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Andrea Monteriù
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Preface

The tremendous progress that new technologies have had in the last decade, together with their significant reduction in cost, provided a formidable impetus to the development of increasingly flexible and customizable technological solutions to different user needs. This development had a particular impact on the progress of Ambient Assisted Living (AAL) technological solutions that aim to improving health, psycho-physical well-being, and the independent living of users with different needs or with disabilities. The result is that nowadays, AAL technologies are recognized by the European Commission as the enabling drivers to build the quality of life of our current and future society, to address 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.

All these aspects were explored and discussed during the Tenth Italian Forum on Ambient Assisted Living (ForItAAL), held in Ancona, Italy, in June 2019. The Italian Forum on AAL is one of the most important annual events for researchers, professionals, developers, policy-makers, producers, service providers, carriers, and end-user organizations working in the different fields of AAL, who present and disseminate results, skills, prototypes, products, and services. The book presents the refereed proceedings of the Forum and reviews the status of researches, technologies, and recent achievements on AAL. The coverage is wide ranging, with topical sections devoted to human monitoring, smart living services, biomedical and robotic solutions, including different case studies and real-world examples where AAL technologies are successfully applied. Using a multidisciplinary approach and different points of view, the book offers interesting insights, from research to practice, to all those directly or indirectly interested and involved in the field of AAL.

These insights will inspire the readers to continue their exploration of AAL technologies, promoting new technological solutions that will increasingly adapt to the user rather than the user adapting to these technologies.

Ancona, Italy

Andrea Monteriù
Alessandro Freddi
Sauro Longhi

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Human Monitoring

Measuring Environmental Data and Physiological Parameters at Home to Assess the Caregiver Burden in Assistants of People with Dementia

Sara Casaccia, Andrea Calvaresi, Nicole Morresi, Lorenzo Scalise, Andrea Monteriù, Luca Romeo, Emanuele Frontoni, and Gian Marco Revel

Abstract Measuring the behaviour and health status of informal caregivers of people with dementia can predict the personal well-being of the caregivers. Informal caregivers struggle to remain active during the daily life activities avoiding the care burden. For this reason, in this work, an analysis of both the environmental data coming from PIR sensors, installed in the home environment, and physiological parameters, directly measured by the user, is performed to highlight, unusual behaviors that can increase the stress level of the caregiver. In addition, daily survey and personal interview provide further information about the progression of the illness and the amount of the care burden. Coupling this information with the physiological quantities can provide an overall health status of the caregiver. Results show that the caregiver presents a decreasing trend of her daily self-reported health status associated with a change in the pattern of the domotic data. The questionnaire also exhibits

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a high correlation with body weight measurements (Pearson Coefficient of -86%) suggesting that the caregiver health status is limiting the normal daily activities, may be due to an increase of the care burden associated to a worsening of the illness.

1 Introduction

Behavioral and physiological measurements define the well-being, health and stress condition of caregivers [1]. Introducing Information and Communication Technology (ICT) solutions in the home environment can monitor the status of a patient for informal and formal caregivers that are outside the home [2] and the behavior and stress condition of the informal caregiver that lives with the patient. Sensor network are used to acquire data and signals of inhabitants and data processing can be performed to extract specific features as the care burnout. Several works indicated that caregivers of people with dementia are inclined to an increase of care burden [3]. The number of informal and formal caregivers of people with dementia are enormous and it is correlated with the number of people with dementia. The global number of people living with dementia was estimated at 43.8 million in 2016, an increase from 20 million in 1990. In 2050, this number is predicted to reach at 131.5 million [4]. This increase is coupled with a need of care which can results in care-related stress and burden among caregivers. Both professional and informal caregivers experience stress and repetitive negative emotions, not only at home, but also at work and outside [5]. The continuous demand and stress can result both in physical disease (e.g. cardiovascular, musculoskeletal) or mental disease (e.g. burnout, depression) [6], resulting in formal- and informal carers struggling to remain active during the daily life activities.

Most people with dementia live at home where they are dependent on informal caregivers for their daily care. In particular, female, spousal caregivers appear to be at risk of depression, anxiety and caregiver burden [6]. To decrease the negative influence of such critical home condition, measurements of the environment and health status may identify the decline of the caregiver well-being. At the same time understanding the factors that influence the caregivers' health state is fundamental for the development of effective support [7].

This paper is focused on an accurate analysis of the data and signals measured on an informal caregiver that lives with a person with dementia to identify changes in the behavior, physiological parameters and mental conditions. To measure the personal well-being of the caregiver, data provided by different Passive InfraRed (PIR) sensors installed in the home environment are investigated and they are associated to the physiological parameters acquired by the user three times a week for a year. A validation period of two months is performed using a daily survey and monthly interview to the user to study a correlation between the physiological parameters' trend and the behavior of the caregiver as the care burden increases with the worsening of the dementia.

2 Methodology

This paper aims at identifying the burden of a caregiver which lives and takes care of a person with dementia by measuring the behavioral change in the home environment and correlating it with the increasing burnout of the caregiver.

To monitor the personal condition of the caretaker, three main physiological quantities such as mean arterial pressure (MAP), heart rate (HR) and body weight (W) are acquired. Sensors' characteristics are reported in Table 1.

These devices are selected by the authors since a combination of the measured variables can be representative of the overall valuation of the general health status of the monitored user. In addition, these devices can be easily adopted by older people as they are widely spread among the daily routine of the user.

For this particular analysis, a family was chosen from a bigger pilot case that includes 8 apartments and 13 older users in a town in Italy [8]. This work is part of the Italian Smart Cities project "Health@Home: Smart Communities for citizens' wellness" (H@H).

The selected family is characterized from a couple of married people. The man (77 years old) is affected from dementia at the mid-stage. His wife is 71 years old and she is in a good health condition, not presenting any severe pathology. Every day from Monday to Friday, she brings him to the daily center for people with dementia at 9 am and she brings her husband back home at 4 pm. In the evening, during the night and weekends, she takes care of her husband alone in the home environment.

2.1 Monitored Parameters

The physiological parameters considered for the study are the body weight, heart rate and blood pressure. The physiological data are collected using a tablet with a customized User Interface (see Fig. 1).

The system architecture, data connection and Cloud database are described in [8–10].

Table 1 Technical specifications of the devices used by the caregiver for the physiological measurements

Device	Description	Accuracy	Resolution	Range
Taidoc TD3128B	Blood pressure meter to monitor diastolic, mean and systolic blood pressure and HR	Systolic: ±3 mmHg (±2%) Diastolic: ±3 mmHg (±2%) HR: ±4%	1 mmHg (systolic, diastolic) 1 bpm (HR)	Systolic: 60–255 mmHg Diastolic: 30–195 mmHg HR: 40–199 bpm
Taidoc TD2555B	Body weight scale	±0.3 kg (±0.5%)	0.1 kg	4–250 kg

Fig. 1 The customized user interface for data collection, a blood pressure meter to monitor the blood pressure and heart rate and a body weight balance to acquire the body weight

The dataset is characterized from behavioral data coming from domotic sensors installed in the domestic environment and physiological signals collected during the daily measurements [11].

For what concern the behavior analysis, the data comprised of the signal outputs of three PIR sensors, installed in the living room, bedroom and bathroom (see Fig. 2).

2.2 *Questionnaires Data*

The questionnaire is divided in two parts.

The first part is a daily survey based on the SF36 and SF12 questionnaires [12, 13] and related to the physical activity and condition of the caregiver which filled the questionnaire every day for two months before going to sleep. For this specific analysis, one question, representing the global health condition of the caregiver is analyzed. The question is:

1. Did your health limit you in your daily routine?

The user can answer the question with 1 (representing that the user has been totally limited in doing daily activities from its health), 2 (the user can do its own activity but in a limited way) or 3 (the health status does not affect its health at all).

