, through Multi-Protocol Gateway (Zigbee-TCP/IP communication) and processes them;
- integrating Fall Detection algorithm (developed by the Research Lab CNR-IMM) in order to recognize the fall episode of patients wearing the Zephyr BioPatch device;
- sending relevant data to Omnicare Platform.

2.2 Scenarios

The prototype that will be developed in the framework of this project contemplates the existence of at least 4 possible usage scenarios related to the Care@Home system and to be provided by the means of ICT devices.

A first scenario concerns the remote assistance and monitoring of frail and/or elderly users through wearable and non-invasive smart sensors able to detect their vital parameters and to send data collected to a Central Server. The mobile device allows the users to interact with the family network or caregivers when they need to, enabling then the elderly to carry out their life in their own living environment in independence conditions, as long as possible.

Secondly, other modules of the research project concern, instead: the possibility to measure subjective pain for patients with mild cognitive impairments; the development of a fall-risk detector in order to define an algorithm able to evaluate and detect events, signs and features leading to a fall episode and thus avoid it and finally the effectiveness of monitoring of cardiac patients through the Care@Home system.

2.2.1 Android Application for Subjective Pain Measurement

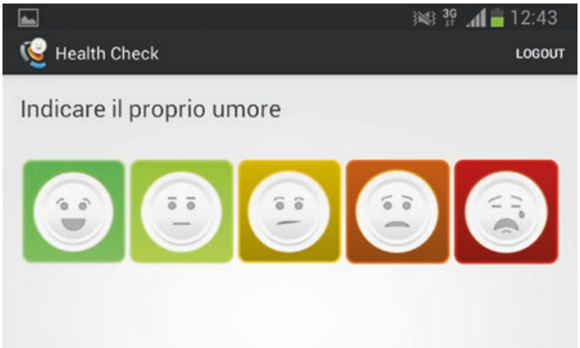
A software android application for subjective pain measurement for patient with mild cognitive impairment has been developed. The application is able to define the analgesic therapy and the time intervals during which the patients will have to take the therapy.

The application is configured with specific reminders according to the time intervals of the therapy program. Each time a patient should take the painkiller medication the system reminds the user to take it and presents him/her with a scale of discomfort or well-being level represented by a set of images with a differentiated scale of colors which represents the individual mood, as showed in Figs. 3 and 4.

All information is then collected in a database. Medical providers and caregivers can thus monitor each patient and decide if and when it is necessary to intervene to support the patient and the proper tools to be used. If the max level of pain is then recorded an alert message is also sent to one's own caregiver.

Fig. 3 Discomfort level

Fig. 4 Options for mood level to choose from



2.2.2 Monitoring of Elderly Cardiac Patients

Heart failure is often one of the leading cause of hospitalization in the elderly. About 20 % of discharged patients tends to be re-hospitalized with a poor prognosis. A recent meta-analysis has shown that the use of tele-monitoring systems can reduce the rate of mortality of 17 % and even the re-hospitalization rate of almost 7 % in reference to the only cardiac failure.

In this perspective, the multidimensional assessment resulting from a combination of biological, functional, psychological and environmental factors, may be of concrete help in the identification of frail patients that could benefit from the use of these technologies.

Another significant goal of the project is to assess the effectiveness of the Care@Home monitoring services, specifically, by applying them to cardiac patients. This part of the project is still in the experimental stage. In particular, two cohorts of patients are examined for the purposes of the research:

1. patients treated according to the current standard treatment protocols;
2. patients treated by the means of the Care@Home integrated system of tele-monitoring.

The study is carried out according to the rules of good clinical practice and in accordance with the privacy policy and current legislation. Each patient included in the trial will be followed at his/her premises for 2 weeks by using a small seized monitoring system able to detect the following vital signs: ECG, respiratory rate and heart rate.

Primary outcomes will be on the one hand of technological nature (acceptability, functionality, ease of use of the device, etc.) and on the other hand of clinical nature (mortality rate at 1 month, re-hospitalization with its cause and duration, institutionalization, weekly number of medical checks, quality of life, mood level).

3 Experimentation Process

The experimentations phases have just started and are going to be carried out throughout the months to come. Two are the principle bodies involved in this stage: on the one hand the IRCCS—“Casa Sollievo della Sofferenza” and on the other hand the Neurophysiopathology of Pain Unit of the University Aldo Moro, Bari.

Both of them will be engaged in recruiting potential patients for the purposes of the project and in particular over-65 frail and/or elderly users or individuals affected by heart problems or mild cognitive impairments such as Alzheimer at its first stages or Huntington’s Disease. Medical providers and researchers involved in the project will present its goals to them and propose the opportunity to take part in the experimentation stages providing them with all of the necessary information. Those who wish will be provided with the prototype of the technological kit and its mobile devices in order to carry out the testing and validation phases related to the tools and solutions already developed.

In particular, the University of Bari will be responsible for the experimentation stage concerning the android application for subjective pain measurement for patient with mild cognitive impairment. It will recruit potential patients—approximately 40 users—who are undergoing analgesic treatment and ask for their willingness to try out the application developed.

It will be tested the acceptability degree of the proposed technologies, their effectiveness in comparison with the traditional current standard treatment protocols and their ability to meet the users' needs and requirements.

Moreover, at the "IRCCS—Casa Sollievo della Sofferenza", it will be implemented a counseling center in order to take charge of the patient, once dismissed, collecting all the information suitable to create the user's profile through the system and to manage the monitoring activities during the rehabilitation phase.

4 Conclusion

Most of the development process of the whole system, both in terms of hardware and software components, has been almost completed and experimentation phases are planned. The *Health Check Application* for subjective pain measurement for patient with mild cognitive impairment has been already entirely developed and testing and validation phases are already in progress as planned.

Concerning the implementation of the abovementioned fall-risk detection device, instead, the CNR-IMM has already developed a proper algorithm [5] able to detect the information, parameters and signs related to the recognition tasks of the fall episode. Testing stages are going to be undertaken in the next weeks.

Also the electronic medical record accessible via the Internet from remote has been developed by Sabacom SRL with particular regard to cardiac records, but with possible future integrations concerning the recording of parameters related to other diseases.

Finally, researchers and personnel involved in the project have already accomplished the integration stage of the whole system, putting together each tool and device developed up to now, integrating all the different libraries, components and applications and shaping thus a first prototype of the integrated ICT system to be further improved with the next two cycles of the experimentation activities.

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Combining EEG and EMG Signals in a Wireless System for Preventing Fall in Neurodegenerative Diseases

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Abstract We present an innovative wireless wearable, low power, noninvasive neuroprosthetic system that is geared towards detecting and preventing falls. The system allows continuous monitoring of EEG/EMG, detecting in particular premotor potentials to prevent falls of elder and motor-impaired patients by introducing a feedback action to stabilize gait.

1 Introduction

Recent studies [1, 2] show that a shift in population distribution towards older age groups is currently occurring in Europe. Recent estimates predict that the rate of the population aged over 65 will reach 30 % by 2060 and that the one over 80 will rise from 4.4 % (2008) to 12.1 %. Falls are the leading cause of both fatal and nonfatal injuries (e.g. lacerations, fractures, or head traumas) for older population. In 2010, 2.3 million nonfatal fall injuries among older adults were treated in emergency departments and more than 662,000 of these patients were hospitalized. In 2011, the direct medical cost related to falls was $36.4 billion and it is expected to

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increase, as the population ages, reaching $61.6 billion by 2020 [3, 4]. The current government policy is to promote healthy aging and prevent the occurrence of those events by giving the possibility to treat them at home, insuring the well-being, and, at the same time, getting economic benefits. Apart from long term prevention (e.g.: safer homes, physical activity and diet [5]), recent short term solutions use the combination of accelerometers and gyroscopes for detecting movements and body position, 300 ms before a fall, so that a wearable airbag can be inflated to prevent injuries [6]. More recent studies show that inertial sensor can detect fall 700 ms before impact [7]. Considering only noninvasive neuro-prosthetic devices, several Brain Computer Interface (BCI) devices use EEG to recognize the beginning of movements [1, 8], while EMG has been studied for artificial limb control in order to increase power strength and, in particular, only after the movement is started [9, 10]. Several researches have proved that voluntary EMG activity is preceded by preparation in the primary and supplementary motor areas, expressing the intention to move. This premotor signal, called "Bereitschaftspotential" (BP), starts about 1.0–2.0 s before the movement onset [11, 12]. The absence of this premotor signal shows the lack of intentional movement. However, the cortical implication during gait is still unclear, since the movement is largely automatic. Cortical EEG rhythms, as the mu-rhythms, may also change in term of synchronization over the bilateral central derivations, expressing the intention to move [13]. Cortical involvement in muscle activation during human gait was detected by means of coherence between EMG and EEG rhythms [14]. Moreover, co-contraction around the ankle during static balance challenges can predict performance on a dynamic balance test, and, consequently, fall risk. The detection of EMG-EEG features of normal walking opens interesting scenarios in fall prevention: once the monitor detects the beginning of a fall, a feedback system could avoid the occurrence of this event by an alert signal.

Our contribution starts from these studies. In this paper, we explore EEG and EMG signals synchronization for the detection of wrong movement occurrence, and for delivering a feedback command to correct the movement. Our study is supported by experimental results. Synchronized EEG/EMG signals have been acquired on voluntary people with a wired, medical equipment. The lower limb movement related to the BP spectral feature have been extracted and then used to recognize that i.e. the Tibialis Anterior contraction is intentional. We propose to take the benefit from such information and make use of a fast algorithm to drive an actuator to alert the person to correct the limb wrong position. Starting from this idea, a noninvasive wireless BCI architecture for preventing falls in elders at home, while performing normal daily activities [15], is proposed. The outlined architecture performs a frequency analysis to discriminate the BP signal. The paper is organized as follows: Sect. 2 describes the characteristics of EEG in case of voluntary (normal motor activity) and involuntary movement (fall). Section 3 shows the results of the proposed frequency analysis over measurements on an healthy subject by using a medical equipment. In Sect. 4 the novel measurement system architecture is presented in detail. In Sect. 5 the conclusions summarize the achieved results and offer ideas for future work.

2 Voluntary and Involuntary Movements

Generally, electroencephalographic (EEG) activities linked to a performing movement are referred as movement-related potentials (MRPs). Kornhuber and Deecke (1964) first studied activity preceding volitional movement in humans [16]. They named this signal as Bereitschaftspotential (BP). It is a measure of the activity in the motor cortex and in the supplementary motor area that leads to voluntary muscle movement. BP is a slow positive component (in medical treatments it is generally indicated as negative) that increases progressively appearing even 1–2 s before the voluntary movement onset ("early BP"). About 400 ms before the movement onset, BP gradient suddenly increases ("later BP"), reaching its peak about 100–200 ms before the movement beginning. The maximum amplitude of this signal is in the order of 10 μV. Typically, it is more visible in the midline centro-parietal area (symmetrically and widely distributed over the scalp regardless of the site of movement) contralateral to limb involved in the movement [17].

The onset of BP can be significantly different depending on movement conditions and subjects: i.e. a repeated action has a preparatory phase longer than a single movement. Moreover, automatic actions, like walking, could lead to less clear BP peaks. Early in the 1980s, MRPs were found to be also related to the rate of force development because of preparation and control of movements. Since then, investigations on the relationship between MRPs' behavior and force exertion have been intensified with observations regarding, for instance, fingers, elbow, and knees [11].

According to the International 10–20 System (see Fig. 1), the cited positions of major interest correspond to F_3, C_3, C_Z, C_4 and F_4 electrodes, and, particularly, midline for leg/foot movement. Typically, noise is subtracted from MRPs by averaging several trials of the same action because of its small amplitude. However, in our case we analyze the spectrum of single trials, comparing them to the features of the leg movement BP mean spectrum. More details about this approach are presented in the next section. BP is used for detecting the intentionality of muscle

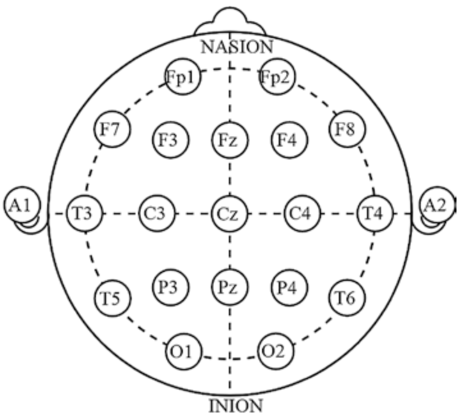

Fig. 1 International 10–20 system

contractions [17]: if a muscle contraction is sensed by lower limb EMG without the previous (about 0.6 s) presence of BP, this means that muscle contraction is due to an unintentional action so that a fall event can be detected.

3 Experimental Results: BP Detection

Here we describe the premotor and motor EEG signals on a healthy subject, male of 28 years old, performing right leg movements in a laboratory scenario. Twenty-one synchronized EEG/EMG signals were acquired with a wired medical grade bio-amplifier. The premotor signal covers a frequency band between 1.5 and 4 Hz, for the measured signal the full band considered for the EEG was of 30 Hz. The resolution of the amplitude generated by the medical equipment was of 100 uV/div (shown in Figs. 2 and 3). The sampling rate was 256 Hz. The premotor potential is defined as the maximum positivity in the interval of 200 ms preceding the regular movement detected by the EMG. The peak is evaluated respect to the maximum value reached by the EEG signal in absence of motor signal over the EMG. Pre-gelled electrodes placed on the Tibialis Anterior muscle and on Gastrocnemius muscle recorded surface EMG. The subject was told to raise and lower repeatedly his right foot with pauses of 10 s. Data were stored on a PC and analyzed numerically for identifying BP spectral features. The onset of movement was clearly on Tibialis muscle, so it was used as trigger point to detect typical BP lapse in time domain, as in Figs. 2 and 3. The channels of interest are F_3, C_z, C_3, Tibialis, Gastrocnemius before and after the Tibialis muscle contraction. A 100 μV amplitude threshold has been set for identifying the movement onset.

Figure 3 shows that early pre-movement positivity (early BP) starts 1.7 s before the onset of EMG of the right Tibialis Anterior extensor muscle and that it is maximum at the midline central electrode (C_z). Later BP starts 400 ms before the EMG onset and is much larger over the left central region (contralateral to the

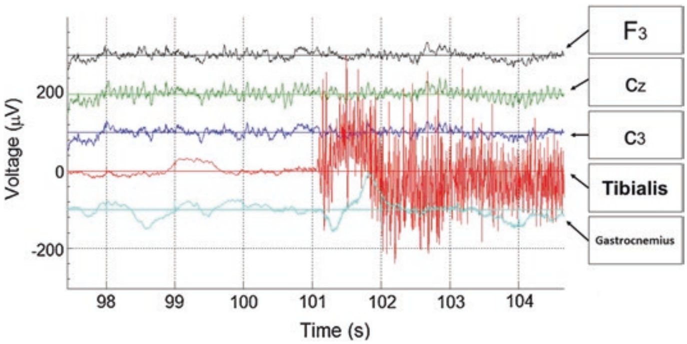

Fig. 2 Time domain comparison of F3, Cz, C3, Tibialis, Gastrocnemius channels

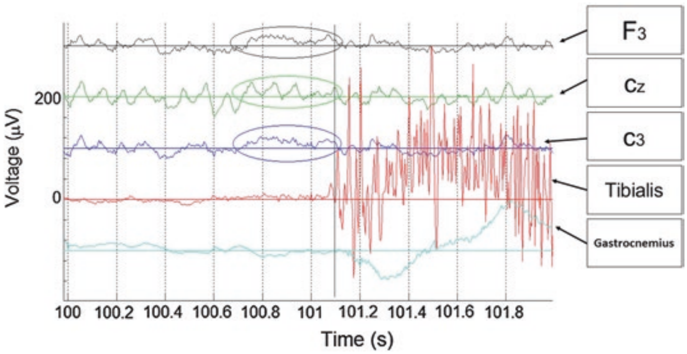

Fig. 3 Zoom of Fig. 2: in evidence the movement onset (EMG) and on the *top* signals the pre-motor positivity (EEG) inside the *circles*

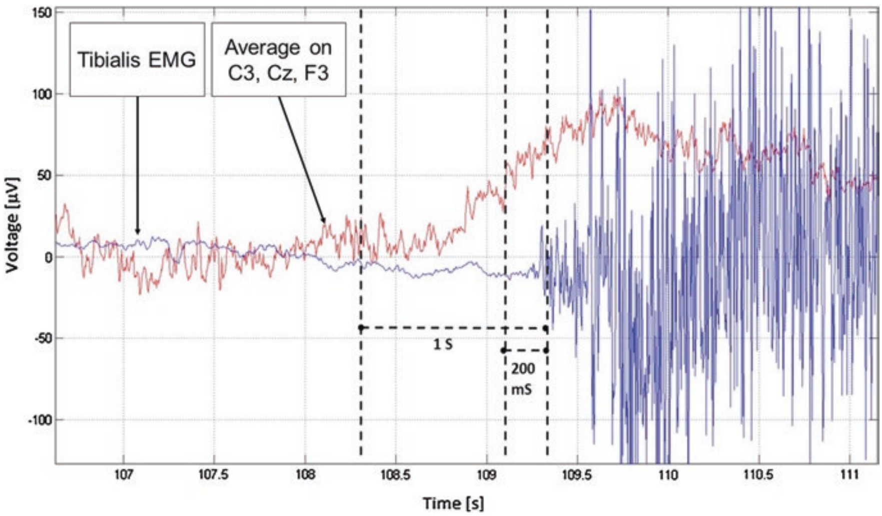

Fig. 4 Average over the C3, Cz, F3 EEG signals and the Tibialis EMG

movement). Figure 4 represents, from a different data set, the average over three synchronized EEG pre-motor potentials coming from the left C_3, C_z, F_3 electrodes and the correspondent Tibialis EMG signal from the right leg. The time width of the BP potential has been outlined: analyzing a time interval of 1 s before the movement: it is possible to clearly detect the BP as positive slope of 200 ms before the movement.

To get a better detection of the BP potential, we suggest performing a frequency analysis over the average. We employed the Fast Fourier Transform to estimate the spectra of signals, selecting a window of 1 s immediately before the movement onset. We obtained the signal spectrum showing BP bandwidth of 4 Hz with a spectral resolution of 1 Hz in the frequency domain.

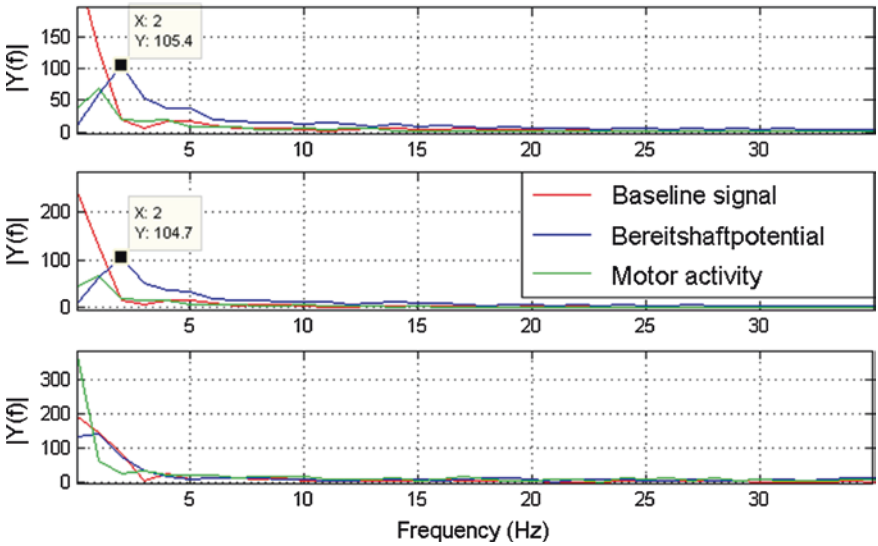

Fig. 5 Amplitude spectrum of C3, Cz, F3 channels

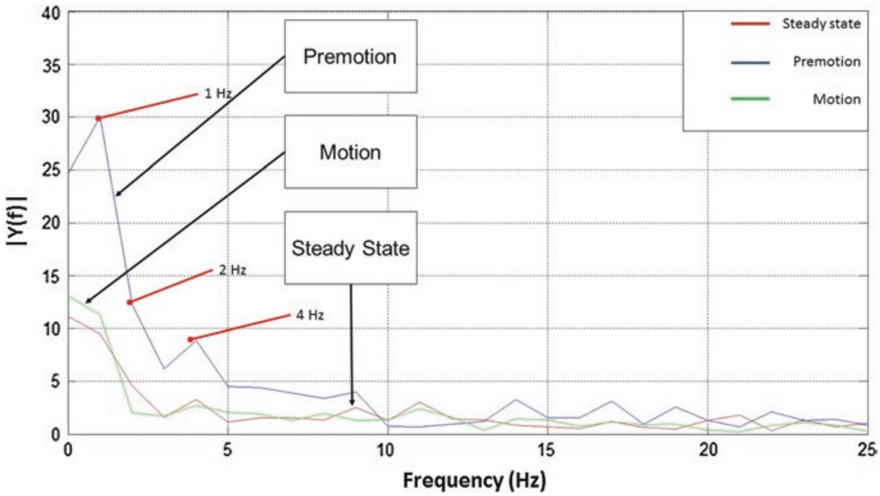

Fig. 6 Frequency analysis over the averaged EEG signal and EMG signal

A remarkable feature of the BP signal in all the selected channels (Fig. 5) or on the average of the three motor potentials (Fig. 6) is the peak of amplitude of the frequency components between 1 and 2 Hz: The maximum amplitude variation was about 30 dB. This difference is enough to identify if a contraction is preceded by movement preparation and allows faster detection respect the time domain analysis.

4 Wireless Monitoring and Control of the Movement

An overview of the proposed architecture is given in Fig. 7. The system architecture is split in two sections: the Wireless Body Area Network (WBAN) performing fast fall detection and the Wide Area Network (WAN) dealing with collecting, post-processing, and cellular network linking. The WBAN consists of the EMG/EEG smart electrodes communicating wirelessly with a mobile device equipped with a processing unit and detecting the fall. After processing, the device generates the feedback signals, if necessary to prevent the fall. The mobile device (e.g. a smartphone or a tablet or a full-custom device such as a "smartwatch") acts as a gateway node connecting the sensor nodes to the Internet cloud and processing raw signals in order to send them to a cloud storage system (Fig. 7) and to an actuator node. Stored information can be accessed by authorized caregivers' mobile devices for diagnostics. In the next subsections, detailed operations for those units are described.

4.1 WBAN: Sensor Node Architecture

Figure 8 illustrates the EEG/sEMG system architecture. The need of continuous monitoring of EEG/sEMG potentials calls for wearability and noninvasivity of the electrodes. This is possible by using wireless dry electrodes (0.5 × 0.5 cm) with embedded readout and communication electronics. Carbon electrodes penetrating only the epidermis without causing pain and bleeding [17] could offer a possible solution. Skin abrasion, gel treatment and hair wash are not required,

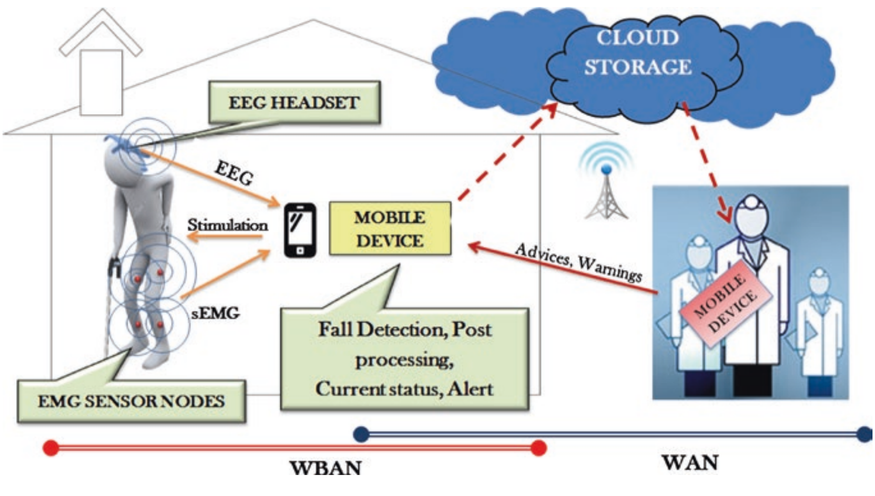

Fig. 7 System architecture

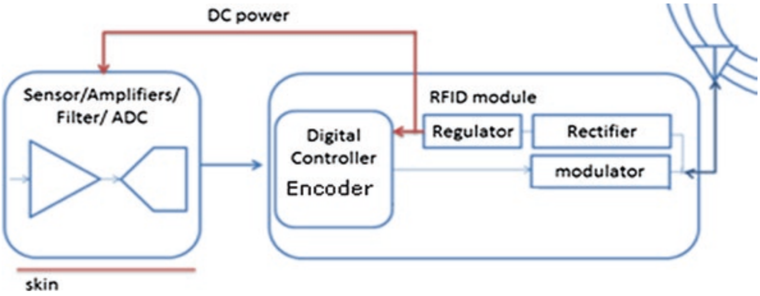

Fig. 8 Block diagram of EEG/sEMG smart electrodes

allowing rapid set-up time and reasonable comfort. Scalp electrodes are mounted on a headset according to the international 10–20 electrode systems. Bipolar and self-adhesive electrodes, whose area is less than 2 cm^2, record the surface EMG signal. For our application, leg electrodes acquire signals from Tibialis Anterior/ Gastrocnemius and Biceps/Quadriceps Femoralis.

The smart electrodes act as RFID passive nodes. Power can be supplied by the RFID transceiver. A rectifier circuitry has to be allocated on the electrode headset where also energy storage is possible.

4.2 RFID Transceiver and WAN

An RFID mobile device is the heart of this wireless noninvasive system. As shown in Fig. 9, this platform is managed by a control unit whose tasks are:

- to control BAN and WAN interfaces;
- to drive a fast Feature extraction processor and post-Processor;
- to store data in a memory;
- to manage the internal bus;
- to drive the input/output peripheral.

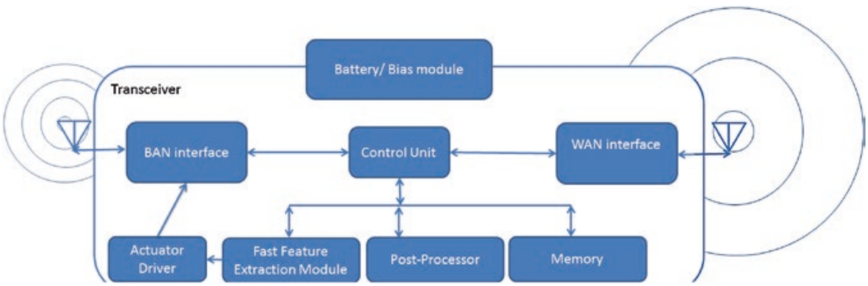

Fig. 9 The RFID transceiver architecture

The Fast Feature Extraction Processor (FFEP) receives raw EEG data from the channel sensing legs BP (typically those corresponding to supplementary motor area and motor cortex). It performs spectral estimation over 1 s length interlaced (every 0.3 s) blocks of samples. If the subject is intentionally moving a limb, approximately 0.7 s before the movement onset, a slight slope appears both in central and in contralateral C-electrodes signals. This gradient reaches a positive 20 μV peak 400–500 ms before the movement onset and its main spectral feature is a 2 Hz peak. If BP is recognized, then the FFEP controls if the EMG reveals contraction in the subsequent 0.6 s. Involuntary contraction—like in falls—is revealed when sEMG amplitude exceeds a threshold and there is absence of BP or of the Movement Related spectral feature in the previous 0.3 s. The FFEP transmits to the Control Unit an alert signal, so a feedback signal could be sent to the subject. The signal could be visual, acoustic or somato-sensorial.

The Post Processor acquires, organizes and compresses all raw data for subsequent cloud upload. It provides the possibility to perform other types of analysis at home, such as recognizing patterns in a subject who suffers from neurological diseases and alerting caregivers in case of abnormal EEG signals. The sensor node raw signals and the extracted features are stored and forwarded to cloud storage. Memory is used to store data until the end of packet transmission because of possible absence of the cellular network signal. The physician can have access to all this information by his mobile device/PC. All internet communications are performed via TCP/IP. The sensed signals from the body have secure and limited access both during wireless transmission and while stored in the cloud. In particular, only the doctor and close relatives can access the system database, for example, by vocal recognition. A simplified computation cost for feature extraction is now presented. Consider, for example, a 24 bit digital logic. A 1 s data block of N samples is stored to perform FFT. Every string in the frequency domain has N elements and 1 Hz resolution. (N/2)*log2 (N/2) computations are required for each block. Estimating the 2 Hz component amplitude and comparing it to a threshold requires at most 24 bitwise comparisons. Considering a sampling rate of 256 Hz (N = 256), the total operations are approximately 34,000. Considering 0.2 s as the maximum required time for feature extraction, the processor should be characterized by 170 k logging events per second. If each operation requires 4 clock cycles, the minimum processor frequency should be 670 kHz.

5 Conclusions

Applied neuro-engineering is capturing the attention of an increasing number of researchers given government policies in assisted living for welfare and health care. Nowadays, BCI systems, wired gelled electrodes and medical grade EEG/EMG instrumentations do not fit for daily use, because of their limitations and invasiveness in the normal life of the patients. Limitations are due to the presence of cables that do not allow their use during normal life: signals are corrupted by artifacts and by the environment while performing daily actions and cannot be simulated. A solution is offered by the real-time monitoring among wearable, wireless, ultra-low power, smart electrodes and a mobile device. This Wireless Body Area Network (WBAN) could use the mobile device also as a gateway for safe cloud storage for physician remote assessment.

In this paper we propose a wearable, wireless noninvasive neuro-prosthetic system based on the combination of EEG active dry electrodes mounted on a light headset and surface EMG sensors that do not require skin treatment. The proposed system, here described as a possible architecture, allows fall detection in daily scenarios using a combination of online continuous EMG analysis and the detection of presence or absence of Movement Related Potentials (MRPs). We also found that the analysis of the signal in frequency domain is more suitable. The measurements on a man of 28 years old shows that the absence of MRP can be detected by spectral estimation. The bandwidth of the BP is less than 5 Hz. The peak is around 1–2 Hz. The time slot to be investigated is of 1 s before the EMG activation. Once the BP is not observed, the movement can be considered not voluntary and then the proposed system can supply a feedback signal to the patient in order to prevent the fall. The feedback (acoustic, electrical or mechanical) signal supplied to the patient will be the subject of future investigations.

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AAL Technologies for Independent Life of Elderly People

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Abstract Assistive technologies have the objective to improve the people quality of life of in daily living, with a special aim to those who suffer of physical disabilities or cognitive impairment, which may be caused by an accident, disease or the natural process of ageing. The present paper describes the main results of a study realized for the INTERREG IVC INNOVAGE project, where the domain target addressed are: home and building automation and assistive robotics. The project provides a quick overview of the typical needs of elderly people, describes

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the state-of-the-art technologies which can be adopted to satisfy these needs and presents a critical analysis of the functionalities, which present and future assistive technologies should possess. The result of this study is a detailed assessments of requirements and limits of nowadays domotics and robotics technologies aimed to improve people quality of life.

1 Introduction

The use of technology to improve the people quality of life is becoming a common trait of modern societies. Quality of Life (QoL), however, is not easy to define, since it is an elusive concept connoting a multidimensional appraisal of a variety of important aspects of life [1]. The wider this variety is, the more difficult is to give a single definition which includes all possible technological solutions related to it. For this reason Quality of Life Technology (QoLT) is generally defined as any technology which impacts the QoLT of individuals who are using it. When addressing people with special needs, the definition of QoLT usually becomes more specific. It refers to intelligent systems that augment body and mind functions for self-determination of older adults and people with disabilities [2], which is basically an alternative definition of Ambient Assisted Living (AAL) technology.

AAL is typically classified according to the functional domain targeted, and might include safety systems, medical devices, telemedicine platforms, assistive robots and many others [3–6]. The present paper provides an overview of the typical needs of elderly people, describes the state-of-the-art technologies which can be adopted to satisfy these needs and presents a critical analysis of the functionalities, which present and future AAL technologies should possess. More in detail, the following domain targets are taken into account: home and building automation and assistive robotics. The analysis presented in this paper is part of a pilot action realized within the INTERREG IVC INNOVAGE, which aims to foster innovation processes for small and medium regional enterprises in the sector of assistive technologies for the elderly. The choice of the domain targets is thus related to the themes addressed within the INNOVAGE project.

The document structure is as follows. In Sect. 2, a short description of typical needs of elderly people is given. Section 3 provides an overview of the technologies which can be adopted to satisfy those user needs and improve an active and independent life of the elderly. In Sect. 4 the main characteristics which should be possessed by AAL technologies are detailed. Section 5 presents a selection of the previously addressed technologies, with a full description of functionalities and problems to be dealt with in the near future. Conclusion and future remarks end the paper.

2 Study and Analysis of Elderly People Needs

According to Maslow's theory, human needs can be classified in a hierarchy model [7]. When this model is applied to the needs of the elderly, it shows five areas that contribute to quality of life for the ageing, while the common health care focuses on longevity of life. Longevity is no longer the unique aim for the elders, but today it must be coupled with a high quality of life. Having a good amount of awareness about special needs of the elders, can have a direct impact on their health and welfare. Moreover, the knowledge of the elders' needs can help, not only elderly, but also family and caregivers in achieving the highest level of satisfaction, self-esteem and self-actualization. From Maslow hierarchy model, the special needs of elders could be resumed as follows [8]:

- *Physiological needs*—All people needs, no matter their age, start with the common physiological requirements. Food, drink, shelter, sleep and treatment of illness and injury are fundamental to survival.
- *Safety and security needs*—Once physical survival is safeguarded, attention has to be paid to safety and security. This is especially true for the elders who usually have to remain at home, alone and for long time.
- *Social needs*—Humans need to be social and dislike feeling isolated or cut off from others. Due to health issues or lack of ability to get out, the ageing often find their social opportunities shrinking and they spend more of their time alone. The elderly need opportunities to become involved socially with family, friends and the community.
- *Self-Esteem needs*—The elderly, like all people, want to feel recognized and appreciated for their ideas, abilities and talents. The elders need to do something or to have sought-after opinions to be considered worthwhile. The ageing often lose their sense of worth when illness, disability or frailty limits them.
- *Self-Actualization needs*—The self-actualization is a status reached by relatively few people and those who do share some common traits. They tend to concentrate on the reality of life, are problem solvers and also have a viewpoint that their life's journey is just as important as their final destination. With all the experience of life and maturity, the elderly should be prime candidates to reach self-actualization. Yet the process of ageing often strips our elders of the higher levels of the self-actualization, self-esteem and social connection, leaving today's ageing just hanging on to the lower levels of survival.

The new technological AAL systems have great potential for compensating for age-related impairments. Emerging ambient assistive technologies present a considerable potential for enhancing the quality of life of many elders by providing additional safety and security while also supporting mobility, independent living, and social participation.

3 AAL Technologies to Support the Independent Living

The analysis conducted in the previous section led to a set of thematic areas related to specific needs which can be (partially or totally) satisfied using AAL technologies. In the following, a review about assistive technologies is presented and divided into categories, highlighting the development stage for each one.

3.1 Physical and Psychological Well-Being

The technologies for physical and psychological well-being have heterogeneous characteristics. These technologies are classified in the following main technological areas:

- *Environmental systems* for monitoring (cameras, laser sensors, presence sensors, bed sensors, etc.);
- *Wearable multi-sensory systems* for monitoring and measurement of physiological signals (chest belts, bracelets, etc.);
- *Intelligent robots* for continuous home care and activity monitoring.

The *environmental systems* for human activity monitoring are based on exteroceptive sensors, that ensure a simultaneous monitoring of user and environment. They are not physically invasive for users, but nevertheless they can have a negative influence on their privacy. The most commonly used technologies are: Red Green Blue (RGB) sensors like those used in common video cameras, RGB-Depth (RGB-D) sensors like those used in kinect cameras [18–20], laser scanners, bed sensors, occupancy sensors, etc. They allow to monitor the users' lifestyle in order to recognize the occurrence of possible alterations in their daily habits as well as sleep disorders. These anomalies are often crucial for early diagnosis of diseases such as cognitive impairment. Although the number of vital parameters that can be acquired by these systems is limited, they allow a correlation among the measurements of such vital parameters and environmental parameters.

The *wearable multi-sensory systems* are based on proprioceptive sensors, which allow the monitoring of the daily activities and measurements of physiological signals. They are more invasive than exteroceptive systems, though they do not negatively affect privacy. The most commonly adopted technologies are: accelerometers (three axials), gyroscopes (three axials), galvanic skin response, body temperature and oximetry sensors. For the best monitoring of vital parameters, it is desirable an interaction between the two systems (e.g., environmental and wearable), which requires a dedicated communication channel. In this way, the acquired data are then processed by a dedicated telemedicine system.

In the field of *intelligent robots*, there are various types of mobile robots to support the physical and psychological well-being of the elderly. Typically, these robots are based on wheeled platforms and are equipped with vision sensors,

Table 1 Technologies for physical and psychological well-being support

Needs	Project	Description	P/C[a]	References
Monitoring and maintenance of lifestyle	DOMEO	Personal robot	P	[9]
	FLORENCE	Home care system	P	[10]
	IROBOT	Robotic vacuum cleaning	C	[11]
	TURTLEBOT	Personal robot	C	[12]
	SENSERWEAR	Multi-sensory band	C	[13]
	PerMMA	Wheelchair with manipulators	P	[14]
Supporting cognitive activity	MAMORU	Supporting memory robot	P	[15]
Monitoring of vital signs	Zephyr BioHarness	Sensorial chest strap	C	[16]
	ZydaDoc	Tele-monitoring system	C	[17]

[a]*C* commercial product, *P* prototype

microphone, speaker and display to interact with the surrounding environment. They provide a dual type of assistance: passive and active. Passive assistance means to monitor the users, support them on finding a lost object, and provide secretarial functions like reminding of the day's commitments. Conversely, active assistance regards the robot's ability to autonomously interact with elderly people by proposing a series of activities that can stimulate both their mind and their body (such as games, cooking support, etc.). Mobile robots can be classified according to the different tasks that they perform, [21]: home care, human activity monitoring, cognitive impairment and unconventional pet therapy to improve social condition of the elderly people. Table 1 summarizes the most significative technologies currently employed.