Fig. 2 Plan of the apartment and location of the 3 PIR sensors (placed in the living room, bathroom and the bedroom, respectively)

The raw survey is processed using a moving average technique that creates a series of averages of different subsets of the full dataset as described in [14]. This technique provides a trend in the person's behavior and aims at forecasting the well-being changing over time.

The second part of the questionnaire consists on a face-to-face interview made once a month for two months from an external assistant. The interview aims to investigate both mental and physical status of the caregiver and in turn, the caregiver gave an update of the disease status of the person with dementia.

2.3 Data Analysis

The information extracted from PIR sensors indicates whether the user has entered the room and/or is moving within the room. Therefore, data are processed by counting the number of occurrences of the sensor switch-on. In particular, PIR activations are hourly counted and then processed by aggregating the total number of activations recorded in a time interval of one hours. Then hourly aggregation is grouped together in 4 time intervals of 6 consecutive hours that represents: night (0–6), morning (7–12), afternoon (13–18) and evening (19–24).

The methodology has been applied considering a validation period of two months in which data are processed to evaluate if there are some differences in the behavior of the family unit. The discrepancy between the two months are evaluated on the basis of the total activation of the PIR for a specific time frame respect to the number of the activation of the overall two months period according to the following equation:

$$\%Activation_{m_i} = \frac{\sum Activation_{m_i}}{\left(\sum Activation_{m_i} + \sum Activation_{m_k}\right)} \tag{1}$$

where m_i refers to the i-th month while m_k is the k-th month. The numerator is the number of total activations of the selected sensor occurred in a single month and the denominator represents the total number of activations during the two months period.

3 Results

In this section, some observations and results are presented. Data analysis provides the number of the total activations of the PIR sensors in the different time frame of the day for each month. Therefore, the variation of this quantities is analyzed.

Figures 3, 4 and 5 show the percentage of activation of each PIR (installed in the living room, bedroom and bathroom) for the two months over each daily period. In particular, the attention is focused on the PIR installed in the living room and bathroom. The activations of these sensors in month 2 are higher than in month 1

Fig. 3 Percentage of activation of the PIR installed in the living room through different time frame of the day, for the 2 months monitored for the validation phase

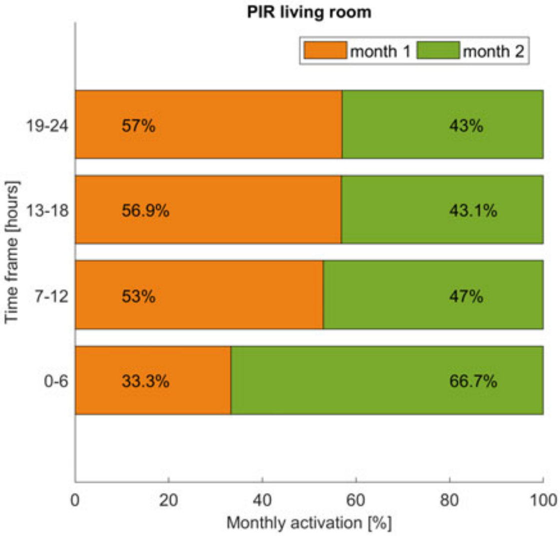


Fig. 4 Percentage of activation of the PIR installed in the bedroom through different time frame of the day, for the 2 months monitored for the validation phase

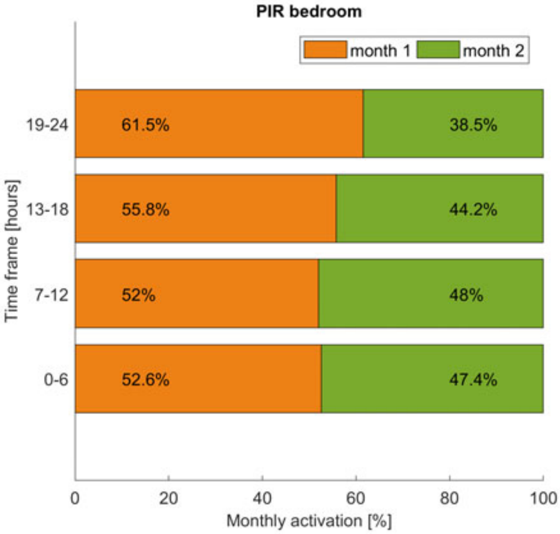
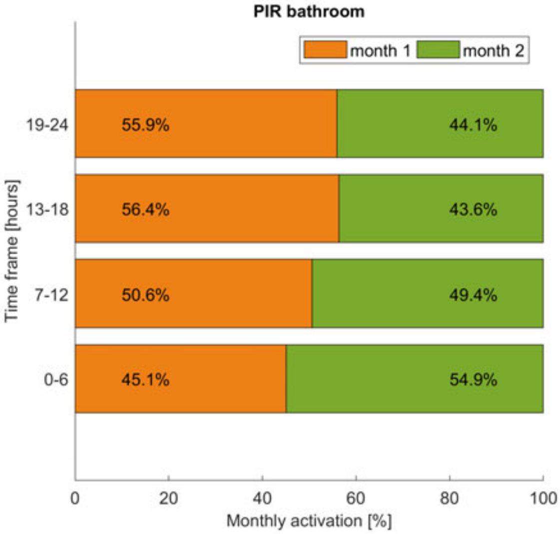


Fig. 5 Percentage of activation of the PIR installed in the bathroom through different time frame of the day, for the 2 months monitored for the validation phase



for the time slot 0–6. These results show how the family changed their nocturnal behavior.

In particular, the increasing of the activities in the living room and bathroom can be associated with a worsening of the dementia disease. This result is in line with medical findings in the scientific literature which highlights how the changes in the sleep patterns can be associated with the illness drop [13].

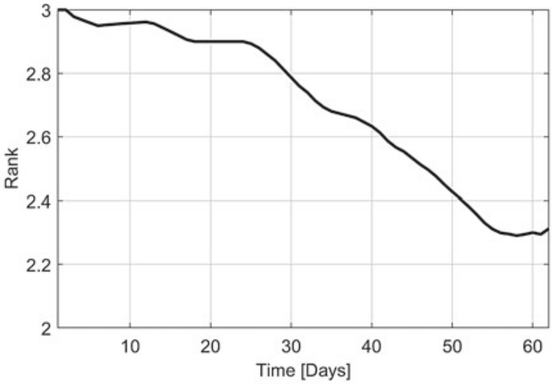


Fig. 6 Trend of the daily survey provided by the caregiver across the two months of validation period

On the other hand, observing the time frames 7–12, 13–18 and 19–24 it is possible to note that the activations number decrease: a possible explanation is that in these specific time frames the house is only occupied by the caregiver since the dementia patient is supposed to be at the health center. Moreover, during the interviews she declares a repeated back pain that limits her daily routine.

The second observation is focused on the daily survey and monthly interviews.

Figure 6 shows the trend of the daily survey provided by the caregiver, processed with a moving average technique, for the 2 months of validation period. A decrease of the rank from 3 to 2 denotes that the caregiver perception of her personal health condition is lower in month 2 than in month 1. This can be associated with the higher nocturnal activity of the family in month 2. The decrease of the self-reported health status is also correlated with the self-reported interview: the caregiver reported an increased repeated back pain events during the second month.

In particular, from the monthly interviews, the authors extracted that the caregiver is more stressed in month 2 than in month 1 caused from a back pain and a worsening of her husband's conditions.

The last observation is related to the correlation of the processed daily survey with the physiological parameters monitored 3 times a week from the caregiver using the blood pressure meter and the body weight scale. Table 2 reports the results of the Pearson's coefficient that indicates the existing correlation from the physiological parameters (e.g. heart rate, mean blood pressure and body weight) and the daily survey processed with the moving average technique.

Table 2 Pearson correlation coefficient standardized from 0 to 100% computed between the survey provided during the validation period and the physiological parameters measured by the caregiver

Parameter	Mean arterial pressure	Heart rate	Weight
Pearson coefficient (%)	39	−46*	−86*

*p-val < 0.05

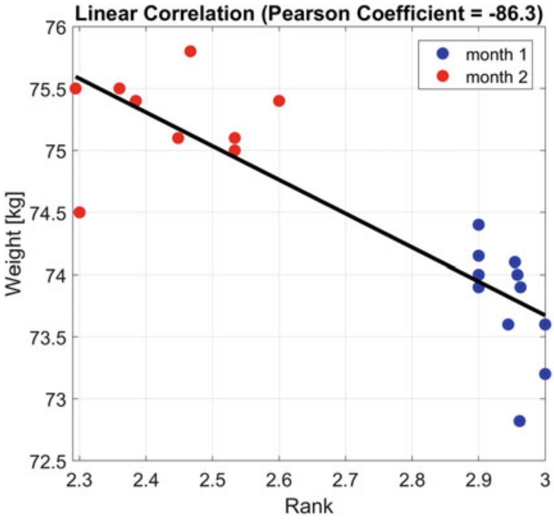


Fig. 7 Plot of the linear correlation between the weight measured by the caregiver and the respective self-reported health status provided in the survey. Note that there is a decreasing trend of the weight as the caregiver rank its day with a higher vote

To test the meaningfulness of the data, P-value (p) was set at 0.05 (significance level). When $p < 0.05$, the correlation between the data and the survey is statistically significant [15]. Table 2 highlights that the survey correlates most with the body weight ($R = -86\%$) of the caregiver.

Figure 7 suggests that an increase in the body weight is strictly connected with a decrease in the questionnaire rank (i.e., a decrease of the self-reported health status) which means that the caregiver health status is limiting the normal daily activities causing a more inactive and steady condition. The decrease of the caregiver health status may be due to an increase of the care burden correlated with the worsening of the patient's dementia state.

4 Conclusions

In this work, a heterogeneous sensor network installed in the home environment is used to monitor the behavior of a family (a person with dementia and his wife) and the health status of the informal caregiver to identify the caregiver burden together with questionnaires and interviews. In this paper, the authors process environmental data and physiological signals to understand the stress and health condition of the informal caregiver associated with the worsening of the dementia of the patient at home. In particular, domotic quantities acquired from PIR sensors installed in the home environment were monitored: the analysis shows an increasing nocturnal activity in the period 0–6 for month 2 of the validation period.

This condition can be associated with the degeneration of the illness of the patient, which results in a discontinuous sleep pattern that causes extended awake phases during the night. For this reason, the caregiver presents an increasing level of personal stress confirmed by the daily survey and the monthly interview. In fact, there is a decreasing trend in the rank of the questionnaire that accentuate the decaying status of the health and an increasing care burden. Moreover, the interview reports how the caregiver itself is affected by some back pain due to the advanced age that contributes both to the limitation in the daily activities' routine and a major effort for taking care of the dementia patient.

More in detail, studying the correlation between the biomedical data and the questionnaire during the validation period, it is possible to observe that a decrease in the caregiver's self-reported health status representing a higher limitation in the daily activity of the caregiver is strictly connected with an increase of the body weight. The correlation between the daily survey and the body weight shows a Pearson coefficient of -86%. A possible explanation is the limited amount of the daily activity performed by the caregiver due to the caregiver health status and to the repeated stress condition associated with the caregiver's task.

This consideration comes from an accurate analysis provided by the association of multiple quantities which are domotic data, physiological data and information provided by the caregiver. Therefore, weight measurements can be interpreted as a partial index of the caregiver health status that as to be linked to the progress of illness. In conclusion, this paper shows that with a heterogeneous sensor network installed in the home environment is possible to extract the behavior and health status of people inside the home and evaluate the behavioral variations in different period of time. The aggregation between environmental data, physiological parameters and questionnaire provides relevant information to identify the caregiver burden.

Future works will be focused on increasing the number of participants to the experimentation to test the methodology and improve the statistical analysis. Patients at different stages of dementia and their caregivers could be included in the study and a longer period of daily report could improve the results.

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References

1. Visser-Meily JMA, Post MWM, Riphagen II, Lindeman E (2004) Measures used to assess burden among caregivers of stroke patients: a review. Clin Rehabil 18:601–623. https://doi.org/10.1191/0269215504cr776oa
2. Mitabe N, Shinomiya N (2016) Support system for caregivers with sensor network and machine learning. In: 2016 IEEE 5th global conference on consumer electronics, pp 1–4
3. Black W, Almeida OP (2004) A systematic review of the association between the behavioral and psychological symptoms of dementia and burden of care. Int Psychogeriatr 16:295–315. https://doi.org/10.1017/S1041610204000468

4. Launer LJ (2019) Statistics on the burden of dementia: need for stronger data. Lancet Neurol 18:25–27. https://doi.org/10.1016/S1474-4422(18)30456-3
5. Hategan A, Bourgeois JA, Cheng T, Young J (2018) Caregiver burnout. In: Hategan A, Bourgeois JA, Cheng T, Young J (eds) Geriatric psychiatry study guide: mastering the competencies. Springer International Publishing, Cham, pp 433–442
6. Jütten LH, Mark RE, Sitskoorn MM (2019) Empathy in informal dementia caregivers and its relationship with depression, anxiety, and burden. Int J Clin Health Psychol 19:12–21. https://doi.org/10.1016/j.ijchp.2018.07.004
7. Quinn C, Nelis SM, Martyr A et al (2019) Influence of positive and negative dimensions of dementia caregiving on caregiver well-being and satisfaction with life: findings from the IDEAL study. Am J Geriatr Psychiatry. https://doi.org/10.1016/j.jagp.2019.02.005
8. Casaccia S, Pietroni F, Scalise L et al (2018) Health@Home: pilot cases and preliminary results: integrated residential sensor network to promote the active aging of real users. In: 2018 IEEE international symposium on medical measurements and applications (MeMeA), pp 1–6
9. Monteriù A, Prist MR, Frontoni E et al (2018) A smart sensing architecture for domestic monitoring: methodological approach and experimental validation. Sensors 18:2310. https://doi.org/10.3390/s18072310
10. Scalise L, Pietroni F, Casaccia S et al (2016) Implementation of an "at-home" e-Health system using heterogeneous devices. In: 2016 IEEE international smart cities conference (ISC2), pp 1–4
11. Pietroni F, Casaccia S, Revel GM et al (2019) Smart monitoring of user and home environment: the Health@Home acquisition framework. In: Casiddu N, Porfirione C, Monteriù A, Cavallo F (eds) Ambient assisted living. Springer International Publishing, pp 23–37
12. Hurst NP, Ruta DA, Kind P (1998) Comparison of the MOS short form-12 (SF12) health status questionnaire with the SF36 in patients with rheumatoid arthritis. Br J Rheumatol 37:862–869
13. Mallinson S (2002) Listening to respondents: a qualitative assessment of the short-form 36 health status questionnaire. Soc Sci Med 54:11–21
14. Elbayoudi A, Lotfi A, Langensiepen C (2019) The human behaviour indicator: a measure of behavioural evolution. Expert Syst Appl 118:493–505. https://doi.org/10.1016/j.eswa.2018.10.022
15. Lee H-A, Lee H-J, Moon J-H et al (2017) Comparison of wearable activity tracker with actigraphy for sleep evaluation and circadian rest-activity rhythm measurement in healthy young adults. Psychiatry Investig 14:179–185. https://doi.org/10.4306/pi.2017.14.2.179

A Vision-Based Approach for the at Home Assessment of Postural Stability in Parkinson's Disease

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Abstract Postural instability is one of the main burdens of Parkinson's Disease as it increases the risk of falls and injuries. Monitoring any changes in postural stability, as a consequence of therapies and disease progression, is therefore highly desirable to preserve people's safety and quality of life. In this context, we present a vision-based system built around an optical RGB-Depth device for the automatic evaluation and home monitoring of postural stability. The system is able to track and evaluate body movements, and can be self-managed by people with impairment through an easy-to-use human–machine interaction. A set of static and dynamic balance tasks are delivered and analyzed by the system to estimate some postural and temporal parameters used for the objective and automatic assessment of postural stability. Compliance between automatic and clinical assessment is supported by a machine learning approach with supervised classifiers. Preliminary results of the study are presented and discussed.