3.2 Sociality

Sociality is a key factor for the psychological well-being of the elderly and it can be supported by common smart systems. Some software companies are developing innovative social networks in order to involve even special users as elderly.

Their main function is the video-call with friends and family. Moreover, these social networks will include group activities (community) such as card games, to increase social relations among users of the same age. Users can access to these services by using common PCs or ad hoc interfaces integrated with the robotic platforms; for instance, a social assistive robot, or rather robots developed for communication with user, without physical interaction [22]. These ones are typically used in behavioural therapies in substitution of human educators, or for unconventional pet therapy. Table 2 summarizes the main technologies to support the social relations of the elderly people, reducing their social isolation.

Table 2 Technologies for social relations support

Needs	Project	Description	P/C[a]	References
	PARO	Robot for pet therapy	C	[23]
	AMSCOP	Manager devices with user-friendly interface	P	[24]
	NAO	Man-like robot for education therapy	C	[25]
	COMPANIONABLE	Home care system	P	[26]
	PIENI PIIRI	Video-call system for ageing	C	[27]
	PEPPER	Social robot able to converse with people	C	[28]

[a] *C* commercial product, *P* prototype

3.3 Mobility

The physical mobility of elderly people is of outmost importance since it is strictly related to autonomy and sense of independence. In this field the assistive devices can be classified into following activities:

- Mobility in outdoor and indoor environments;
- Ambulation;
- Accessibility to public transportation/infrastructure;
- Physiotherapy rehabilitation.

The *mobility in indoor and outdoor environments* of elderly people can be simplified by the use of assistive mobile robots, which can provide assistance to the user and are able to move independently. They allow the autonomous and/or semi-autonomous movement of disabled people within known and/or partially-known environments [29, 30]. These kind of technologies are made up of various parts, such as motorized wheelchair, proprio/exteroceptive sensors, electronic control, software control and intelligent user interface.

Regarding *ambulation*, innovative robotic solutions can adapt to the user posture and speed, in order to improve his/her comfort [31]. In addition, they have mechanical structures which are able to facilitate the mobility of the elderly on a variety of terrains, and thus to provide assistance even in outdoor environments.

Concerning the *accessibility to public transportation/infrastructure* aspect, the latest technologies provide useful services that can improve security and well-being of the elderly travelling whether by car or by public transport. Smart mobile devices are widely used. They can interact with the user through a voice mode in order to avoid the driver distraction or disorientation. The use of these devices is quite simple, in fact they only require some simple information about journey, such as the place to get to and the arrival time, while the path is scheduled automatically by the system.

Finally, the last field on mobility regards *robotic physiotherapy rehabilitation*. Robotic rehabilitation has introduced substantial benefits to both the patient and the physiotherapist. Specifically, the robotic rehabilitation is able to emulate the

Table 3 Technologies for supporting of mobility

Needs	Project	Description	P/C[a]	References
Mobility in outdoor and indoor environment	RADHAR	Assistive navigation system	P	[32]
	ASSAM	Automatic steering system	P	[33]
	HLPR CHAIR	Electric wheelchair with lift	P	[34]
Deambulation	IWALKACTIVE	Active walker device for elderly	P	[35]
Falls detection/ prevention	FATE	Wearable fall detection device	P	[36]
	AUTOALERT	Wearable fall detection device	C	[37]
	CARE	Visual system for falls detection	P	[38]
Mobility in ambient urban	ASSISTANT	Urban guide software	P	[39]
	ICITYFORALL	Support system to driver	P	[40]
Physiotherapy rehabilitation	TITANARM	Exoskeleton for upper limbs	P	[41]
	GENTLE/S	Rehabilitation system for limbs	P	[42]
	REHAROB	Robotic rehabilitation for limb	P	[43]

[a]*C* commercial product, *P* prototype

physiotherapist's treatment in order to be practiced autonomously at home. The last prototypes consist in exoskeletons wearable by the patients, for helping them in the recovery of the limb motor ability through the simple actions of domestic life [44]. The latest studies on exoskeleton materials are aimed at reducing the weight of the exoskeletons structure making them less invasive towards the patient. Table 3 summarizes the main technologies for supporting mobility of ageing people.

3.4 Environmental and Personal Safety

The environmental and personal safety technologies can be included in the wide field of the smart home. The traditional smart home functions are typically divided into: active safety, automatic systems, micro-climatic system and energy management. These functions can be oriented towards assistive aims, so they are included in the assistive smart home, as a specific field of the smart home. It integrates, implements and coordinates assistive technologies in order to facilitate the compensation of residual skills [45]. In spite of these purposes, the home automation system is based on the detection of parameters and environmental events, such as:

Table 4 Technologies for environmental and personal safety

Needs	Project	Description	P/C[a]	References
Domestic control and home security	CANARY	Device network for home security	C	[46]
	SAVANT SYSTEM	Home remote monitoring	C	[47]
	DOMINA	Anti-intrusion alarm system	C	[48]
Smart Home	GLOUCESTER SH	Home for users with mental disease	P	[49]
	MILLENIUM HOME	Home with lifestyle monitoring system	P	[50]
	PROSAFE	Home with motor behaviour monitoring	P	[51]

[a]*C* commercial product, *P* prototype

- danger signals related to the environment (e.g., leave the tap running, etc.);
- behavioural alarms, or rather the detection of dangerous events that may happen to the people (e.g., fainting or falling);
- activation of multisensory signals (see what it is normally heard and hear what it is usually seen).

Table 4 summarizes the main available technologies to guarantee safety in home environment.

4 General Requirements of AAL Technologies

The QoLT definition as state in Sect. 1 is elusive, thus it is difficult to precisely delineate the characteristics that the above mentioned technologies should have in order to be considered as “assistive”. Though remaining within a framework of partial subjectivity, some fundamental functional requirements are provided, which are applied to technologies to be used in the assistive field.

4.1 Design for AAL

A technology to be truly accepted, it should be developed to meet the needs of a wide group of users, or rather it is necessary that it satisfies the standards of the Design for All: “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” [52].

4.2 Low Invasivity and Privacy

The contact technological solutions should be non-invasive, in order to not cause drawbacks that may negatively affect the usability of the technology. Both in the case of active technologies, and in the case of passive technologies, it is essential that the users' personal data are kept confidential by secure protocols, while data acquisition should not violate the user's privacy (monitoring solutions by audio/video capture would be typically avoided).

4.3 Simplicity of Use

The user interface is the communication system between the technology and the person who uses it. It should be simple to use as described below:

- simplicity from a cognitive point of view: the operations of input (from user to technology) should be easy to understand, and they require a minimum of training time; similarly the output operations (from technology to user) should be easily intelligible, and they do not require particular know-how for their good understanding and interpretation;
- simplicity from a physical point of view: the interface should be easily accessible and, preferably, it should allow the use with different stirrings (e.g., tactile, auditory and visual) in order to facilitate interaction even for subjects with physical disease.

4.4 Integrability with Existing Environments

AAL technologies oriented to a weak user should ensure two levels of integration:

- integration within existing structures: AAL technologies should adopt wireless communication in order to do not require invasive interventions;
- integration with other technologies: AAL technologies should be able to communicate with standard protocols to grant compatibility with the highest number of possible technologies.

5 Functional Requirements and Limit of Use of Selected Technologies

In order to analyse the desirable functionalities of the technology to come, authors choose a subset of AAL technologies which covers most of the needs addressed in Sect. 3, while remaining at the same time within the specific themes of the

INNOVAGE project. The present section does not aim to provide a full coverage of AAL technologies, however it represent a good cross-section of the requirements and the typical functions and limits of use of AAL technologies. More in detail the analysed technologies are: personal robots, assistive wheelcharis, personal monitoring, fall detection and assistive domotics.

5.1 Personal Robots

Personal robots are mobile and autonomous systems which can be integrated with home care services and dedicated to assist elderly people, both at cognitive and physical level [53]. This technology has a degree of artificial intelligence that allows the execution of multiple features, in addition to an appropriate interaction with the user. The assistive robotic platforms are available both at prototype and pre-commercial stage. To consider an assistive robotic platform as innovative, it is essential that it satisfies the widest possible number of functional requirements, and provides the solution to at least one of the limits of use among those listed below.

Functional requirements	Limits of use
• Video-call functionality • Training cognitive abilities • Secretarial services • World news services • Displaying family photos • Recognition vocal command • Home care services • Emergency management • Sharing information robot-home	• User identification among different people • Recognition vocal command on noisy environments • Localization and navigation problem in case of a changing environmental layout • Identification of the user when his/her orientation with respect to the robot changes • Robot design is not yet able to satisfy the criteria of good usability and acceptability of the user • Difficulties in the production of low-cost solutions (less than 1.000,00 €)

5.2 Assistive Wheelchairs

The traditional wheelchairs are among the most common health care systems. In recent years, electric versions have spread rapidly and several prototypes were designed to ensure a high capacity of autonomous or semi-autonomous navigation [54]. The wheelchairs are available both at prototype and commercial stage, even if the systems with assisted navigation are only at the prototype stage yet. Below a set of functional requirements are reported we report the functional requirements list that a smart wheelchair should possess, as well as some limits of use already present on traditional ones and that could be overcome in the new generations of wheelchairs.

Functional requirements

- Obstacle avoidance
- Autonomous navigation indoors and outdoors
- Simplified user interface
- Override manual interface
- Block security system in case of accidental shove

Limits of use

- Overcoming architectural barriers
- Limited integration with home automation platforms and current navigation systems

5.3 *Personal Monitoring*

The monitoring systems include wearable and ambient sensors. Their main scope is to monitor the user's habits and health in order to detect anomalies [55, 56].

The wearable sensors for the recognition of daily activities consist of low power multi-sensor systems placed inside the clothes or accessories appropriately worn by the user. The sensors are equipped with a radio interface useful for the transmission of acquired data to medical service centres [57].

The ambient sensors realize a distributed sensor network in a domestic environment, since a unique sensor is not sufficient to accurately detect an event.

Such systems exist both at prototype and commercial stage and their characters are shown below.

Functional Requirements

- High range of detectable activity: heart rate, respiratory rate, body temperature, galvanic skin response and dissipation of body heat
- Integration of the system with tele-health platform
- Warning of abnormal human behaviour

Limits of use:

- Limited integration with existing domotic systems
- Invasive installation
- Limitations of correlation among proprioceptive and exteroceptive data

5.4 *Fall Detection*

Fall detection systems consists in both environmental and wearable multi-sensory technologies which work together in order to detect and warn a fall in the monitored environment. The most complex technological aspect of fall detection system is to distinguish a fall from a normal change of posture respect to the upright position.

These systems are available both at prototype and commercial stage, and their functional requirements and limits of use are shown below.

Functional Requirements

- It forwards emergency requests to medical centre by autonomous or manual way
- Gateway device guarantees the operation of the system even in case of temporary outage
- Wearable devices should be waterproof
- It should store the data of fall, so to allow a better clinical diagnosis

Limits of use:

- User should not wear any extra instruments
- Non invasive device must protect the user's privacy
- Some devices have buttons which are not easily usable by patients with osteoarthritis

5.5 Assistive Domotics

Assistive domotics is typically realized through motorized furniture and smart appliances. The former allows to reach objects placed in locations not easily accessible for people with reduced mobility. The second can be considered as "smart objects", that in addition to their "classic" function, are also able to perform advanced functions such as integration and communication with the home automation system.

In order to consider these devices as innovative solutions, it is essential that they satisfy the widest possible number of functional requirements and provide a solution to at least one of the limits of use among those identified below.

Functional Requirements

- Motorized furnitures can be integrated in cabinets or in kitchen to lower hanging rails or adjust the shelves
- Refrigerators can recognize foods and are able to signal their lack
- Washing machines can automatically recognize the type of laundry and the degree of soiling

Limits of use:

- Motorization is typically very slow
- Invasive installation
- Appliances should have a policy to remove non-priority loads leaving in operation the most important devices for the person at that moment

6 Conclusions

The present paper provides an overview of the needs of elderly people, a description of the state-of-the-art technologies which can be adopted to solve them, and a critical analysis of their pros and cons. The overview of the user needs is based on data provided by the national and regional statistical system, while the technology description is based on a research of products and services which are available both as research prototypes and commercial solutions. The critical analysis highlights the functionalities which should be possessed by today technologies in order to be considered as "assistive technologies" and provides an insight on those functionalities which are now not possessed by current assistive technology, or partially possessed at the research level only, but should be taken into account for the assistive technologies of the future.

Even if the authors tried to be as objective as possible, the provided analysis should be considered partially subjective. The readers should remind that the sector of technologies for supporting an active and independent life of the elderly is a research subject at international level. Moreover, it still represents a young market, fastly growing and highly differentiated according to the different geographic areas. Thus, the category of technologies which can be used to satisfy the user needs, is not unique, as well as the functionalities that such technologies should possess at the present state or in a near future. It is in the authors opinion however, that the presented overview of user needs, description of state-of-the-art technologies and critical analysis represent a good synthesis of nowadays ambient assisted living technology.

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Part VI
Living with Chronic Conditions

Giving Voice to Images: Audio Description and Visual Impairment: Technological Solutions and Methodological Choices

Stefania Pinnelli and Andrea Fiorucci

Abstract This paper proposes a reflection on issues related to Audio Description: an additional narration track intended primarily for blind and visually impaired people of visual. Starting from the analysis about the users' needs, the paper proposes a comparison between three types of technology solutions, taking into account and evaluating, in a perspective of social inclusion and Ambient Assisted Living, their strengths and weakness.

1 Cultural Policies for Inclusion and Accessibility

According to the World Health Organization, a disabled person is any individual with limited ability or inability to perform daily activities. In ICF the Functioning and Disability are understood as "umbrella terms denoting the positive and negative aspects of functioning from a biological, individual and social perspective" [31]. The social and environment components can become the most important factors that can transform a disease in disability. Accessibility is not the creation of specific areas reserved to disabled people, but rather one mode of rethinking systems and environments, which can be used by all [31].

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It is necessary, therefore, to invest efforts in the research and development of accessible device through the perspective of a universal design. Accessibility besides to indicate the usability level of an environment, a good or a service, also refers to the virtual barriers and to the difficulties faced by different types of users in the management and use of the technologies. The cultural perspective of the accessibility concept refers, firstly, to a model of inclusive design of cyberspace, that takes account of the plurality of users' needs and gives the same services and the same interaction and participation spaces in compliance with criteria and official guidelines (www.w3c.it) and foreseeing the use of the assistive technologies. In addition to this first aspect, there is function that technologies play to improve the inclusive capacities of social contexts, turning them into participatory and interactive contexts. The design for all, also called *universal design*, began focusing on physical aspects (buildings, urban spaces, transport, health, leisure), and nowadays is extended to the digital world (computer networks and communication systems). In this perspective, accessibility is defined as "a condition for use with security and autonomy space, furniture and urban facilities, the buildings, transport services and devices, systems and media and information for people with disabilities or reduced mobility" [7]. The right to accessibility of an asset or service must be ensured equally to all citizens. It follows that the needs of people with difficulties must be taken into account in designing a strategy for the development of an egalitarian society, to avoid creating, even in "virtual contexts", new forms of social exclusions.

Within the European Disability Strategy 2010-2020 the *accessibility* is a precondition for participation in society, the second key words on which the Document points the attention is Participation: there are still many obstacles preventing people with disabilities from fully exercising their fundamental rights [1]. In the cultural sector is an important milestone was reached in 2003 with the *Resolution of the Council of the European Union on May 5* on equal opportunities for pupils and students with disabilities in education and training. It relates to the access of disabled persons to infrastructure and cultural activities and devotes specific attention to the role of new technologies in this action. More and more legal regulations in relation to media accessibility are being passed now, e.g. the Audiovisual Media Directive 2007/65/EC which requires implementation in the various EU Member States [10].

Even the world of art and cinema make use of language and means of expression that are often inaccessible or hardly accessible: for example blind and deaf people have several difficulties when they want to "see" or "hear" a film or a theatrical performance. In a society basically anchored to the visual content as a source of information, entertainment and education, people with a severe impairment or absence of vision are likely to be culturally and cognitively disabled [6]. For some time, museums and art galleries offer verbal descriptions (audio guide) of paintings, sculptures and other parties combined visual, often, a "touch tour", in order to give the blind the opportunity to access the art world, chance thwarted by the, by now too well known rule of "see, but not touch". Compared to audiovisual content (TV shows and movies) or artistic- performances (dance, theater etc.). The social context is even less "attentive" to offer concrete answers to the needs of visually impaired people. The problems of Web data, digital data, broadcasting and cinema product accessibility, and usability for blind users have become an active research field for the past decade. In recent years there has been witnessed a proliferation of efforts aimed at making audiovisual programs accessible to people with visual impairments through audio description (AD) [19]. ICTs, domotic technologies and anything that could be Ambient Assisted Living (AAL) and Assistive Technologies (TA) are undoubtedly an excellent opportunity to improvement in the person's life, especially for those who live in situations of disadvantage, disability, illness and aging [21]. Smart houses and living environments have been designed to meet this needs becoming today an area of very active research. There are several main applications of the AAL, but one nearest to the scope of study of AD is the one to make your life easier by compensating their disabilities through home automation or other technology. AD, therefore, can be a valuable tool to meet the needs of the users with gradual or total loss of visual acuity, but also of older people that due to a deterioration of view or sometimes cognitive they need a voice/audio support.

2 AD: Characteristics and Aims

The first audio descriptive support is the human one: blind ask for significant people (family, friends, spouses) questions about visual elements. If the *whisper mode*, as defined by Snyder [23], on the one hand makes request for help spontaneous, on the other hand doesn't release the person with visual disability by dependence.

In recent years there has been a proliferation of initiatives designed to make accessible the audiovisual messages [19], through a technological process called audio description (AD): assistance and support service, composed by a set of techniques, methods and skills whose main goal is to reduce the visual deficit by making accessible any visual message with appropriate audiovisual substitute information in relation to the specific needs of potential users. It is a voiceover, aimed at describing aspects of audiovisual products that are not accessible: visual component (shares, body language, facial expressions, setting, clothes/costumes). Everything that is used to refer to the "visual world" is made accessible by a verbal description that fits between the dialogues, does not overlapping to the significant music and sound effects.

AD may include information about actions, change of scene, text appearing on screen to the descriptions of the characters, their movements and body language, the explanation of the sound effects, etc. [17, 29].

It formed by several audio comments: narrative captions that are generated in order to decode the silence moments of the audiovisual to make them accessible to the blind. Audio comments, subject to restrictions of time (time codes) required by the parent track, merge into a script (cloth) which is subsequently read by a professional narrator and recorded by audio technician. Recordings of audio commentaries, associated with the respective silence moments of the audiovisual, give life to the new audiovisual product audio described. From a theoretical point of view, AD can be defined as a specific form of inter-semiotic, inter-modal or cross-modal translation or mediation [2, 5, 13, 16, 18]. AD, however, can be regarded as an act of translation not entirely pure, because it does not determine a direct passage between two equal semiotic codes. For this reason, scientific community [9, 27], when it relates to this particular act of translation, uses of the umbrella word *accessibility*.

OFCOM guidelines [17] drawn up by the *Independent regulator and competition authority for the UK communications industries* are the coordinates and operating recommendations to make AD. They are a result of a long process of empirical research with blind people: they are seven steps.

Step 1 Choosing Suitable Programmes for Description
Step 2 Viewing the Programme
Step 3 Preparing a Draft Script
Step 4 Reviewing the Script
Step 5 Adjusting the Programme Sound Level
Step 6 Recording the Description
Step 7 Reviewing the Recording

3 AD: Educational Potentialities

Studies about AD conducted in recent years, have focused on the evaluation of the benefits that such support may have about: **learning processes**, **mentalistic abilities** and **social inclusion** [12].

Learning processes. According to Vygotskij [30] the sensory deprivation produces a functional re-organization: blind people activate vicariant processes aimed to knowledge construction. They should follow a path much longer and harder order to build the world of objects, give them a name and give them quality and actions of which he hasn't direct experience. Language is considered the compensatory tool most functional [3] because through it blind can see what is happening. Blind people, like everyone else, build mental models to represent the world around them, abstract concepts or sequences of events and use them to give an explanation to its events to understand their experiences and cope with the new situations.

AD can: generate, through few words but carefully chosen, long-lasting and clear images in the mind of blind, in particular through the use of new vocabulary, comparisons and simple metaphors, thus facilitating learning and by improving their skills language [24]; can help to develop or acquire new visual knowledge especially for those who are blind from birth [14, 15].

Mentalistic abilities. The view, therefore, is the preferred channel to access the mental life of the other and its absence, or severe impairment, generates a delay in the development of Theory of Mind or mentalistic abilities [4, 11]. Some studies confirm that blind people have a solid verbal memory [28] with high compensators potentialities [22, 26] and that memory takes lifeblood by language because it turns dark into word.

Social inclusion. Television is one of the main sources of information, education and entertainment for citizens. Lack of accessibility can lead to the large scale social exclusion of people with vision impairments and other disabilities. Conversely AD can become an inclusive tool: it can transform a movie theater, a lounge projection, a multimedia classroom into cultural places for all. Therefore AD may promoting a sense of independence, equality and participation.

4 Implementig AD: Technological Approaches and Methodological Differences

The three approaches, that will be presented, have been chosen on the basis of three distinct experiences applied research carried out in the last 3 years, at the working Group of the Center for new technologies for disability and inclusion at the University of Salento. They are: the post-post production of the AD on the audio track of the film; the Movie Reading system and the technology of text to speech conversion.

Any work of AD, should observe three fundamental principles: (1) Respect for the work that you are describing. AD should try to preserve the atmosphere of audiovisual products while preserving the pace and adapting the description to the genre and style of the original; (2)Respect for the user. AD must consider the heterogeneity of users [14]; (3) Respect for the objectivity. The AD must not impose an emotional connotation but verbalize what appears on the screen without interpreting it.

We analyze three approaches:

Post production work. This approach involves an assembly work in the post post-production of a film already edited and on which the working group writes, calibrate, adjust and add the audio track of the AD. Construction of an audio described using that more traditional approach happens within a process of research and experimentation that provides different stages of post-editing. The process of AD is very large and complex and it requires inevitably a team work. The collaboration of a blind person is crucial. Using this approach has been realized, from research group in the 2011 the AD of an audiovisual for children: *Kirikou et la sorcière*, written and directed by Michel Ocelot in the 1998 [20].

This approach allows you to create AD very accurate and understandable by a wide audience, or for a targeted audience (for example, children as in our case), allows to treat all the elements of intonation, prosody, conceptual clarity related to the hermeneutic dimension of language and, therefore, it is particularly suitable in AD aimed at processes of learning and promotion of language development. This approach consists in fact a single track with images, audio and AD, the product is usable on all devices, free from particular technical requirements and devoid of issues related to sync, remote controls, specific requirements of the operating system. However, it is expected a long time to manufacture, and therefore higher costs. This approach also raises a fundamental problem: the copyright. Another element that in some cases it may be considered a disadvantage, but in most cases it was considered, as our research argues, an advantage for understanding, storing information and attention [20] is the fact that the entire audience, the blind and visually impaired, uses a film with audio description.

MovieReading system. A second solution is the application MovieReading, it allows to go to the cinema and search on your smartphone or tablet subtitles (for deaf people) or tracks AD (for blind people) of the film screened in room. In fact, the process of production reduces the steps compared to the previous solution, requiring a dialogist that plays the movie and write the dialogues for AD; checking recursive comparison with the blind person to validate the quality of the message, then proceed to the registration of dialogues in a separate file for MovieReading. The recorded track is tagged by the system in a few points allowing you to synchronize the audio of the film. MovieReading "listens" to the audio of the movie through the microphone and is able to identify the exact point of the movie you are watching, synchronizing AD and/or subtitles. The AD of movies are downloadable, with a small cost (about € 2), with a specific APP for I Pad, I Phone, tablet and smartphone.

Using this system has been made the AD of "The Great Beauty", Oscar-winning film in 2014 on which we have done a workshop to test the effect on the public with visual impairment and not (http://goo.gl/BeabWA). In this experiences has been possible to assess the MovieReading App: it is a quite good solution and is an Italian product but it needs to be improved in functionality to sync the sound track audio described. The advantages of this type of solution resides in the first instance in the reduction of costs and the use of copyright the original film . In fact, the user purchases the AD and this allows him to re-use that track as many times as you want . It 'also the reduction of costs for staff involved in the development of AD, lacking the entire post post production, audio-video presentations on the film. Each AD can be done with about 1.500/2000€. One problem is that the purchased track to sync with the original track of the film, it needs a sound quality similar to that of the cinema, otherwise it loses sync, it is not always what is achievable, if we think of solutions to home television or movies in educational context. Another problem could be that the blind person can be disturbed because has one ear that hear the general sound of the film and the other the AD voice.

Technology of text to speech conversion. The third approach shows the text-to-speech audio description (TTS AD): AD is read by speech synthesis software. Modern text-to-speech applications convert text input into a speech waveform with the use of special algorithms [8], producing an effect far more natural than speech synthesizers did a few years ago [27]. Text-to-speech audio description has several advantages. From the perspective of the audio description provider, TTS AD offers unequalled cost-effectiveness in terms of AD production in comparison with conventional methods of producing audio description. TTS AD does not require the recording of the AD script (for pre-recorded AD), nor does it incur any human labour costs for the reading out of the AD script (for live AD). Furthermore, in contrast to audio describers involved in the production of conventional AD, who need to be able to develop “the vocal instrument through work with speech and oral interpretation fundamentals” [25], audio describers for TTS AD do not need to have any particular vocal skills [27]. From the end user’s point of view, TTS AD also helps many blind and partially sighted people save money, as they already have speech synthesis software at home or at work and are accustomed to using it in their daily lives. Thanks to the high quality of speech synthesis software available now in many languages, watching a film with synthetic AD can be an enjoyable and entertaining experience. For those watching the audiovisual programme another advantage is that the solution does not require access to a high-speed Internet connection because the viewer is simply offered a text file with the AD script (in .txt or .sub format) to be read out by a text-to-speech programme. The solution seems particularly attractive to those visually impaired people who live in small towns and villages and thus cannot enjoy cinema screenings or theatre performances with AD, as these are usually organized in large cities only. Furthermore, TTS AD allows spectators with visual impairments to watch films and other audiovisual programs on their own, without depending on others or being restricted to the explanations of their sighted friends or family. At the moment the most used software are Ivona, Acapela, Loquendo, Readspeaker. Ivona is the better Italian female and masculine voice. Field surveys carried out by following this model of audio description, testify that many blind people prefer a speech because it allows you to better distinguish between original audio and audio description.

5 Conclusion: The Power of Words

In conclusion we can say that the solutions of AD are varied, the choice should be made on the basis of time available, the skills available, costs and the purpose of the product that you want to accomplish of course, a traditional system of AD provides enhanced quality and responsiveness to the needs of interpretation and decoding of the person who is blind, however, this often means a reduced amount of film production and film often outdated. From my point of view if you intend to practice the way of accessibility and autonomy of the person with the highest visual deficits is appropriate to think of textual summaries of quality that would reduce to a maximum of three professionals work, dialogue writer, editor and blind person who regards the product. In fact, the common denominator among these or other solutions that you can choose to be the presence of human validator, that the blind person who verifies and checks the result. This step is almost inevitable and what really can safeguard the quality of the final result. So thinking about an AD solution we needs to adopt a User-Centred Design approach to address the interpretation of blind people needs, involving them not only as stockholders but also as real validator.

In technology in recent years there have been several advances on the expansion of refining and humanization of synthetic speech. The use of speech synthesis, such as text-to-speech AD [27] is more advantageous for at least two aspects.

The first is related to the economic aspect: the speech with audio descriptions are much cheaper because (their) implementation process covers only the figures of the describers (descriptors which draw up the script) and the technical editing of audio. The second aspect is related to practicality: an AD read by a speech synthesizer can be more practical and easy to generate, thus allowing a more massive and rapid spread and rapid translation into multiple languages.

The audio description voice against human turns out to be more expensive and more complex, however, experimental studies [8, 27] confirm that the recording of a human voice is much favored by people who are blind, even the report of the technical expertise that requires the use of a summary with respect to the use of an audio description sound already assembled and with the human voice. The usability and ease of access to synthesis systems, therefore, is one of the most significant variables in the choice between audio description with human voice and digital synthesis. Especially for older people's audience. The most important thing is that the blind people, regardless of the means and the way in which it is made an AD, can experience all this in autonomy. AD, therefore, is emerging as a powerful instrument of culture and social inclusion, but unfortunately, still "limping" in the Italian context.

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Metabolink: m-Health Solution Enabling Patient-Centered Care and Empowerment for Well-Being and Active Ageing

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Abstract Metabolink is a smartphone-based telemedicine solution that allows the proactive participation of elderly people or patients with chronic diseases to the monitoring of their own lifestyles. The patient uses a smartphone to collect and to send to doctors or caregivers information about his/her lifestyle or about physiological parameters measured using integrated medical devices. The doctors use a tablet or a computer to communicate with their patients, to check real-time their health, to receive alerts about unsafe health conditions and to update the treatment. The data collected by the patients populates the personal health records and can be used afterwards to find correlations between lifestyles and the onset or progression of chronic diseases. This solution empowers the patients for active ageing and enables them to easily cooperate with the doctors in the management of their wellness or chronic diseases.

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1 Background

Well-being, active ageing and e-health are all elements that contribute to achieving better health.

The WHO defines health "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" [1]. Well-being is a key component for active ageing: it aims to extend healthy life expectancy and quality of life for all people as they age. The word "active" refers not just to the ability to be physically active, but also to continuing participation in social, economic, cultural, spiritual and civic affairs [2]. Also maintaining autonomy and independence for the older people is fundamental to allow active ageing.

Strategies. Healthcare professionals can generally adopt three strategies to support well-being and active ageing: empowerment, patient-centered care and home care.

Different research groups conducted studies to test the effectiveness of the empowerment in helping people to change their health behaviors. Suntayakorn and Rojjanasrirat [3] carried out a 12 weeks study in which participants at-risk for stroke were enrolled in two different groups using match pair for sex, age, blood pressure and blood sugar. The experimental group, unlike the control one, received empowerment based on the Gibson's model (discovering reality, critical reflection, taking charge and holding on) [4]. The results showed that the health behaviors of patients in the empowered group were better than those of the control one.

As the number of people with chronic conditions continue to increase, health system has to focus on the person and not on the disease, requiring the patient to act in first person in the healthcare processes. Patient-centered healthcare (PCH) is the care model that places patients at the center of the system of care, developing customized services that revolve around them [5]. PCH, complying with patient's needs, wants and preferences in the care management, allows to achieve a better quality of health and life as subjectively perceived by the person. Evidences from different studies [6] show that the patient-centered approach leads to an increase in patient satisfaction and commitment, to a reduction in anxiety, to a better quality of life, to doctor satisfaction and to an increase in efficiency, resulting in fewer diagnostic tests. From this point of view PCH may be the most cost-effective way to improve health outcomes and resource use. A report from WHO also suggests that PCH approach encourages patients to adhere to their treatments [7].

Different approaches of PCH can produce different results: good physical health outcomes are more closely associated with healthcare professionals involving the patients in the management of their own health than when healthcare professionals adopt an approach which does not actively involve the patients [8]. Patient participation can also give a real added value in preventing diseases, as well as in monitoring and managing them.

The home care approach, which consists in the care at home of not self-sufficient people, completes the PCH strategy. With this approach, healthcare professionals of the public healthcare system must go periodically to the patient home to administer the care as provided by the treatment plan.

These strategies to healthcare management can bring to a better quality of life and to a reduction of hospitalization if a caregiver supervises the patient.

These approaches must, however, be supported by technology to simplify the way patients share information about their health and lifestyle and how the healthcare professionals use these pieces of information to care about the patients.

Technologies. The WHO adopted a resolution (WHA58.28) to promote e-health to support healthcare services, health surveillance and health education, reaching also vulnerable groups like elderly, with e-health services proper to their needs.

A comparison conducted by Blusi et al. [9] between a group of patients monitored using e-health and a control group using usual care showed that, for the e-health group, flexibility and being able to personalize the support were essential factors, while the caregivers of the control group reported that the usual care was non-flexible.

Telecare potentially contributes to the improvement in the mental health quality of life of the users; even if it not radically transforms the life, it may bring benefits on some psychological outcomes on users who only receive usual care [10]. A study to rate the variables influencing the use of a telecare service program by the elderly [11] showed that elderly persons who perceived telecare as useful in solving health problems, prove willing to use telecare also in the future and have a better perception towards quality of life about their interpersonal relationships and living environment.

An e-health technology, which supports how the patient empowerment improves health, is mobile Health. mHealth applications consist in the use of mobile devices for collecting clinical health data, in the delivery of healthcare information to caregivers and in real-time monitoring of vital signs. An increasing use of mHealth tools allows the delivery of healthcare with greater consumer involvement and decentralization [12]. Among these tools there are applications in the nutrition field, that allow to keep a food diary, and applications able to manage physical activity; some other applications deal with lifestyles suggestions and tips [13]. Mobile applications supported by education prove a beneficial impact in reducing physical inactivity and/or overweight and obesity [14]. mHealth may also help to increase treatment adherence and, then, leads to improved control of indicators of vital signs, like blood pressure [15]. This technology, which enables data collection, informs patients about vital health metrics, giving them more control on health or illness [12]. Smartphones are transforming the ways of communication, but excluding the healthcare professionals from the management of the patient is one of the main risks related to their use [13].

2 Metabolink

Metabolink is a smartphone-based telemedicine solution which adopts innovative care models, consisting in the proactive participation of the patient in managing his/her chronic disease, with the aim to simplify the monitoring of lifestyles

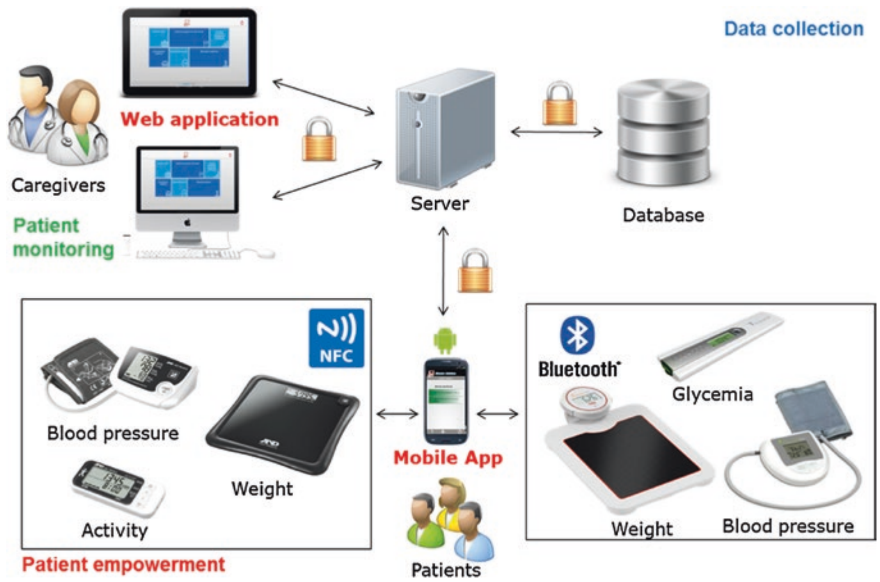

Fig. 1 Schematic representation of Metabolink solution

and vital signs. By using this system, the patient collects information about his/her lifestyles and physiological parameters. The doctor or the caregiver receives the collected data automatically and real-time; these data are then used to check patient's health, to adapt treatment, to correct inappropriate lifestyles and, because it is possible to find correlations between lifestyles and the onset and course of chronic diseases, for prevention. Our prototype focuses on simplifying the collection of information about physiological parameters integrating medical devices. In our system, patients use an app for Android smartphones to collect data, while doctors use a web application to view collected data and check the health of their patients. Figure 1 shows a schematic representation of the solution.

2.1 Functionalities for Patients

The app allows the patient to collect data about the food intake, the performed physical activity, the drug therapy and the values of physiological parameters.

The patient can mark down not only the food intake of the diet provided by the doctor, but also the extra food. He/she also can report how he/she feels the amount of food taken (subjective vs. the objective measure). Similarly, the patients can report the drug taken (both provided by doctor or taken for other necessities).

The patient can mark down the performed physical activity in three different ways: writing the activity duration, using the smartphone as a pedometer or using an external activity tracker integrated with the app. The patient can also measure weight, blood pressure, pulse and glycaemia through NFC or Bluetooth enabled medical devices; the app gets the measured values without any need for manual typing. We have implemented a common interface for all compatible medical devices with which the patient do not have to select in the app the medical device to use, but he/she only needs to measure and tap the device with the smartphone (for NFC) or wait the delivery of the measure to the app (for Bluetooth); the app detects the medical device and adapts automatically the user interface. If the measured values are out of ranges, the app shows an alert to the patient and, at the same time, sends an alert to the doctor.

Patients can also check the trend of their lifestyle accessing to a section where they can view charts that summarize all the collected data. The app has also a section in which patients can share the results of their lifestyle with an anonymized community; this approach has the goal to create a competition that could induce patients to follow healthy lifestyles.

The app sends to the doctor the information collected by the patients through a secure communication channel and it does not save anything on the smartphone.

2.2 Functionalities for Doctors

Doctors, or caregivers in general, use a web application to manage all the information about the patients, to view the charts that describe the trend of the lifestyle, to receive alert messages if vital signs are out or range, to communicate with the patient and to use these pieces of information to change real-time the provided drug therapy. Because the target of our solution are the chronic patients that do not need a continuous monitoring, the caregivers do not have to stay 24/7 in front of the web application to check patients' lifestyle, but they can monitor all of them, for example, one hour per day focusing on the people with unhealthy lifestyles.