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1 Introduction

The alteration of postural stability is one of the symptoms in Parkinson's Disease (PD) which negatively affects the people's safety and quality of life, as it increases the risk of falls and injuries [1], and worsens with the disease progression causing a significant cost for the healthcare system [2].

Several clinical scales are available to assess the postural stability and balance dysfunctions: Time Up and Go (TUG) test [3]; Postural Instability and Gait Difficulty (PIGD) [4], a sub-score of Unified Parkinson's Disease Rating Scale (UPDRS) [5]; Berg scale [6]. The combination of multiple balance tests [7] and the execution of concurrent cognitive or secondary motor tasks in steady standing conditions [8] can provide a better assessment of postural stability in PD than each scale separately.

Recent studies on standing stance [9] and dopaminergic treatments [10] in PD have shown the strong correlation between balance dysfunctions and postural sway, which refers to the continuous movement of the Center of body Mass (CoM) activated to maintain balance. Therefore, frequent monitoring of postural sway is desirable to control alterations of stability that could cause the subject to fall.

Recently, several non-contact approaches to body movement analysis based on low-cost optical tracking devices [11] have been successfully proposed as non-invasive alternatives to on-body inertial sensors [10] in different applications. In PD and other neurological diseases, non-contact approaches have been employed for the evaluation of Time Up and Go test [12], automatic classification of gait patterns and disorders [13], and objective assessment of UPDRS tasks [14].

Considering both the importance in PD of evaluating postural stability frequently as a predictor of the risk of falls and the advantages of several balance scales and concurrent tasks, it is desirable to develop solutions for the characterization of postural stability through the analysis of body movements in multiple dedicated tasks.

Along this line of research, a vision-based system has been developed for the automated assessment of postural stability at home. The system captures and analyzes the subject's body movements while performing specific tasks designed from standard balance scales. The aim is to emphasize balance dysfunctions by concurrent cognitive tasks (dual-task condition) and multiple balance tests, this to produce different types of postural stress and provide a more complete assessment [7]. The quantitative evaluation of postural stability is based on objective parameters estimated from CoM movements. A machine learning approach with supervised classifiers is used to automatically evaluate postural stability through postural and temporal parameters correlated with standard clinical evaluations. Preliminary results on the effectiveness and accuracy of the system, compared with clinical assessments, are presented and discussed.

2 Framework Description

2.1 System Description

The acquisition system has been designed to be low-cost, based on non-contact measurements and suitable for home monitoring: particular attention was paid to Human–Machine Interaction (HMI) to make it easily manageable without technical skills.

2.1.1 System Hardware, Software and Human–machine Interaction

The developed solution is a vision-based system built around an RGB-Depth camera. As part of a broader implemented solution for the remote monitoring of PD subjects, the setup makes use of Microsoft Kinect v.2, a long-range camera that provides synchronized color and depth streams at 30 FPS. The camera is connected to a mini-PC (i.e., Intel® NUC i7) via a USB port. A monitor is used to display the Graphical User Interface (GUI) to provide visual information and feedback to the user (Fig. 1a).

The software running on mini-PC consists of dedicated C++ and MATLAB routines to access and analyze the information provided by the Software Development Kit (SDK) of the camera, in particular video streams and skeletal model. The acquisition and data processing of the skeletal model in real-time are crucial to ensure a reliable human–machine interaction based on simple gestures or actions such as positioning, raising or moving some parts of the body (Fig. 1b).

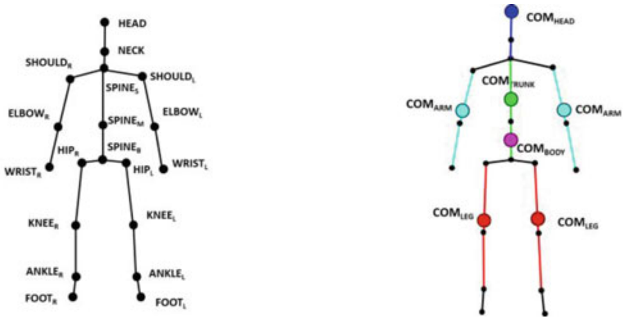
Each GUI consists of interactive objects and implements an augmented reality (AR) environment in which the user see her/his movements by a real-time visual feedback. In addition, the interactive objects are arranged to limit the movements required and are customizable to ensure good visibility. Finally, each GUI uses text messages, video and audio to suggest the steps required to complete the test session.


UP-STAND-DOWN TASK

Muovi la mano su INIZIA per cominciare

(a) Acquisition system (b) GUI with interactive object

Fig. 1 **a** The vision-based system consisting of RGB-Depth camera, mini-PC and monitor. **b** Example of GUI with interactive objects to perform selections



(a) Skeletal model with joints position (b) $\mathrm{COM_{Body}}$ position

Fig. 2 **a** Skeletal model and joints positions (joints related to hand and fingers are not represented). **b** Example of $\mathrm{CoM_{Body}}$ position (magenta) with the position of CoM of body segments used for Eq. 1

2.1.2 Body Center of Mass Estimation

The skeletal model consists of 25 three-dimensional joins (Fig. 2a) that follow the real-time body movements. The 3D coordinates of the joints are resampled at 30 Hz and filtered with a second order low pass Butterworth filter (cut-off 8 Hz) to remove high frequency noise. The Center of Mass of the body ($\mathrm{CoM_{Body}}$) is calculated as a weighted average (Eq. 1) of the center of mass ($\mathrm{CoM_i}$) of six body segments (namely head, arms, trunk and legs), as in [14].

$$\mathbf{CoM}_{\mathrm{Body}} = \frac{1}{6}\sum_{i=1}^{6} \mathbf{CoM}_{\mathrm{i}} * \mathrm{w_i} \qquad (1)$$

$\mathrm{CoM_i}$ are evaluated from the joints of the skeleton model; weights ($\mathrm{w_i}$) are set from anthropometric tables [15]: Head = 0.081 ($\mathrm{w_1}$); Total Arm = 0.05 ($\mathrm{w_2}$,$\mathrm{w_3}$); Trunk = 0.497 ($\mathrm{w_4}$); Total Leg = 0.161 ($\mathrm{w_{5,}w_6}$). An example of $\mathrm{CoM_{Body}}$ position is shown in Fig. 2b. Note that $\mathrm{CoM_{Body}}$ is a 3D point since it is estimated from 3D joints.

2.2 Participants

Ten PD subjects were recruited, according the UK Parkinson's Disease Society Brain Bank Clinical Diagnostic standards [16], with no history of neurosurgical procedures, previous injuries to lower limbs, excessive tremor (severity <= 1) or cognitive impairment (Mini–Mental State Examination Score >= 27/30). An expert neurologist assessed the subjects' scores for the Berg scale, the TUG test and the PIGD score, defined as the sum of four UPDRS tasks namely: arising from chair, gait, posture and postural stability. Subjects characteristics were: Hoehn and Yahr score (average 2.4, min 1, max 3); PIGD score (average 8.2, min 3, max 12); Berg score (average 53.8, min 52, max 56); TUG time (average 10.2, min 9.7, max 14.3); age 54–75 years; disease duration 3–9 years. An age-matched control group (CG) of 10 volunteers was created: the exclusion criteria were previous falls and any neurological, motor or cognitive disorders. All participants subscribed informed consent according to the Declaration of Helsinki (2008). They were initially instructed by technicians on the use of the system in a laboratory environment, then they used the system autonomously via the HMI. CG subjects performed the same set of tasks under the same operative conditions of the PD subjects.