The doctor is able to define for each patient which elements of the lifestyle to check, i.e. what food has to take, what physical activity has to perform, what drugs has to take, which vital signs has to measure and which ranges are normal. Finally he/she can also export collected anonymized data to carry out statistical and epidemiological analysis to find correlations between lifestyle and course or onset of chronic diseases.

2.3 Mobile Assistance for Home Care

If the elderly or the patients are not self-sufficient, to guarantee, as far as possible, well-being to the patients, the healthcare professionals must adopt the home care strategy and supply the healthcare activities directly at patient's home.

Besides Metabolink, we have developed another solution which completes the offer for a suitable assistance to elderly or patients and which has the goal to support the work of healthcare professionals in planning and in delivering home care; we have called this solution "Mobile Assistance for Care" (MA4C). This solution is integrated with the health information system to gather information about the patients like the registry, the clinical history or the individual care plan as defined according to the needs of the patient. This solution is flexible and allows to deliver not only healthcare, but also social welfare plans. In this way it is possible to satisfy the need for social inclusion, for support to care management and for a more efficient and effective physical rehabilitation.

MA4C, like Metabolink, consists of a web application by which healthcare managers are able to manage and plan the activities for home care, both from the patients' and healthcare professionals' point of view. The healthcare professionals, instead, use an app for Android smartphones by which they are able to get access (real-time and at patient's home) to pieces of information like the registry, the patient health record, the trend of vital signs measured and the planned care activities.

2.4 Comparison with the State of the Art

Many apps available on the market applies to nutrition control, weight loss, healthy living, fitness, physiological parameter collection and pathology management. For example *MyFitnessPal*, *Noom* and *My Diet Coach* help people to lose weight using different approaches like tracking the food intake, suggesting exercises, health tips and using motivational prompts or sharing the results with the social networks communities to boost the weight loss. Other apps like *RunKeeper* and *Runtastic* focus on fitness and physical activity tracking. Among pathology focused apps, those that apply to diabetes like *Diabetes tracker* and mental health like *Five Ways to Wellbeing* are widespread in the app stores. Generally, the patients that use these apps are not supervised by healthcare professionals. Apps like *eCAALYX*, *FolUp* and *Medweb* allow patients not only to collect data about physiological parameters, but also to send the information to caregivers that are able, in this way, to check the data and monitor patient's health and well-being. Some of these apps are also integrated with medical devices.

Metabolink differs from the solutions cited above in the fact that it adopts a general purpose approach, which means that it is not focused on a specific monitoring element or pathology, but it is able to collect data about different elements at the same time with a lesser level of detail than that of an app that is, for example, focused on fitness. The goal of our solution is to check patient's health and to collect as many data as possible (food intake, physical activity, drug therapy compliance, vital signs) to allow healthcare professionals to find correlations between the patient's lifestyle and his/her health condition. Similarly to *eCAALYX* and *Medweb*, our solution allows healthcare professionals to monitor real-time physiological parameters thanks to the connected medical devices, but differently from them it integrates medical devices commonly available on the market; in particular the NFC ones that are simpler to use, in our opinion, for elderly people because they do not need to pair with the smartphone and insert the PIN as it happens for devices with Bluetooth technology.

3 Future Work

We are planning to evolve our solution with the aim of improving how the patient interacts with the mobile device and how the doctor checks the patients.

Our first goal is to adopt ICT solutions to simplify human-machine interaction in particular for elderly or patients not accustomed to the technology. To collect as much information as possible about patient's health and lifestyle, we will integrate other medical devices to offer a great variety of vital signs that the doctor can check. We will also introduce wearable devices like smart watches with the aim to detect events like falls, the moving away from safe zones (particularly useful for elders affected by Alzheimer's disease) or the prolonged inactivity with an automatic alert sent, in case of detection, to the caregiver.

Finally, to have a measure of the well-being of the patient, we will allow the elderly person to express his/her mood or symptoms using rating scales evaluated by the caregivers and used to decide how to deliver a more effective care, giving to the patient, at the same time, a tangible perception of inclusion.

4 Conclusions

The Metabolink prototype allows patient's empowerment leveraging on patient propensity to stay in home environment, but, at the same time, still well assisted by healthcare professionals; this approach enables a patient-centered care with less risks and encourages active ageing and well-being. Together with monitoring of lifestyles (nutrition, physical activity, etc.), patients can communicate in an easy way and real-time information about vital signs to the doctor, who can evaluate them remotely. The prototype uses the smartphone as a hub to send data everywhere (not only at home) and it is able to create a personalized patient health record with data collected by the patient improving self-management of health and disease prevention. The solution is flexible and enables the monitoring not only for patients, but also for young or old healthy people.

To check the effectiveness of the solution in improving patient health, we will carry out experimentations in two scenarios: patients suffering from diabetes or obesity and students of the secondary school with the goal to monitor and prevent childhood obesity.

Future work will focus on simplifying the interaction between the users and the smartphone and on the introduction of new functionalities and the support for wearable devices.

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Brain.me: Low-Cost Brain Computer Interface Methods for AAL Scenarios

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Abstract A Brain-Computer Interface (BCI) is an alternative/augmentative communication device that can provide users with an interaction path, based on the interpretation of his/her brain activity. Such technology, applied to AAL contexts, could potentially have a major impact on daily-living, extending the ageing at home paradigm also to users with severe motor impairments, for whom the interaction with the surrounding environment is troublesome. In this paper, a low cost BCI development platform is presented and its performance assessed by means of an illustrative application example using SSVEP paradigm to switch on and off lights. Comparison against other SSVEP signal processing methods in literature is also made.

1 Introduction

Ambient Assisted Living Technologies (AAL) aim at making the home environment more cooperative and intelligent, providing help to accomplish daily living tasks; AAL solutions have been successfully applied for supporting and promoting independent life of elderly people. However, individuals affected by severe impairments could be potential beneficiaries of AAL services too (such as those aimed at environmental safety and control): the main issue is to provide these users with an effective interaction path to the AAL system.

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A possible approach to this problem involves Brain-Computer Interface (BCI) technologies. BCI are alternative/augmentative communication means [1] that aim at providing the user (for instance lacking voluntary muscle control) with an interaction path, based on the interpretation of her/his brain activity. BCI is being exploited since a relatively long time to support communication, and effective solutions have been developed, featuring high accuracy and processing speed [1–3]; such performances are obtained by exploiting sophisticated setups and powerful computing environments. However, considering AAL systems as primary application target, "conventional" BCI approaches may result somehow unfit (i.e., possibly outsized with respect to the application at hand), and inexpensive, lightweight and scarcely invasive devices are to be preferred. Interoperability with highly heterogeneous environments is also required. In our view, the BCI device must be seamlessly integrated into CARDEA [4], the flexible, LAN-based, AAL system developed by the University of Parma. Of course, interaction with other AAL systems is still possible, provided that a plug-into support the particular communication protocol is developed. However, the general view holds true: the BCI should act transparently towards the system (i.e. it should be self-contained, and the interaction with the environment should be limited to issuing high-level commands), mimicking a conventional input device.

In [5, 6] the interaction scheme between CARDEA and a simple BCI was presented. With respect to most literature works, our approach aims at developing tools and methods for low-cost, standalone embedded BCI modules, making high-performance acquisition hardware unnecessary. Also, efforts are made to design computationally efficient signal processing algorithms that could easily fit into these implementation targets, where large computing powers are not available. Finally, we also address the issue of designing BCI methods which do not require any initial or periodic system calibration phase, which could be perceived as excessively bothersome by the user (whose number of interactions with the system is going to be quite low and sparse in time, with respect to other applications, such as wheelchair control).

2 Overview on EEG-based BCI Technology

Among many possible brain signal acquisition techniques, ElectroEncephaloGraphy (EEG) is the most popular: EEG signals can be non-invasively acquired from the scalp, by sensing the electrical signal with skin-surface electrodes (dry or wet, the latter involving the use of conductive gels). Overall, EEG still provides the best tradeoff between compactness, space and time resolution, and cost containment: we will therefore consider on EEG-based BCIs.

In order to operate a BCI, several features in the brain activity can be exploited to infer the user's will: the collection of such features, along with the (optional) external stimuli applied to the user, is called a paradigm. Among them, we can cite:

- Slow Cortical Potentials (SCP), i.e., potential shifts in the EEG waves voluntarily induced by user, who can learn to control them through biofeedback-like approaches [7].
- Event Related De-synchronization (ERD) and ER Synchronization (ERS) [8, 9]: this paradigm exploits the brain response arising when preparing (or just imagining) to start a movement. In such conditions, neurons tend to de-synchronize from their idling state, to be allocated to motor processing, this reflecting in a decrease of spectral energy in the μ and β bands (8–12 Hz and around 20 Hz, respectively). After ERD, a pattern consisting in increase in the energy band after the completion of the motor task can also be observed (ERS).
- P300 [10–12]: when a rare target stimulus is presented to the user during a sequence of repetitive, non-target stimuli, a characteristic pattern can be observed in the EEG signals, approximately after 300 ms from the target stimulus appearance.
- Steady State Visual Evoked Potentials (SSVEP) [6, 13, 14]: this paradigm exploits brainwave features elicited by the involuntary response to a continuous, repetitive stimulus, such as a blinking LED. In particular, within a typical 4-40 Hz range, the blinking frequency reflects on the onset of an iso-frequency component in the brain signal spectrum.

In the following, we are going to focus on SSVEP, which was chosen as our primary operating paradigm. In fact, SSVEP responses are regarded as reliable features [14] for BCIs, given their inherent higher SNR (Signal to Noise Ratio). Moreover, SSVEP detection and classification can be carried out, in principle, without any calibration data at all [6, 14]: this makes SSVEP particularly attractive in terms of improved user comfort, fostering a plug and play type of interaction with the device. In fact, calibration sessions could be long and time consuming, and, in order to optimize the performance of methods relying on training data, periodic recalibration may be required. Considering the application we are targeting, i.e. enabling control of AAL systems in daily living contexts, undergoing long training sessions for optimizing the system performance may seem an overkill, given the more relaxed constraints on data throughput. Finally, another advantage of the SSVEP paradigm is that it usually operates in the frequency domain, and no time synchronization between the stimulating unit and the acquisition unit is required. This allows to greatly simplify the BCI design, and to explore more compact and cost-effective solutions. This is in accord with our purposes, and simpler architectures and signal processing methods are more easily implementable on embedded systems, were computational resources are limited.

3 A Tour of Brain.me Based on a Worked Example

In this section, we present the platform's features and architecture by means of an illustrative application example, namely the control of ambient lighting through CARDEA (a schematic representation is shown in Fig. 1, where the BCI is interfaced to the CARDEA system, acting as a conventional input device).

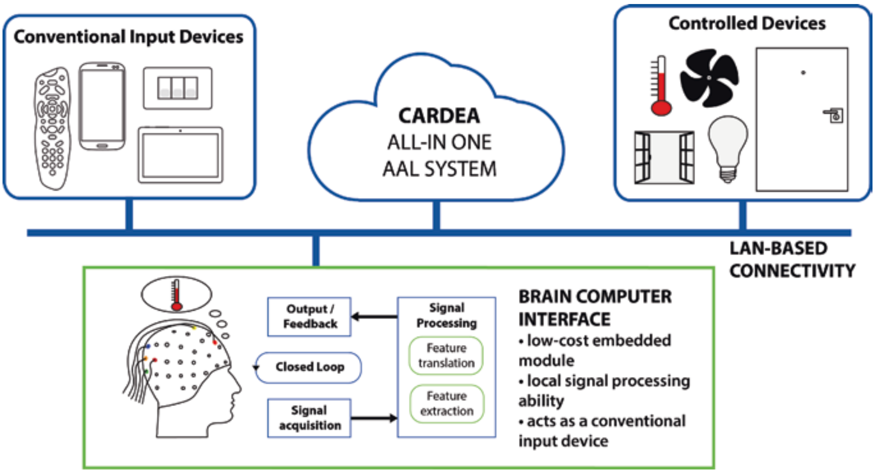

Fig. 1 Application example: control of ambient lighting through the CARDEA AAL system. The BCI module is seen by the AAL system as a simple remote control device, which can access the whole services provided

In a typical BCI setup, three main units can be identified (shown in the lower rec-tangle in Fig. 1): (i) an Analog Front End (AFE) for the acquisition of the EEG signal, (ii) a digital signal processing unit, implementing feature extraction and classification and, (iii), an output/feedback unit for display and implementation of active controls; such blocks are described in the following subsections. Together, these building blocks form the general architecture of a BCI system; as previously mentioned, our approach focuses on the development of a compact, self-contained, module being able to process signals locally, and to interface towards the AAL system as a simple, conventional input device, such as a remote controller. In this case, BCI was used to switch on and off ambient lights. Even though this is a simple illustrative example, it is important to underline that the approach is general, and system configuration just requires trivial mapping of BCI output onto CARDEA command space.

The BCI setup was the following: 4 healthy volunteers (age 23–26, two of them without any prior BCI experience, with normal or corrected to normal vision) were instructed to stare at one of the four simultaneously flickering LED in order to switch on/off a certain light. During the test, volunteers rested on an armchair at approximately 1 m distance from the visual stimulus source. Each trial lasted for 6 s, and each LED presented a different stimulation frequency (16, 18, 20, 22 Hz); EEG was acquired at 250 SPS (Samples Per Second) from 6 scalp locations (namely O1, O2, P3, P4, P5, P6, according to the International 10–20 system), using standard 10 mm Ag/AgCl disk electrodes with conductive gel applied.

In the following, we describe the key features of the BCI.

3.1 Analog Front End

Acquiring EEG signals, whose amplitude can be as low as a few μV, poses tight constraints on the electrical specifications of the acquisition system. However, high-end, clinical grade EEG equipment making use of a large number of electrodes are scarcely suitable for our particular application, and low-costs, small-size devices are to be designed, suitable for extracting basic information on brain activity. The adoption of low-cost, standard electronic components also fosters product interoperability. On these grounds, the custom AFE circuitry has been realized [5, 6]. Low-noise design techniques were adopted, to ensure that the informative content of the signal is not corrupted by the noise contributed by the instrumentation. In the aimed application context, further sources of Signal to Noise Ratio (SNR) degradation may come from electrical and power line interference or mechanical artefact induced by cable movements. While the use of active electrodes may help in mitigating those issues, the related higher costs and complexity made us opt (at this stage, at least) for the worst-case design, adopting passive electrode technology. Furthermore, a Driven Right Leg (DRL) circuit was also introduced to improve common mode noise rejection [15]. In addition, two spare, fully-differential channels are available on the AFE, and can be used, for example, for simultaneous recording of other bio-potentials, such as ElectroMyoGram (EMG).

Noise performance of the AFE was tested with input terminals shorted, extracting an input-referred noise lower than 1.8 μV_{pp}, which is more than sufficient for our purposes.

Finally, it is worth mentioning that, at this stage of the research, the AFE is inter-faced to a host PC via USB connection. An ARM-based microcontroller board (ARM Cortex-M4) takes care of proper AFE control and initialization, allowing acquisition parameters (e.g. individual input channel gain) control directly from the PC.

3.2 SSVEP Signal Processing

A first SSVEP classification algorithm, based on Power Spectral Density (PSD) estimation was first introduced in [6], with the aim of maximizing the accuracy of the BCI, i.e. the number of correct outputs. Results obtained with variable EEG window length (i.e. different speed versus accuracy tradeoffs) are reported for convenience in Table 1 (Information Transfer Rate, ITR, is also reported, as defined in [1]).

The aforementioned algorithm privileges selection accuracy rather than speed: in strict terms of AAL systems control, where the number of choices is limited and the interaction between user and the system is not very frequent, this is the most important parameter, indeed. Nonetheless, we can think of developing a second algorithm, with the aim of improving selection speed, to provide the user with a more prompt, reactive interface. These apparently contrasting behaviors can

Table 1 Accuracy and ITR (shown between brackets) of the PSD-based algorithm as a function of EEG window length

Subj.	3 s	4 s	5 s	6 s
1	90.0 % (27.45)	83.3 % (16.27)	86.7 % (14.66)	90.0 % (13.73)
2	91.7 % (29.08)	91.7 % (21.81)	100 % (24.00)	100 % (20.00)
3	87.5 % (25.17)	95.0 % (24.52)	92.5 % (17.96)	97.5 % (17.92)
4	94.1 % (31.68)	94.1 % (23.76)	94.1 % (19.01)	91.2 % (14.31)
Avg.	90.8 % (28.35)	91.0 % (21.59)	93.3 % (18.91)	94.7 % (16.49)

actually converge into a cooperative vision, in which the interface adapts its speed in relation to the desired task: new functionalities that need higher speed can be added, such as, for example, typewriting. Another possibility is to operate with the faster algorithm as default and resort to the more accurate one when the estimated error rate is too high.

In the following, a new algorithm, named MaxDeltaVar is presented and compared with other common SSVEP processing algorithms, such as Minimum Energy Combination (MEC) [16], Average Maximum Contrast Combination (AMCC) [17] and Canonical Correlation Analysis (CCA) [18].

In general, the voltage time series of a single electrode $y_i(t)$, can be modeled as

$$y_i(t) = \sum_{k=1}^{Nh} a_{i,k} \sin(2\pi kft) + b_{i,k} \cos(2\pi kft) + E_i(t), \tag{1}$$

where the first term is the model of a SSVEP response corresponding to a stimulus frequency f (considering up to N_h harmonics), and $E_i(t)$ is a noise and nuisance signal. Given an EEG epoch of N_t samples, the input signals from the N_y electrodes can be represented as a matrix $\boldsymbol{Y}$ of size $N_t \times N_y$, whose columns are the potential readings from each electrode site. In the same way we can represent the SSVEP term in Eq. 1 as a multiplication between a SSVEP information matrix $\boldsymbol{X}$ having size $N_t \times 2N_h$ and containing N_h (*sin*, *cos*) column pairs, and a weight matrix $\boldsymbol{G}$ of size $2N_h \times N_y$, containing all the $a_{i,k}$, $b_{i,k}$ coefficients. Equation 1 then becomes:

$$Y = XG + E, \tag{2}$$

with

$$X = \begin{bmatrix} \sin(2\pi ft_1) & \cos(2\pi ft_1) & \dots & \sin(2\pi N_h ft_1) & \cos(2\pi N_h ft_1) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \sin(2\pi ft_{Nt}) & \cos(2\pi ft_{Nt}) & \dots & \sin(2\pi N_h ft_{Nt}) & \cos(2\pi N_h ft_{Nt}) \end{bmatrix} \tag{3}$$

MaxDeltaVar proceeds as follows: at first suitable filtering is applied to remove low frequency and out-of-band contributions. Then, input channels are normalized in order to have the same variance. Projection on the space spanned by the sinusoidal components of $\boldsymbol{X}$ is performed to remove any potential SSVEP activity from the recorded signal:

Table 2 Comparison of the MaxDeltaVar algorithm with respect to other SSVEP signal processing algorithms, as a function of accuracy and ITR (between brackets)

Subj.	MEC	AMCC	CCA	MaxDeltaVar
1	62.5 % (18.05)	85.0 % (46.10)	87.5 % (50.33)	87.5 % (50.33)
2	94.1 % (63.32)	94.1 % (63.32)	94.1 % (63.32)	91.2 % (57.23)
3	70.0 % (25.73)	86.7 % (48.94)	90.0 % (54.90)	86.7 % (48.94)
4	72.5 % (28.62)	77.5 % (34.97)	82.5 % (42.14)	80.0 % (38.44)
Avg.	74.8 % (33.93)	85.8 % (48.33)	88.5 % (52.67)	86.4 % (48.74)

$$\tilde{Y} = Y - X(X^T X)^{-1} X^T Y \tag{4}$$

$\tilde{Y}$ then approximately contains only noise, artifacts and background brain activity. We assume as (computationally inexpensive) features the difference in variance before and after projection, summing the contribution of all channels. The matrix $\boldsymbol{X}$ which induces the larger decrease in the overall variance is assumed to be the stimulus frequency.

Performance of MaxDeltaVar and its comparison to other SSVEP processing is methods shown in Table 2, with all the algorithms being tested on the same recorded dataset, using a 1.5 s EEG segment (which implies up to 4x speed increase with respect to the previous algorithm in [6]). Results show that our MaxDeltaVar algorithm, despite its simplified approach, performs close to, or better than, MEC and AMCC methods. It is worth noting, though, that MaxDeltaVar was explicitly designed for low-electrode count setups, and does not perform any dimensionality reduction as MEC or AMCC do. However, in our scenario, where the number of electrodes is intentionally low for cost and comfort constraints, computational demand is significantly lower, as shown in Table 3 (where execution time on a standard desktop PC, Intel® Core™ i5 @ 3.20 GHz, 8 GB RAM is taken as a simple indicator of computational efficiency and as a basis for comparisons). On the other hand, CCA has better accuracy and ITR than our method; in this case too, dimensionality reduction is also not taken into account in this method, and all the EEG channels are considered. Still, CCA is more computationally intensive than our algorithm.

It is important to highlight that both the presented algorithms operate on the basis of relative comparisons, thus virtually eliminating the need of calibration procedures. This could be a great improvement in the accessibility of such interface, resembling a plug and play device; of course, if we accept calibration steps, the performance of the BCI could be further improved. In addition, the optimized computation complexity of both methods better scales towards embedded implementation of the BCI.

Table 3 Comparison of mean execution time between the algorithms reported in Table 2

	MEC	AMCC	CCA	MaxDeltaVar
Mean time (ms)	9.65	5.25	1.13	0.82
Time reduction (proposed vs. others) (%)	−91.5	−84.4	−27.4	–

4 Conclusions

In this paper, the realization of a low-cost platform for BCI modules development was presented. The platform is built around a custom, versatile AFE board, whose main acquisition parameters can be directly controlled via software (connectivity is established via a USB 2.0 link). Noise performance of the module (below 1.8 μVpp RTI) makes it suitable for BCI applications.

Besides flexibility and re-configurability, main design focus was placed at enabling implementation of BCI solutions on small, low-cost embedded system. More specifically, the primary target was that of building a BCI-based controller suitable for (even though not restricted to) AAL system management.

In this paper, a BCI prototype based on such board and exploiting the SSVEP paradigm was demonstrated. The whole control chain was implemented, including the BCI module into the CARDEA AAL system and allowing for actual control of ambient lighting. Of course, besides such an example, mapping of different AAL functions on the BCI controller is a trivial task and may straightforwardly be extended to many different and personalized actions.

In addition to a previously introduced algorithm [6], focusing at maximizing selection accuracy, a novel classification algorithm was presented, based on the SSVEP paradigm, aiming at improving ITR and responsiveness. Features of the algorithms include calibration-less operation and optimized computational effort, making it suit-able for implementation on low-cost, embedded modules. Comparison with other reference SSVEP processing methods proved good results in terms of accuracy and computational efficiency.

Finally, a hybrid-BCI [19] approach is also being evaluated, adding to the BCI module the capability of recording neuromuscular activity too, exploiting some acquisition channels for surface EMG (ElectroMyoGraphy). Such an approach seems to be particularly promising when daily-life support functionalities are targeted: the EMG additional channels can make the interaction scheme more flexible, reliable and customizable, and relieve the user from the bother of continuous BCI-based interaction. I.e., simpler tasks (or even switching on the BCI interface itself) can be activated by the (less demanding and more comfortable) EMG-based control.

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Alzheimer Patient's Home Rehabilitation Through ICT Advanced Technologies: The ALTRUISM Project

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Abstract The AL.TR.U.I.S.M. project—*ALzheimer patient's home rehabilitation by a Virtual Personal TRainer-based Unique Information System Monitoring*, funded by the Apulia Region, aims at developing a home rehabilitation system through the implementation of a Virtual Personal Trainer in order to remotely monitor and support patients affected by Alzheimer's disease in performing exercises and rehabilitation programs, autonomously and directly in their home environment. It is a solution aimed at patients with mild to moderate cognitive impairments and which makes use of advanced ICT technologies such as a set-top box with Internet access and connected to a TV, a camera with gesture recognition features and an electronic device able to detect vital and biomedical parameters. Moreover, this system is designed and configured to be used both in home environments such as nursing homes, user's premises and apartments and in hospital facilities as well. This paper gets through the project goals, the experimentation stages and the initial results.

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1 Introduction

Demographic trends and the current increase of life expectancy not only lead to an ageing population phenomenon, but also put individuals at a greater risk of cognitive impairment, frailty and social exclusion, with significant negative consequences regarding their independence and quality of life [8]. This inevitably reverberates also on the activities of those who, day by day, take care of these patients and on health care systems and social costs as well. In particular, it is possible to record an increase in neurodegenerative pathologies and among them the Alzheimer's disease.

If it seems to be quite promising the use of the cognitive rehabilitation programs [2, 3] which consist in performing personalized exercises that are executed exclusively in hospitals or specialized healthcare facilities with the constant presence of a psychologist and/or physician, however it often happens that waiting lists may be quite long, running the risk of not being able to access the therapy and accelerating so the decay phases.

When individualized rehabilitation exercises are assigned to patients at home, instead, it is not possible to check neither the continuity nor their proper execution.

The ALTRUISM project, which falls within the Ambient Assisted Living (AAL) [1] framework and is thus supported by the AAL Italian Association, tries to solve these aspects. It proposes an innovative solution to this problems by developing a domestic rehabilitation system which contemplates the support of a Virtual Personal Trainer, allowing, by the means of a 3D camera placed at the user's premises, an independent performance of the rehabilitation therapy. The ALTRUISM system enables a remote monitoring both of the videos and the results accomplished.

In fact, thanks to the kit of technological tools provided and later described in detail, it is possible to track the evolution of the therapy in real time, monitor the user's vital parameters while performing the rehabilitation therapy and, if necessary, to apply corrective changes to it in real time.

A highly innovative aspect of the system concerns, indeed, the exploitation of active vision technologies which make possible the measurement of patients' movements (gestures), accurately assessing then the eventual deviation from a preset sequence of rehabilitation exercises by the therapist, along with the implementation of intelligent wearable microsystems which communicate wirelessly with a home server in order to detect and collect vital signs to be remotely monitored by the physician or the health providers.

The project aims thus to the creation of an integrated service which is suitable both for the patients suffering from Alzheimer's disease or affected by moderate cognitive impairment—assisting and monitoring them from remote—and for physicians, therapists or healthcare providers as well, in order to be able to manage a greater number of patients and with more efficiency in real-time.

2 Design Methodology and System Structure

The technical feature, the graphical, visual and auditive user's interfaces as well as the choice of the interaction patterns between patient and rehabilitation program originate from the results of a sample case analysis involving both the patient and the caregiver, from some Focus Groups with healthcare specialized providers and personnel and from the adoption of a UCD—"*User Center Design*" approach [5].

This analysis and these approaches are aimed at giving back some reference scenarios within which evaluating the effectiveness of the developed system, the proposed solutions and technologies and the rehabilitations therapies suggested.

In particular, they allowed to learn and then to meet the habits and needs of the patient, in relation to his/her living environment and health status and to verify also the compatibility of the proposed rehabilitation system with the personal abilities and skills of the end-user and its acquaintance with ICT technologies use as well.

The purpose of the UCD—"*User Center Design*" methodology is, indeed, to tailor the system around the user's needs, expectations and limits, employing a co-design procedure, which implies that designers, technicians and providers have to necessarily work in direct and close contact with end-users in each of the design phases.

It contemplates to place the end-user then at the center of each of the development process stages in order to optimize the final product around the user's needs, limits and expectations and increasing thus the acceptability degree of the final service.

This multi-level co-design approach leads to the development of a first prototype and to a following test and assessment stage leading in turn to the development of the next prototype, a more defined and shaped one. Each cycle therefore leads up to the creation of a product that is closest to the real and practical needs of the user.

2.1 System Architecture and the Virtual Personal Trainer

The system makes use of ICT advanced technologies and integrates the features already offered by the OMNIACARE platform developed by eResult S.r.l.

The OMNIACARE platform [7], which is a hardware/software system specifically designed for the healthcare and social welfare of the elderly and/or frail people, provides a set of hi-tech tools to relieve both the patients and the caregivers providing assistance. The platform is specifically developed to promote the independence of frail users. In order to help them carrying out an independent life as long as possible in their own home environment, the system makes use of advanced technologies that allow to perform a continuous remote monitoring of the health status of the patients. Besides, it has a central server able to store—in accordance to security and privacy communication protocols—data originating from the smart sensors worn by the patient or placed directly into the environment.

The proposed system, in particular, consists of a kit which includes the following elements:

- a set-top box with Internet access connected to the TV;
- a Microsoft Kinect able to perform a gesture recognition;
- an electronic device (such as a wearable and non-invasive t-shirt equipped with smart sensors or a body gateway) able to detect biomedical parameters and allowing a continuous monitoring of vital signs.

A graphical scheme of the technological kit is shown in Fig. 1.

The micro-system devices, (which measure almost 5 × 4 cm) worn through the electronic shirt or the body gateway will be able to send continuously the data collected which refer to the vital signs (such as ECG, Breathing Rate, Heart Rate) to the central server by the means of wireless technology, allowing so a non-invasive assessment of the health status of the user while performing specific exercises related to the rehabilitation therapy.

The system will give instruction about the exercises of the rehabilitation program to the user by the means of the Set Top Box connected to the TV and interface with the wearable sensors and the 3D camera for gesture recognition.

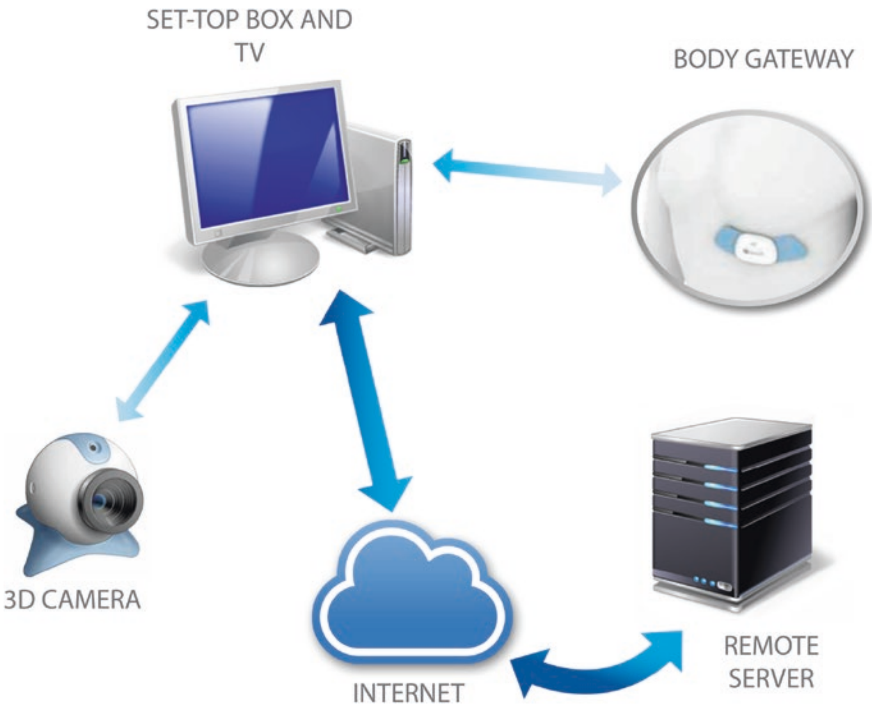

Fig. 1 A graphical representation of the components of the system

In the meanwhile, the camera will record the performance of the exercises assigned to the patient by the therapist/physician and allow an assessment of its correctness as well. The medical team, indeed, will be able to inspect then the sequence of customized rehabilitation exercises through a web portal whose configurations are automatically synchronized with the client set-top box.

The system will guide the patient through the correct performance of the rehabilitation exercises by resorting to specific algorithms able to assess the correctness of the execution. These data will be then sent to an external server, allowing so the physician to remotely assess the trend of the assigned therapy, to visualize the performed exercises and modify the number and typology on the basis of the progress achieved by the patient as well. Besides, concerning the possible privacy issues which can arise from using a 3D camera at the user's premises, it can be stated that the Kinect will be recording only the performance of the exercises under authorization provided by the end-user.

Every performed exercise, indeed, is stored on the server of a stream video which will record even the score gained by the patient at the end of the activity along with the vital parameters collected during the exercise performance. It will be therefore possible to keep an updated record of the performed exercises in real-time, creating so a user's profile containing all of the clinical and useful information in order to properly monitor and assist the patient. The platform is thus meant to become a *Personal Health System* containing the customized configuration of the rehabilitation program to be performed on the basis of the end-user's needs and a record of the already executed exercises with their relative scores gained.

The core of the system is represented by the central server that collects data from sensors, contains users' profiles, device configuration and web interface access to the system. The central server is accessible via an Internet connection.

The home server is another element of considerable importance since it interfaces with various detecting sensors, with the appropriate communication protocols and make a preliminary analysis of the data collected as well, sending them to the central server according to the settings and the periodicities defined on the central server itself.

Moreover, the server makes available some analysis tools in order to assess the collected data, evaluate the course of the therapy over time and the necessity to possibly apply changes to the set of exercises assigned.

Medical providers, physicians and therapists may interface then directly with the patient and in real-time while monitoring the performance of the rehabilitation activities or choose to inspect the performed exercises at a later stage accessing the data recorded through the server-supported video-streaming service. The system contemplates, indeed, the possibility for the physician to interact with the patient in real-time, while monitoring the exercises performance, by means of video conferencing tools. Whether the physician interacts with the end-user in real-time or inspects the performed exercises at a later stage, the proposed technology allows in this way the development of a virtual personal trainer enabling so to implement a customize rehabilitation therapy directly at the user's premises (The whole

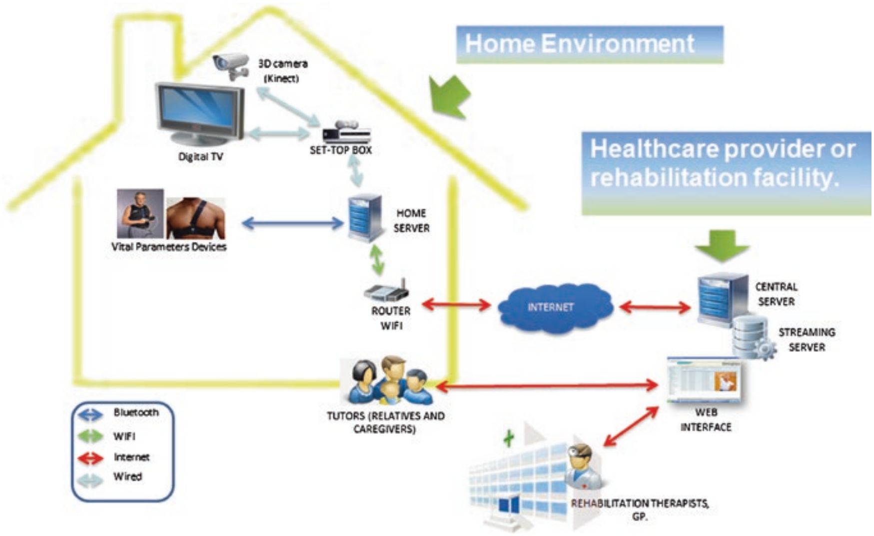

Fig. 2 System architecture

system architecture is shown in Fig. 2). Concerning the event that the standard web-connection is absent or not properly working, the therapy re-updates as soon as the web-connection is again available.

To sum up, this integrated system allow then to implement a regular and effective rehabilitation path and to maintain a constant stimulation level of the patient as well, both in cognitive and in physical terms, relieving at the same time him/her and the caregivers from heavy cognitive loads.

Finally, the use of a remote monitoring system is able to allow the physician or the medical facilities to manage a greater number of patients with a much higher frequency in inspecting the trend and course of the therapeutic path.

3 Experimentation Stages and Initial Results

The experimentation stages have begun at the end of 2013 and at the current stage of the project, the research group has implemented a working prototype of the "Virtual Personal Trainer", which is based on a limited number of exercises. The prototype was subjected then to initial tests to more effectively configure the graphical interface, mainly based on gesture recognition patterns and carefully developed by considering the peculiarities of the elderly, their cultural level, movement difficulties and cognitive impairment they might be affected by. It was employed a base of 20 patients assisted by caregivers and located through the territory of the Apulia Region.

But behind that, an important and complementary analysis stage aiming at detecting the users' orientations and proficiency degree in the use of new technologies, took place.

3.1 Preliminary Analysis Stage

A first part of this study was carried out between January and April 2013 at the Alzheimer Evaluation Unit (A.E.U. Center) of the U.O. Geriatric Hospital "Casa Sollievo della Sofferenza", based in San Giovanni Rotondo, Apulia Region. Each of the almost 20 patients selected, aged over 65 and affected by mild cognitive impairment, went through an assessment of the cognitive aspects on the base of the psychic aspects that direct the behavior of individuals according to the personal assets, both mental and emotional. The assessment tests of cognitive functions included both simple screening tests of cognitive status and tests that evaluate in detail some specific cognitive area. The test that has been used was "Mini Mental State Examination" (MMSE) [4] which assesses attention ability, space-time orientation, short and long term memory, calculation and praxic-constructive ability and the ability in executing commands and writing.

Furthermore, it has been used the "Clinical Dementia Rating" (CDR) [6], which is a tool for the global assessment of the severity of dementia in elderly subjects with cognitive impairments, whether suspected or confirmed.

During a second phase of this preliminary analysis, instead, 72 family members, relatives and/or caregivers of patients affected by mild or moderate Alzheimer disease and being treated at the IRCCS of San Giovanni Rotondo, were involved. Each of them was administered a 17-item questionnaire in order to assess:

a. role and cognitive/physical load for family network or caregivers;
b. degree of the patient's cognitive or sensory impairment;
c. familiarity towards the use of new technologies by the patient;
d. the role of the ICT systems in order to improve the patient's quality of life, healthcare and safety;
e. compliance by the patients in the use of an interactive TV, the detecting vital parameters sensors and a remote gesture recognition system;
f. the role of the devices in order to improve the patient-family network/caregiver-medical facility communication, home rehabilitation and reduction of specific risks;
g. consent by the patients suffering from Alzheimer for the use of ICT systems;

3.2 Impact and Initial Results

The results of the survey underlined some significant and promising data in relation to the use of remote ICT rehabilitations systems.