2.3 Experimental Procedure and Data Acquisition

Each test session consists of the following tasks, built on standard scales for the assessment of balance dysfunctions: Up-Stand-Down (USD), Tandem-Standing (TS), Reaching-Standing (RS), One-Leg-Standing (OLS) and Time-Up-and-Go (TUG). During the USD task, the subject has to get up from a chair, stand without support for 1 min and sit down; in the TS one, she/he has to stand for 1 min with feet spaced one step ahead; in RS one, she/he has to stand for 1 min with arms outstretched; in OLS one, she/he has to stand for 10 s on the dominant leg; while in the TUG one, she/he has to get up from a chair, walk 3 m, return to the chair and sit down.

The USD, TS, RS and OLS tasks are designed directly from the Berg balance scale. To ensure safety at home without supervision, only few of the Berg scale tests were considered, excluding those requiring closed eyes, rapid body movements or rotations. The TUG task is the standard 3-m long walk. All tasks are performed with open eyes. In the USD (Fig. 3), TS and RS tasks, the 1-min phase is divided into two

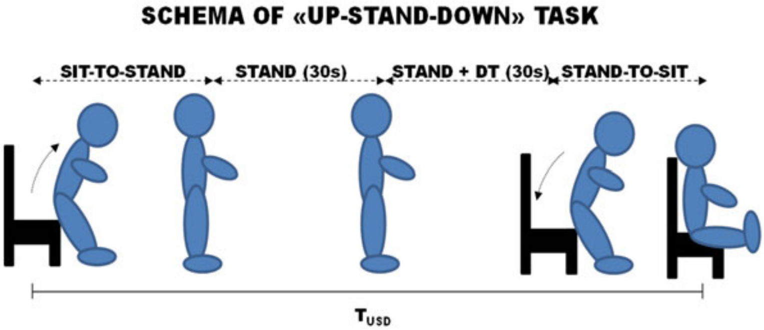


Fig. 3 Schema of the USD task: Sit-To-Stand, Stand for 30 s (ST), Stand for 30 s (DT), Stand-To-Sit. T_{USD} is the total time to complete the task

30-s sub-phases: the first is a simple balance test, so a single-task condition (ST); the second is a dual-task condition (DT) during which the user is asked also to read some words, performing a concurrent cognitive task to emphasize stability dysfunctions [8]. Subjects perform tasks about 3 m away from the camera, starting in sitting (USD and TUG) or standing position (TS, RS and OLS): three rapid movements of the arm are performed to start and to end each test. The ST and DT sub-phases are analyzed and assessed separately also according to UPDRS scale by considering the correlation with the PIGD sub-score [14]. Data and videos are collected by the system both for the post-analysis of the performance and to verify the correctness of the execution. Although the system is able to acquire and analyze all the defined tasks, in this preliminary study only the USD task will be analyzed in detail: the same methodology will be extended to the other tasks in a subsequent study.

2.4 Characterization of Postural Stability

Postural stability is characterized by temporal and postural kinematic parameters. The time to complete the USD task (T_{USD}) is estimated. There is a strong relationship between greater time and balance dysfunctions [17], due to sit-to-stand and stand-to-sit phases. Postural parameters are obtained from CoM_{Body} sway along the medio-lateral (ML) and antero-posterior (AP) directions, the orthogonal components of CoM_{Body} in the Horizontal body plane. They are evaluated both for single-task (ST) and dual-task (DT) conditions as in [14]. Table 1 shows the postural and temporal parameters for the USD task. The maximum sway range is calculated relative to the starting position; the total sway length is the total distance covered by CoM_{Body}; the speed is the maximum CoM_{Body} velocity; the sway area is the smallest area that contains the CoM_{Body} trajectory. Excluding sway area, other postural parameters are calculated along the AP and ML directions.

Table 1 Postural and Temporal parameters estimated for USD task

Name[a]	Meaning	Unit
AP_r	AP maximum sway range	(cm)
ML_r	ML maximum sway range	(cm)
AP_t	AP total sway length	(cm)
ML_t	ML total sway length	(cm)
AP_v	AP sway velocity	(cm/s)
ML_v	ML sway velocity	(cm/s)
Area	Sway area	(cm^2)
T_{USD}	Time to complete USD task	(s)

[a] Postural parameters are evaluated for the ST and DT phases separately

2.5 Statistical Analysis

No significant differences have been detected by the Mann–Whitney U test between the PD and CG groups regarding their descriptive statistical data (sex, age, etc.): as a result, data have been collected safely in two separate groups for the next analysis.

The statistical significance of each parameter, in discriminating PD and CG groups, is verified by the Mann–Whitney U test ($p < 0.05$). Furthermore, the relevance of temporal and postural parameters is estimated by the absolute value of the correlation coefficient with respect to standard clinical scores (Berg and PIGD scores).

In particular, their relevance and significance is verified by Spearman's non-parametric rank correlation ($p < 0.05$): a positive value of the correlation coefficient indicates a direct relationship between a parameter and instability score, while a negative value indicates an inverse relationship.

2.6 Automatic Assessment of Postural Instability by Machine Learning

A supervised machine learning approach has been used for the automatic assessment of postural instability. According to our previous experience [14], Support Vector Machine (SVM) classifiers have been considered to explore the discriminatory potential of temporal and postural parameters. In this preliminary work, only the assessment of USD task has been automated, but the same methodology is applicable to other tasks.

Three SVM classifiers have been trained by the pairs "USD parameter vector – standard clinical scores". The USD parameter vector is the same for all classifiers and consists of postural parameters for the single-task (ST) phase and the T_{USD} temporal parameter. In contrast, three different "standard clinical scores" have been used to train each classifier: the average Berg score (SVM_{BERG}), the average PIGD score (SVM_{PIGD}) and the TUG score based on a fixed threshold (SVM_{TUG}). The average value of the clinical scores is calculated by considering all the items of the clinical scale (i.e., Berg and PIGD).

Considering the group of PD subjects, SVM_{BERG} and SVM_{PIGD} classifiers solve a three-class classification problem: PD subjects have been evaluated in a normalized scoring interval of 1–3 for PIGD score and 0–2 for Berg score, respectively. The SVM_{TUG} solves a binary classification problem: according to [18], the T_{TUG} parameter is compared with the proposed cut-off threshold to establish in which class subjects are classified. The accuracy and consistency of each classifier have been evaluated by applying the leave-one-out cross-validation method.

3 Experimental Results

3.1 Measurement Accuracy of the Parameters

In a previous experimental campaign, CoM_{Body} trajectories for subjects in standing stance were measured simultaneously by our approach and an optoelectronic system according to a standard biomechanical setup [14]. The average Pearson's correlation coefficient (ρ_{avg}) demonstrated a good correlation of measurements between systems, both for AP (ρ_{avg}: 0.84 ± 0.11, p-value: 3.18×10^{-3}) and ML (ρ_{avg}: 0.90 ± 0.09, p-value: 8.94×10^{-3}) components. Postural parameters are extracted from CoM_{Body} using the same methodology [14], so similar accuracies are expected on postural sway. T_{USD} is compared with the duration of the task measured by a stopwatch.

The average Pearson's correlation coefficient confirms the good correlation (ρ_{avg}: 0.83 ± 0.12, p-value: 6.42×10^{-3}) for postural parameters, even if the measured times are not exactly the same: this depends on a difference in the manual and automatic estimation of the sit-to-stand and stand-to-sit events.

3.2 Discriminant Power of Parameters

The preliminary results on ST condition indicate that postural and temporal parameters are able to discriminate PD and CG, as confirmed by the Mann–Whitney U Test (Table 2). Spearman's correlation indicates that parameters have a moderate to strong correlation ($|\rho > 0.4|$, p-value < 0.05) with standard clinical scores, although not all parameters show the same discriminatory power. For instance, the ML_r parameter has a low correlation: this could depend on the more stable posture required by USD task.