Firstly, the abilities of the assisted in relation to the “traditional” technological devices such as a TV, a telephone, a remote controller, a PC etc. turn out to be very high, since almost 92.2 % of them is able to turn on and off the TV, whereas 45.3 % of them succeed in using the telephone (even though by calling already existing numbers on the phone) and 79.7 % of the patients is even able to use a PC, even if properly supported by someone.

Furthermore, more than half of the patients likes watching TV programs and 85.9 % of them is capable of choosing programs autonomously as well. What is more, a high percentage—almost 67 %—is also able to maintain a good level of attention from beginning to end of the program, thus portending a high and potential level of involvement by the end-user towards a system which makes use of ICT technologies and devices such as a TV connected to a Set Top Box.

In addition to that, the caregivers’ point of view about the proposed technologies proved to be affirmative: more than 70 % of them thinks the AL.TR.U.I.S.M system may be very useful in order to improve the living standards and quality of life both of the patients and also of those who daily take care of them.

This analysis represented a point of crucial importance not only in developing and improving the system by taking into considerations the end-users’ (both patients and caregivers) expectations and needs, but also in leading to the development of a first prototype and to the experimentation stage as well.

The first prototype of the system and its principal features have been then tested by some volunteers patients suffering from mild or moderate Alzheimer disease and properly assisted throughout the testing phase by the researchers involved in the project. The prototype was based on a limited set of exercises and had an affirmative feedback by the users who benefited from the features of a remote rehabilitation system with user-friendly interfaces.

4 Conclusions

The testing stages are still ongoing in order to improve the working patterns of the system and to better integrate all of its elements with particular and always renewed regard to the end-users and their needs, limits and requirements.

This first stage of experimentation activity aimed mainly at drawing clear conclusions on the interaction between the user and the Virtual Personal Trainer and in general on the acceptability level of this integrated system by the patient.

These data, however, are of great importance since they not only give useful indications to assess what has been accomplished up to now, but also they provide important guidelines in order to improve the system while specific clinical experimentation stages are expected to be carried out over the next months.

The work achieved through a fruitful and continuous interaction among the different subjects involved in the process of development of the system and stakeholders enabled the implementation of a platform which can be further and easily integrated and improved.

Expectations concerning the clinical field are relevant along with the positive benefits of rehabilitation cycles for patients affected by moderate cognitive impairments. In this perspective the introduction of a home care rehabilitation system, such as that proposed by the means of the ALTRUISM system, could be useful and of great interest. In addition to that, it must be taken into consideration that the cognitive rehabilitation therapy is a complex process itself and it requires a certain level of personalization of the treatment to be better performed in the proper manner. This is also at the core of the ALTRUISM system.

Finally, the collected and abovementioned data show a satisfactory integration between the patient and the system along with a great level of acceptability of this platform by the end-user, both the patients themselves and the caregivers or medical providers, those who, day by day, take care and assist their patients.

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Smart Environments and Systems for Maintaining Health and Independent Living: The FARSEEING and CuPiD Projects

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Abstract Home Control and Automation systems are often modular and offer the flexibility and dependability to make life easier. Wearable sensor systems for health monitoring are an emerging trend and are expected to enable proactive

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personal health management. Using home-based technology and personal devices the aim is to motivate and support healthier lifestyle; this is a challenge which has been addressed in the framework of FARSEEING and CuPiD EU projects. Contrary to visions that consider home automation and personal health systems as a mean to replace or to simplify the subject control and actions, in the FARSEEING and CuPiD approach smartphones, wearable devices, and home based technology are used to stimulate the user by making life mentally and physically more challenging but without losing comfort.

1 Introduction

Home Control and Automation (HCA) systems are often modular and offer the flexibility and dependability to make life easier. Every aspect of the home environment can be monitored and controlled both indoor and remotely through remote controls, touch screen panels, personal computers, tablets, or even smartphones (SPs). HCA systems can integrate a variety of environmental sensors that allow early detection and warning of equipment failures or conditions that exceed user-defined limits.

Wearable sensor systems for health monitoring are an emerging trend and are expected to enable proactive personal health management and better treatment of various medical conditions. These systems, comprising various types of small physiological sensors, transmission modules and processing capabilities, promise to change the future of personal care, by providing low-cost wearable unobtrusive solutions for continuous all-day and any-place health, mental and activity status monitoring.

Using home-based technology and personal devices the aim is to motivate and support healthier lifestyle decisions related to exercise, nutrition, TV/internet use, maintaining social relationship—in order to delay or even prevent the onset of a variety of medical problems and improve the quality of life. The great challenge is to exploit the computational capabilities of the HCA system, body-worn, and mobile devices to detect the best time to provide feedback and provide it in a way that is tailored both to the user and the situation.

FARSEEING, as well as CuPiD, aims to introduce and exploit unique features offered by ubiquitous and user-friendly ICT solutions. While FARSEEING has a focus on elderly persons, CuPiD targets specifically needs and symptoms of persons with Parkinson's Disease (PD). PD strongly affects a person's ability to move and particularly to walk, with severe consequences on participation in everyday activities and quality of life.

Contrary to visions that consider HCA and personal health systems as a mean to replace or to simplify the subject control and actions, in the FARSEEING and CuPiD approach SPs, wearable devices, and home based technology are used to stimulate the user by making life mentally and physically more challenging but without losing comfort. The aim of the present paper is to present and discuss the FARSEEING and CuPiD approach for designing and implementing smart environments and systems to extend the time people can live in their preferred environment.

2 Methods

FARSEEING aims to develop a predictive model of mobility and risk of falls in elderly individuals by introducing and exploiting some unique features offered by pervasive but unobtrusive ICT solutions. The design of the FARSEEING architecture is based on a mixed-strategy involving both community dwelling and high-risk subjects. More than 300 real falls have been collected so far through wearable sensors and SPs, which represent the world's largest fall repository ever established. The database enables, for the first time, researchers to study the aetiology of a fall based on enough objectively measured data, also in association with most relevant biomarkers. The FARSEEING technological 'cocktail' allows the measurement and analysis of movement patterns during daily life activities, motor performance, and environmental/contextual information to identify fall risk factors. SPs, further than a communication tool, become a transparent companion (Fig. 1a, b) ultimately able to: (i) early detect changes in the fall risk profile of its users and, in consequence, (ii) adapt the degree of living assistance; (iii) timely involve carers and family, as and when needed. Another important ingredient of the FARSEEING recipe is the HCA system, based on the BTicino MyHome system (http://www.bticino.com), which is able to support elderly users in their daily activities. An RFID-based locator system is integrated with the HCA system; the user wears a small RFID tag that can be hidden in clothes, embedded in the SP, or in the wearable sensing unit; the latter is a system specifically designed for long-term monitoring at home (Fig. 1c). The integration of the HCA and control system with the RFID technology, a gateway, and a processing unit, makes it possible to provide contextual information to the user generating a series of warnings or simply providing useful reminders and suggestions.

The CuPiD project has a focus on people with PD. Until recently, treatment goals for PD focused almost exclusively on symptom relief, but motor learning and rehabilitation principles can be effective even in the presence of PD. It is critical to make rehab-like therapies accepted by patients since long-term treatments in clinical settings are not feasible, cost effective, or likely something that patients can comply with year after year. CuPiD is designed to meet this challenge. ICT-enabled systems have been developed to provide, in the home settings, personalized treatment integrated into PD person's everyday routine; and tailored solution to target balance, walking performances, safety of movements, cognitive function, and debilitating symptom (e.g. freezing of gait). Motor rehabilitation programs include: (i) "exergaming" by means of virtual reality, to train balance, onset of movements and upper limb motor function, (ii) "training of walking" by means of an intelligent tutoring system able to guide and promptly correct patient gait pattern and (iii) "training for preventing Freezing of Gait episodes".

Fig. 1 **a** Elderly person wearing the smartphone as a monitoring unit by means of a custom elastic waist belt. **b** Waist belt used for wearing the smartphone for both activity monitoring and functional assessment. **c** FARSEEING wearable monitoring unit specifically designed for long-term monitoring of people at high risk of falling

Table 1 reports the topics which have been investigated and developed in the framework of FARSEEING and CuPiD projects; details about the specific implementation are reported in the following subsections.

2.1 Stimuli Provision

The FARSEEING Smarthome user interface is developed by customizing the BTicino touchscreen interface used to control the standard HCA (Fig. 2a). Due to the fact that the screen size of the SP is much smaller than that of wall mounted touchscreens, the user interface cannot be the same of the smarthome. The interaction with the user is minimized and the SP mostly act as a reminder (Fig. 2b): (i) to inform the user that a specific message is available on the wall mounted touchscreen; (ii) to remind the user that an activity is scheduled at a certain hour of the day.

Table 1 Topics investigated and developed in the framework of FARSEEING and CuPiD projects

Topics	FARSEEING	CuPiD
Stimuli provision	Yes	Yes
Long-term monitoring	Yes	No
Training/Rehabilitation at home	No	Yes
Exergames	Yes	Yes
Functional assessment	Yes	Yes
Telemedical service	Yes	Yes

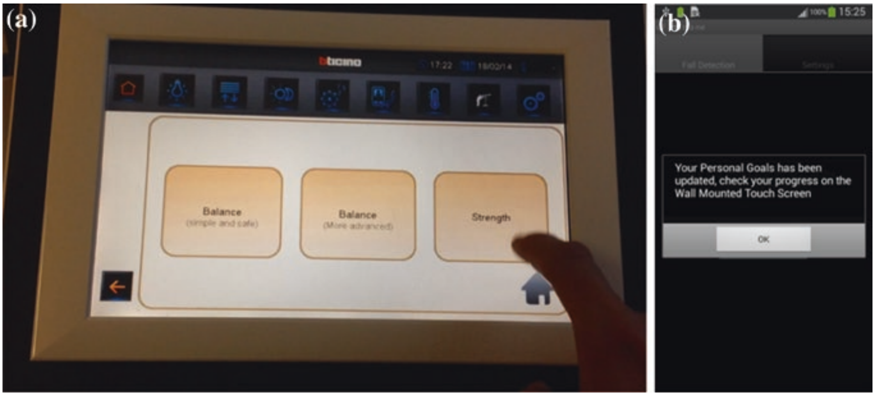

Fig. 2 **a** Wall-mounted touchscreen used for providing tips, feedbacks, and exercise guidance to the user. **b** The Smartphone provides remainders and inform the user about the content available on the wall-mounted touchscreen

In CuPiD, the Virtual Reality (VR) system implementing the exergame platform, is adaptive to enable individualization and graded levels of difficulty to fit patients' performance. To enhance motor learning and provide motivation and engagement, the VR simulation will provide immediate feedback about performance in the form of auditory and visual cues, as well as knowledge of results in the form of a score pertaining to the success rate and error rate in achieving the target goals. The gait rehabilitation system developed in CuPiD (Sect. 2.3) is able to provide real-time customized feedback to patients on how to maintain an effective and safe walking pattern. Target values for each specific gait feature (e.g. step length) are decided by the patient's usual therapist during a training session performed at the clinic. The system used at home acts as a virtual therapist: a SP application continuously process the data in real time and generates vocal messages like those that their usual therapist would say for correcting patients' errors.

2.2 Long-Term Monitoring

The FARSEEING smarthome continuously monitor all the peripherals installed in the home environment like switches, buttons, touchscreens, PIRs, RFID system, etc. Any interaction between the user and the smarthome is recorded by means of a listener-like or a polling approach depending on the specific device. Behaviour is seen as the product of the person, the context of the environment, and the task being performed; the latter is identified and assessed by means of the long-term activity monitoring of the user. Depending on the mounting option, the SP or the dedicated wearable unit are used for estimating:

- Mounting option 1—the device is used/placed without any constraints. Available features: Sedentary/active periods; walking bouts; lying times; energy expenditure; number of steps.
- Mounting option 2—the device is worn on the lower back. Available features, in addition to the mounting option 1: Temporal gait parameters like cadence, regularity, symmetry, coordination, and smoothness; analysis of the turns including turning angle, duration, mean velocity, peak velocity, and smoothness.

2.3 Training/Rehabilitation at Home

Gait in PD is impaired particularly in its semi-automatic nature, precluding patients to walk while thinking or planning other activities. People with PD, in order to perform an effective and safe walk dedicate each attentional resource to accomplish what normally, instead, is a fully automatic activity. They drive feet and lower limbs trying to maintain an augmented speed, large steps, good clearance from the ground, increased gait rhythm, upright trunk posture, etc. This continuous focus on motor movements prevents the possibility of executing contextually any other task and hence to carry out with ease the everyday activities that make up our personal, domestic and social lives.

With the progress of the disease, many of the balance deficits as well as gait impairments become resistant to most pharmacological and surgical treatments. However, it has been demonstrated that also motor learning and rehabilitation principles can be effective to limit these motor deficits. Considering that PD is a chronic neurodegenerative disease, to make rehabilitation exercises maximally effective persons are in need of a continuous training integrated into everyday routine. CuPiD has therefore developed systems for being used at home. CuPiD solution consists of a wearable and stand-alone system able to perform an accurate gait analysis and at the same time to act as an intelligent tutoring system for gait rehabilitation. The system consists of a wireless body area network (Fig. 3a) of 3 inertial sensors, 2 worn on top of the shoes (Fig. 3b) and one on the waist, and a SP acting as central processing unit (Fig. 3c).

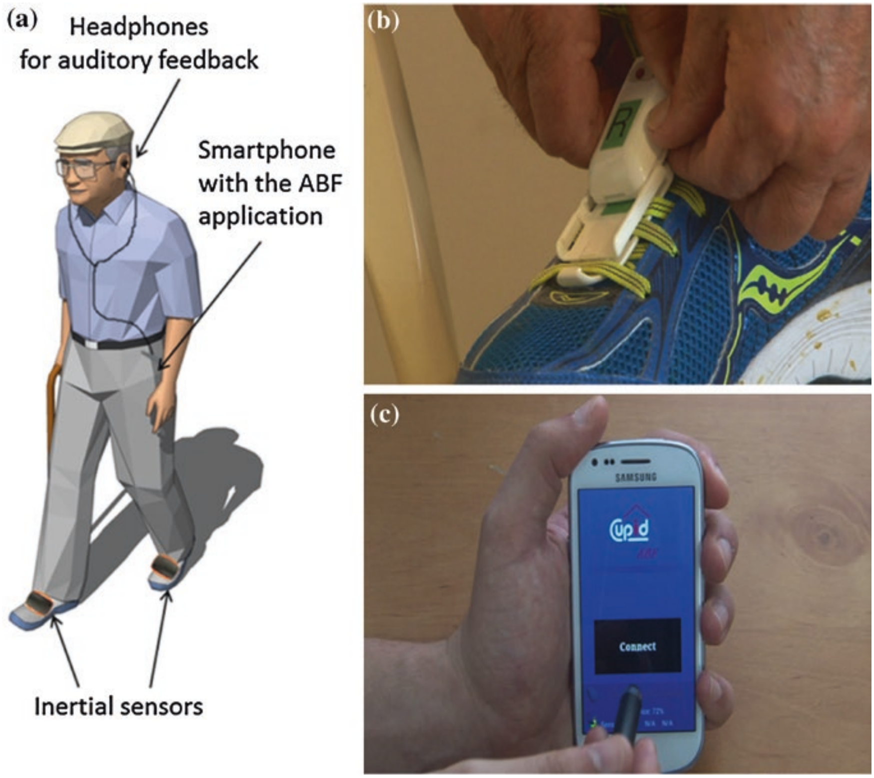

Fig. 3 **a** CuPiD system for gait rehabilitation at home composite of three inertial sensing units, a smartphone, and headphones. **b** Inertial sensors placed on the shoes by means of a dedicated clip. **c** CuPiD Android application which is able to collect and process the data in real-time and to provide vocal messages to the user

2.4 Exergames

Exercise games or exergames are games aiming to improve and increase the users' physical activity through exercise [1–3]. Exergames are designed specifically to track body motion and provide the player with entertainment during exercise.

The CuPiD exergaming platform includes three dedicated serious games for Parkinson's patients developed to increase physical activity and specifically address problems in balance control, sit-stand transition, and onset of walking. The three games that were developed for this purpose combine a motor as well as a cognitive component. The rationale is that activities of everyday living are goal-oriented movements that in essence are a series of combined tasks involving both motor and cognitive aspects such as information processing, planning, strategic choices and execution of movement.

Unlike CuPiD, FARSEEING has chosen a commercially available system, Silverfit (http://www.silverfit.nl), for exergame-based interventions at home. Commercially available exergames were examined to assess the user preferences and movement qualities when performing the games, operationalized as weight shift, step size, movement speed, vision attention, and movement direction.

2.5 Functional Assessment

The same system used in CuPiD for gait rehabilitation at home also allows clinicians to remotely assess motor skills of the patient on a daily basis. Gait features like step length, foot clearance, spatio-temporal step/stride variability, single/double support, etc. can be accurately assessed and monitored over time.

For investigating motor-related fall risk factors in older adults, instrumented versions of some of the most popular clinical functional tests have been developed. Instead of using a body area network like in CuPiD, a minimal set-up has been chosen in FARSEEING; the set-up consists of a single inertial sensing unit placed on the lower back by means of a waist belt or directly applied to the skin (Fig. 1). Automatic algorithms are used for activity recognition and features extraction. Completely standalone applications are also used to allow the user to self-administer the test at home.

2.6 Telemedical Service

CuPiD provides a telerehabilitation service, which addresses the concerns of recent telemedicine reviews: interoperability, accessibility and reliability. Each individual component of the telemedical service is developed as a web application with a clear clinical-base/home-base split.

One of the FARSEEING objectives is to develop feasible telemedicine service models for detection of accidental falls, fall risk assessment and exercise counselling. Service models are independent of the system infrastructure. Telemedical services make use of the FARSEEING infrastructure for exchanging information between the user and the caregivers; the aim is to provide individualised guidance based on data on activity patterns collected through the SP or the wearable sensor and the HCA system.

3 Discussion and Conclusions

An issue we have well in mind is that technologies themselves present a series of challenges for older people and for chronic-disease patients like PD and for those implementing technological solutions for everyday living problems. Technologies may be viewed as intrusive. Non-acceptance and non-usage can be regarded partly as a consequence of the failure of designs and operational procedures to respond to the wishes and feelings of a very heterogeneous group as the older people.

Evidence from the FARSEEING and CuPiD studies shows that there is great diversity in the acceptance of, and willingness to use, different technologies. Some older adults are very confident using various technologies such as personal computers, SPs, and games consoles. Others describe being afraid of using devices and systems. They are afraid of something going wrong; that they might break the equipment; that the technology will fail; or that their privacy is being compromised. Our research [4, 5] indicated that it is more important to find out what motivates individuals to use technologies. It was reported that the key factor in overcoming the 'entry barrier' to adopting technologies is finding a motivation.

With the use of wearable technology, able to monitor and support an intervention strategy, the user can play an active role in her/his prognosis with an increased emphasis on health education, patient empowerment, secondary prevention and self-management of individual conditions, including co-morbidities and frailty. CuPiD and FARSEEING solutions can have a beneficial impact on empowering the user/patient for improving health-related quality of life in the comforts of their own home.

The importance of maintaining independence with regard to the acceptance of technologies has been reported in several studies [6–10]. Maintaining independent physical function was cited by many participants as a primary reason for older adults accepting technologies in their homes. Being able to live in their own homes, by themselves, for as long as possible and thus avoiding a change in their lifestyle habits was a strong motivation for acceptance. Therefore in the FARSEEING and CuPiD approach, stimuli and messages provided to the user have a focus on the possibility of regaining or maintaining independence. We envision that the health-care burden would be dramatically lowered just by adopting consumer electronic devices like SPs as front-ends for the delivery of services like self-assessment tools, feedbacks about own mobility, and guidance for training and rehabilitation at home.

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Design of a Secure Habitat for an Enhanced Long Living: Case Study S.H.E.L.L Project

Niccolò Casiddu, Claudia Porfirione and Matteo Zallio

Abstract The present work has been developed from an accurate study on the Wearable Devices within the S.H.E.L.L. project (Secure Habitat for an Enhanced Long Living), led by the Department of Architecture in Genoa, which focuses on "Made in Italy" industrial innovation. The project seeks to create a new assistance system for mentally disabled people or people with reduced mobility (Stikic et al., PervasiveHealth 2008, Second International Conference on Pervasive Computing Technologies for Healthcare, 2008) [1] using *S.H.E.L.L. Personal Kit: a Secure Habitat for an Enhanced Long Living Personal Kit*, a series of environmental devices that should be stationary and easy to use and implement and a modular system. The aim is to turn them into mass products. The S.H.E.L.L. Personal Kit is made up of an smart wearable device, a tablet docking station and a series of environmental elements for localization and to receive/transmit data. The principal goal of the project is enhancing safety and autonomy for its users through automatic alarms, integrated in a wireless sensor net. The system can detect specific habits of the people that are being monitored, thus allowing them to move freely in their surroundings. It guarantees constant assistance by interacting in the case of an emergency and alerting family members or caretakers of any anomaly in the observed data.

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1 Introduction

Nowadays technologies spread quicker and on a large scale, becoming part of our everyday life [1]. With this in mind, wearable devices offer the chance to explore new interesting solutions [2].

Thanks to miniaturisation, computers are successfully integrating among people and our environments. A revolution is taking place on where and how computers are used. Starting from computers constrained to use in one room, we moved to more portable devices arriving to today in which wearable computers/devices can be worn directly on the body or on clothing. These developments led to the birth of a new category of accessories/products, achieved with advanced measurement systems alongside innovative monitoring methods. These products have applications in many different fields: healthcare, sport and personal safety. Particularly, it is pivotal to develop more efficient sensor nets in changing the modern approach to dealing with the quantity of acquired and transmitted information. These strategies can improve environmental control and localisation in order to gain a better understanding of users through their day-to-day activities.

In this exciting new field, Design can become fundamental in helping users accepting these new smart devices, which are often designed without paying enough attention to the users' real needs.

These smart technologies lack appropriate interfaces (both graphic and physical) that allow intuitive and human-friendly communication. These kinds of interfaces should be based on a Human-Centred design and are essential to dynamic and efficient interaction.

2 Research and Analysis on the Status of the Art

Previous research indicates that the current trend is to offer consumers higher comfort and functionality and this is what determined the success of portable devices together with the wide array of services provided (from a simple calculator to complex applications).

Portable devices—especially wearable ones—are becoming increasingly more popular; their diffusion all around the world was increased by the so-called intelligent devices. One could claim that we are at the beginning of an important step forward in computer technology.

It is estimated that the sales of tablets will outnumber that of PCs within 2015. A survey published by the research society International Data Corporation (IDC) explained that tablet popularity would have increased by 60 % in 2013 to outsell PCs by 2015. From SMS, to video and then social mobile, portable and wearable devices are starting to play an important role.

Therefore, designing objects that are able to communicate, such as tablets and smartphones, is a new challenge for the ICT market.

The major international companies are heading towards wearable devices as examined in the survey by the renowned “Freedonia Group”. A significant growth is expected in sensoristic technology, going from 11 billion in 2013 to 16 billion in 2016 thanks to the sales of these devices.

Assistive devices will become the leading branch in the market of wearable devices for bio-medical applications to help people with physical and sensory disability. It is worth noting that the term “wearable devices” does not apply to smart clothing technology but other kinds of wearable applications, for example embeddable implants.

3 Design Stages

The research project was divided into different sections, which were assigned according to the competences of each single partner: analyses; evaluation of the status of the art; structuring of the system architecture; providing specifications of the different components; study of design and function of both hardware and software; research into characteristics and hardware design of wireless communication units, the localisation module, the environmental monitoring tools and finally study of software design of the entire system architecture and functional modules to manage all different services.

In the first stage of the research, the design section of the Department of Sciences for Architecture (DSA) summarised the outcome of the research in order to set guidelines for ergonomics and usability of the smart wearable devices. These analyses became the basis by which to outline the concept and subsequently the definitive project.

Research on the status of the art observes how wearable devices position slightly higher within the market than expensive gadgets.

It was also shown that most products on the market target young people using them for edutainment, lifestyle, sport and music. This highlights the necessity of new strategies and products for elderly consumers.

Currently, devices for elderly people mainly focus on monitoring and assistance but the users still fail to accept them because they identify the devices as medical tools.

From a technical point of view, the research underlined that nearly all examined devices normally use one sensor only (accelerometer) and have less durable charge for long or complex functions. Increasing energy autonomy and using more complex sensors are some of the issues that technology and design still have to find a solution to. Within the project the DSA sought to illustrate a design for this new kind of product, which should be at the same time useful and long-lasting to fit into a wider market, targeting the elderly population and weak users (the physically and mentally handicapped) (Fig. 1).

Fig. 1 Examples of wearable devices studied in the present research

4 Application Scenarios and End Use

The concept of smart homes for elderly or handicapped people to improve their autonomy is not a new one. As widely explained in literature [3], through the years there have been many attempts to create smart environments.

The SHELL project brought something new to the table by researching into a realistic and feasible solution: implementing available technologies to create a “kit”. This kit is a highly modular system characterised by a series of fundamental functions which can be improved thanks to the advanced features available as plug-in accessories. The system provides continuous monitoring with a sound and vocal alarm in case of an emergency, allowing the utmost autonomy to its user.

SHELL has different application scenarios according to its use and to the different levels of autonomy. The kit is designed to be self-installed in a domestic environment but it can also be utilized within a healthcare facility in the same way.

5 Smart Device Design Process

In the preliminary stage of design research all possible concepts were analysed before realization and testing of the different prototypes. This long process led to one consolidated prototype and during the final stage the definitive mathematical structure was settled. The smart device performs a series of on- and off-line activities: detecting vital parameters (i.e. temperature and heartbeat), posture monitoring and movement analysis that is then compared with predefined parameters in order to understand possible dangerous situations or the progression of the user pathology [4].

To design the device a UCD (User Centred Design) approach was followed [5]. This approach focuses on the user and specifically on usability, adaptability and ergonomics. The term ergonomics describes the capacity to perceive the different dimensions of the user [6]. For a wearable design, proportions are calculated on potential users and they aim to be comfortable with specific attention being paid to hygiene and safety. Consequently, the choice of materials was extremely important as they should be appealing, biocompatible and environmentally friendly [7]. "Invisibility" in terms of its design is considered as a vital feature and it influenced the technical choices of the product shape and ergonomics. "Invisibility" means the device is not perceived and the final user is not bound to display it within the house but at the same time it is easily accessible to healthcare operators (or family members)[8].

The SHELL personal Kit showcases many important features for its potential end user: a high level of affordance (i.e. the device is easy to use and it intuitively suggests its function) and the possibility to customize it, thus making it more easily accepted, even in situations of psychophysical disadvantage.

5.1 Functional Prototype

The first prototype was meant to execute general tasks and to be improved through lab tests in order to integrate all functions into one circuit board (Fig. 2).

5.2 First Prototype—Concept

The wearable device should act like an everyday life object and it is designed to adapt to different lifestyles and to its different functions which vary depending on the user habits, health conditions and on general data to be collected (the last

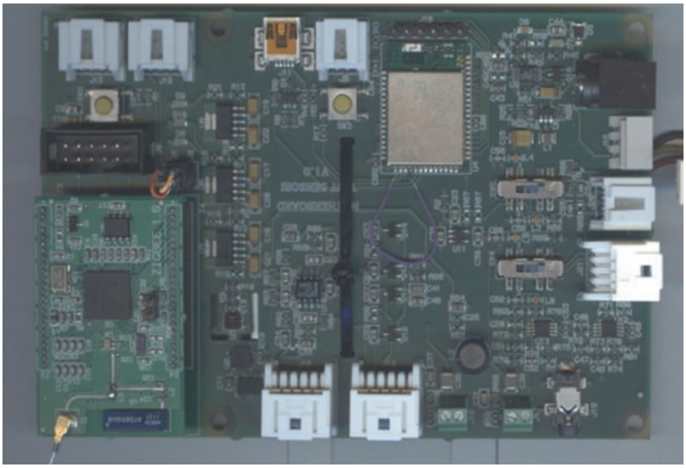

Fig. 2 PCB functional prototype

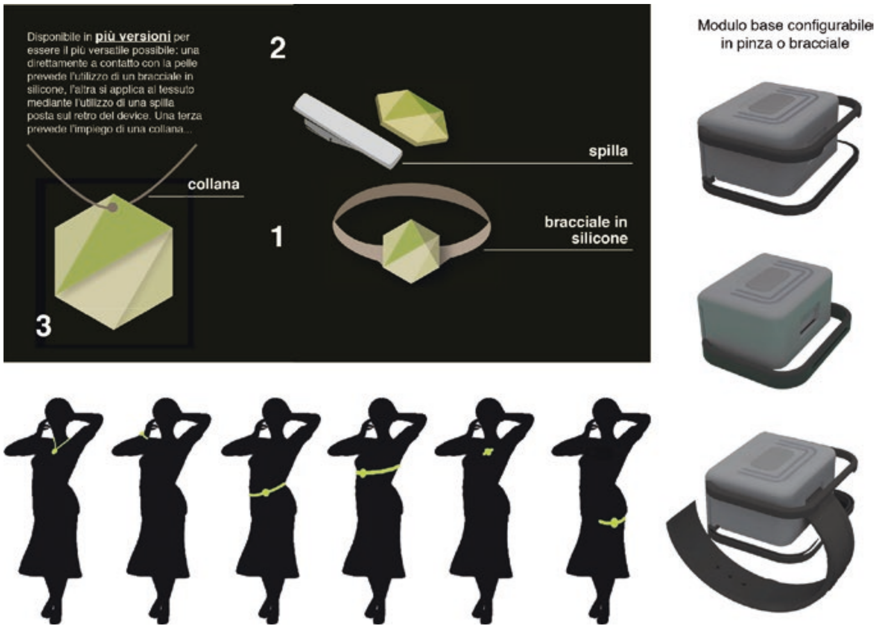

Fig. 3 Wearable device concept

being identified as the most fundamental element in the intermediate stage of the project)[9].

By taking into account dimensional constraints and sensor and hardware position, a module was created which could be designed into a pendant or a hairclip (if worn singularly) or into a bracelet if integrated with a wristband (Fig. 3).

5.3 Second Prototype—Test

In creating the prototype stress was placed on cover ergonomics and the user (reducing the hardware dimensions and increasing comfort levels)[10]. After having defined the semi-definitive features regarding dimensions (base, height, depth), functionality (i.e. button for emergency calls) and connectivity (battery charge), some components of the device were positioned on the lateral wings (integrated on the side of the wristband): speaker, microphone, charging pins and a temperature sensor. It was agreed to 3D print some intermediate shells to test the improved ergonomics and usability before proceeding with the final version of the shell to be tested by end-users [11] (Fig. 4).

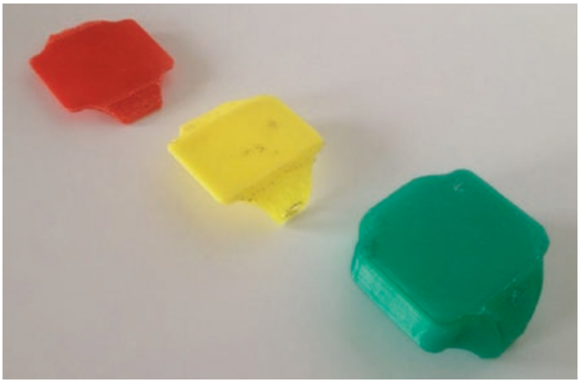

Fig. 4 Mock-up covers realized with a quick low-cost

Fig. 5 Concept sketches board

5.4 *Product Design Concept*

At the end of the design process (consistent with a Human Centered Robotic Design approach), the Product Design Concept of the smart wearable device was finally achieved.

The device adapts to the needs and taste of the user and it is highly customizable and empathic. It aims to relate with the user through a process of psychic and body memory connotation: by interacting though a button (which was preferred to a touch screen option) all functions are actively accessible, enhancing physical contact [12]. Reminiscence therapy demonstrated that recalling an object from the past (i.e. a pocket watch in the present research) consolidates a natural empathy with the elderly user. The upper surface of the device can be personalised, in order to generate positive reactions and obtain the utmost acceptability [13] (Fig. 5).

6 Environmental Device

The environmental device detects all data recorded by the smart wearable device, it then analyses it and in case of an anomaly it contacts the healthcare structure or family for first aid. It also initiates dialogic communication with the user to check on his actual condition. All environmental devices need to be connected to the main power supply and are equipped with a buffer battery. They should also be positioned at a certain height (for instance above doors) because this helps to collect data without any physical interference (caused for example by furniture).

Environmental devices have different sensors and different functions (beside its principal function of localisation): temperature measuring; humidity measuring; sound and communication detection (through a microphone and speaker); detecting gas and CO_2 leaks.

Fig. 6 Concept docking station and tablet position

7 Docking Station and Tablet Location

The SHELL project offers a docking station, i.e. a recharging platform to which it is possible to plug in the wearable device and the tablet (or smartphone). It works in a fixed location to visualise the collected parameters or the data selected by the user, thanks to a specific application installed for the present research. The docking station is equipped with a sliding connector that allows the platform to adapt to the various dimension of the tablets currently on the market. It can also be divided into two elements, autonomous and independent, thus enabling the user to decide their positions in the surrounding (Fig. 6).

8 System Interfaces Specifications

An essential step in the SHELL programme is pointing out a series of requirements for the system interfaces. The design of the system interface took into account the aesthetics and the graphic rules of usability [14]. The use of colours, shapes, fonts and animation was always strictly connected to the user. As a result, the graphic interface should be hierarchically organised in relation to the user perception and it should also be easy to read and browse [15].

9 Conclusion

The "Ambient Assisted Living" and other innovative technologies for assistance are leading the way to new forms of social services. In particular they are creating a net of sustainable assistance that is not bound by physical presence where the elderly user lives. The SHELL project proves that mixing different competences in researching and designing smart devices can lead to interesting applications that, with the right additions, are easily accepted by the user without the need for technological training.

Fig. 7 Current stage of the experimental test

The project is nearing its conclusion; a further examination of data and subsequent surveys will perfect the whole system. The observations gathered in the present stage of the project will help pinpointing the potential and limits of the adopted application (Fig. 7).

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Neurophysiological and Behavioural Variables in Cognitive Impairment: Towards a Personalised Monitoring System

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Abstract The social changes and the population aging process increase the incidence of problems ranging from simple para-physiological reduction of psycho-physical and sensorial capacities to the cognitive impairment of different degrees. In this scenario, telemonitoring and telemedicine are useful tools for support, care and prevention. This paper shows how several clinical data can be acquired by personalized monitoring and used to evaluate in the follow up possible therapeutical results. Sleep modification that arises with the physiological aging process and in the presence of neurodegeneration were correlated to a dramatic reduction of the Slow Wave Sleep (SWS). These results improved the knowledge regarding the relation between sleep and wellbeing. Different ICT tools can be in perspectives considered within diagnostic and therapeutic personalized programs, i.e. Surface ElectroMyoGraphy, olfactory tests, wearable devices, sleep monitoring and metabolic characterization.

1 Introduction

In the actual scenario of ageing population, a personalized program of maintaining physical activity together with a physiological sleep can be implemented using several telemedicine tools. Furthermore, by considering the sensory reduction with age it appears important a deep knowledge of different playing variables. It is now

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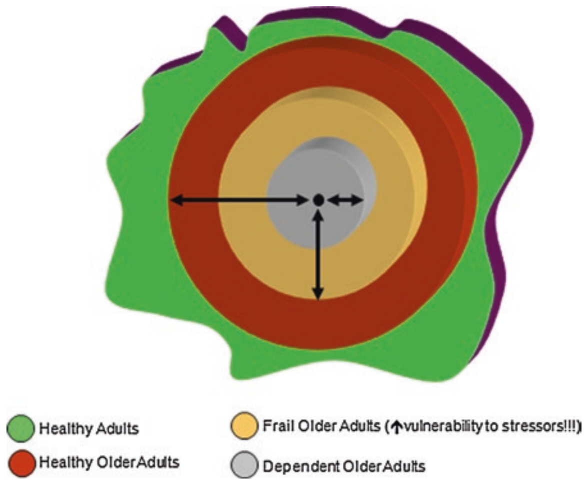

Fig. 1 Variability decreases as a function of age

largely accepted that the concept of health is not strictly related to the concept of homeostasis, in the literary sense. In fact, lack of variability is often associated to risk of pathological conditions (i.e. heart rate variability). An example of how variability decreases in function of age is given in Fig. 1. The frailty can be described as a reduction of homeostatic oscillations and in elderly a further reduction of physiological variability worsens the capabilities to interact with environmental and internal changes. The final outcome is the lack of independency.

2 The Sleep Importance

The benefits of restorative sleep include: (i) improved alertness, (ii) greater ability to learn and retain motor/sensory/mental skills, and (iii) beneficial effect on mood and socialization. In addition, restorative sleep protects cardiovascular and immune systems against the deteriorating effects of ageing and stress [23, 24]. These positive effects of sleep have recently been attributed to the Slow Wave Sleep (SWS), particularly to its very slow component, namely the less than 1 Hz oscillation (Sleep Slow Oscillation—SSO).

Intracellular recordings in animals and EEG studies in humans (including intracortical recording) show that all cortical neurons oscillate between states of electrical silence and states of wake-like firing when EEG traces display slow waves (SSO, K complexes and delta waves) [26]. Sleep unconsciousness and memory consolidation are related to SSO's basic properties: SSO is more frequently located in areas involved in hebbian plastic arrangement of cortical circuits and groups fast EEG activities for replying neural information, thus allowing memory consolidation [20, 21, 26]. SSO seems to play a crucial role in the large-scale sleep-related synaptic downscaling of wake-related upscaled cortical

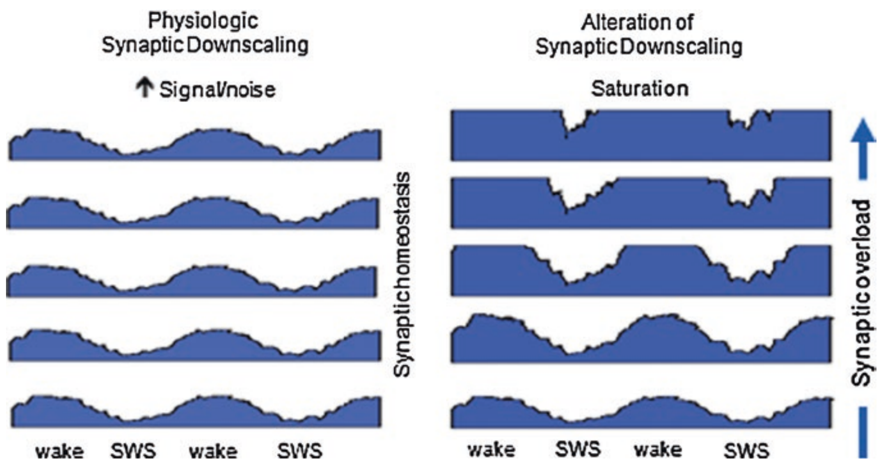

Fig. 2 The *left panel* depicts the role of Slow Wave Sleep (SWS, including SSO) in reducing the synaptic weight (synaptic downscaling) enhanced by wake-related learning mechanisms (Tononi and Cirelli, 2014). The final result is a circadian cycle of synaptic weight, which is sculpted during the night by a specific effect of SWS. The right panel depicts a hypothetical case of synaptic saturation caused by an alteration of SWS and hence of SSO

circuits, which represents the "core" of the Synaptic Homeostasis Hypothesis [29] (see Fig. 2). Finally, SWS (and possibly SSO) favors and protects the formation of newborn neurons in the hippocampus, the so-called neurogenesis, whose functional role is to provide the substrate for ongoing information processing, memory and mood [19].

One of the best known ageing-related changes is the alteration of the quality of sleep and thus of its homeostatic functions. Older adults' complains about the quality of their sleep include shallow and fragmented sleep (high number of brief episodes of wakefulness after sleep onset), decreased total sleep time, early morning awakening, and excessive daytime sleepiness. A meta-analysis (65 overnight sleep studies pooling a sample of 3,577 subjects across the adult lifespan) highlighted a specific age-effect on sleep with an increase of shallow sleep (N1 and N2) and a decrease of REM and SWS as a function of age [22]. Qualitatively, the dramatic reduction of SWS (including SSO, delta waves and K complexes) represents the crucial factor of age-related sleep changes [3].

According to recent hypotheses on sleep functions, the reduction of SWS reflects, on one side, the inability to plastically sculpt the wake-related cortical synaptic weight [29] (see Fig. 2) and, on the other side, the reduction of beta-amyloid clearance [30]. In this light, sleep loss-related symptoms, e.g., cognitive impairment and depression, might be related to (i) synaptic overload within neocortical and limbic circuits, (ii) reduction of neurogenesis and/or (iii) pathological protein accumulation.

Sleep disturbances are indeed intimately associated with neurodegenerative disorders (such as Alzheimer Disease, Fronto-Temporal Dementia, Prion diseases, Parkinson's disease) caused by accumulation of pathological proteins like tau, amyloid, prion, alpha-synuclein [6]. Independently from pathophysiological mechanisms and from anatomical localization of neurodegenerative damages, a stigma of all these pathological conditions is the dramatic reduction of SWS [6].

Beyond aforementioned age-related mechanisms, in the neurodegenerative disorders the reduction of slow neural synchronization is amplified by diffuse lesions altering anatomical connectivity among cortical circuits (Alzheimer disease, Fronto-temporal dementia, Vascular Dementia etc.) or by segregated lesions in subcortical nuclei crucial for the SWS, such as the thalamus (Fatal Familial Insomnia) and basal ganglia (Parkinson disease). It is now clear how insomnia can be a trigger factor for several pathological conditions in elderly and vice versa a symptom.

An early and effective intervention on insomnia can interrupt the vicious circle. Physical exercise, positively acting on brain plasticity, neurogenesis and SWS, can be adopted as straightforward countermeasure to ageing-related negative effects (both in normal and pathological elderly). Over the last decade, exercise has been extensively recommended for improving health in the elderly and a large body of scientific literature points out the efficacy of exercise in improving sleep functions and mood in elderly patients with insomnia and depression [31]. Exercise programs have been used for reducing cognitive decline in Mild Cognitive Impairment [32]. These programs have also been designed for enhancing social interaction since social isolation in aged people acts as a dramatic stressful condition, yielding an hypothalamic-pituitary-adrenal axis overactivity, hence impairing sleep restorative effects.

In synthesis, the relation between sleep and wellbeing has become crystal clear in many aspects, in particular as far as sleep disorders and many mental and somatic diseases are concerned. This means that also sub-threshold sleep disorders in elderly call for immediate care, as general practitioners typically underestimate their negative effects. On the other hand early ecological intervention on sleep may represent an economic and effective approach for the globally ageing population health care.

3 Surface Electromyography Study and Remote Monitoring

Ageing is associated with progressive loss in function across multiple systems, including sensation, cognition, memory but also motor control, bone and muscle strength [11]. Age-related muscular strength decline is mainly due to quantitative loss of muscular mass (sarcopenia), however also qualitative changes of muscle fibers and tendons, such as selective atrophy, and neuronal modifications, such as lower activation of the agonist muscle and higher coactivation of the antagonist muscles, contribute to this phenomenon. The process associated to the decline of muscle strength is known as "fatigue", defined as the loss of voluntary force-producing capacity during an exercise. Muscle fatigue is a symptom of a number of neurological diseases, including multiple sclerosis, stroke and Parkinson's disease [5].

The preserving of physiological function and the prevention of functional decline with aging is essential for maintaining independent mobility for daily living and community access. Thus, exercise training may be applied as a potential intervention strategy for older people. It has been proposed that exercise may have beneficial effect in healthy young and older adults by increasing angiogenesis, neuroplasticity, neurogenesis, neuroprotection, anti-inflammatory effect, improving mitochondrial function and oxidative stress, increasing brain connectivity and levels of neurotrophic factors such as brain-derived neurotrophic factor.

Monitoring muscular fatigue at home can be extremely important in elderly in order to get a continuous evaluation of the user, to monitor and coach rehabilitation exercise, as well as to enable early detection of excessive fatigue and activity abnormalities. Muscle fatigue is commonly assessed through surface electromyography (sEMG). Nowadays, thanks to the rapid progress in unobtrusive computing with small, non-invasive sensors and wireless communication, sEMG can be obtained by simple, inexpensive and portable devices.

To this end we have realized a remote monitoring system based on wirelessly connected wearable platform for the acquisition of sEMG signals for monitoring of muscular fatigue at home [27]. The acquisition system is based on light, wireless wearable sensors. sEMG signals are acquired by a dedicated application while the subject perform an exercise. The signal acquired are sent to a central database and processed by the support system and then the report is sent to the physician. The support system implements pre-processing, signal features extraction and selection, as well as classification modules. In particular, the classification module is based on a Kohonen self-organizing map predictive model, which allows accurately classifying the level of muscular fatigue.

The system allows a continuous monitoring of exercise and related muscle fatigue at home. In this way, the device helps the elderly in enhancing muscular strength during exercise and clinicians in the analysis of physiological parameters and in the decision making process.

4 Olfactory Tests

Olfactory assessment was found to be extremely relevant in clinical practice since early 2000, when Hawkes demonstrated a clear link between smell loss and neurodegeneration [14] and found several pathologies strictly correlated with olfactory decrease (hyposmia) or completely olfactory loss (anosmia). Among them are Alzheimer's (AD) and Parkinson's Disease (PD), Lewy body disease, Huntington's chorea and Motor neurone disease [14]. Senescence process, often related to brain aging, is another risk factor for olfactory function, with several evidence of odor perception decrease in elderly people, due to the worsening in brain areas connectivity [17]. Moreover, olfactory testing could be also an useful method to assess damage to neurogenesis possibly brought by exposure to neurotoxic agents, such as chemicals and ionizing radiation, known to inhibit neurogenesis at hippocampus and olfactory bulb, representing a possible pathophysiological mechanism of the cognitive and emotional impairment characterizing neurodegenerative conditions [28].

One of the most employed approaches for the evaluation of the olfactory function are psychophysical olfactory tests, often chosen due to their easy administration. Many of those tests are actually available on the market and, in this context, tests for odor threshold, discrimination and identification are among the most widely used.

The odor threshold test aims to calculate the minimum concentration of a given odorant that can be detected by a subject. In most cases, the reference odor is phenylethyl-alcohol (a rose-like odor) or n-butanol (a rancid-like, unpleasant stimulant). In the first case, a "pure" olfactory response is expected, while n-butanol is known to be also a trigeminal stimulant, able to activate the Cranial Nerve (CN) V pathway. Among the commercially available kits for olfactory threshold assessment are the "Smell Threshold Test", distributed by Sensonics, Inc. (Haddon Heights, NJ, USA) and the "Sniffin' Sticks Test", by Burghart Medizintechnik, GmbH (Wedel, Germany). The odor discrimination test assesses the ability of a subject in discriminating different odors. Several approaches are used for this category of testing: in one of them, the subject should indicate, on a given trial, whether two given stimuli are the same of different, while in another, named "triangle test" and probably more frequently used, the subject is asked to pick the "odd" stimulus from a set from which only the "odd" stimulus differs. The most common commercially available test is the Sniffin' Sticks Odor Discrimination Test, by Burghart Medizintechnik, GmbH.

The odor identification test evaluates the ability in correctly identifying odors. Usually, sets of odors are presented. For each stimulus, the subject is asked to identify the odor detected from a set of four descriptors. Most widely used odor identification tests include the University of Pennsylvania Smell Identification Test (UPSIT), by Sensonics, Inc., and the Sniffin' Sticks Odor Identification Test, by Burghart Medizintechnik, GmbH.

5 The FP7 SensorART Experience

SensorART "A remote controlled Sensorized ARTificial heart enabling patients empowerment and new therapy approaches" has been an FP7 large-scale integrated project, funded by the European Commission (www.sensorart.eu).

Heart Failure (HF), a rapidly increasing cardiovascular chronic disease, is the main cause of mortality and poor quality of life in western societies [13].

According to the European Heart Failure Association, 26 million people experience HF globally and 3.6 million people are diagnosed with HF, every year. For this reason, together with the difficulty of having a sufficient number of donor organs, it is recognized that the device-based therapeutic approaches will assume an increasingly important role in treating the growing number of patients with advanced heart failure, not only as bridge to transplant, but also as destination therapy, by considering also the ageing population. Current treatment of heart failure consists of ventricular assistive devices (VADs), namely mechanical pumps implanted in the patient's body used to restore blood circulation. At present, however, VADs are used mainly to bridge heart transplantation.

The SensorART project intended to turn VADs from mechanical devices to intelligent systems, by endowing them with dedicated sensors (i.e. flow, pressure). In this way, VADs could be adjusted to the patients physical needs and monitor his/her status. Most importantly, intelligent VADs systems could be used not only as bridge to transplant, but also as destination therapy. These purposes need an upgrading of the actual VADs and this program will require a long time, even if within SensorART the proofs of concept have been acquired and demonstrated.

Up to now in clinical arena wearable systems used for monitoring VAD implanted patients can give information about the state of patients and suggest possible change of circulatory support during different activities in the daily life.

In the setting of wearable sensors, MagIC system [7] was adopted as one of the sources of Heart Rate (through single ECG-lead), Respiratory Rate (through textile), posture and movement signals. It is a washable sensorized vest including fully woven textile sensors for ECG and respiration rate monitoring together with posture and physical activity. After the implementation of MagIC in SensorART platform, a test session on real patients was needed in order to verify the correct interaction between all modules and to test the effective output. According to patient characteristics and ability, MagIC was tested in three conditions: (1) at baseline, (2) during a 6 min walking test (6MWT), and (3) during an exercise test performed with a stationary bicycle. From the data acquisition, even if in a small number of patients, it is important to underline the big amount of information and data which could be derived by the wearable platform linked to telemedicine tools in chronically diseased patients.

A different wearable system, WINPack device (http://www.winmedical.com/) was also used on VAD patients. WIN Medical has a specific expertise in realizing real time wearable systems for continuous patient's monitoring. The wearable system WINPack is able to monitor parameters as heart rate, SpO2, posture, temperature and ECG. WINMedical products have the CE marking approval (CE0434 according to 93/42/EEC) and are registered in the Medical Devices database of the Italian Health Ministry. A total of 16 patients were monitored using this device at the follow up visits. Data were recorded at rest and, when possible, before, during and after the 6MWT, also in old patients.

6 Pharmacological Perspective

Ageing is associated with deterioration of glucose tolerance, insulin resistance, type 2 diabetes (T2DM) and cardiometabolic diseases [18]. Aging is also associated with decreased brain function, neuronal activity and metabolism. In patients with T2DM the risk of cognitive dysfunction, e.g., dementia, Alzheimer's (AD), Parkinson's disease (PD) and mild cognitive impairment (MCI), is higher than in the general population [8]. T2DM is highly prevalent in the old population and developed mainly because of impaired insulin secretion and action [12].

Beside insulin, other hormones, like glucagon like peptide-1, GLP-1, are involved in both the regulation of peripheral glucose metabolism [4] and cerebral glucose metabolism and function [16, 25]. GLP-1 is secreted in response to a meal by the L-cell of the intestine and the main action of this hormone is to potentiate pancreatic insulin secretion [4]. Other GLP-1 pleiotropic effects have been described, in particular on the protection of the heart, the endothelium and the brain [4, 15].

GLP-1 can cross the blood brain barrier and act through binding to its receptors [4, 16]. Several areas of the brain expresses GLP-1 receptors, in particular hypothalamus, frontal, occipital and temporal areas [1]. However, the half-life of GLP-1 is only of few minutes and the secretion of this hormone is reduced in subjects with prediabetes and T2DM [15] (Fig. 3).

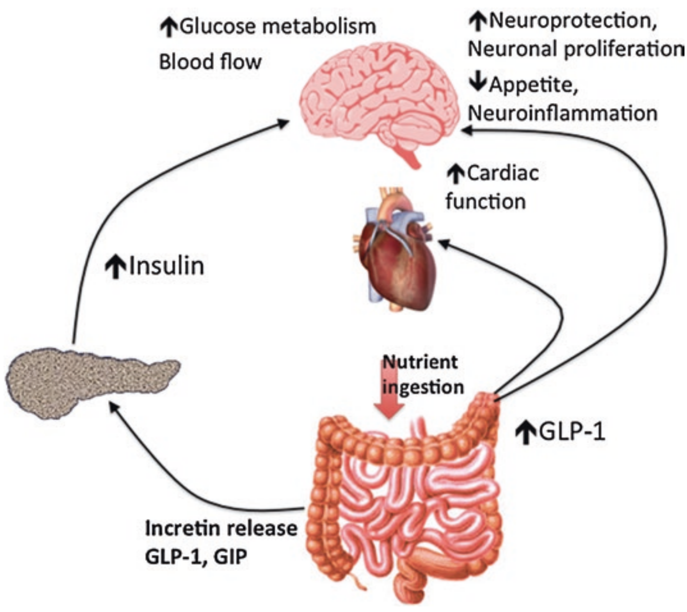

Fig. 3 The gut-brain cross talk. After a meal, in response to nutrient ingestion, the gut releases incretin hormones, GLP-1 and GIP (Gastric inhibitory polypeptide). GLP-1 is acting on several organs, mainly on pancreas, brain and heart

Recently GLP-1 analogs with longer half-lives than native GLP-1 (3 h to 7 days vs. 2-3 min) have been developed and approved for the treatment of diabetic hyperglycemia (i.e., exenatide, liraglutide or lixisenatide). Initial studies using position emission tomography (PET) and functional magnetic resonance imaging (fMRI) have shown that GLP-1 and GLP-1 analogs can improve cerebral glucose metabolism and blood flow [9]. It has been hypothesized that these drugs, beside reducing blood hyperglycemia, could prevent neurodegeneration. Thus they have been used off label in patients with Alzheimer's [2] and Parkinson's [10] disease founding good clinical responses and providing evidences that pharmacological treatment of older subjects with GLP-1 analogs can improve brain metabolism and prevent neurodegeneration and cognitive dysfunction.

7 Conclusions

By considering the different aspects of ageing in the old population with the complexity scenario of multiple variables, it seems important to plan a specific and multidisciplinary study in order to better understand the needs of an early diagnostic procedure as well as a personalized program for counterbalance and care.

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ALPHA: an eAsy inteLligent service Platform for Healthy Ageing

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Abstract Dementia is one of the biggest global public health challenges facing our generation. Alzheimer's disease (AD) is the most frequent cause of dementia in elderly people over 65 years of age. The typical characteristic of AD is impairment of memory. As the disease progresses, other cognitive domains such as language, praxis, visuo-spatial and executive functions become involved, eventually resulting in global cognitive decline. Behavioral Psychological Symptoms of Dementia (BPSD) problems are constant in AD and have a highly negative impact on the quality of life of patients and their families. ALPHA project aims at developing an intelligent situation-aware system to collect and process information

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about Alzheimer Disease patients' life style. Starting from various data provided by caregivers and a set of non-invasive sensors and devices, ALPHA will provide clinicians with new quantitative and qualitative information about patients' abnormal behavior which, along with medical data, will enhance the accuracy and reliability of monitoring and assessing the patient's health status. Clinicians will be supported by a suite of specifically designed tools and interfaces to analyze the metadata captured, improve management of personalized care plans and interactions with both patients and caregivers. Furthermore studies of antique records of a former psychiatric hospital will give the chance to widen the knowledge of behavioral disorders thus allowing to compare the ancient and the recently ones and to probabilistically determine relation between type of dementia and behavioral disorders.

1 Introduction

Dementia, including Alzheimer's disease, is one of the biggest global public health challenges facing our generation. Today, over 35 million people currently live with the condition and this number is expected to double by 2030 and more than triple by 2050–115 million [1]. Dementia is a degenerative condition with no known cure. Symptoms, such as memory loss, cognitive impairment, difficulty in communicating and changes in mood get worse over time. These experiences are distressful for the individuals and upsetting for their relatives. To date, the patient and her/his caregivers are the primary source of information during follow-up visits. Information such as the description of abnormal behaviors manifested by the patient are essential for the assessment of health status and for the quality of drug therapy, especially in the early stages of the disease. Patients and caregivers, however, may not be reliable in providing such information, for example in assessing whether an improvement in symptoms has resulted from use of a particular medication or in describing quantitatively anomalous behaviors.

The eAsy inteLligent service Platform for Healthy Ageing (ALPHA) project aims to develop a new, intelligent, situation-aware system able to collect, process and store information about the daily lifestyle of AD patients; starting from heterogeneous data both provided by caregiver inputs and from a set of non-invasive sensors and devices, ALPHA will provide clinicians with new quantitative and semantic information about the behavior of patients which, in conjunction with medical data, will enhance the accuracy and the reliability of the monitoring and assessment of the patient's health status. It is clear that the system does not replace direct contact between patients and physicians, but it may permit AD patients to increase their chances of better care provision, so reducing the risk for inappropriate or useless support and the need to frequently recur to healthcare facilities.

Furthermore, a subsystem will be designed and created in order to provide clinicians with advanced analysis and care planning tools; in particular, an Alzheimer patient profile interoperable with standard Electronic Health Records (EHR) will be defined to integrate clinical information with a passive monitored data system, also to enhance care coordination.

2 Related Works

Understanding the nature of human activities is itself a significant research question in many disciplinary traditions, such as in psychology, sociology, and ergonomics. The variety of perspectives creates problems, since each discipline may exploit different tactics to uncover human actions. Understanding how to represent human activities for the purpose of having intelligent environments draws upon these different traditions, and represents a significant multidisciplinary challenge [2]. An emerging field of application for human behavior representation and recognition techniques is Ambient Intelligence [3]; Nater et al. [4] propose a data-driven hierarchical approach for the analysis (by means of visual scenes). In [5], a model-based behavior analysis system for assisted living is proposed. Monitoring human behavior is achieved with unsupervised learning algorithms. Behavior is defined as a recognizable pattern in a sequence of events or activities and is represented by means of Hidden Markov Models (HMM).

The state of art provides also a lot of examples of solutions to monitor some of Abnormal Behaviors (AB) related to AD such as Wandering, Sleeping Disorders and Anxiety. Some solutions can be useful to prevent wandering behavior of Alzheimer patients. There are, however, few examples of outdoor wandering prevention tools. Campo et al. [6] developed methods for determining normal trajectory classes and triggering alarms when the trajectories are unusual. They compared each extracted path to all types of trajectories in order to classify them using a neural network. OutCare [7] determined a set of points of interest on a map, the system use the GPS signal to detect patient's location by analyzing the distance between his/her position and the nearest point of interest. Another kind of interesting AB is related to sleeping disorders. ICT solutions aiming to monitor those have been described in the literature. Poree et al. [8] proposed a sleep recording system to perform the monitoring of sleeping disorders; the solution adopts five electrodes: two temporal, two frontal and a reference. This configuration enables to avoid the chin area to enhance the quality of the muscular signal and the hair region for patient convenience. The electroencephalopgram (EEG), eletromyogram (EMG), and elctrooculogram (EOG) signals are separated using the Independent Component Analysis approach. Occhiuzzi and Marrocco [9] investigated the feasibility of the passive RF identification technology for the wireless monitoring of human body movements in some common sleep disorders by means of passive tags equipped with inertial switches. Panagiotakopoulos et al. [10] detected and tracked the anxiety disorders of patients. In their study a context-aware approach is proposed, aiming to provide medical supervisors with a series of applications and personalized services targeted to exploit the multi-parameter contextual data collected through a long-term monitoring procedure.

2.1 ALPHA Contribution

ALPHA will improve, moving beyond previous approaches, the detection and classification of abnormal behaviors by extending well assessed approaches for normal behaviors and integrating them with methods emerging in different fields of application for the detection of faults. In particular, ALPHA will extend hidden Markov approaches by (i) incorporating information from heterogeneous sensors, (ii) exploring how Markov models can be combined with a priori rules formally describing behavior to better capture it, and (iii) using behavioral multiple models associated with different levels of disease progression to estimate long term behavioral trends and classify behaviors, (iv) using the historical and archival data extracted from clinical records of psychiatric hospitals no longer in use which, in the past, combined with advanced molecular biology technologies, allowed to reach the unexpected goal such as the isolation of causal genes for inherited Alzheimer's disease [11]. In addition, abnormal behaviors will be detected and classified from historical records by means of the definition and runtime verification of correctness properties.

3 Abnormal Behaviors

ALPHA focuses on the monitoring of abnormal behaviors deriving from AD. For this reason it is worth to survey which are the common ABs that affect patients with AD and then describe the ones that are subject of our work.

- *Aggressive Behaviors*: Patients with Alzheimer Diseases could show aggressive behaviors both verbally and physically. The reasons which could entail such behaviors are: fear, anxiety or frustration due to difficulties to communicate their feelings.
- *Anxiety*: When PADs are agitated or nervous, they usually show irritable and restless behaviors. Documented cases show that these emotion states cause to wander or touch everything.
- *Quick changes of the state of mind*: The mood of the patient changes quickly and due to not apparent reasons. However, these quick mood changes are due exclusively to the disease.
- *Depression*: People with dementia who suffer from depression may show more behavior problems, such aggression. It is hard to describe the difference between depression and some of the symptoms of Alzheimer's disease.
- *Wandering*: Wandering behavior is quite common among people with dementia. Some wander in the house, others try to get out, others still walk at night when other people sleep.
- *Sleeping Disorders*: Abnormal sleep can be the result of a wide variety of causes, and is not thoroughly understood in cases involving people with dementia. It is known that people who suffer from dementia spend less time in deep

sleep, awaken more often during the night, are more likely to wander at night, and nap more often during the day.

3.1 Anxiety

A person with Alzheimer's may feel anxious or agitated. He or she may become restless, causing a need to move around or pace, or become upset in certain places or when focused on specific details. Anxiety and agitation may be caused by a number of different medical conditions, medication interactions or by any circumstances that worsen the person's ability to think. Ultimately, the person with dementia is biologically experiencing a profound loss of his/her ability to negotiate new information and stimulus, as a direct result of the disease. People with dementia may also show behavioral symptoms including agitation, hoarding and demanding constant company (not wanting to be left alone) or closely following their caregivers around. Many of the things that can cause people to feel depressed can also cause people to feel anxious, and vice versa. The exact causes of these conditions vary from person to person and there are often several contributing factors.

3.2 Wandering

The term *wandering* is used throughout this document to refer to a variety of behaviors that may result in people with dementia becoming lost or having their safety at risk. Wandering refers to the need to keep on the move, often seen in people with Alzheimer's disease; wandering behavior may appear to be aimless, confused, stereotyped and sometimes quite focused, the person may be trying to get to a particular destination or accomplish a task such as meeting someone or going to work. It may occur at any time of the day or night, and may take the person out of the home. It is important to give attention to outdoor wandering that can expose the person to such dangers as traffic or extreme weather conditions. Wandering is a direct result of physical changes in the brain, leading the person to want to move around, search for someone or something or remove himself/herself from their current surroundings. It is important to understand that wandering, like walking, is not in itself a dangerous activity. But short-term memory loss and the impaired ability to reason or to make judgments can contribute to unsafe wandering behaviors.

3.3 Sleeping Disorders

People with Alzheimer's often have problems with sleeping or may experience changes in their sleep schedule. Scientists do not completely understand yet why these sleep disturbances occur. As with changes in memory and behavior, sleep changes somehow result from the impact of Alzheimer's on the brain. When managing sleep changes, non-drug coping strategies should always be tried first. The amount of sleep disruption in AD patients usually depends on the stage of disease in which they are. Patients in the early stages of AD may sleep more than usual or wake up disoriented. As the disease progresses, patients may begin to sleep during the day and awaken frequently throughout the night.

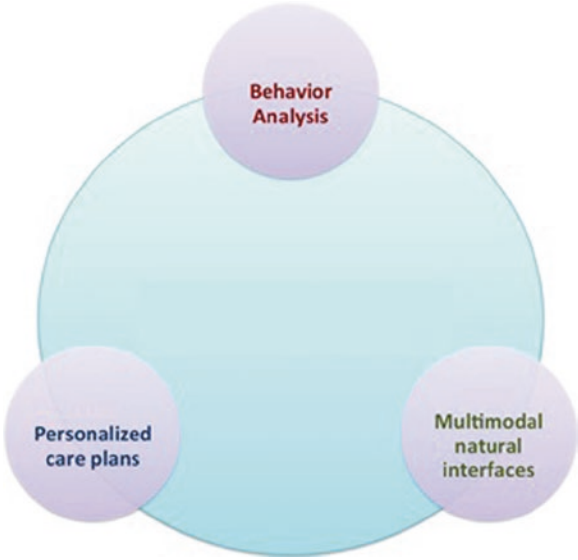
4 Proposed Approach in ALPHA Project

The approach for achieving the outlined tasks can be described according to three main stages. In detail, all three phases include significant components of innovation and research. As a matter of fact, ALPHA will adopt agile development methodologies and relying on continuous interactions between research tasks and development activities. The three main project phases are:

- *Behavior Analysis*: The main objective of the activity is to design and realize a subsystem that will enable to understand patient behaviors and detect and annotate abnormal ones. In particular, in order to describe and analyze patient behaviors, specific formal methods will be studied and adopted, international standards will be used to classify observed patient behaviors. In addition, analysis tools will be developed according to two different approaches: statistical and formal checking;
- *Multimodal Natural Interface*: The objective of this activity is to define advanced interfaces for different kinds of users such as patients, caregivers and clinicians. Multimodal and natural interaction metaphors and techniques will be analyzed and user interfaces will be selected, adapted and validated;
- *Personal Care Plans*: The main objective of the activity is to design and realize a subsystem to provide the clinician with advanced analysis tools and care planning. First, the work package will uniquely define an AD patient profile by using LOINC codes (Logical Observation Identifiers Names and Codes) in order to be interoperable with standard EHR systems. Using LOINC codes will ensure understanding and reusability of the designed model, overcoming language differences. An innovative risk profiling model combined together with recent epidemiological data and diachronic clinical data coming from clinical records of psychiatric hospitals no longer in use will also be defined, in order to better comprehend genetic and neuropsychiatric diseases, and determine probability-based contemporary manifestation and evolution of them. The work package will define and realize advanced tools to analyze the amount of data collected by ALPHA.

Finally, a care plan tool will be realized to assist clinicians in managing personalized care plans (Fig. 1).

Fig. 1 ALPHA Approach



5 Software Architecture

The system has been designed as a three-layered Service Oriented Architecture and is being realized as a specialization of Uranus [12], an OSGi-based platform [13] for indoor and outdoor vital signals monitoring. At the bottom layer, a set of software components collects data from a variety of sensors such as: (1) accelerometers, for the detection of patient's motion; (2) electrodermal sensors, for the detection of the patient's degree of stress and agitation; (3) actigraphs, for the measure of the quality of sleeping; (4) ambient sensors, for the collection of parameters such as temperature, light and sound in the surrounding environment. Currently, this layer is in charge of setting up the communication between sensors and the rest of the platform and is able to handle three kinds of connections: Wi-Fi, Bluetooth and USB. The middle layer is in charge of processing and correlating all the data-flows in order to detect abnormal behaviors and provide the clinicians with new quantitative and semantic information. Such data, in conjunction with other clinical data, will enhance the accuracy and the reliability of the assessment of the patient's health status. The top up layer includes a set of functionalities for presenting to the clinician relevant clinical information inferred from the collected data in a proper way. It would be almost completely useless, indeed, for the clinician, the full set of collected data. On the contrary, the clinician will be driven by the system directly to *the point of interest*; that is, the system will automatically emphasize abnormal signals during the manifestation of an abnormal patient behavior. Finally, in the frame of the ALPHA project, a subsystem will be designed and created in order to provide the clinician with advanced analysis tools and care planning; in particular an Alzheimer patient profile interoperable with standard Electronic Health Records (EHR) will be defined to integrate clinical information with a passive monitored data system, also to enhance care coordination.

6 Conclusion

There are approximately 65 million people in Europe over the age of 65 and this number is expected to rise in the foreseeable future. Since about one person out of twenty over the age of 65 suffers from AD (and less than one person out of a thousand under the age of 65), there is an enormous number of people for whom ALPHA could have a beneficial impact. From a social perspective, the project has a real chance to produce a major impact on society as a whole, in terms of the quality of services provided to patients. ALPHA will lead to a higher quality of services provided to patients, improving the quality of the entire care process. It will also enable a more intensive, frequent and continuous follow-up of therapy after patients leave specialized centers and a continuous monitoring of patients progress during the whole care process. Additionally, also the working conditions of doctors, nurses and medical staff will be significantly improved.

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GOJI an Advanced Virtual Environment Supporting Training of Physical and Cognitive Activities to Prevent Dementia Occurrence in Elderly with Minor Cognitive Disorders

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Abstract Dementia incidence in populations of 65 years or over is about 9 % and doubles every 5 years of age and might be higher than 50 % at the older ages of human life, international epidemic studies foreseen dementia cases up to 48 million in 2020. Cognitive deficits affecting the person's independence are main manifestations of dementia. The pathological process of disease precedes of decades the clinical manifestations and it suggests the possibility of early interventions in asymptomatic or early mild symptomatic individuals. This work presents the Goji project and its design phase of preventive program composed by a Virtual Environment for visuospatial (VSP) training and physiological evaluation of its efficacy.

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1 Introduction: The Goji Project

AD (Alzheimer Disease) is an age-related degenerative brain disorder characterized by brain atrophy, synapse loss, and the abnormal accumulation of amyloidogenic plaques and neurofibrillary tangles in medial temporal lobe limbic structures and the association cortices of the frontal, temporal, and parietal lobes [1]. It manifests clinically as a dementia, that usually begins with a progressive decline of memory capabilities, accompanied by deterioration of other cognitive domains—such as language and semantic knowledge, abstract reasoning, executive functions, attention, and VSP abilities [2]—and rather specific behavioral and psychological symptoms, which progressively interfere with patient autonomy in activities of daily living (ADL), leading, through time, to complete disability.

AD is a progressive disorder: prior to developing dementia, affected subjects show for long no symptoms or only a minor cognitive decline not enough severe to affect significantly their independence. Mild cognitive impairment (MCI) [3] is a useful construct that assists clinicians and researchers in identifying older adults at risk for dementia. MCI is generally defined as objective cognitive impairment, with preservation of autonomy in ADL [4]. At present, drug treatments for AD have only symptomatic effects and preventive measures centered on modifiable risk/protective factors for dementia could represent the preferred strategy to delay the onset of symptoms or reduce patients' disabilities. Accordingly, MCI may be an important target for screening and possible intervention [5, 6].

The project aims to define a comprehensive preventive program for elderly people with minor cognitive disorders possibly due to neurodegenerative diseases. A cohort of persons impaired in one/two of the four cognitive domains (memory, visuo-spatial capacities, language, executive functions) will be identified. A comprehensive preventive program will be tailored on the individual and group characteristics of the cohort. Goji will develop a virtual environment with the purpose of constructing an effective and easy accessible technological tool for cognitive stimulation. Being a one-year project, Goji will limit the attention to visuo-spatial capacities. Such impairment limits physical activity and impact on the daily living. The tool will be implemented with a pilot study in a sample of the cohort. In the proposed project the partners will concentrate on the preventive program definition and on testing the virtual environment as first implementation [7].

2 Visuo-Spatial Impairment in AD

Visuospatial (VSP) abilities are the high-order non-verbal cognitive processes responsible for the analysis of the spatial properties of visually perceived objects and mental representations, which allow individuals to interact with the environment [8]. VSP abilities are essential for translating visual signals into a correct mental impression of where the subject and objects are located in 3D space.

Therefore, impairment of VSP function profoundly affects the performances in everyday activities [9–11].

Patients with AD often exhibit disorders in VSP abilities, such as difficulties with reading, discriminating forms and colors or perceive contrasts, failures to identify objects (agnosia) or to locate them into the environment, deficits of spatial orientation and motion detection, difficulties in developing visual strategies (i.e. to avoid obstacles, point to or grasp objects) [12]. Changes in VSP skills are also apparent on constructional tests (i.e. when the patient is asked to copy a drawing or a block-construction) [8]. AD may also initially present with relatively circumscribed posterior cortical atrophy that is hallmarked by progressive VSP dyfunctions [13].

Visual motion detection and spatial navigation have been shown to be early impaired also in some individuals with MCI [14, 15], and it's been suggested that VSP impairment may constitute an independent marker of AD, possibly preceding the clinical onset of the disease. Individuals with MCI show preserved brain plasticity [16] and indication exist that cognitive rehabilitation can be a potential efficient method to enhance their cognitive and functional abilities [17].

3 Design and Implementation of GOJI Environment

In order to improve the effect of the training, the task has to be contextualized within daily activities. The choice of the project is to concentrate on "shopping at market" related activities according to the storyboard hereafter described.

3.1 Training at Market & Virtual Shopping

The environment for cognitive training is composed of two main steps and structured according to five difficulty levels. In the first step the patient has to select the appropriate lane of the market containing the products to be purchased from the shopping-list. The second one deals with the detection and selection of the correct product on the shelf. After the patient is virtually entered in the market, a shopping list containing a set of products is presented on the screen. At the same time a number of lanes varying from two to four, according to the difficulty level considered, appears on the background. At the top of each lane, as in a real market, a sign indicates the name of the kind of goods included. The different objects in the list are randomly selected by the system from a database and their ranking in the list changes time by time. The number of elements in the list increases according to the difficulty level. The system highlights the item, which has to be selected according to the completion of each purchase action.

At this point the patient has to correctly read and recognize the name of the item and to detect which is the lane, which contains it. The number of products displayed in the lane sign varies from one to four and can include, aside the target object, perceptively similar or dissimilar names of different objects. Different kinds of aid are provided to patients who show problems in facing the task. At this point the patient view is transferred in front of a shelf where different products are placed. Here the products presented on the shelf vary from one difficulty level to another, increasing progressively in number and types. Also the position of the products changes from a central position to a peripheral one. Moreover, in the upper levels, different formats of the same products or special offers are included (Fig. 1).

The virtual shopping is an interactive environment simulating, through a 2D and 3D virtual representation of a market, namely a grocery shopping, different aspects have been taken into account during its design: immersion, interaction and presence.

Technology selection for developing the environment has been driven by the four-factor solution for presence as states by [18]: physical space, engagement, naturalness and “negative effects”. According to [19] the selected environment in scale 1:1 answers to the second level of immersion or “semi-immersive” (the extent of display is less than 360°). One of the possibilities was to go shopping with a Head mounted Display (HMD), the selection considered [20] and [21]. They pointed that the use of the HMD in an interactive environment may provoke different undesirable effects like dizziness, disorientation and nausea during and for 60 min after the use. The projected video wall has been selected.

On the interaction side, five different systems have been evaluated: Kinect, Leap Motion, Touchless Touch, mouse and interactive whiteboard. The first four are low cost technologies (less than 200€) while the interactive white board is quite expensive (around 3000€). For each technology, usability tests have been performed.