Table 2 Discriminatory power and correlation coefficients for parameters of ST phase in USD

	Mann–Whitney U test				Spearman coefficient[b]	
Parameter	CG (mean ± std)	PD (mean ± std)	Z	p-value[a]	ρ	p-value[a]
AP_r	0.71 ± 0.20	1.38 ± 0.68	2.73	6.37×10^{-3}	0.56	3.12×10^{-3}
ML_r	0.63 ± 0.15	1.13 ± 0.65	1.68	9.24×10^{-2}	0.38	1.71×10^{-2}
AP_t	1.50 ± 0.16	8.78 ± 2.68	3.33	8.73×10^{-4}	0.62	3.23×10^{-3}
ML_t	0.98 ± 0.10	9.01 ± 4.18	3.33	8.73×10^{-4}	0.60	3.01×10^{-3}
AP_v	0.94 ± 0.12	1.87 ± 1.02	1.99	4.66×10^{-2}	0.52	2.31×10^{-3}
ML_v	0.62 ± 0.09	2.11 ± 0.91	3.33	8.73×10^{-4}	0.43	1.92×10^{-2}
Area	0.42 ± 0.08	1.80 ± 1.72	1.83	6.69×10^{-2}	0.58	3.27×10^{-3}
T_{USD}	67.5 ± 1.62	72.5 ± 4.46	3.23	8.89×10^{-4}	0.61	3.32×10^{-3}

[a] Significance level < 0.05; [b] Correlation respect to PIGD subscale scores

Table 3 Average difference of postural parameters between ST and DT conditions, for PD and CG

	Mann–Whitney U test				T test
Parameter	CG (median)	PD (median)	Z	*p*-value[a]	*p*-value[a]
AP_r	0.475	1.170	2.69	7.24×10^{-3}	6.88×10^{-3}
ML_r	0.480	1.120	2.30	2.13×10^{-2}	6.04×10^{-3}
AP_t	0.945	4.735	2.23	2.58×10^{-2}	7.67×10^{-4}
ML_t	0.295	1.720	2.27	2.33×10^{-2}	6.66×10^{-3}
AP_v	0.680	1.720	2.68	7.12×10^{-3}	2.57×10^{-5}
ML_v	0.670	1.310	2.15	3.44×10^{-2}	3.44×10^{-2}
Area	0.350	1.430	2.50	1.24×10^{-2}	2.91×10^{-3}

[a] Significance level < 0.05

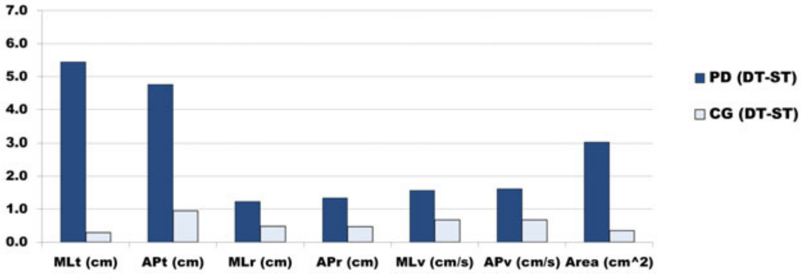


Fig. 4 Average difference of postural parameters between ST and DT conditions (for PD and CG)

As expected, greater differences is highlighted by the DT condition, in particular for AP_t and ML_t, AP_v and Area: this indicates greater difficulties for PD subjects in maintaining a stable posture when concurrent tasks are executed (Table 3). In Fig. 4, the average differences of postural parameters between ST and DT conditions are shown.

The initial hypothesis of greater instability in case of concurrent cognitive task is supported by the results in Table 3. The dual-task condition clearly increases the postural parameters (all the differences are positive), indicating a worsening of postural stability compared with the single-task condition: although this happens both for PD and CG, it is more evident for PD subjects, as expected, as it is shown by the total movement of CoM_{Body} (ML_t and AP_t parameters).

3.3 Postural Instability Assessment

Classifier performance is expressed in terms of accuracy, that is the percentage of correct predictions: accuracy generally decreases when the number of classes increases. Preliminary results on USD task show that classification accuracy is 67.3%

for SVM_{PIGD}, 65.7% for SVM_{BERG} and 75.4% for SVM_{TUG}. SVM_{TUG} performs better since it resolves a classification on two classes. However, the performance is not so good as expected, probably because the "static" USD task conveys less information on postural stability than a "dynamic" task like TUG.

Another experiment was conducted to analyse the performance in DT condition using the probability vector returned by the classifier, where each element is the probability associated to the corresponding input class [14]. In this experiment, postural and temporal parameters for DT condition were used as input vectors for trained classifiers. Degradation in stability has been successfully detected by classifiers as a shift to a worse class (for 3 subjects) or as a redistribution of the predicted class probability towards worse classes (average: 10%, min: 5%, max: 23%): this clearly indicates a worsening in postural stability and suggests that supervised classifiers can be used for the automatic detection of balance dysfunctions.

4 Conclusions

A vision system for the automatic assessment of postural stability based on low-cost RGB-Depth device has been presented. The system management is obtained by a HMI based on visual feedback and simple gestures and actions, which make the solution user-friendly and suis for home use also for people without particular technical skills.

Postural stability is evaluated by means of postural and temporal parameters that characterize body movements in tasks derived from standard clinical scales commonly used for the assessment of balance dysfunctions. The use of multiple balance tests and dual-task conditions in the task design aims to stimulate different types of postural stress and to force the onset of instability. Postural parameters are estimated by the sway of the body CoM, which has been proved to be strongly correlated to postural instability.

The preliminary results on the USD task show a significant difference between PD and age-matched CG subjects, both in postural and temporal parameters. Furthermore, the selected parameters have a good correlation with standard clinical assessments. Particularly interesting is the analysis of the dual-task condition: postural instability increases for both groups when a concurrent cognitive task is performed, but the differences between the two groups is wider than in single-task condition. This confirms the initial hypothesis of greater balance dysfunctions in PD subjects when motor and cognitive tasks are performed simultaneously. Finally, classification results encourage the use of supervised classifiers for the automatic assessment of postural stability.

Certainly, further investigations are necessary to confirm the preliminary results obtained for the USD task, for example by increasing the number of subjects, or by extending the analysis of the other tasks for a more robust assessment of instability. Nevertheless, these results are encouraging, in particular considering the impacts on safety and quality of life of the monitoring of postural stability at home.

As a final note, although Microsoft Kinect v.2 has been declared as discontinued, other commercial alternatives are available: Microsoft Kinect Azure, Orbbec Astra and Intel RealSense D400 series, combined with new body tracking algorithms (e.g., Nuitrack software) could led to results similar to those presented here.