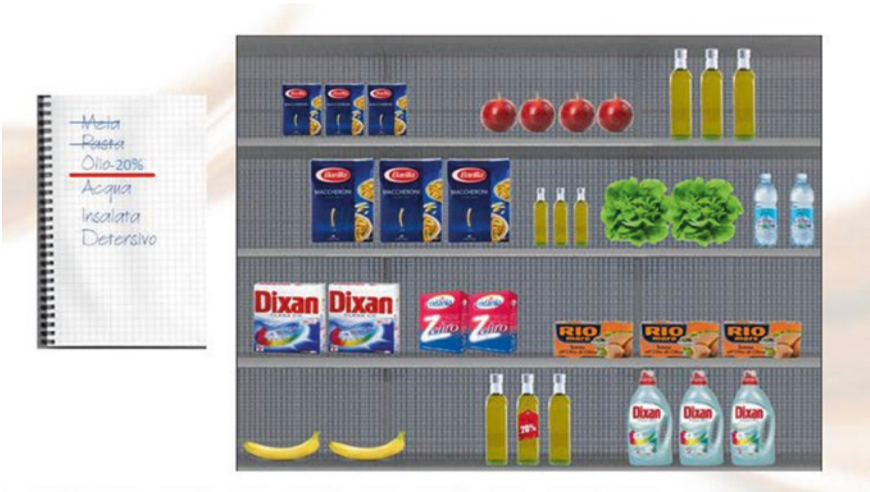

Fig. 1 A screenshot of the first version for the virtual shopping

The Kinect sensor uses the depth camera to recognize dynamic gestures, for this reason the user do not need to use any kind of remote control apart from his hands. [22] showed that the Kinect is more performing in the 3D pointing tasks (+9.7 %) than in the 2D ones (−39 %) compared to a mouse. The test performed provides the same results and highlights another critical issue: the arm fatigue.

The Leap Motion, using two monochromatic IR cameras and three infrared LEDs, transforms hand and finger motion in input, but requiring no hand contact or touching. The Leap Motion operates in a 3D box of around 40 cm around the device. Emerged criticisms in product review are in relation to app control, motion sensitivity and arm fatigue. The detection loses accuracy when the hand obstructs the controller's ability to track. It happens when the hand is perpendicular respect to the device and when the fingers are closer [23]. The gestures recognition requires learning specific hand movements for interacting and is influenced by light.

The Touchless Touch can harness the power of one or more Kinect sensors, which are placed around the outside edge of the display/surface. Once the sw is calibrated, the information from the sensors is analyzed and turned into real touch events. For single-touch applications only one sensor is needed. For multi-touch applications or larger surfaces, using two or more sensors is recommended. However installation and the calibration are challenging, moreover, heavily influence the accuracy of the touch events detection [24].

The mouse and 3D mouse are the best solution to do the point and click task but they provide a lower sense of presence compared with the other technologies [25]. Since the interaction to complete the visuo-spatial exercises inside the Virtual shopping, is essentially a point and click task and it is performed in a 2D environment for 20 min, the Interactive whiteboard provides the same benefits of the mouse and enhance the sense of presence. The body engagement and the presence are, actually, in relationship [25].

Taking into account the evaluations made, an interactive whiteboard and an ultra-short throw lens projector compose the hardware system while the virtual environment has been developed using Unity 3D. In the design of the 3D virtual environment, particular attention was paid to the emotional aspect of being (sense of presence) in a market: background noise and realism of the scene.

3.2 Go to Market & Virtual Cycling

As previously underlined the visuo-spatial impairment in AD is not secondary in comparison to the memory one: it is characterized by getting lost in familiar and non-familiar places [26]. Beside the shopping task in a close environment that could result familiar not because is exactly patient's own market, but because has all characteristics of a common stereotype market, the trainee has to "go" to the market. Ability to determine and maintain a route from one place to another [27] utilizes multiple spatial strategies recruiting distinct brain regions.

The environment presents a street on which the patient has to cycle using an ergo-cyclometer. With a subjective point of view he/she cycles for 20 min with a stable velocity to assure a physical exercise that is explained later. During the route to reach the market the user has to cross the street sometimes either stopping and waiting for the green on the traffic light or stopping and control the traffic. The second possibility is much more complicated because implies that the patient sees the cars, calculates their velocity and the velocity of his/her cycling. The patients don't turn right and left the head to check the traffic but they use a kind of joystick to visualize both sides of the road.

In order to simulate the approach to the market through an ergo-cyclometer, an automatic controller will be designed and modelled by tuning (regulating) the applied ergo-cyclometer power (workload) according to a priori defined Heart-Rate (preset value). The main purpose of this step of the project is to control/regulate the cycling intensity, evaluating how the level of fatigue during the practice session affects subsequent tasks (selection of products on the market shelves, etc.). The devices used for this purpose are:

(a) a PC-controlled ergo-cyclometer [28] (via USB/RS232)
(b) an electronic t-shirt (Smartex) worn by the end-user for wireless acquisition of clinical signs (HR—Heart Rate, BH—Breathe Rate)
(c) a commercial embedded pc [29] for data processing and 3D rendering on a wide flat screen. Figure 2 shows the overall architecture.

The design of the automatic SISO controller (Single-In, Single-Out) must takes into account only the ergo-cyclometer workload and HR data (*input/output*

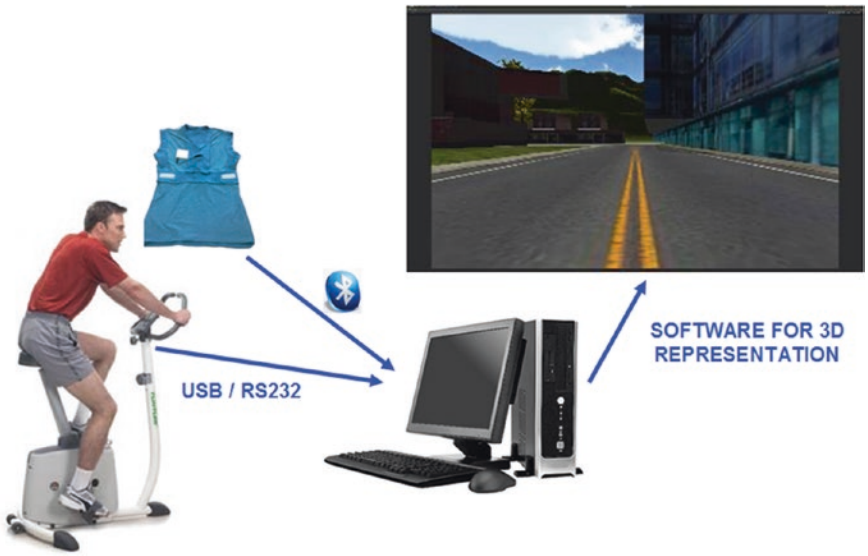

Fig. 2 Overall architecture for fatigue level control at constant Heart-Rate

variables), since they are the main expressions of the exercise intensity. It can be assumed that the controlled execution of long-training exercises can be expressed in terms of HR reference profile.

A double track strategy will be addressed in order to compare closed-loop controllers (in negative feedback configuration) integrating both well-known linear models (e.g. PID control [28]) and the most recent non-linear models (e.g. Hammerstein control [29]) in order to define the best tread-off between system stability, noise level and computational workload.

4 Design and Implementation of GOJI Environment

Multiple lines of evidence have shown that oxidative stress plays an essential role in the pathogenesis of several neurodegenerative diseases such as Alzheimer's disease (AD). Indeed, it has been suggested that oxidative damage caused by free radicals may result in neuronal cell death in AD patients. Oxidative stress is generally characterized by an imbalance in production of Reactive Oxygen Species (ROS) and antioxidant defense system, which is responsible for the removal of ROS; both systems are considered to have major roles in the process of age-related neurodegeneration and cognitive decline. Electron Paramagnetic Resonance (EPR), and/or the damage to biomolecules markers such as protein and DNA oxidation and lipid peroxidation may evaluate oxidative Stress measuring the ROS production. Mini-invasive method detecting ROS concentration by EPR is now demonstrated suitable to monitor physiological and pathological conditions [30, 31].

Two possible strategies for the treatment of AD are postulated: ne approach is the treatment that prevents the oxidative stress generation by means of physical training [32]. This might slow disease progression or delay onset of disease and eventually prevent the development of AD. Another approach is the symptomatic treatment that treats the cognitive symptoms of the disease and protects from further cognitive decline by means of an advanced virtual environment for supporting training of cognitive activities. This includes treating the cognitive impairment, decline in global function, deterioration in the ability to perform activities of daily living and behavioral disturbances.

The design of the study evaluates the combined presence of the different interventions and their potential interactions in terms of oxidative stress generation.

Two approaches are available in order to prevent the oxidative stress generation: physical training and physical exercise associated to advanced virtual environment. In order to evaluate the efficacy of both approaches X-Band-EPR ROS levels determination and enzymatic assays of lipid peroxidation (ThioBarbituric Acid Reactive Substances, F2-isoprostanes), protein oxidation (protein carbonyls), DNA oxidation (8-hydroxy-2-deoxyguanosine) and Antioxidant Capacity (TAC) in patients affected by AD are analyzed as markers of oxidative stress.

5 Conclusions and Further Development

The activities presented are part of the Goji[1] project aiming to define a comprehensive preventive program for elderly people with minor cognitive disorders possibly due to neurodegenerative diseases. Goji is going to test the VE with the purpose of providing an effective and easy accessible technological tool for cognitive stimulation. The project is now defying the protocol and recruiting patients for the first validation of the VE. The group is composed by: 5 subjects for the whole protocol (VE training and movement analysis), 5 subjects just within the VE, and 5 subjects as control group. Being a one-year project, Goji has limited the attention to visuo-spatial capacities. A new project is under definition for tackling the whole five cognitive capacities and to extend the validation to a larger cohort as well as its duration.

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Training and Retraining Motor Functions at Home with the Help of Current Technology for Video Games: Basis for the Project

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Abstract Chronic diseases are an international concern, for their increasing incidence and the strain on individuals and on healthcare systems. In order to enable the healthcare system to cope with increasing demands and to avoid strong decrements in subject's functionality and well-being, a variety of changes for the management of chronic disease care have been advocated by the World Health Organization. The objective of the research is to verify the feasibility and acceptability of a technological solution that allows to transfer a tailored rehabilitation program for patients with disabilities in the home environment. The first step of the study is to identify the correct technological solution on the basis of the International Standard of Organization (ISO) definition of usability and acceptability. The second step is to verify the capacity of the system to perform correctly what is requested. The third step will be to verify the system efficacy in the patients' training.

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1 Introduction

Epidemiological and social background. The incidence of chronic diseases is increasing and approaching epidemic levels. On individuals, chronic diseases determine protean long-lasting and progressive disability, worsening of quality of life and reduced social participation [1]. On the healthcare system, they lead to increasing resource and economic burden [2]. Therefore, it is crucial to develop strategies that effectively lead to reductions in the burden of disability [3, 4].

The prevalence of disability, in Europe, has been estimated at the 16 %, on average, in the adult age and depend on age and gender [5]. The contribution of diseases to the prevalence of disability depends both on the increased rate of disabling diseases and the raising survival rate of chronically disabled people. Musculoskeletal disorders and cardiovascular diseases have the highest prevalence both in males and females. Musculoskeletal diseases comprehend arthritis, back pain, neck and arm pain, as well as musculoskeletal degenerative disorders; the cerebrovascular diseases comprehend cerebral stroke, heart and peripheral vascular diseases [5]. All the disease categories lead to gait and balance disorders. Gait and postural control predict quality of life, morbidity, and mortality [6]. To reduce the burden of disability, efficacious methods may target the axial symptoms, such as gait posture and balance disorders.

Rehabilitative background. Chronic disabilities lead to a progression of functional and participation difficulties if a correct and continuous multidisciplinary rehabilitative support is not provided. But a continuous inpatient rehabilitation program is problematic in terms of patients adherence, acceptability and of human and economic resources [7]. Indeed low entity chronic diseases are more widespread than others and are considered unsustainable for the healthcare systems. Figure 1 shows pyramid of the chronic diseases diffusion.

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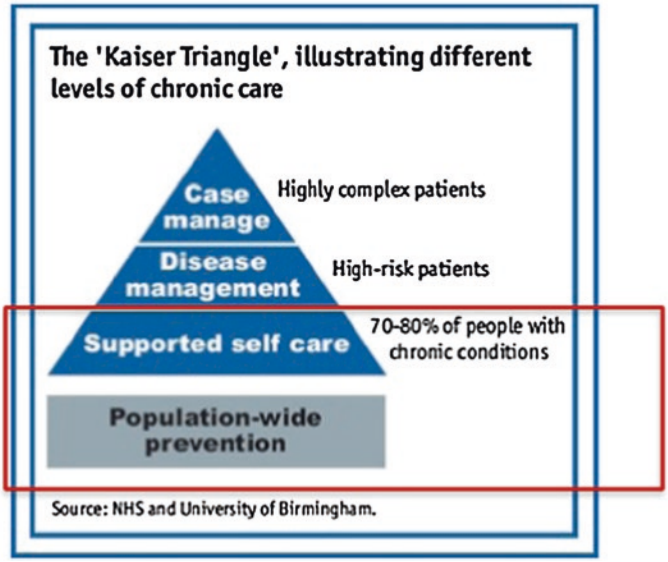

Fig. 1 Kaiser Triangle exploiting the levels of chronic care

Patients adherence and acceptability may be limited by motor (endurance), non-motor (fatigue, pain, dysautonomic symptoms) motivational and cognitive deficits. To overcome these pitfalls, a program of exercising has to be easy to reach daily, exciting and has to promote motivation and adherence. Moreover, it is remarkable that, in order to be efficacious, a rehabilitation has to be **meaningful, task-oriented, intensive, difficult** and **context interactive** (i.e., virtual reality) [7, 8]. Moreover, the exercise has to be **quantifiable** and **monitored** in real-time in order to give a feedback.

The control and feedback about posture and motion during exercise execution is normally guaranteed by the physiotherapist. Otherwise, complex, invasive, expensive technologies are able to provide the same effective function.

Tele-rehabilitation: possible benefits. A remarkable solution to exceed problems of both healthcare systems and subjects is tele-rehabilitation. It is an emerging method of delivering rehabilitation that uses technology to serve patients, clinicians and systems, minimizing the barriers of distance, time and resources. The driving force behind this has been the need for an alternative to face-to face intervention, enabling service delivery in the natural environment that is in patients' homes [9]. Tele-rehabilitation offers an opportunity to provide individualized rehabilitation intervention beyond the hospital setting, by regular monitoring and evaluation of the patients' needs and progress, with a range of services suited to the individual and their environment [9–13]. The benefits and advantages of tele-rehabilitation have been documented [10, 13–21] in some studies on neurological and orthopedics diseases. A systematic review that analyzed rehabilitation therapies delivered at home in stroke survivors showed positive outcomes, with a reduction in the risk of deterioration, improved ability to perform activities of daily living, reduced costs and duration of rehabilitation in a frail elderly population [22].

Usability and acceptability of technology for health. Tele-rehabilitation can present problems of efficacy, generalization and increasing patient participation and satisfaction. Problems that have emerged from the experience so far carried out and identified by factors affecting staff acceptance: in fact negative impact of service change, staff-patient interaction, credibility, autonomy, and technical issues emerged from the study of Khan et al. [23]. On the other hand, patients considered tele-rehabilitation helpful as a complementary or follow-up treatment, rather than an autonomous treatment. Patients valued the benefits such as reduced transportation barriers, flexible exercise hours and the possibility to better integrate skills into daily life. However, many patients feared a loss of treatment motivation and expressed concerns about both reduced fellow sufferer contact and reduced face-to-face therapist contact. Few arguments related to social norms and effort expectancy [24].

Moreover, technological systems for tele-rehabilitation lack efficiency and effectiveness because of the low capacity of monitoring human movements and the low usability and acceptability.

The two last arguments are mainly related to the Unified Theory of Acceptance and Use of Technology (UTAUT—[25]). Usability is a property that defines the effectiveness, efficiency and satisfaction with which specified users achieve specified goals in particular contexts using a certain technology; properties that allows a system to be effective, efficient and simple enough to use, satisfying the easy way and exhaustive as possible the needs of the user are:

- **Performance expectancy**: The degree to which an individual believes that using the system will help him or her to attain gains in job performance.
- **Effort expectancy**: The degree of ease associated with the use of the system.
- **Facilitating conditions**: The degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system.
- **Social influence**: The degree to which an individual perceives that important others believe he or she should use the new system.
- **Non-invasiveness**: not being invasive to personal privacy [25].

The term usability does not refer to an intrinsic characteristic of the instrument, as to the process of interaction between classes of users, product and purpose [25]. The degree of usability rises proportionally rapprochement of the two models: designer model and user model [25].

A usable system has many advantages: it increases efficiency, productivity, security, acceptance and trades, whereas it reduces errors, the need for training and user support and development costs.

Project Objectives. Our project idea is to design and implement ICT rehabilitation devices on the basis of acceptability, low cost and connectivity principles. At home, devices have to be able to provide and, at the same time, to monitor patients' tailored motor and cognitive exercises.

The first step of the study has been to identify the correct technological solution on the basis of the International standard of Organization (ISO) definition of usability and acceptability and the results are showed in this paper.

2 Materials and Methods

A systematic search was performed in PubMed (up to January 2012) to identify low-cost yet-available instruments that are able to deliver and monitor human movement in a enhanced environment. Several key words were used: Exergam* OR active video gaming OR Microsoft Kinect OR Kinect OR Nintendo Wii OR Wii OR Sony EyeToy OR IREX OR Dance Dance Revolution and "movement disorder". In order to select the best device we looked for UTAUT usability characteristics (Performance expectancy; Effort expectancy; Facilitating conditions; Social influence; Non-invasiveness) grading they as excellent, good, sufficient and insufficient. Moreover we looked for some technical note: accuracy of action monitoring; software adaptability; quality of exercise.

In order to study device accuracy, detecting motion, several key words were used searching in PubMed (up to January 2012): *device name*, accuracy, movement, posture, detect, monitor. Variants and combinations of the key words were used.

3 Results

The results of our research are explained in Tables 1, 2 and 3 for device selection and device accuracy of motion monitoring, respectively.

Table 1 Device selection

		Wii system	Kinect	Television	Play-station
UTAUT: Unified theory of acceptance and use of technology Venkatesh et al. [25]	Performance expectancy	Good	Good	–	Good
	Effort expectancy	Good	Good	–	Good
	Social influence	–	–	Excellent	–
	Facilitating conditions	Low cost, widespread	Low cost, widespread, easy to use	Low cost, popular, widespread	Low cost, widespread
	Non-Invasiveness	–	Markerless	Remote control	Joystick
Technical note	Accuracy of the action monitoring	Good	Good only for some movement	No	Not yet proved
Technical note	Software adaptability	No	Freely programmable	No	Not yet proved
Technical note	Quality of exercise	–	More excursion than Play-Station	–	–

References van Diest et al. 2013 [26], Goble et al. 2014 [27], Pietrzak et al. 2014 [28]; Parry et al. 2014 [29]; Barry et al. 2014 [7], Plow et al. 2014 [30]

Table 2 Kinect's accuracy detecting motion (part A)

References	Galna et al. [31]	Raspa et al. [32]	Clark et al. [33, 34]
Subjects	9 Parkinson's Disease	5 Parkinson's	21 young healthy
	patients +10 controls	Disease patients	sbj
Study design	Kinect versus Vicon system (optoelectronic system of movement analysis OSMA)	Kinect versus Elite sys (OSMA)	Kinect versus 3D motion analysis (3DMA) System
Types of studied movement	Quiet standing, multi-directional reaching, stepping walking on the spot, hand clasping, finger tapping, foot, leg agility, chair rising and hand pronation	Squatting, gait inition, walking, turning	Gait
High accuracy	Timing of movement repetitions gross movements such as sit-stand		Gait speed, step length stride length Land mark location linearity
Medium accuracy	Spatial data for Leg agility, walking, stepping		Foot swing velocity
Low accuracy	Hand clasping, pronation suspination, shoulder and elbow movements		Step and stride time overall agreement

Table 3 Kinect's accuracy detecting motion (part B)

References	Schmitz et al. [35]	Van Diest et al. [26]
Subjects	Multiple positions of a jig with a ball-and-socket joint that was built to simulate leg	Healthy adults (n1/4 20)
Study design	Kinect versus 3D based motion capture system (C Motion, German-town, MD, USA)	Kinect versus Vicon3D
Types of studied movement	In six static postures where each rotational degree of freedom was separately manipulated while the others were approximately zero	Balance:Played a weight shifting exergame under five different conditions with varying amplitudes and speed of sway movement
High accuracy	Flexion and extension	Shoulder ROM Back movements velocity ROM and sway
Medium accuracy	Abduction	ROM of extremities
Low accuracy		Increased sway frequency leg lifted hand and foot movements

The Microsoft Kinect system results the most usable and acceptable low-cost yet available system to home-based motion analysis and exercise delivering. However, Kinect provides a low accuracy, particularly, for movement of small joints.

In Tables 2 and 3 'High accuracy' means low bias, 95 %; limits of agreement <10 % of the group mean ICCs > 0.90 and Pearson's r > 0.9; 'Medium accuracy' means 10 % < SE < 20 % or ICC ≥ 0.80; 'Low accuracy' means SE > 20 % and ICC < 0.80.

4 Discussion and Future Work

Delivering rehabilitation programs at home through dedicated technology may represent a good option for frail subjects but the efficacy has to be proved while costs, safety, accuracy and acceptability have to be defined.

The UTUAT criteria, defining the usability of technology for health, may highlight that low-cost, markerless, widespread, easy to-use systems may be useful as system for tele-rehabiliation.

There is growing interest towards exergaming as a potential rehabilitation tool, anyway the available systems are unable to satisfy the following clinical and technical requirements [7]: (i) target specific clinical features of subjects with motor and cognitive disabilities; (ii) be easier to face than commercial games; (iii) avoid negative feedback; (iv) include very clear instructions and goals; (iv) introduce cognitively demanding aspects, slowly and sparingly; and (v) examine the use of new exergaming systems that do not require balance platforms or handheld controller [7], but reach an acceptable level of accuracy in motion detection.

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Low Cost RGB-D Vision Based System to Support Motor Disabilities Rehabilitation at Home

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Abstract Physical rehabilitation is an important medical activity sector for the recovery of physical functions and clinical treatment of people affected by different pathologies, as neurodegenerative diseases (i.e. multiple sclerosis, Parkinson and Alzheimer diseases, amyotrophic lateral sclerosis), neuromuscular disorders (i.e. dystrophies, myopathies, amyotrophies and neuropathies), neurovascular disorders/trauma (i.e. stroke and traumatic brain injuries), and mobility for the elderly. During the rehabilitation, the patient has to perform different exercises specific for the own disease: while some exercises have to be performed with specific equipment and under the supervision of professional staff, others can be

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performed by patients without the supervision of physiotherapists. In this last case, it is possible to reduce the costs of health and care national system and to accomplish the treatment at home. In this work, a computer vision system for physical rehabilitation at home is proposed. The vision system exploits a low cost RGB-D camera and open source libraries for the image processing, in order to monitor the exercises performed by the patients, and returns a video feedback to improve the treatment effectiveness and to increase the user's motivation, interest, and perseverance. Moreover, the vision system evaluates an exercise score in order to monitor the rehabilitation progress, an helpful information both for the clinician staff and patients, and allow physiotherapists to monitor the patients at home and correct their posture if the exercises are not well performed. This approach has been implemented and experimentally tested using the Microsoft Kinect camera, demonstrating good and reliable performances.

1 Introduction

In recent years, researches in the field of computer vision have given rise to different applications with significant impact on the life of people with disabilities or temporarily affected by motor difficulties: to support them, many approaches have been investigated. Physical and cognitive rehabilitation is a complex and long-term process that requires clinician experts and appropriate tools [1]. Conventional rehabilitation training programs typically involve extensive repetitive range-of-motion and coordination exercises, and require professional therapists to supervise the patients' movements and assess the progress. This approach provides limited objective performance measurement and typically lacks engaging content to motivate individuals during the program. To address these problems, new rehabilitation methodologies are being developed and have recently gained significant interest in the physical therapy area. The main idea of this rehabilitation approach is to use sensing devices to capture and quantitatively assess the movements of patients under treatment, in order to track their progress more accurately [2]. In addition, the patients need to be more motivated and engaged in these physical activities [3,

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4]. People often cite a lack of motivation as an impediment to them performing the exercise regularly [5]: this study indicates that only 31 % of people with motor disabilities perform the exercises as recommended which can result in negative consequences such as chronic health conditions. Results show that video capture virtual reality technology can be used as complement to conventional physiotherapy. This technology is cheap, easy to use by users and therapists as a home based rehabilitation tool. Further it helps stroke patients to use this technology as part of their home based rehabilitation program encouraging self-dependability in performing activities of daily living [6]. The aim of this paper is to develop a Kinect-based assistive system, who can help people who have movement disorders to perform rehabilitative exercises program at home [7]. Kinect is a cheap and easy to set up sensor and can be used in both home and clinical environments; his accessibility could significantly facilitate rehabilitation, allowing more frequent repetition of exercises outside standard therapy sessions [3].

In literature it is possible to find different approaches to these rehabilitation systems. In [7] is presented a Kinect-based rehabilitation system to assist patients with movement disorders by performing the "seated Tai Chi" exercises at home. By this system authors can evaluate if patients achieve rehabilitation results correctly or not. By using skeletal tracking of Microsoft Kinect sensor, each gesture of the patient, performing Tai Chi is recognized and validated. In [8] a system for physical rehabilitation is proposed, called the Kinerehab and based on Microsoft Kinect, which is webcam-style add-on peripheral intended for the Xbox 360 game console. Kinerehab uses image processing technology of Kinect to detect patient's movement, detecting automatically patient's joint position, and uses the data to determine whether the patient's movement have reached the rehabilitation standard and if the number of exercises in a therapy session is sufficient. Using this system, users can evaluate the accuracy of their movements during rehabilitation. The system also includes an interactive interface with audio and video feedback to enhance patient's motivation, interest, and perseverance to engage in physical rehabilitation. Details of users' rehabilitation conditions are also automatically recorded in the system, allowing therapists to review the rehabilitation progress quickly. In [9] is presented the analysis of the use of Kinect sensor as an interaction support tool for rehabilitation systems: using a scoring mechanism, the patient performance is measured, as well as his improvement by displaying a positive feedback.

Authors propose a RGB-D camera vision system to monitor patients affected by motor disabilities and evaluate the precision by which they repeat the rehabilitation exercise at home. Particularly, the vision system supports the physiotherapists' work of controlling the validity and efficacy of each exercise and aims to increase the user motivation. Microsoft Kinect camera is used, and after the calibration, a set of functional body joints and a body skeleton are mapped and extracted. These features allow an Artificial Neural Network (ANN) to recognise, from the start position, which exercise is realised. Then, the Online Supporting Algorithm evaluates user performance during the exercise execution. It also provide a video feedback to the user if position and/or speed of execution are not correct respect to the right exercise. Moreover the vision system is able to compute a score about the exercise helpful both for the clinician staff and the patient.

This paper is organized as follows: the Sect. 2 proposes the system details with the hardware and software for the RGB-D camera. In Sect. 3 is described the exercise recognition method by means of the Calibration Algorithm and neural network. In Sect. 4 authors present the online support algorithm, which allows to obtain the score feedback on how the patient is performing the exercise. In Sect. 5 the experimental results are presented, with the two kind of exercises tested and in Sect. 6 conclusions and future works are given.

2 System Configuration

In this section the computer vision system details are provided. The proposed algorithms exploit a low cost RGB-D camera and the open source software Open Natural Interaction (OpenNI) [10]. More information about *OpenNI* applications are given in [11]. The vision algorithm has been developed in Robot Operating System (ROS) [12]. This choice is motivated by the fact that ROS is spreading exponentially [13].

2.1 Hardware

A Microsoft Kinect camera is adopted as RGB-D vision sensor. A RGB-D camera allows to reach better performance in people and objects identification, even if the background and the person or the object have the same color, and recognize overlapped objects by calculating the distance for each of them. More in detail, the Kinect camera falls within the category of Structured Light (SL) cameras. These images are captured by a normal 2D camera and analyzed. Then, depth information is extracted. Using a SL camera, the depth can be recovered from simple triangulation by giving a specific angle between emitter and sensor. An SL camera is composed by an IR projector, a diffraction grating and a standard Complementary Metal-Oxide Semiconductor (CMOS) detector with a band-pass filter centered at the IR light wavelength. The diffraction grating is a Computer-Generated Hologram (CGH) that produces a specific periodic structure of IR light when the laser shines through it. The projected image does not change in time. The IR CMOS sensor detects this pattern projected onto the room and scene, and generates the corresponding depth image. Compared with cameras based on Time of Flight (TOF) technology, SL cameras have a shorter range and images appear to be noisier and less accurate, but thanks to post processing capability, it is possible to address these issues. Moreover SL cameras are cheaper than TOF cameras. More information about SL cameras can be found in [14].

2.2 Software

OpenNI is used to implement more functionality of the vision sensor. It is a multi-language and multi-platform framework that defines the API (Application Programming Interface) for writing applications that use natural interaction, i.e. interfaces that do not require remote controls but allow people to interact with a machine through gestures and words typical of human-human interactions. This API has been chosen because it incorporates algorithms for background suppression and identification of people motion, without causing a slowdown in the video. The proposed algorithm has been developed in ROS, an open source framework for robotic applications. ROS is a message-based, tool-based system designed for mobile manipulators: the system is composed of libraries that are designed to work independently. ROS is based on the Unix-like philosophy to building many small tools that are designed to work together.

3 Exercises Recognition

In order to track the exercises, the subject has to be identified. This operation is called *Calibration*. The *Calibration Algorithm* recognizes different points of interest of the person's body, associating a joint to each of them, as shown in Fig. 1. The calibration operation is required by the vision sensor to find the user in its field of view and is performed by using the functionality already available within the OpenNI library.

After the user calibration, the system starts the exercises recognition procedure. This procedure allows to identify the performed exercise by the user in order to

Fig. 1 Person calibration

set-up the online algorithm for the user support. In this work, the motion sequence of the considered exercises are shown in Figs. 3 and 4. After the action recognition, the online algorithm chooses the joints of interest for evaluating the action in order to monitor the movement, evaluates if the exercise is well performed and returns a feedback to the user. The exercises recognition procedure is based on the Artificial Neural Networks (ANNs) [15], which are computational models inspired to the human brain. ANNs allow to detect patterns and data relationships through a training process that is based on learning and generalization procedures. ANNs are found in almost all fields of contemporary science, and are associated with a wide variety of artificial intelligence applications which are concerned with problems of pattern recognition and classification.

In the present work a feed-forward neural network, with three weighted layers (i.e. input, hidden and output layer) is considered [16]; the network is used to classify two exercises performed by users. The ANN is used to classify the initial position assumed by a user, in other words users can perform an exercise as they like, without setting the system before. Once the patient is correctly calibrated, then the system waits until the user is standing still in the initial position. After the classification is performed, the ANN updates the online supporting algorithm with the actual exercise that the patient starts to perform.

4 Online Supporting Algorithm

The online algorithm allows users to obtain immediate feedback on how they are performing the exercises. The proposed *Online Supporting Algorithm* gives a feedback during the exercise execution. The *Online Supporting Algorithm* is defined by the following steps:

1. **Identification of the joints of interest**: after the exercise identification, as described in Sect. 3, the joints of interest for evaluating the specific exercise are selected, in order to monitor the movement.
2. **Waiting for the starting position**: if the user does not take the correct starting position, he receives a feedback with the explanation about what he is doing wrong. When the user has taken the correct starting position, he receives a video feedback, which invites him to start the exercise.
3. **Tracking the movement**: during the performance, the joints of interest are tracked and two features are computed and compared with the same features stored from the physiotherapist performance, which are taken as reference. The first feature is defined by the position error computed at each time instant of all joints of interest. The error is given by the euclidean distance between the reference position (i.e. the physiotherapist stored features) and the user actual position, and it is defined as:

$$Perr_{\alpha}(k) = \sqrt[2]{\sum_i (c_{\alpha,i} - \tilde{c}_{\alpha,i})^2} \quad i = 1, \ldots, N_{\alpha}, \tag{1}$$

where $Perr_{\alpha}(k)$ is the position error computed at time k for the exercise α, $c_{\alpha,i}$ is the ith body coordinate considered for the exercise α and $\tilde{c}_{\alpha,i}$ is the reference ith body coordinate (i.e. form the physiotherapist stored features), of the same exercise; N_{α} is the number of coordinates taken into account for the exercise α.

Assumption 1 Note that Eq. 1 holds in the Euclidean space, even if an arbitrary set of coordinates from body joints is taken, due to the hypotheses that the set of N_{α} coordinates taken into account, for the exercise α, defines a new Euclidean space of N_{α} dimensions.

This feature is used to evaluate if the position is correct at each time step. The position error integral is computed over each sample and used for the score computation at the end of exercise execution.

At the same way the second feature is defined by the velocity error as:

$$Verr_{\alpha}(k) = \sqrt[2]{\sum\nolimits_{i} (\dot{c}_{\alpha,i} - \dot{\tilde{c}}_{\alpha,i})^2} \quad i = 1, \ldots, N_{\alpha}, \tag{2}$$

where $Verr_{\alpha}(k)$ is the velocity error computed at time k for the exercise α, $\dot{c}_{\alpha,i}$ is the ith body coordinate velocity considered for the exercise α and $\tilde{c}_{\alpha,i}$ is the reference ith body coordinate velocity (i.e. form the physiotherapist stored features), of the same exercise; N_{α} is the number of coordinates taken into account for the exercise α. The following Assumption 2 remarks the validity of the defined velocity features.

Assumption 2 Note that Eq. 2 holds in the Euclidean space, even if an arbitrary set of coordinates from body joints is taken, due to the hypotheses that the set of N_{α} coordinates taken into account, for the exercise α, defines a new Euclidean space of N_{α} dimensions.

This feature is defined to assess if the user performs the exercise at the right time. The velocity error integral is computed over each sample and used for the score computation at the end of exercise execution.

During the performance, the user receives feedback on how he is performing the exercise. The feedback can relate both if the speed is right and/or if he is taking an incorrect position. The exercises should be performed at a constant speed and without abrupt movements.

4. **Detection of the final position and evaluation**: once the user reaches the final position and the algorithm recognizes it, a score is computed as an inverse proportionality factor of the sum of the final position and velocity errors. If the user does not reach the right final position he receives a feedback and the exercise receives a negative evaluation.

A flowchart describing the proposed algorithms is provided in Fig. 2.

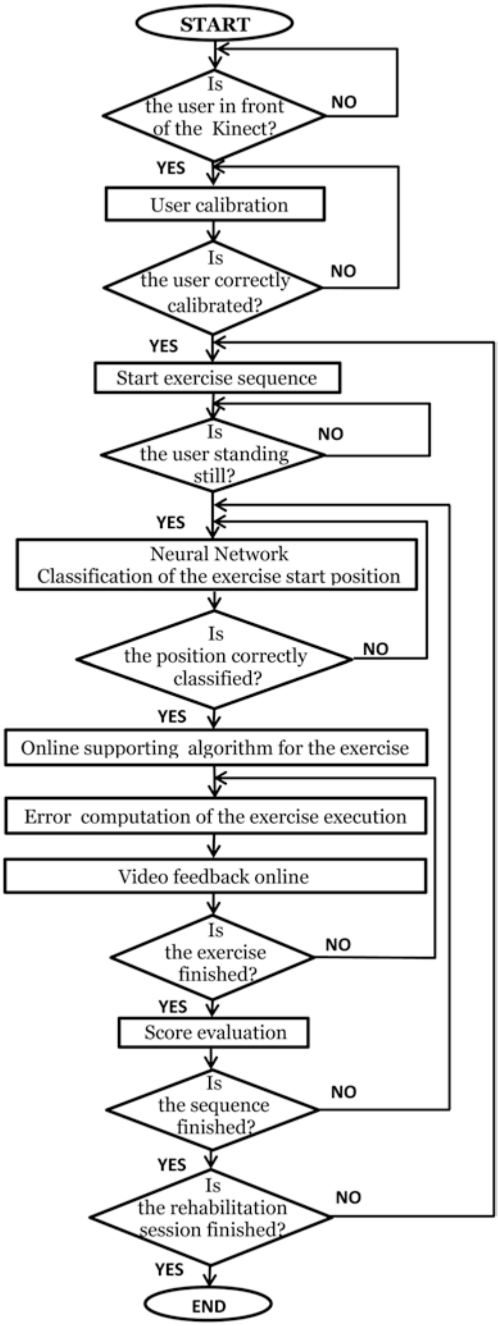

Fig. 2 Flow chart of the proposed computer vision system procedure

5 Experiment and Results Discussion

In this section the proposed methodology is tested considering two postural exercises for the back performed by 10 actors. Users should stand up in front of the RGB-D camera with legs slightly apart. The execution of the first exercise consists of lifting the upper limbs extending arms up over the head. The elbow should stay extended throughout the exercise execution. For the second exercise patient starts holding a stick with both hands with arms in elevation (above the head), with his elbows extended. The exercise consists in tilting the torso slowly to the left, returning to a neutral standing position and then proceeds with the same exercise on the right side.

The chosen postural exercises are shown in Figs. 3 and 4 respectively, the photo sequences shown start from the initial position, the left photo, to the end position, the right photo. For each exercise a set of coordinates of interest are is selected as reported in Table 1, these sets of coordinates are considered crucial for the evaluation of the movements during the exercises execution and avoid the use of all joints information: 20·3 coordinates.

The ANN for the exercise classification uses 20·6 input signals and has 2 outputs, one for each considered exercise. In this work, 20 joints are tracked and 6

Fig. 3 Motion sequence of first exercise

Fig. 4 Motion sequence of second exercise

Table 1 Skeleton joints coordinates selected as features for each exercise

Joints	Exercise 1			Exercise 2		
	x	y	z	x	y	z
Hand right	♦	♦	–	♦	–	♦
Hand left	♦	♦	–	♦	–	♦
Elbow right	♦	–	–	–	–	–
Elbow left	♦	–	–	–	–	–
Foot left	♦	♦	♦	♦	♦	♦
Foot right	♦	♦	♦	♦	♦	♦
Head	–	–	–	♦	–	–

features are considered for each joint: the x, y and z positions and the $\dot{x}$, $\dot{y}$ and $\dot{z}$ velocities. So the input and output layers are composed by 20·6 and 2 neurons respectively. The neurons number of the hidden layer is set to 10.

5.1 Exercises Execution Results

Figure 5 shows the exercises classification results, which are described through the confusion matrices. In the test, the training data are the 40 % of all data, while the validation and testing data are each the 30 % of all data. The neural network is trained using the scaled conjugate gradient (SCG) back-propagation algorithm both with exercises well performed and not [17]. The Fig. 5 shows as the neural network is able to detect the initial positions assumed by the users.

When the user assumes the right starting position, the exercise starts and the *Online Supporting Algorithm* computes the errors defined in Eqs. 1 and 2 between the coordinates selected of the joints of interests, at each time instant.

For the Exercise 1 the errors on position and velocity are shown in Fig. 6. The black straight lines denote the error limits. If the user error exceeds the limit on position or velocity at a certain time instant then the *Online Supporting Algorithm* gives a feedback. The feedback messages that the algorithm can send to the user are: “Too fast”, “Too slow”, “Do not spread your arms”, “Stretch out your elbows”, “Do not move your feet”. If the user assumes the right position at the right time, he will take the right final position. At the end of the exercise, the performance is evaluated calculating the score, as described in Sect. 4. In Fig. 6a, b, the patient denoted by blue lines performs the exercise correctly, while the red lines show a patient who makes position and velocity errors and is unable to retrieve the error.

For the exercise 2 the errors on position and velocity are depicted in Fig. 7. If the user error exceeds the limit about position or velocity at a certain time instant then the algorithm gives a feedback to the patient. In this case the feedback messages that the algorithm can send to the user are: “Align arms with the body”, “Fold more the torso”, “Do not move your feet”. If the user assumes the right position at the right time, he will take the right final position. At the end of the exercise, the performance is evaluated calculating the score, as described in Sect. 4. In Fig. 7a, b, the patient

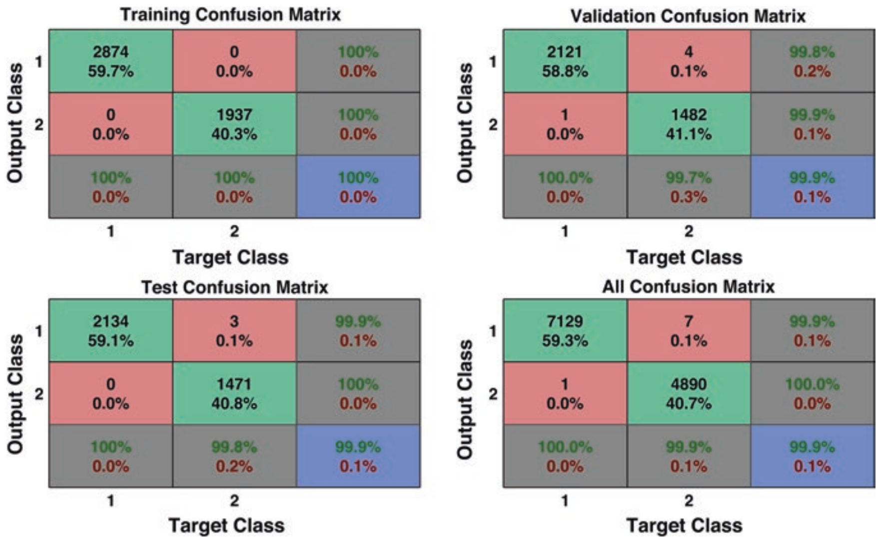

Fig. 5 Exercises recognition confusion matrices

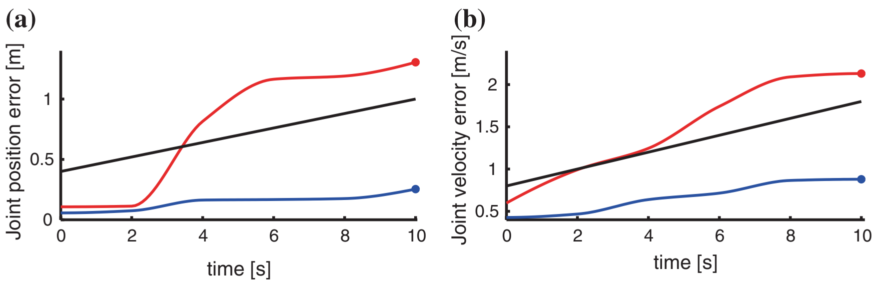

Fig. 6 Exercise 1, the *black straight line* denotes the error threshold, the *blue line* denotes the error in case of correct execution. **a** Position; **b** Velocity

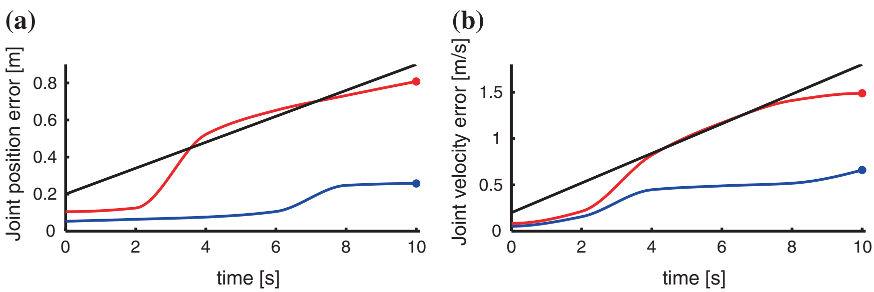

Fig. 7 Exercise 2, the *black straight line* denotes the error threshold, the *blue line* denotes the error in case of correct execution. **a** Position; **b** Velocity

denoted by blue lines performs the exercise correctly, while the red lines show a patient that makes position and velocity errors and later retrieves the error.

6 Conclusions and Future Works

Physical rehabilitation aims to enhance and restore functional ability and quality of life of people with physical impairments. Since some exercises can be performed by patients at home without the supervision of physiotherapists, a smart solution is needed to monitor the patients. The authors main contribution is the development of a computer vision system able to evaluate the correctness of the exercises performed by the patients, to return a video feedback in order to improve the treatment effectiveness and increase the user's motivation, interest, and perseverance. The vision system exploits a low cost RGB-D camera and the open source libraries OpenNI for the image processing and it is developed in ROS framework. Preliminary results show that the proposed procedure is able to detect the exercises and evaluate reliably their correctness. The authors are currently considering the employment of patients, instead of actors, for the validation of the proposed system to support them in the rehabilitation care.

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Part VII
Robotic Assistance for the Elderly

Design of Cloud Robotic Services for Senior Citizens to Improve Independent Living and Personal Health Management

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Abstract A cloud robotics solution was designed and initially tested with a mobile robotic platform and a smart environment, in order to provide health-care management services to senior citizens and improve their independent living. The solution was evaluated in terms of Quality of Service (QoS) and tested in the realistic scenario of the DomoCasa Living Lab, Peccioli, Italy. In particular, a medication reminding service, a remote home monitoring and a user indoor localization algorithm were outsourced in the cloud and provided to the robots, users and carers. The system acquired data from a smart environment and addressed the robot to the user for service delivery. Experiments showed a service's Reliability of Response at least of the 0.04 % and a Time of Response of the same order of magnitude of the processing time required by the user localization algorithm.

1 Introduction

The ageing of the EU population is a long-term trend that will almost triple the share of those aged 80 years or above between 2011 and 2060. This will increase the demand for nurse practitioners (+94 % in 2025) [1] and physician assistants

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(+72 % in 2025) [2] with several implications for the quality of care and for the configuration of future cost-effective care delivery systems. One of the greatest challenges in the next few years will be to adapt to the reduction of funds for social-medical services, with the opportunity to provide socially sustainable home care services for senior citizens. Seniors prefer to live as independently as possible [3] and to maintain their quality of life. Their well-being depends on the opportunity to efficiently manage medication and care. Often they lose their independence because of difficulties with medication self-management and health status monitoring [4]. Cognitive impairments and the complexity of the care negatively impact on their independent living [5]. For these reasons, several works [6] have investigated the opportunity to provide medication reminders, self-monitoring and family therapy, and have demonstrated that this could reduce hospitalizations from 33 to 69 %.

2 From Service Robotics to Cloud Service Robotics

Service robotics for the ageing population aims to support senior citizens with cognitive and physical impairments. In particular, assistive robotic services were identified as a potential solution to improve quality of life by enhancing mobility and communication, and monitoring physiological parameters and daily activities [7]. Robots were developed to support the elderly in the management of daily activities [8] and the monitoring of their health state [9, 10].

Many stand-alone and networked robots, also integrated in smart environments, were developed to perform specific tasks [11, 12], acted as simple companion robots [13, 14] or provided complex assistive services [15, 16]. Stand-alone robots autonomously planned and acted depending on their sensing capability and their internal model of the surrounding environment. These robots usually required high computational capabilities and expensive technologies that made them unaffordable [17]. Networked robots were defined as a group of autonomous robots that made important use of wireless communications among them or with the environment and living systems, in order to fulfil complex tasks [18]. Smart environments, and intelligent agents, such as wearable and personal devices, extended the effective sensing range of those robots and improved their planning and cooperation capability. Nevertheless, stand-alone and networked robots faced inherent physical constraints as all computations were conducted on board the robots or on wireless devices, which had limited computational capabilities [19]. This configuration could be insufficient to provide continuous and effective assistive services to fulfil seniors' needs. Recently a cloud robotic paradigm extended the concept of networked robotics. Cloud robotics and cloud networked robotic paradigms were introduced by [20] to improve networked robotics and design a new generation of cheaper and smarter robots by exploiting cloud computing infrastructures. The main advantages of using cloud infrastructures, compared to classic client servers, are: (i) they dynamically address physical and computational resources depending on the required workload for service delivery; (ii) they improve quality of service by requiring no downtime for hardware and software upgrades; and (iii) they reduce costs because there is no need for hardware [21]. In cloud robotics, complex algorithms run on the cloud, which acts as a modular and always connected remote brain. The cloud reduces time and energy expenditure for service delivery [22] and could improve the QoS [23] and cost-effectiveness of demanding Ambient Assisted Living (AAL) robotic services.

Because of the novelty of cloud infrastructures, several definitions of cloud robotics exist. In particular, Ken Goldberg emphasized the benefits of the great computation capacity and memory allocation provided by the cloud in providing a new form of collective robot intelligence through learning and sharing paradigms [24, 25].

In authors' opinion, Cloud Service Robotics (CSR) could be defined as the integration of different agents that allows an efficient, effective and robust cooperation between robots, smart environments and humans, to provide continuous services to senior citizens. CSR could be applied in many robotic applications, to offload CPU-heavy tasks and access base knowledge to expand robot consciousness beyond their physical body [19] (see Fig. 1). Two main paradigms were introduced in literature to improve service robotics: the Robot as a Service (RaaS) and the Software as a Service (SaaS) approaches. In the RaaS approach [25] the cloud is introduced to resolve issues of continuity of services. The relationship between users and robotic platforms is mediated by a robot management system on the cloud, which coordinates and selects the proper hardware platform to fulfil user needs and provide robotic services. In this model, the user is not required to own a specific robot, and the same robot could be used by several citizens. The SaaS approach enables low-cost robots to offload storage and processing capabilities to the cloud. Complex algorithms on the cloud could be provided on request, to improve the reasoning, sensing and planning capability of robots with limited

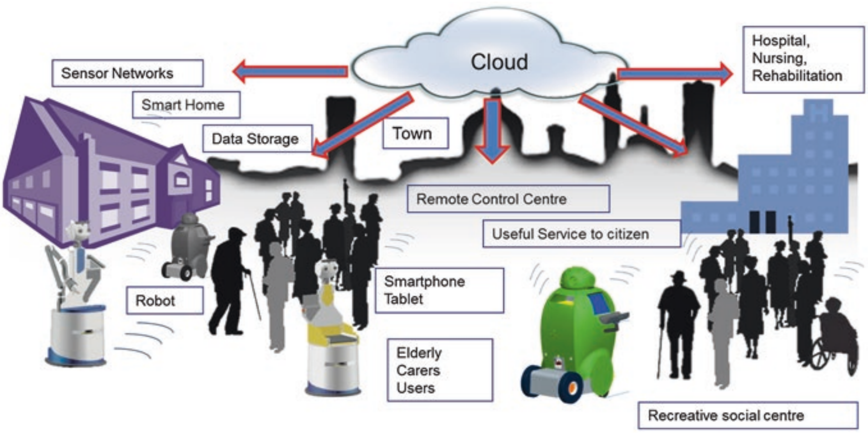

Fig. 1 Cloud Service Robotics paradigm. It shows the integration of different agents that allows an efficient cooperation between robots, smart environments and humans

hardware. Recently, the SaaS paradigm was investigated to offload computationally intensive tasks such as object recognition and user localization. In the RobotEarth project [26], the knowledge required to recognize objects was opportunely aggregated and stored in a cloud infrastructure, and provided as a service to the connected robots in order to improve their interaction and manipulation capability.

Several researchers [27, 28] investigated the opportunity to provide Localization Based Services (LBS) by using cloud solutions, in order to improve the cost-effectiveness and the QoS. User localization systems allow robots to know the position of the users without the need to implement a seeking procedure. In a cloud robotic solution, robots could have the user position on demand, and seniors wouldn't need to own computers running localization algorithms in their homes, reducing the system installation and maintenance costs.

3 Proposed Services

The proposed system was designed to provide high-quality and continuous assistive services for independent living. In the proposed service, according to the RaaS paradigm (see Fig. 2), an assistive robot was provided as a service to alert the user in case of critical situations, and to remind them to take drugs or attend a medical therapy, whereas in the SaaS paradigm, indoor user localization and environmental monitoring algorithms were developed and offloaded onto the cloud. This architecture improved the robot's functionalities without increasing the computational load on board. The list of implemented cloud services is shown below:

1. *User indoor localization service*. The system was able to locate users in need of robot support in the continuous care service. A localization software acquired data from heterogeneous commercial and ad hoc sensors, to estimate the position of the user. A sensor fusion approach was investigated to locate people in a robust and scalable manner. The accuracy and cost of the indoor localization service will depend on the typology and number of the installed sensors. In the case of a sensor fault, the user position was estimated by fusing data from the remaining ones, improving the reliability and robustness of the service.

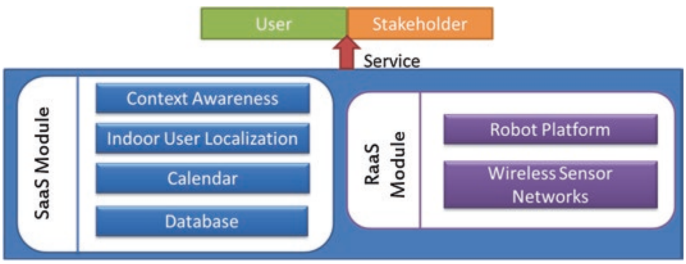

Fig. 2 SaaS and Raas modules

2. *Care reminding service*. A calendar for medication and care management was integrated into the system, and provided as a service to carers and users. This service was based on the Google Calendar tool. In this way, users and carers were allowed to schedule therapies and medical visits on the calendar. The system automatically addressed a robotic reminding service at the scheduled time, to remind the user about appointments or medication.
3. *Environmental monitoring service*—A sensor network monitored the home status by using a switch on the entrance door, PIR (HC-SR502 from Elecfreaks), light (ISL29023IROZ-T7 from ST Microelectronics), humidity (HIH-530 from Honeywell), temperature (STCN75 from ST Microelectronics) and water leak sensors (from Cleode). Data acquired from the sensor network were collected and processed by a software module on the cloud. The software monitored the home status and alerted users and carers in the case of critical situations. Low-cost companion robots could be improved by the proposed system, which allowed environmental monitoring and user localization to be carried out, independently of the robot computational capabilities. The same SaaS could be used by different robots and agents.

4 System Architecture Description

The system hardware, software and user interfaces are described in the following section.

4.1 System Hardware

The hardware consisted of a mobile robotic platform and two ZigBee-based Wireless Sensor Networks (WSNs), one for user localization and the other for environmental monitoring. The personal robot was based on a SCITOS G5 platform (Metralabs, Germany) that communicated with the user by means of an embedded touch screen. It exchanged data with the cloud through a Wi-Fi module. The user localization network was designed to locate multiple users at the same time, using Received Signal Strength (RSS) [29]. It was composed of a ZigBee coordinator, a Data Logger (DL), a wearable mobile node and a set of fixed ZigBee routers, also called anchors. The mobile node periodically sent messages to all anchors within one communication hop. Each anchor computed the RSS on the received messages and transmitted this value to the DL. The sensor network was developed for home monitoring and presence detection. It was composed of a ZigBee coordinator, a DL and a set of sensor nodes, which was connected to a selection of sensors as described in the previous paragraph. The two networks were set on different channels to avoid interferences and ensure the proper bandwidth for the localization and environmental monitoring services. Each DL was connected to a PC using a USB connection, to upload data on the cloud platform.

4.2 System SaaS

The proposed SaaS included a database (DB), DB Management Software (DBMS), a User Localization Module (ULM), an Event Scheduler Module (ESM) and a Data Analysis Module (DAM). The DBMS managed DB entries and queries while the DB contained data from the connected robotic agents. The DB was composed of several tables: one for each observation from sensor outputs, one containing the list of installed sensors (typology and unique identification number) and another table recording the user's estimated position. Outputs from physical agents and the estimated user position were sent to the DBMS and recorded into the DB. A dedicated localization algorithm was implemented by the ULM to estimate the user position from RSS observations and presence sensor outputs. A sensor fusion approach based on a Kalman Filter (KF) for user localization was implemented exploiting both range-free [30] and range-based [31] localization methods.

Fig. 3 The Web Interface

Presence sensors were used to improve positioning accuracy and carry out host detection. Numeric values (x,y) and semantic information on user position were given to the robots to efficiently provide assistive localization based services. The ESM knew the current date time, the user's commitments and appointments and scheduled the reminding services. After scheduling, at the proper time it retrieved the user position stored in the DB and told the robot to contact the user and provide the required reminding service. The DAM periodically analysed the data in the DB and alerted the system in the case of critical situations.

4.3 Web Interface

The system interface consisted of a Web application for remote home monitoring. It was connected directly to the DB on the same remote server with a public static IP, and the access was restricted to authorized people only. The interface home page provided mean light, humidity and temperature values for each sensorized room (see Fig. 3) and the entrance door status. An alarm web page provided a list of the alarms that occurred, while the localization web page reported the room where the user was located.

5 Application Scenario

The systems were subjected to preliminary evaluation and tested in the realistic scenario of the DomoCasa Living Lab, Peccioli, Italy—a 200 m^2 flat with a living room, a kitchen, a bathroom and two bedrooms. Each room was equipped with at least a temperature, a humidity and a light sensor, while 15 anchors, six PIRs and five sensorized carpets and pillows were installed for user localization. A local PC called a domocasa-PC gathered all the sensor outputs and sent them to a further remote PC, called a remote-PC, which acted as a cloud and implemented the assistive robotic services. In the application scenario, the user stood wherever he wanted in the kitchen and the companion robot, at the scheduled times, automatically moved from the living room to find him/her and remind him/her to take drugs. After the interaction with the robot, the user gave feedback to the reminding service through a specific app installed in the robot's tablet. Data from the SE were sent to the cloud for home monitoring and critical situation recognition. The Web interface on the robot's tablet allowed the status of the house and the calendar to be checked (see).

6 Evaluation Metrics

The performance of the cloud platform was estimated through two parameters: the Time of Response (ToR) and the Reliability of Response (RoR) [32]. The ToR was defined as "the time needed for a client to receive a response after a request for service". The RoR, on the other hand, was defined as "the measure of confidence that the retrieval data is free from errors" and its value was given in per cent and calculated as the ratio between the successful requests and the total requests. The RoR was computed as the ratio between DB data recovery that has been successful and the total requests.

Now the analysis of the system focused on the ToR and RoR estimation to evaluate the QoS. The evaluation of the localization service will be conducted as a future work. Nevertheless, during the experimentation, the ULM provided an in-room localization granularity, allowing the robot to be driven into the room occupied by the user.

7 Results

QoS was assessed by the analysis of the ToR and RoR system in the DomoCasa environment. The total service system time was 65.56 ms plus transmission time. The ping time was acquired during the experimentation as a benchmark to assess the effective ToR of the network. Table 1 shows the complete results of ToR analysis. ToR was divided into two values: (i) ToR to save data into the DB (ToR_DB), which was obtained by mediating the ToT_DB provided by each sensor typology; and (ii) ToR related to service requests (ToR_SR) was the time that the system needs to provide the user position to the client who made the request. RoR value was computed as the ratio between successful requests from the ESM for user position and its total requests to the DB. This module inquired about user position at the rate of 1 Hz. The number of service failures was less than 0.04 %.

Interference between the wireless sensors in DomoCasa was avoided by setting the localization and the sensor networks on different ZigBee channels. The sensor network nodes were provided by the plug-and-play feature, which allowed them to automatically join the network and send data at the start-up, in order to reduce

Table 1 ToR values in milliseconds

Parameter	Time (ms)
Mean ToR_DB over all data	32.08
Mean ToR_SR	24.27
Mean time of processing for localization	9.21
Mean ping time (benchmark)	5

the installation complexity. The localization system was able to locate multiple users at the same time, thanks to the synergic use of information coming from the ZigBee wearable radio devices and presence sensors in the environment. An in-room localization granularity was provided by the ULM, and thanks to the cloud DB, the user's movement could be recorded for historical behavioural models and analysis for up to one year.

8 Conclusion and Future Work

CSR introduced several challenges that should be addressed to improve assistive robotics: (i) the contemporary management of several robots over different environments; (ii) the delivery of high-quality services; and (iii) the design of dependable and acceptable services.

The proposed system was tested in a realistic environment, and the CSR approach seemed to be effective in terms of QoS when providing AAL localization-based services (see Fig. 4). The services were provided with a time comparable with classic state-of-the-art robotic services [33]; nevertheless, ToR depends on the adopted communication technologies. Incidentally, smartphones with wireless broadband capability are becoming an indispensable part of elderly daily life [34]. Nevertheless, wireless broadband could negatively impact on the reliability of communication. Further investigations into the proper communication technologies and infrastructures for cloud robotics should be performed. For this reason, future works will focus on the evaluation of the QoS of the proposed system using LTE and 3G and wired ADSL technologies. In the future, specific algorithms for the proper allocation of robotic resources and mission planning should be developed, ensuring a high quality of service and taking into consideration dependability issues.

Fig. 4 The domestic robot found the user in the kitchen and acted as a physical reminder

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OMNIAROBOCARE: A Robotic System to Ease Loneliness and Foster Socialization

Gianfranco Borrelli, Massimo Pistoia, Ludovico Fabbri and Paolo Casacci

Abstract The OMNIAROBOCARE project, funded by the Tuscany Region, aims at developing a technological-robotic kit prototype which is functional to the progressive prolongation of life expectancy, social assistance and home care for the elderly or frail users. This system makes not only an accurate and steady monitoring of daily life activities available to them, but it provides frail users with a system able to defeat loneliness conditions and to foster socialization activities as well. Miscellaneous testing and experimentation activities are going to be undertaken over the months to come in order to develop a first prototype represented by a solution able to support patients during daily life activities, enabling them to carry out their life in their own living environment and to remain independent as long as possible. This paper illustrates the project and its main goals, the analysis activities and experimentation stages.

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1 Introduction

As the quality of life and the living standards improve, our societies inevitably witness today a gradual ageing-population phenomenon [1]. And with it also the number of self-sufficient elderly but in need of continuous monitoring and assistance is expected to grow, thus causing a simultaneous increase in social costs related to hospitalization and social welfare.

The frail person is often forced to a long stay in his/her own home environment because of the diseases or impairments resulting from the aging process and experiences burdensome loneliness situations or of very limited possibility of social interaction.

If much has been done to make new technologies available to frail users and their caregivers, in order to improve the quality of life for those who need special attention in performing daily activities and those who, day by day, take care of them, however, much more has to be done in terms of acceptability of ICT and advanced technologies and solutions by the end-user.

Idiosyncrasies towards modern technology can be reduced by working on the implementation of highly innovative user interfaces, as robotic ones, able to improve the elderly's quality of life at the same time by diverting users' attention from the perceived negative aspects of their condition and thus contributing to their general well-being [2].

Technology may be helpful if it is conceived and built around the users' needs, limits, expectations and requirements. It is therefore crucial to focus attention on usability and acceptability issues. Research must be actively focused then on the creation of user-friendly interfaces in order to overcome technical barriers that stand forth at installation and usage phases.

In this context, the aim of the project is to develop an integrated system for remote monitoring of the elderly on the one hand and to spur their social inclusion by making use of highly innovative interface devices like robots with anthropomorphic features, on the other hand.

2 The OMNIAROBOCARE System

OMNIAROBOCARE [3] is an integrated robotic system based on the OMNIACARE platform [4] and the features it offers which allows monitoring functions of vital parameters and remote assistance for home care and social welfare of frail people, with particular regard to the elderly. Through the use of miscellaneous wireless environmental sensors or smart medical parameters detecting-sensors, wearable and non-invasive or placed on the robot or deployed in the environment, is it possible, indeed, to collect data concerning vital and/or environmental parameters and to monitor then patient's health status. Data will be stored—by using appropriate security protocols—in the central server of a database which can be accessed by all of the pre-authorized stakeholders allowing so an assessment of the end-user's medical conditions in real-time and to intervene promptly, if necessary.

The system makes use of advanced tools of communication integrated with the OMNIACARE platform that facilitate the interrelationship of the elderly with other individuals and with their circle of support, including the other elderly as well. Through the use of wireless broadband connections integrated into the robotic devices and by means of a Tablet PC placed on the Robot itself, it is possible to avail of services of Internet browsing, audio and video conferencing, messaging, including the possibility to access targeted social networks.

Through this platform, indeed, the user can also demand home care or cleaning services or purchase medicine or food which may be dispensed and delivered directly to his home address, facilitating so the achievement of a degree of comfort and independence as greater as possible.

At the same time, the system can provide support during the daily life activities of the elderly, both in physical terms—by facilitating the elderly's mobility or access to different objects of daily use– and in cognitive terms, by providing, when necessary, information or reminding them things or planned activities to do during the day.

The use of robotic systems will improve usability as well by limiting the user's need to directly interact with the technical platform to activate devices. Moreover, the robots will reduce barriers and spatial constraints (as they move autonomously) and the anthropomorphic features of such devices—it is widely believed—make them more acceptable to users' perspective [2, 5, 6].

2.1 The ICT Robotic Platform

The OMNIAROBOCARE system, which is still in the experimental stage, will aid caregivers and medical operators to remotely assist their patients by monitoring vitals parameters and living environments through smart sensors and by the means of an ICT robotic integrated platform. Devices will interact wirelessly to ease placement and communication in the living environment and users will thus benefit from remote assistance and monitoring activities, as well as services for home care and personal assistance, therefore pursuing as much comfort and autonomy as possible.

The system makes use of an ICT robotic platform which integrates both the OMNIACARE platform developed by eResult and the robotic devices. Through the use of wireless broadband connections and by means of a Tablet PC placed on the robot itself, it will be possible to implement both health status assessment and socialization activities.

The OMNIACARE platform is designed for the social welfare and healthcare sector and to promote the independence of frail users helping them to carry out an independent life as long as possible in their own home environment, the system makes use of advanced technologies that allow to perform remote monitoring of the patients' health status in real time.

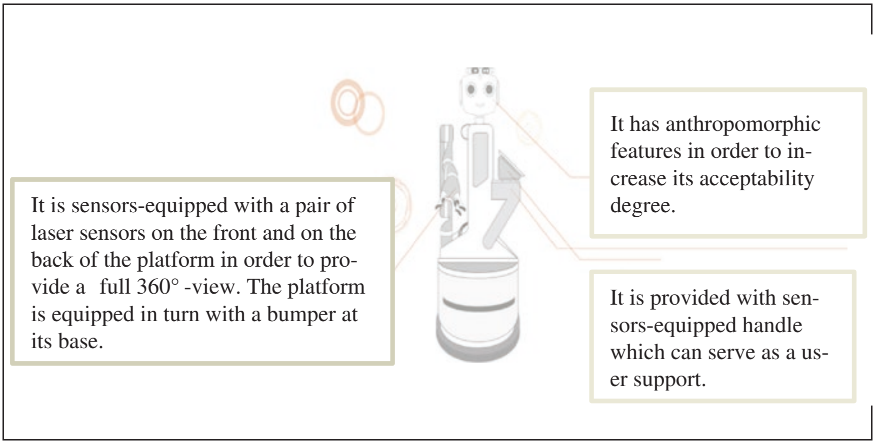

Fig. 1 Structure of the robotic device

The robotic device is equipped, instead, with a pair of laser sensors on the front and on the back in order to provide a full 360°-view. The platform is equipped in turn with a bumper at its base and its mobility is ensured by a system based on differential electric motors able to move it at a full-speed of 1.4 m/s in translation and up to 200°/s in rotation and able to operate up to 50 kg of load. It has anthropomorphic features in order to increase its acceptability degree and it is thus equipped with a "head" installed on a trunk at a height of 150 cm. Finally it is provided with a sensors-equipped handle as well, which can serve as a user support. A detailed structure of the robotic device is shown in Fig. 1.

3 Developed Methodology and Subject Population

The development of the OMNIAROBOCARE system follows the so-called UCD—*User Centered Design* approach [2–8]. This process—which considers the involvement of the end-user of the product throughout the whole conception, design and development cycle—can be described in its core as "the practice of designing products so as to allow the user to carry out his duties with minimum stress and maximum efficiency".

This approach places at its center the user's needs, limits and requirements and tries to develop solutions, services and products shaping them around these types of considerations precisely centered on the user's expectations.

The UCD methodology is characterized by a multi-level co-design and problem solving process which requires to test and validate their assumptions by taking into consideration the end-user's behavior during the usability and accessibility tests into the real world along with analyzing and foreseeing how the end-user will utilize the final product.

In this regard, it is necessary to adopt a systematic and structured approach which allows to record all of the information related to the users' habits, daily activities, expectations, needs and limits and which involves the end-users throughout all of the design stages of the product.

This process resorts to quantitative and qualitative measurements concerning the usage characteristics of the product along with an interactive design pattern based on the "first design > test > second design>" structure to be applied since the early stages and in a cyclical manner throughout the product development process.

A multi-skilled approach by the usability team characterized by a cross-knowledge of miscellaneous fields and subjects such as marketing, human factors, multimedia and education, completes this process and makes it more effective.

In the framework of the planned analysis activities, as contemplated by the first deliverable of the project, the AeA "Abitare e Anziani" Association, subcontractor of the Abitcoop of Prato—a housing cooperative operating in the territory of the city of Prato—in cooperation with the partners of the project, has promoted the implementation of a Focus Group involving the group of elderly volunteers of the Auser of the small Tuscan town, Fornacette [9, 10]. The Focus Group aimed at detecting the elderly's habits and needs in relation to the living environment and their health status, the compatibility between the proposed robotic device and the user's needs and expectations as well and the acceptability degree of the new technologies by the end-users. The group of the elderly, which numbered almost 20 individuals, of both genders and aged between 55 and over-85, helped then to identify the different scenarios belonging to daily life in order to define which daily activities may need support, which parameters should be depicted, which environmental aspects should be secured and finally which services should be offered.

3.1 Scenarios

The prototype which is being developed and on which the researchers are carrying out their experimentation phases contemplates at least 5 different scenarios related to the use and services that can be provided through the OMNIAROBOCARE system (see Table 1).

1. The first scenario concerns the aid to the movement of the user:
   (a) Since the elderly and/or frail user may encounter mobility difficulties, indeed, which can prevent or make ordinary activities complicated—such as walking or getting out of bed or a chair—the user, through a microphone directly connected to the robot, can call it.
   (b) The robot will be then moving towards him/her and help to get out of bed by letting him/her hold on to its handle and lift him/herself up as shown in Figs. 2 and 3.

Table 1 Services and features which can be provided through the integrated robotic system

Service /Feature	Description
Audio/Video conference	The user may call the robot through a microphone in order to bring him/her the Tablet PC. By the means of its user-friendly interface the user can receive and answer an incoming video call or make it, contacting so the loved ones, a caregiver, friends or just keeping in touch with the family network
Access to social network and entertainment features with other users on-line;	The user expresses his/her will to access one of the entertainment features offered by the OMNIACARE platform such as playing cards, listening to music, reading newspapers or magazines, or just interacting with other users including other elderly
Support to user's movement	The user is lying down on a bed and through the microphone directly connected to the robot, he can call it. So the robot will be moving towards the user letting him/her hold on to the handle and lift up
Company	Users can request the company of a volunteer for a certain period of time, which is specified in a way similar to the one used for deliveries
Help with managing operations/practices	Users can also request help of a volunteer in managing their practices, like paying bills or rents, filling forms etc
Booking cinema and/or theatre tickets	Users can book tickets for cinemas or theatres by means of links to websites that provide these facilities and which are accessible through the application
Reminder	This feature gives the user the possibility to set a reminder, specifying a description, date and time and notification mode, that is: vocal message (that reads the description), sound notice (beeps), or any combination of these
Requested services	This feature enables users to check a list of the services they have requested, checking their progress status as well
Booking medical exams	Users can book medical exams or check-ups if they need to, by using the proper links of the application providing such facilities

2. The second scenario is related to the management of domestic emergency situations. Unexpected events or domestic accidents may represent, indeed, a risk for the elderly, in particular for frail ones:

    (a) Environmental sensors installed at the user's premises will warn of the possible domestic risky situations such as gas or smoke leakages and on the alert the robot warns in turn the user against the danger detected as shown in Figs. 4 and 5.

Fig. 2 The robot moves towards the user

Fig. 3 The user can use the handle of the robot as a support

Fig. 4 Example of environmental sensor

(b) The user now aware of it will be able to handle the situation in person or by contacting his family network or caregivers through the Tablet PC placed on the Robot.

3. A third scenario contemplates instead the possibility of a daily life activities reminder service. The elderly often are affected by loss of memory and may find it difficult to remember simple activities such as taking a specific medicine, following a therapy or going to somewhere. But if properly supported,

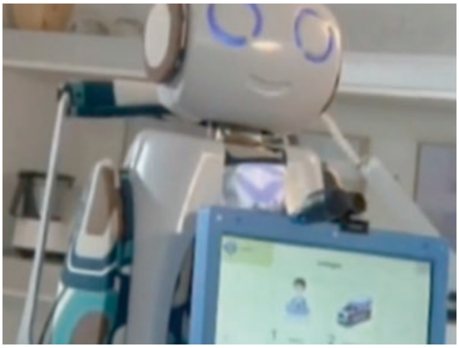

Fig. 5 The robot warns the user against a detected danger

Fig. 6 An example of reminder service through the Table PC

they can ease the sense of frustration resulting from this condition. The user may set, indeed, some reminder messages and sentences by using the Tablet PC and as soon as the memo runs out of time, the robot will be initiated and get through to the user who can read the reminder message showed on the Tablet PC. An example is given in Fig. 6:

4. The fourth scenario is related to the possibility to use the robotic device in order to bring the user specific items or to act as a glove compartment for small sized objects fitting the structure of the robot. The user can call it through the microphone and the robot, once captured the commands, will be moving towards the required object performing the request.
5. Finally, the robotic device can be suitable in order to foster socialization and social inclusion offering to end-users entertainment features. Through the Tablet PC placed on the robot, the frail user can take part in recreational activities. By using the proper application, indeed, it will be possible to make and receive video calls, to take part in targeted social networks and to use all of the socialization services operating on the OMNIACARE platform. This feature, which meets one of the main goal of the project, can greatly ease the burdensome loneliness conditions of the elderly, by providing simple and effective tools for keeping in touch with other people, including other elderly, with whom sharing thoughts, experiences and memories.

4 Conclusion

The experimentation stages have just started and are being carried out as planned. During these activities, all the hardware and software components integrated into the system will enable to test the features and services proposed.

In particular, during a first phase, the experimentation activities will be covering the five proposed scenarios. Researchers intend then to verify the *speech recognition* feature in order to test the capacity of the robot to capture the command of the user through the microphone and to move towards the user, providing its sensor-equipped handle as a support to the movement or bringing instead the required item. In this case an object, no bigger than a remote controller, will be placed on the small tray at the front of the robot so that the user, once called the robot, can take the item from its tray. It will be simulated a gas leakage in order to test the reliability of the robot to exchange information with the environmental detection system and to alert the user via a sound message. It is presumed that the Tablet PC is usually placed on the docking station installed on the robot. On the Tablet, it will be installed the OMNIAROBOCARE application with the socialization services and the social network for elderly. The trial will involve testing of all services by the end-users.

During the first experimentation stage, indeed, which has been held in May 2014 at the DomocasaLab in Peccioli, belonging to the Scuola Superiore Sant'Anna of Pisa [11], 3 volunteers from the Fornacette Focus Group [9, 10] took part in the planned activities and represented the first user base to test the system, its features and the proposed services. They have been selected on the basis of their age, family typology (couple, single person, single person with relatives or couple with relatives), education level and health status. The 3 volunteers used both the robotic device and the OMNIACARE platform in different planned situations according to the abovementioned scenarios: for example, they asked for help to the robot through a microphone in order to get up the sofa or the bed or to get some items through the proper tray placed on the robot itself. This allowed researchers to test the "speech recognition" software. The users experimented the video call function and other entertainment features offered by OMNIAROBOCARE from the Tablet PC. It was also simulated a gas leakage in order to test the reliability of the interaction between the robot, the platform and the environmental sensors in terms of data exchange.

In particular, the results originating from this first phase were of great importance in order to shed the light on the positive aspects as well as on those to be improved or better tailored on the user's needs. It was highlighted how useful users perceived the robot as an aid to movement, spurring thus simple physical activity inside the living environment. Also the environmental sensors were considered of great relevance by the testers, since they enhanced their daily life safety perception in their home environment. Positive evaluation received the entertaining features as well, since they allow the users to keep continuously in touch with their relatives or caregivers, defeating therefore loneliness conditions.

In conclusion, the aspects and the possible requests highlighted by users during the testing stage will represent the feedback on the basis of which, in compliance with the UCD methodology, the system will be improved, further developed and better tailored on the user's needs, limits and requirements. It will be also contemplated the possibility to provide the end-user with a training activity in order to better use the technologies employed and not always familiar to the elderly and a tutoring service to familiarize with the use of the robotic platform in the living environment.