References

1. Shoneburg B, Mancini M, Horak F et al (2013) Framework for understanding balance dysfunction in Parkinson's disease. Mov Disord 28(11):1474–1482. https://doi.org/10.1002/mds.25613
2. Wielinski C, Erickson-Davis C, Wichmann R et al (2005) Falls and injuries resulting from falls among patients with Parkinson's disease and other Parkinsonian syndromes. Mov Disord 20:410–415. https://doi.org/10.1002/mds.20347
3. Shumway-Cook A, Brauer S, Woollacott M (2000) Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. Phys Ther 80(9):896–903
4. Jankovic J, McDermott M, Carter J et al (1990) Variable expression of Parkinson's disease: a base-line analysis of the DATATOP cohort. The Parkinson Study Group. Neurology 40(10):1529–1534
5. Goetz CG, Tilley BC, Shaftman SR et al (2008) Movement Disorder Society-sponsored revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS): scale presentation and clinimetric testing results. Mov Disord 23(15):2129–2170. https://doi.org/10.1002/mds.22340
6. Berg K, Wood-Dauphinėe S, Williams JI et al (1989) Measuring balance in the elderly: preliminary development of an instrument. Physiother Can 41(6):304–311. https://doi.org/10.3138/ptc.41.6.304
7. Jacobs JV, Horak FB, Tran VK et al (2006) Multiple balance tests improve the assessment of postural stability in subjects with Parkinson's disease. J Neurol Neurosurg Psychiatry 77(3):322–326
8. Morris M, Iansek R, Smithson F et al (2000) Postural instability in Parkinson's disease: a comparison with and without a concurrent task. Gait Posture 12(3):205–216
9. Frenklach A, Louie S, Koop MM et al (2009) Excessive postural sway and the risk of falls at different stages of Parkinson's disease. Mov Disord 24(3):377–385. https://doi.org/10.1002/mds.22358
10. Mancini M, Horak FB, Zampieri C et al (2011) Trunk accelerometry reveals postural instability in untreated Parkinson's disease. Parkinsonism Relat Disord 17(7):557–562. https://doi.org/10.1016/j.parkreldis.2011.05.010
11. Han J, Shao L, Shotton J (2013) Enhanced computer vision with Microsoft Kinect sensor: a review. IEEE Trans Cybern 43(5):1318–1334. https://doi.org/10.1109/TCYB.2013.2265378
12. Kähär H, Taba P, Nõmm S et al (2017) Microsoft Kinect-based differences in lower limb kinematics during modified timed up and go test phases between men with and without Parkinson's disease. Acta Kinesiologiae Universitatis Tartuensis 23:86–97. https://doi.org/10.12697/akut.2017.23.08
13. Rocha AP, Choupina H, Fernandes JM et al (2015) Kinect v2 based system for Parkinson's disease assessment. In: Proceedings of the IEEE 37th annual international conference on Engineering in Medicine and Biology Society (EMBC), Milan, Italy, 25–29 August 2015. ISBN 978-1-4244-9271-8, 1279–1282. https://doi.org/10.1109/EMBC.2015.7318601
14. Ferraris C, Nerino R, Chimienti A et al (2019) Feasibility of home-based automated assessment of postural instability and lower limb impairments in Parkinson's disease. Sensors 19(5):1129. https://doi.org/10.3390/s19051129
15. Clauser CE, McConville JT, Young JW (1971) Weight, volume, and center of mass segments of the human body. J Occup Med 13:270

16. Hughes AJ, Daniel SE, Kilford L et al (1992) UK Parkinson's disease society brain bank clinical diagnostic criteria. J Neurol Neurosurg Psychiatry 55:181–184
17. Mancini M, Horak FB (2010) The relevance of clinical balance assessment tools to differentiate balance deficits. Eur J Phys Rehabil Med 46(2):239
18. Nocera JR, Stegemoller EL, Malaty IA et al (2013) Using the Timed Up & Go Test in a clinical setting to predict falling in Parkinson's disease. Arch Phys Med Rehabil 94(7):1300–1305

“In Bed” BCG Signal Analysis

Ennio Gambi, Linda Senigagliesi, Elisea Creato, and Manola Ricciuti

Abstract Sleep is an important phase of a person’s life, to which a significant percentage of the day is dedicated. Sleep is a key moment of the day that significantly affects the well-being of our body, so a reduction in sleep often determines serious repercussions on the quality of life and health in general. It is therefore of interest to proceed with an assessment of the physiological parameters of a person during the hours dedicated to sleep. The present work illustrates an experimental activity of extraction of vital parameters of a subject during his stay in bed, based on the elaboration of the BallistoCardioGraphic (BCG) signal. It is shown how the values of heart and respiratory rate can be obtained, and how useful information can be obtained to investigate sleep disorders such as insomnia, sleep apnoea, bruxism, restless leg syndrome, night epilepsy, sleepwalking and narcolepsy.

1 Introduction

Nowadays words as “telemedicine” or “ambient assisted living” have become part of the ordinary dictionary as synonyms of the application of monitoring technologies over health conditions and data transfer, oriented to the person care and to the protection of her/his health status in a domestic environment. The main objective of such a service is, for obvious reasons, the so-called third age. According to the data of the World Health Organization, between 2015 and 2050 the number of people over 60 years is expected to increase from 12 to 22% with respect to the total world

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population, and by 2020 the number of people over 60 will overcome that of the children below 5. In other words, people live longer and while the natural ageing process cannot be stopped, it can be at least kept under control and improved as much as possible.

In this context the use of automatic monitoring systems is gaining more and more attention. In these systems the data generated by sensors are elaborated in order to give information about the health status of the examined person, with an evident cost reduction in comparison to a more traditional approach. In this work we will consider the monitoring of a subject during his time in bed, highlighting different phases during sleep time and extracting some of his vital signs, i.e. the cardiac and respiratory rate. This information is obtained by the elaboration of the BCG signal given by an accelerometric sensor, which is particularly suitable to a monitoring realized in a domestic environment, thanks to its small size and its non-invasiveness.

Sleep analysis through BCG technique is an alternative to polysomnographic (PSG) exam and results less invasive [1] since it avoids the use of electrodes during the electrocardiogram (EKG) measure needed to derive the heart rate and the use of a chest strap to obtain the respiratory rate from strain gauges.

Moreover, analysis based on BCG represents a reliable and non-intrusive way to verify the so called *bed occupancy* in hospitals and hospices. It can also be used for the prevention of sleep apnoea, a critical condition that has dramatic effects on health. In a study published by the American Journal of Respiratory and Critical Care Medicine [2], it emerged that amyloid beta depositions, main responsible of neurodegenerative diseases such as Alzheimer, are more abundant in people who suffer from sleep apnoea. Another work [3], published on American Academy of Neurology Journal, revealed that sleep apnoea and snoring can lead to memory and thought decline in early age. In that paper, both people in the first phases of mild cognitive impairment without memory and thought problems, and people with Alzheimer, were taken into account. It was proved that people with respiratory diseases during sleep had the diagnosis of cognitive impairment almost 10 years, on average, before people without these diseases.

The paper is organized as follows. Section 2 describes the BCG signal, while in Sect. 3 the algorithm for the extraction of heart and respiratory rate is illustrated. In Sect. 4 the results about the study of the characteristics of BCG signal related to particular action during "in bed" permanence are illustrated. Finally, Sect. 5 concludes the paper.

2 The Ballistocardiographic Signal (BCG)

The ballistocardiographic signal shows the mechanical activity of the heart, and in particular it represents the trend of reflux forces generated in the human body in response to the ejection of blood by the heart [4, 5]. The BCG signal was discovered in 1877 by J. W. Gordon, who noted that when a subject was standing on a scale, fluctuations in the balance needle seemed to be synchronized with his heart rate, and

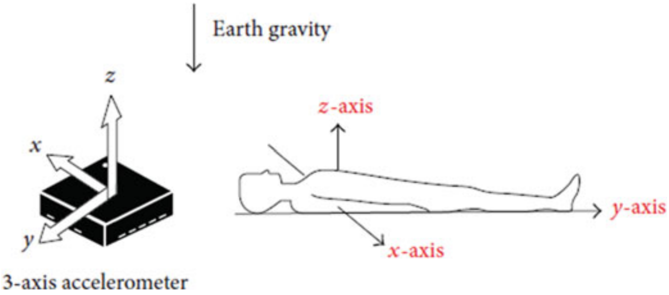

Fig. 1 Recorded acceleration directions

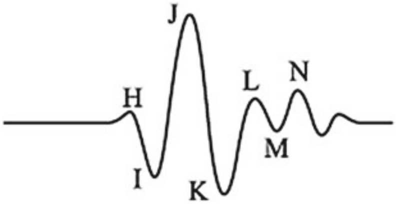

Fig. 2 Typical trend of BCG signal

attributed the cause of these fluctuations to the ejection of blood in the aorta that would have caused a reflux force in the opposite direction [5–7].