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A Smart Walking Assistant for Safe Navigation in Complex Indoor Environments

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Abstract Large and crowded public places can easily disorientate elderly people. The EU FP7 project *Devices for Assisted Living* (DALi) aims at developing a robotic wheeled walker able to assist people with moderate cognitive problems to navigate in complex indoor environments where other people, obstacles and multiple points of interest may confuse or intimidate the users. The walking assistant, called *c-Walker*, is designed to monitor the space around the user, to detect possible hazards and to plan the best route towards a given point of interest. In this chapter, an overview of the system and some of its most important functions are described.

1 Introduction

Information and communication technologies (ICT) contribute to innovation in a variety of ways. At the European level, elderly care is recognised as one of the crucial societal challenges of the near future. With the median age in Europe

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projected to grow from 37.7 in 2003 to 52.3 in 2050, the population potentially afflicted by mobility problems is substantial, not only because their social lives are restricted, but also because they have a limited access to good nutrition, leisure and other activities. Several factors adversely affect mobility, the most obvious being physical impairment as well as loss or reduction of visual and auditory ability. A less recognised, but equally critical problem is the decline of cognitive abilities, which reduces confidence when a person is supposed to move in unfamiliar environments, where the presence of both crowd and multiple points of interest (PoIs) may easily cause users' disorientation. In such situations, the afflicted person gradually perceives public places as intimidating and starts to withdraw.

In order to tackle this problem, the EU project *Devices for Assisted Living* (DALi) aims at developing a smart walking assistant called *c-Walker* able to support navigation and to improve confidence of senior users moving within large and unstructured spaces, such as shopping malls, railway stations or airports. The main features of the walker in terms of functions and usability have been defined in cooperation with groups of potential users in England and Spain under the supervision of a team of psychologists. A key innovation factor of the *c-Walker* is its ability to detect and to interpret human behavioural patterns in order to plan the route that minimises the level of anxiety for the user, while preserving naturalness of his/her navigation.

Robotic walkers have gained an undisputed popularity in the research community working in the field of Ambient Assisted Living (AAL). Closely related to DALi is the system developed within the project *Assistants for Safe Mobility* (ASSAM) [1]. However, ASSAM is focused on the seamless transition from indoors to outdoors, while DALi specifically considers large indoor environments and the interaction with other people around the user. Other projects, such as iWalkActive and E-NO-FALLS [2, 3], have complementary goals, i.e. supporting physical exercise and preventing falls, respectively. Although of interest, these aspects are different from those faced in DALi. In the rest of this chapter the main features of the first *c-Walker* prototype are shortly summarised.

2 Functional and Architectural Overview

In a typical application, the assisted person (AP) selects a destination from a list of possible PoI (e.g. the restrooms, a shop, or a ticket office) on a map of the chosen environment, which is preloaded in a tablet. After selecting the PoI using the tablet touch-screen, a safe route is established and shown to the user. The *c-Walker* is capable to track its own position on the map while approaching the destination point. If the AP wants to move along a different trajectory, he/she is free to do so. In this case, the *c-Walker* suggests a correction, not only by showing it on the screen, but also through a pair of Bluetooth-driven bracelets working as haptic interfaces. Such bracelets vibrate to inform the AP when a left or a right turn should be taken. The use of bracelets has been preferred to the integration of haptic interfaces within the *c-Walker* handles for two reasons. First of all, installing haptic handles with a suitable form factor was quite complex from the mechanical point of view. Secondly, the pressure exerted on the handles while pushing the device could reduce user's sensitivity to haptic stimulation. Alternatively, the route to follow can be indicated to the AP through suitable audio signals generated by Bluetooth earphones.

The sensing part of the system is composed by two encoders CUI Inc. AMT10X mounted on the rear wheels, an inertial measurement unit (IMU) equipped with a gyroscope Inversense IMU-3000, an RFID reader Feig ISC. MR101-USB and a front USB camera or a Kinect. These sensors are used for localisation purposes (see Sect. 3). The front Kinect is used also to detect possible hazardous situations and to track other people moving in the proximity of the device. A second IMU is mounted on the earphones to determine the AP's head attitude with respect to the direction of the walker (see Sect. 5).

A picture of the first *c-Walker* prototype along with its main components is shown in Fig. 1. The block diagram depicted in Fig. 2 highlights instead the system architecture from a functional point of view. The higher level functions (image processing, situation assessment, trajectory planning and guidance) are implemented in a small Intel Barebone mini desktop (11.7 cm × 11.2 cm × 3.9 cm) equipped with a 2.80-GHz Intel Core i5-3427U processor, 8 GB of DDR3 RAM and a 120-GB solid state drive. This platform is powered by an external rechargeable 118-Wh Li-ion battery. Communication with peripherals and subsystems relies on a USB 3.0 port, a Gigabit Ethernet link, WiFi (IEEE 802.11a/b/g/n) and Bluetooth 4.0. The USB link is used to control and to acquire images from the front camera. WiFi provides fast communication between the Barebone platform and a Google Nexus 10 tablet running the graphic user's interface (GUI). The Gigabit Ethernet connection is used to collect the results of the low-level

Fig. 1 The *c-Walker* prototype along with its main components, i.e. Beaglebone platform (***A***), IMU (***B***), encoders (***C***), motors (***D***), RFID Reader (***E***), Camera (e.g. Kinect) (***F***), Barebone platform (***G***), and main battery (***H***)

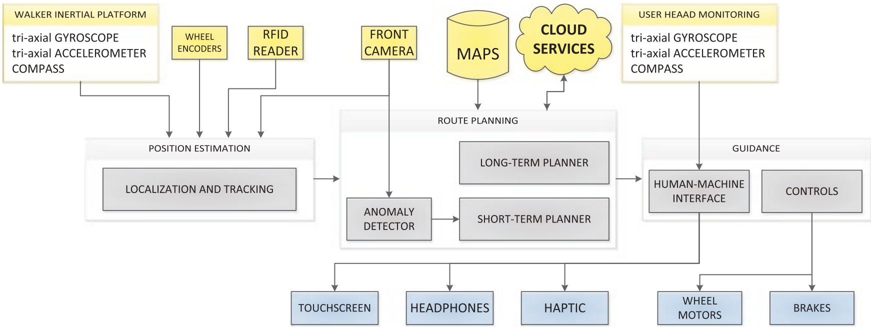

Fig. 2 Functional block diagram of the *c-Walker*

functions (i.e. sensor data acquisition and preprocessing) as well as to control some of the output actuators (i.e. two brakes Liedtke FAS21 on the back wheels and two pivoting motors M1233031 by LAM Technologies located on the front caster wheels). Such low-level functions are implemented in a Beaglebone platform equipped with an ARM Cortex A8 processor running at 720 MHz, 256 MB DDR2 RAM and a microSD memory for storage. The Beaglebone is connected to the RFID reader via USB. The input data from encoders and IMU, as well as the output control signals driving brakes and pivoting motors are transferred to/from the Beaglebone via CAN bus.

3 Localisation and Position Tracking

Walker localisation is essential to support high-level functions such as route planning and guidance. Map construction and localisation techniques play a complementary role. A map of the chosen environment is required to define the allowed areas (namely where the user can move freely) and the forbidden areas (e.g. due to obstacles or boundaries such as walls). Once a map is available, a 2D Cartesian reference frame (given by the position of the origin and the direction of axes x and y) can be defined on it. The position tracking algorithm relies on an extended Kalman filter (EKF). The EKF is built upon a simple five-state unicycle-like kinematic model. A qualitative description of the localisation and position tracking algorithm is shown in Fig. 3. The state vector includes the following variables: the (x, y) coordinates of the midpoint of the rear axle in the chosen Cartesian reference frame, the orientation angle θ with respect to the x-axis and, finally, the linear and angular velocity offsets (referred to as μ and δ, respectively) due to encoders nonidealities and left-side/right-side walker asymmetries. The encoders are used in the prediction step of the EKF to reconstruct the relative position and motion direction of the *c-Walker* with respect to the initial state. Even if the data rate from such sensors is high enough (i.e. 250 Hz) to assure continuous position tracking,

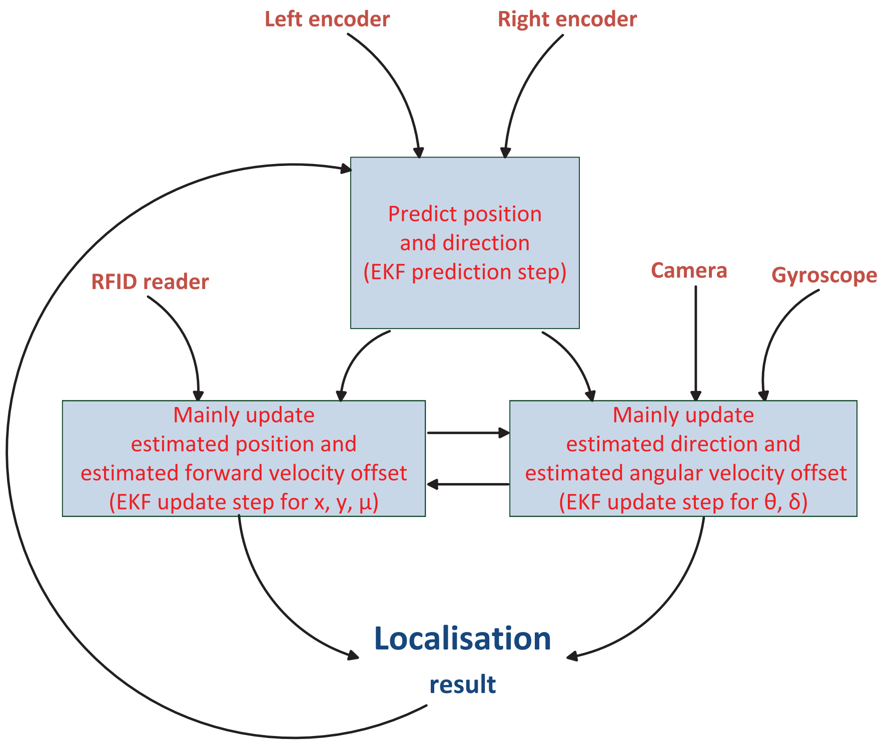

Fig. 3 Overview of the EKF-based algorithm for localisation and position tracking

the open-loop estimation uncertainty tends also to grow indefinitely, as customary when dead-reckoning techniques are used.

In order to keep position uncertainty within wanted boundaries (e.g. ± 1 m with 99 % probability), a grid of low-cost passive RFID tags stuck on the floor at known locations is used. In this way, the position estimated by the *c-Walker* on the map can be updated by simply knowing the ID of a detected tag, with uncertainty no larger than the RFID reading range (i.e. about ± 10 cm). Due to the fusion of odometry and RFID data, the granularity of the grid can be coarser than other solutions found in the literature [4]. Several simulations showed that a tag distance of about 2–3 m can provide a reasonable trade-off between wanted accuracy and deployment costs [5]. Unfortunately, RFID tag detection does not provide precise information about the direction of motion.

In order to update more effectively the estimated direction, the angular velocity values measured by the gyroscope inside the on-board IMU are integrated to update the state of the EKF anytime the walker turns left or right. However, also the gyroscope-based angle measurements are affected by unbounded uncertainty growth. Therefore, sporadic absolute orientation values in the chosen reference frame are needed to reset the angular drift introduced by the gyroscope. Since compasses and magnetometers proved to be unreliable indoors, the absolute orientation values can be obtained by measuring the angle between the direction of the walker at a given time and the *x*-axis direction pointed by a grid of visual markers (e.g. arrow-shaped stickers or QR-codes [6]) put on the floor and recognised in the images collected from the front camera. Again, various simulations showed that a distance of a few metres between adjacent markers is enough to assure a good trade-off between estimation accuracy and deployment complexity [5]. It is worth emphasizing that a localisation fully based on computer vision is not feasible in the case considered, as the camera has to be used also for trajectory planning and the available computational resources are limited. In fact, marker detection relies on low-rate image acquisition (e.g. at 10 Hz).

4 Route Planning

Route planning is based on a two-level approach. The first level, called *long-term planner*, is based on a global view of the environment and computes a trajectory according to the objectives of the AP, while considering fixed obstacles and critical areas known a priori. The second level, called *short-term planner*, exploits the available on-board sensors (particularly the camera) to detect dynamic obstacles (e.g. other people [7]) and to update the trajectory, while assuring comfort and minimising the probability of collisions [8]. Figure 4 shows the main modules of the route planning algorithm running on the Barebone platform.

The long-term planner takes care of building a complete route between the current AP position and the selected PoIs. Route construction takes into consideration static obstacles (e.g., walls, pieces of furniture) and temporarily forbidden areas including, but not limited to, crowded places and critical regions identified by appropriate signs (e.g. wet-floor or out-of-order signs). Such signs are detected by a vision algorithm that uses live images recorded by the front camera. The algorithm relies on both optical character recognition (OCR) and geometric shape recognition and exploits the depth information associated to the images to localize the corresponding signs on the map. The core of the planner is the Dijkstra algorithm executed on a Quadtree

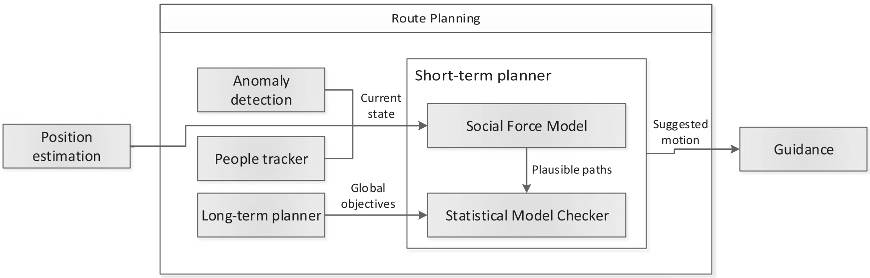

Fig. 4 Overview of the route planning algorithm

representation of the map of the environment [9]. From the technical point of view, the vectorial map and its representation are stored in a spatial database.[1] The set and the weight of nodes and edges of the graph representing the map are periodically updated to reflect the status of the environment at a given time. For example, if a wet-floor sign is detected, the planner disables all the nodes of the graph that are located within a circular area of a few squared metres around the position of the sign.

The short-term planner relies on a control algorithm based on a receding horizon approach, which exploits social rules driving the cohabitation of humans [10]. The algorithm uses the well-known Social Force Model (SFM) that represents people as 2D circles with attractive and repulsive forces [11]. Thus, it is possible to model the force that attracts people towards the same PoI, as well as the repulsive force that naturally prevents people from crashing into walls or other people. The control algorithm predicts the evolution of people moving in the environment and, consequently, it estimates the probability for the AP to reach safely the goal without any collision. In particular, the position of pedestrians is obtained using a people-tracker algorithm that relies on the images collected from the camera. The evolution of pedestrians moving in the environment is predicted by integrating the SFM over a limited time horizon. In principle, there is no upper limit to the number of pedestrians that can be handled by the algorithm. Further details on this algorithm are reported in [8]. Pedestrians' directions can be estimated from the vectors built using pairs of consecutive position values. The control algorithm exploits Statistical Model Checking techniques to verify the evolution of the SFM against temporal-logic high-level constraints [12, 13], such as, for instance, "reach the goal in a finite time, but no closer than 0.5 m from people and no closer than 1 m from obstacles". In order to estimate the probability of success, at first the possible evolution of the people moving around the *c-Walker* in a limited time horizon (a few seconds) is simulated many times. Then, every predicted scenario is verified against the above temporal-logic constraints and, finally, the probability of success is estimated under the assumption that the AP slightly changes its initial direction. This step is repeated till when the algorithm tests all possible directions (e.g. 0°, ±25°, ±50°, ±75°, ±90°). Finally, the direction that maximises the probability of success is suggested to the AP through the guidance mechanism (see Sect. 5). If the AP ignores the suggested trajectory or if an unforeseen obstacle is detected, a new route is computed.

5 Guidance Mechanism

The guidance system has the purpose of gently inviting the user to follow the planned route. In order to improve comfort during navigation, the force feedback has to be perceived as *soft* by the user and it should be properly modulated while

[1]Spatialite: http://www.gaia-gis.it/gaia-sins/.

he/she approaches the boundaries of an area of interest. Guidance is implemented using various complementary techniques, i.e. mechanical, haptic and audio-based.

Normally, the AP is free to push the *c-Walker* according to his/her needs. However, the two pivoting motors mounted on the front caster wheels can be selectively activated by Beaglebone to steer the walker along the suggested path. As long as the user moves within a safety region around the desired path, only sporadic and soft corrective actions are exerted. The control becomes more authoritative when the walker deviates significantly from the path, thus approaching potentially dangerous areas.

Although the mechanical feedback is effective, sometimes it can be perceived as annoying. This is the reason why other solutions (e.g. based on haptic guidance) have been investigated and implemented. Various studies have demonstrated that sensitivity to vibrations is particularly high on hairy skin and in bony areas [14]. Thus, two identical wearable haptic bracelets have been developed to invite the AP to turn right or left. In each bracelet, two cylindrical vibro-motors are controlled independently via Bluetooth. Each vibrotactile bracelet can be fitted to the arm, just below the elbow. This configuration has proved to be very effective to discriminate the haptic stimuli from the intrinsic vibrations of the *c-Walker*.

Another way to inform the AP about the best path to follow is based on the generation of appropriate sound stimuli. In daily life, humans are able to estimate the direction of arrival of sounds because our brain is able to recognise relative differences in amplitude and phase of sound waves impinging the two ears (binaural cues). Also, the brain can identify the spectral cues that originate at a single ear (monaural cues) because of the reflections generated by the pinna folds. These cues depend on the relative position between the listener and the sound source [15]. By modeling and reproducing these phenomena, it is possible to synthesise positional audio signals associating a sound source to the route suggested by the route planner. As a result, the user can be invited to move in the direction where the perceived sound comes from.

Each synthesised audio signal is obtained by means of a convolution between a monoaural sound signal and an impulse response. These Head-Related Impulse Responses (HRIR) can be obtained through direct measurements, or can be synthesised using models that compute the response based on anthropometric measurements. To increase the sensation of spaciousness, the sound rendering algorithm includes the Image Source Method (ISM) that performs reverberation taking care of both the relative position of the virtual sound sources and the size of the environment. The sensation of distance is accentuated by introducing a proper amount of delay and attenuation into the sound signal [16, 17]. In order to ensure a correct displacement of the spatial sound stimuli, the AP's head orientation with respect to the *c-Walker* direction of motion has to be monitored. For this reason, the headphone is equipped with an inertial platform. Moreover, the IMU allows the AP to exploit small head movements to discriminate ambiguous situations. In fact, also in real life humans take advantage of small head movements to collect more cues on the position of the auditory event [18].

6 Experimental Results

The first experiments on the *c-Walker* prototype have been conducted at the University of Trento. Figure 5 shows the results of localisation and guidance in a simple case: an *L*-shaped path along a corridor towards an elevator. In Fig. 5a the planned route (dashed line) and the estimated trajectory (solid line) are compared. Figure 5b shows the difference between the planned and the measured directions of motion along the way expressed in radians. Anytime the difference values exceed ±0.2 rad (dash-dotted horizontal lines) the actuators used to guide the AP (e.g. the haptic bracelets) are activated to correct the user's trajectory. The activation signals for the right-side (dashed line) and for the left-side (solid line) actuators finally are shown in Fig. 5c.

Table 1 shows the average mean value and the average standard deviation of the position and the heading errors, computed over about 40 routes of different length and shape in an room of 150 m^2. In all the experiments the distance between pairs

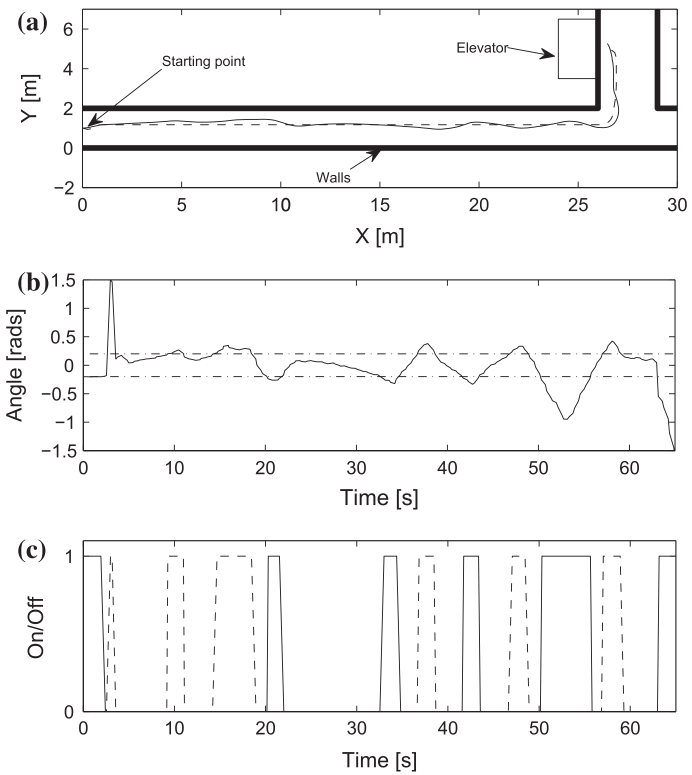

Fig. 5 Planned route (*dashed line*) and estimated path (*solid line*) towards an elevator (**a**), Difference between planned and measured direction angles along the way (**b**), Signals driving the right-side (*dashed line*) and *left-side* (*solid line*) actuators used to guide the user (**c**)

Table 1 Average mean value and average standard deviation of the (x, y, θ) estimation errors computed over about 40 different routes

	Avg. mean error	Avg. std. deviation
x (cm)	5	25
y (cm)	1	24
θ (crad)	0.7	9

In all cases, the distance between pairs of adjacent RFID tags and visual markers is about 2 m

of adjacent RFID tags and visual markers on the floor is about 2 m. The individual errors result from the difference between the coordinates and angles estimated by the EKF and the corresponding values (properly aligned in time) measured by a laser scanner SICK S300 Expert located in the origin of the chosen reference frame (i.e. one corner of the room). The results in Table 1 confirm that the worst-case 3σ positioning uncertainty is well below ± 1 m, as desired.

7 Conclusions and Ongoing Work

The *c-Walker* system developed within the EU project *Devices for Assisted Living* (DALi) has the ambitious goal to assist people with moderate cognitive impairments to navigate safely and with improved confidence in large and complex environments. The system consists of modules for localisation, route planning and user guidance and it is conceived to enhance the sensitive and cognitive abilities of the user, but without forcing him/her to act unwillingly. A first prototype of *c-Walker* has been tested in the laboratories of the University of Trento. Extensive experiments on the field with potential final users are planned in the next future.

Acknowledgments This work has been funded by the EU FP7 project *Devices for Assisted Living* (DALi), GA n° 288917, FP7. http://www.ict-dali.eu/dali

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Robot Interface Design: The Giraff Telepresence Robot for Social Interaction

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Abstract This paper presents the outcome of the Workshop on Robot Interface Design, which was held in Genoa (Italy) over the months of January and February 2014 and was jointly organized by Polytechnic School at the University of Genoa and the National Research Council. The aim of the workshop was to study the design of physical, functional and graphical interfaces for a telepresence assistive robot, starting from the analysis of the current features of a commercial robot called Giraff (http://www.giraff.org). The fielding of the Giraff robot has been studied (within an EU-funded AAL project: ExCITE—http://www.excite-project.eu) in three different European countries as an ICT solution to support elderly people and to enhance social interaction with relatives and caregivers. The evaluation with real end-users of the Giraff brought to light a set of user requirements and issues to be improved in the robotic platform. This workshop sought to present the aspects connected to the design (in which participants had specific expertise), and to the users perception of the robot within a domestic environment. Particular attention was paid to the design of volumes, shapes and anthropometric relationships as well as elaborations on chromatic aspects and the exploitation of different kinds of material. Some of the main results of the workshop were: a design process involving different professionals such as designers, engineers and psychologists working in close contact with a group of end-users; a set of possible modifications/extensions of the robotic platform; a set of new design concepts featuring a higher level of product emotionality.

The workshop was held in Genoa on January 28th 2014 and February 11–13th, 2014 under the patronage of the region of Liguria and Si4Life (http://www.si4life.com).

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1 Introduction

Telepresence robotic systems (see Fig. 1) can contribute in socio-assistive scenarios providing new solutions for remote communication, monitoring and rehabilitation. In particular, telepresence systems can contribute to support the elderly in their living environments [1], facilitating social inclusion and enhancing personal independence. Such platforms are remotely tele-operated by a human operator (called *pilot*) that, through the robot, has the possibility to interact with people. Residents are the *local users* sharing with the robot the same environment.

Therefore, increasing attention has been recently dedicated to the design of new AAL robotic interfaces using different shapes and characteristics, e.g., from human-like shapes to common small objects. In general, the growing exploitation of ICT solutions for socialization and remote monitoring is leading to new design, development and evaluation processes for robotic artifacts particularly focusing on user-friendly features and usability [2]. In addition, safety, security, affordance (meaning the union of shape, dimensions, weight and any other physical/technical characteristic) and aesthetic are also relevant parameters to be considered while designing new integrated technologies, user interfaces and home automation systems for domestic environments. However, psychological and cognitive barriers still exist in the end users (not only elderly) and therefore it is necessary to focus particular attention on the design and evaluation of suitable interfaces that bridge the gap

Fig. 1 Some examples of telepresence robots

between technologies and users in order to ease the access to technological components, facilitate daily activities in living environments as well as adapt to user habits/preferences.

With regards to this, the ExCITE project (Enabling SoCial Interaction Through Embodiment—http://www.excite-project.eu), funded within the Ambient Assisted Living (AAL) Joint Program, aimed to evaluate the features of a telepresence robot, called Giraff, produced by the Swedish company Giraff Technologies AB (http://www.giraff.org). As with many telepresence robotic platforms, Giraff (see Fig. 2) is composed by a videoconference system (with a camera, a display,

Fig. 2 A Giraff robot

speakers and a microphone) enabling video-call interactions between pilot users and elderly people, and it is endowed with engines for its two wheels enabling movements in any direction. The "head" of the robot has an LCD display showing the avatar of the pilot user. The robotic platform can be controlled through a PC exploiting ad hoc software (freely available on the producer web site). From any remote place, a pilot user (e.g., relatives or healthcare professionals) can drive the robot, navigating the environment while the elderly (the end users) stay in their living environment (where the robot is installed) receiving virtual visits through the robot. The evaluation activities within the ExCITE project were focused on investigating the capabilities of the robot as a tool for fostering *social interaction* of the elderly in real world contexts. Another important result of the project is the set of additional requirements elicited to enhance the features of the platform and to reduce the gap between platform features and end users actual needs [3].

A new design process for Giraff should be oriented towards investigating and identifying suitable solutions to maximize the adherence to end users needs. It should aim to foster their independence by means of supporting tools and to provide new stimuli with respect to relationships [4], environments, technologies and healthcare services. Following a human-centered robotic design paradigm means considering the elderly user as an active player in the design process rather than a *passive patient*.

The main perspective of this workshop has been on presenting the aspects connected to design, where workshop participants had specific expertise, and on aspects connected to the users perception of the robot within a domestic environment. Attention has also concerned the design of volumes, shapes and anthropometric relationships, elaborations on chromatic aspects and the exploitation of different kind of materials.

2 Workshop on Robot Interface Design

The Workshop on Robot Interface Design has been organized as a follow up to an event, called FIER'ETA, i.e., an exhibition on active ageing organized by the Welfare Office of the region of Liguria in which public institutions, research entities and companies contributed by providing their own experience and perspectives. With regards to this, the workshop also aims to create a multidisciplinary and integrated "active collaboration laboratory". The workshop has been organized as part of a joint research initiative of the Design School (University of Genoa) and the Institute of Cognitive Science and Technology of CNR focused on active ageing and design for improving quality of life with specific attention paid to domestic environments and following a human-centered design process. The workshop brought together more than 50 attendees with different backgrounds, i.e., students from design, architecture and engineer courses as well as Ph.D. students from Genoa, Milan and Turin universities. Additionally, medical doctors and therapists operating in the area have attended the workshop. To foster interactions and multidisciplinary discussions, the workshop attendees were then divided into 9 different heterogeneous (with respect to profiles) working groups aiming to take advantage of their different skills, experiences and perspectives. Members of the AUSER association in the Genoa area were also invited. The AUSER association was founded in 1994 and it is an active volunteers association operating to address active and healthy ageing issues with almost 5000 members and more than 500 volunteers operating in the Genoa area in 14 daily centers for elderly people. The workshop started with an introductory day (28th January 2014) followed by 3 full-working days (11–13th February 2014) in which design activities were proposed considering both operative, theoretical and cultural aspects of Ambient Assisted Living, Information and Communication Technology, Robotics and Design areas. During the workshop the interface was clearly identified as a more important element than just a contact surface between a human user and the robotic artifact. Indeed, it constitutes a complex, dynamic and interactive open system capable of guaranteeing full access to advanced technologies intended as relevant tools for supporting health and active ageing.

3 Contributions and New Scenarios

As a result of different kinds of analysis performed during the 3 full-day workshop, several issues related to the relationship between human and robot were identified. In particular, reasoning on the potentialities of the Giraff robot mainly related to communication, interaction and assistance, and following the human-centered design approach, a wide set of possible improvements for the Giraff platform were elicited. Also technical constraints such as dimensions, shape-function relation, movement speed, mechanical features and electronic components, were analyzed and connected to the intrinsic properties of the platform. Here follows a list of relevant investigated aspects:

(a) Impact within the context of the environment in which the robot is supposed to operate;
(b) Analysis of current *passive* interactions of the robot with the user;
(c) Elicitation of the need for more active use of the robot in certain specific phases of the interaction process.

Then, the design process led to the definition of several possible interventions on the platform, e.g. reduction of the dimensions to facilitate movement in narrow spaces; furniture-like shape to allow a more graceful integration into domestic environments, clearer warning signals in case of emergency, illumination of the mobile base in order to support navigation even in low light conditions and integration in the interaction process of smartphones or tablets to enable the possibility of controlling the robot also via mobile devices. The pairing of such new functionalities/features with the (already present) main advantages in the use of the robotic platform, i.e., helping the user feel less lonely, maintaining a high perception of the continuity of assistance, low-noise and light presence has been identified as crucial for the design of *objects* with improved characteristics identified according to Human Centered Robotics Design principles [5]. The design of such new objects demonstrate a higher attention to user expectations and the integration of the robot in domestic environments widening its capability to address the actual needs of old persons. This is particularly true in the construction of such objects integrating technical and functional aspects with relational, interface and esthetic aspects as a set of elements for tool acceptability. Following such approach, the relationship between designer and user is crucial for discovering new perspectives to develop technology. In this regard, the problems related the difficulty in the usage of the tool or in the negative/not-so-clear perception of the robot can be solved [6].

4 Shape, Functions and Socialisation

The robot was acknowledged as a useful tool for the safety of the elderly, even though its dimension and height, which were reckoned potentially excessive, can create a sense of oppression for the user. During the workshop a series of proposals were suggested to tackle the issue of height.

A number of users claimed that the robot should not limit the user movement and social life, therefore it should only be used in situations of great need (i.e., hospitalization). For this reason inserting recreational applications was not taken into account.

Potential users participating in the workshop repeatedly underlined the need to actively use the robot. The robot should be managed autonomously with different functions and it should be possible to move it easily and use it for emergency calls. This results in greater control and a greater sense of safety for the user.

In the majority of cases, the user is willing to accept the machine and at the same time requests more functions. It is interesting to note how reactions to the robot differ be-tween men and women: men had less trouble accepting the robot, and they did not care too much about its dimensions. In general though, first reactions to the robot are still negative, but this can be overcome by helping the user become acquainted with the robot's functions and through active interaction. However, for a successful interaction the robot should maintain a simple shape, as if it is too humanoid, the user will feel un-comfortable.

Mostly it was preferred for the robot to be integrated as a piece of furniture—in this way its presence will be evident only when switched on. The absence of mechanical parts on show is another favorable feature and the base of the robot should be illuminated to highlight its dimensions and avoid any collision.

In order to simplify its use and maintain user freedom of movement, an interesting solution could be the addition of a Smartphone to interact with the robot.

It has been illustrated how Giraff is a useful tool for elderly people with reduced mobility who live by themselves. With a few technical, functional and aesthetical changes Giraff could become more than just a simple interaction tool.

5 Context of Use

The concept of telepresence as a new form of interaction and communication through a robot-avatar is just starting to find its space in different market branches:

a. school (lessons can be followed/taught without being in class)
b. workplace
c. private
d. healthcare (virtual continuous care)

According to the context, new elements can be taken into consideration for the robot design: the robot-individual relationship changes if within a personal or domestic sphere as well as the perception of the robot-house and robot-personal space interaction. In the latter case, the following elements are to be considered:

- it must be possible to move the robot manually and easily;
- the robot has to be accepted by the person "hosting" it, who should not be passively subjected to it;
- the robot should be able to signal its movements and its presence should be evident within the house;
- the robot height should be acceptable and it should be tailored to the needs of each user;
- the robot should be able to send visual and luminous feedback (essential for hearing-impaired users) with specific reference to:
  - day and night vision,
  - with an incoming call,
  - when the robot moves;
- the possibility to rotate on itself for greater autonomy and mobility within the house.

Finally, the robot should be conceived as an object to keep them company, thus enhancing the feature of taking care of the person and the materials used for the robot become a vehicle for emotions and sensations in order to identify the robot as a valuable object instead of a medical tool. Materials should create the same atmosphere as when buying a new car: the robot is an object to be displayed with pride, not just a helping tool for people with physical impairment.

In other words, the selected materials should not merely meet the needed requirements to enable the robot's functions, but they should be evocative and stimulate positive emotions so that the user will instantly accept the robot.

6 Shared Design: Shared Design Proposals

The collaboration between designers and end-users has highlighted the importance of communication between the robot and other devices on the market such as smartphones and tablets. Another relevant issue was that the robot should be controlled remotely, through Internet connection and directly by the user.

Here below is a list of other proposals presented during the workshop:

- change of dimensions, weight and space occupancy;
- integration of the robot within the domestic environment;
- possibility to rent the robot for short periods of time;
- use and trial of the robot in retirement homes;
- moving the robot remotely;
- mapping the house to simplify the robot movements;
- providing the robot with personalised vocal controls (adding recordings of familiar voices or similar);
- the user should be able to refuse a call sending an automatic message;
- use of a leaning device to control the robot (i.e. bracelet);
- developing an application for mobile phones to interact with the robot (perhaps a cloud system with the user, family members, friends or caregivers);
- a reminder system shared among the user, family or caregiver;
- mapping the house through sensors integrated with the platform;
- "reach-me" function: thanks to a device the user can call the robot from any part of the house or structure;
- possibility to record vocal messages and send them subsequently to family members in order to stimulate dialogue and family relations;
- simplified music applications to use music as an evocative and relaxing activity for the user;
- applications for audio-books and online articles which would open up a series of potential new functions for visually impaired users.

These findings are compatible with those carried out in the ExCITE project, elicited after an investigation with real end users in 3 different Countries (i.e., Italy, Spain and Sweden) and after several focus groups, questionnaires and interviews implemented to collect evaluation data that were then used to elaborate the final list of additional requirements. The concept of a robot monitoring the Quality of Life of the elderly user is motivated by the need to transmit and enhance a feeling of safety. In this sense the following functions become relevant: (Fig. 3)

- the possibility to measure blood pressure remotely (which is already used in a number of hospitals);
- in case of accidents or natural calamities, the robot would give immediate warning;

Fig. 3 Concept ideated during the three full-day workshop

7 Conclusions

An increasing number of elderly people are becoming more interested in technology, and developing their I.T. knowledge. In this reference scenario, the shape and functions of the robots and especially the possibility to change the device according to the user needs become extremely important.

“Machines are machines and so it should be”: this concept is an essential guideline of the project and it emerged when separating the machines from the participants.

There is a positive reaction towards humanoid machines that have different proportions from humans, similar to kids toys (for example the NAO robot). Participants were able to interact directly during the project and creation of new concepts to improve an already existent device.

In the field of Human Centered Robotic Design, the project acquires the definition of a process in which a role is played by designers, engineers, computer scientists, psychologists and other experts from various fields [7]. They work together as a team, to create a final product that will be the result of their shared inputs and opinions.

The new general assets of the robot created in this study aim to achieve a homogenous shape, coherent functions, organicity and recognisability.

This is achieved by equipping the robot with different tools to provide a tailored service so that the robot will place the user at the centre of its attention.

Nowadays, making a project means confronting this kind of complexity and managing it with a structured methodology, where different competences concur to reach a shared goal. The experience of the Robot Interface Design Workshop has been extremely positive. In these 3 days it was possible to gather different points of view and analyse the issues with the product.

Meeting with the elderly participants was a fundamental step to establish the concrete needs and perceptions of potential users and the interviews were particularly valuable and allowed us to focus and gather their opinions on the integration between the Robot and the domestic environment. When working with the elderly, it is essential to take into account their emotional and social needs and Giraff should be used to stimulate self-care and an active net of relations, so that the user can keep psychophysically healthy.

Giraff is able to create a net of external contacts in order to bring the world at home to the user. The robot can be used to simplify day-to-day activities by providing several online services, for example the function of online payment from home, thus avoiding any inconvenience to the user.

The new elderly are becoming more acquainted with technology, showing a new proactive openness. This supports the prediction that elderly users will not immediately dismiss the robot but on the contrary they will be able to see its potentials. For this reason users are useful to prompt possible improvements of the robotic platforms.

During the workshop one of main concerns was that these platforms should not substitute the individual—they should empower the relationships between the different parties (friends, family members, caretakers, etc.) but without taking the place of the user within these human relationships. Human contact should be kept direct.

However, the sense of safety a robot provides to the elderly user was instantly acknowledged, especially because the robot is programmed to monitor and assist its user.

To complete the object from a functional point of view and to make it "emotionally accessible" it is fundamental to focus on telepresence as much as possible.

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