During each beat, a displacement of the center of mass of the human body occurs, due to the movement of blood in the vessels; we therefore observe micro-movements in the body caused by reflux forces that trigger to counteract this displacement of the center of mass and preserve the total moment [7].

The BCG signal records exactly these micro-movements, which can be measured by displacement, velocity, or acceleration in all 3 spatial dimensions (Fig. 1). However, sometimes the measurement is observed in only one direction so that we can obtain the longitudinal BCG, which measures the deformations of the body in the head-to-foot direction, and the transverse BCG, which measures the back-ventral movements [7]. In the present paper we will refer to the longitudinal BCG only.

Since the ballistocardiographic signal is a signal of strength, it is possible to measure it using different types of sensor (piezoelectric, strain gauge, pressure, etc.). In the present paper the BCG signals have been acquired by a MEMS type sensor [4] which presents remarkable characteristics in terms of response speed and sensitivity to disturbances, and which must be positioned below the mattress. Looking at Fig. 1, longitudinal BCG is measured along the y axis, while transverse BCG is measured on the x axis. As well as the electrocardiographic signal (ECG), also the BCG signal has its own characteristic trend and periodicity that make it possible, at least visually, a simple identification of the heart beats (Fig. 2).

On the horizontal axis we find the time, while on the vertical one the amplitude, since the actual unit of measurement depends on the type of sensor used. The BCG

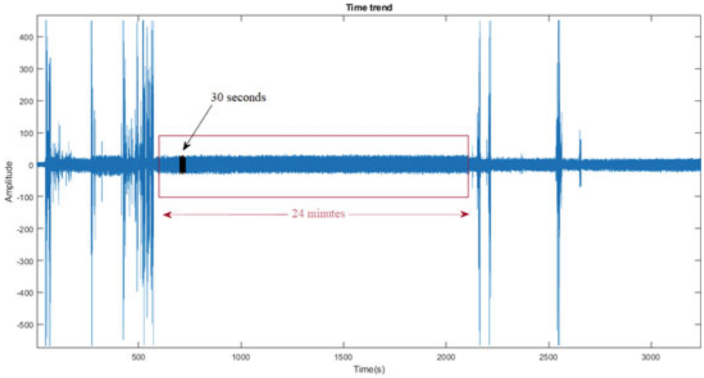

Fig. 3 BCG raw signal of a healthy adult subject during sleep

signal is a representation of the reflux forces recorded in the body in relation to cardiac events [8], so in the phases in which the blood, inside the heart, is pumped in the head-to-feet direction, a force is expected in opposite direction, i.e. a peak with concavity upwards, while the opposite occurs when the blood is pumped in the feet-to-head direction. The reference peak that allows to distinguish the beats and therefore to calculate the cardiac period, is represented by the J peak, as it turns out to be the maximum in amplitude. The J peak represents the maximum peak, analogously to the R peak for the ECG, which represents the acceleration of the blood in the descending aorta and therefore in the abdomen; again for an acceleration in head-to-feet direction there is a foot-head reflux force and therefore a positive peak.

3 Cardiac and Respiratory Rate Evaluation

In our experiments, in order to extract the heart rate we considered an acquisition made on a healthy adult subject during sleep, and from this, for sake of simplicity, we isolated a 24-min portion, framed in red in Fig. 3, during which no movements of the subject were recorded. These movements are highlighted by signal peaks outside the time interval considered. Inside this 24-min range, a BCG raw signal evolution of 30 s is considered, on which our analysis is developed.

The low frequency oscillation of the amplitudes (with period of about 4 s) due to the respiration contribution overlaps the trend of the BCG signal in time [9]. By filtering the components out of the range of significant frequencies for the BCG signal (1–12 Hz) through two Butterworth filters of the 6th order, a high pass one with cutoff frequency equal to 1 Hz and a low pass one with cutoff frequency equal to 12 Hz, we obtain the signal shown in Fig. 4, where the J peaks are visible.

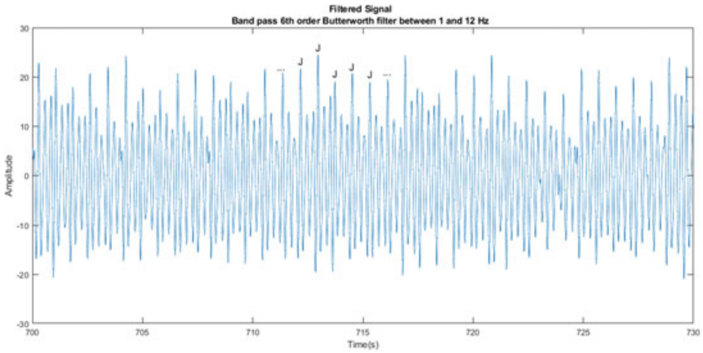

Fig. 4 J peaks of a raw BCG signal after a 1-12 Hz filtering

However, in order to further enhance the J peaks and to make the J-J intervals and consequently the heart rate more easily identifiable, each sample of the signal is raised to the square and its sign is retained, obtaining the signal in Fig. 5c, which is called *Filtered Squared Signal* [10]. By observing it, we can note that, applying a threshold on amplitude and erasing all the samples below this threshold, the *beat signal* represented by all the J peaks is obtained (Fig. 5d). In our work we set the threshold value at 200. The threshold is constant value while the signal experiences a continuous oscillation of the amplitude because of the respiration. Consequently, besides the J peaks, other undesired peaks are included in the *beats signal*, which hinder the extraction of the heart rate. Since the heart rate in healthy adult subjects at rest varies between 60 and 90 beats per minute, frequencies below 0.7 Hz and over 2 Hz have been cut by using a double Butterworth filter of the 6th order. In Fig. 5e we can observe the *beats signal* after filtering, or *filtered Beats*, in which peaks have been highlighted in red. By comparing the *beats signal* before and after filtering we can note that no more undesired peaks are present and only the J peaks remain.

The cardiac period, or the time interval between successive beats, is nothing but the temporal distance between adjacent J peaks, and the heart rate is its inverse. Finally, Fig. 5f shows the trend in heart rate over the time frame of the test.

The respiratory rate is another important vital function which, in cases such as sleep apnoea, represents a parameter to be subjected to continuous monitoring. To extract the respiratory rate, the same portion of signal used for the extraction of heart rate was analyzed, thus we refer to the same healthy adult subject in the same conditions. A similar procedure to the one that led to the extraction of the heart rate is applied: a Butterworth filter of the 6th order of the low pass type with a cutoff frequency of 0.7 Hz is applied to the raw BCG portion of the signal analyzed, in order to eliminate all the signal components with a higher frequency than the respiratory one. The filtered signal clearly shows a slowly variable trend over time of about 4s, which unequivocally is related to the respiratory period.

Apart from the presence of “double peaks”, it is immediately clear that the useful peaks are all those present on the y positive half-plane, Therefore by simply placing a

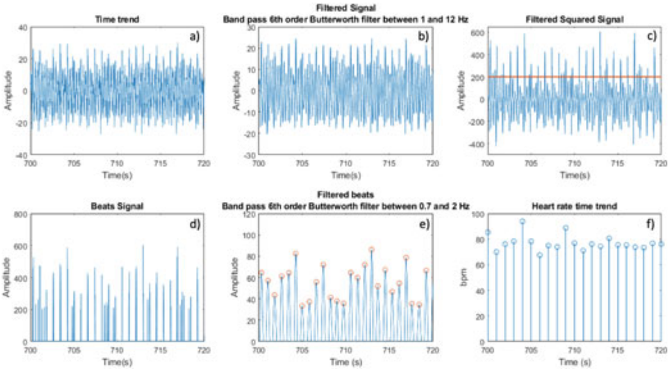

Fig. 5 Elaboration of the BCG raw signal to extract the cardiac frequency

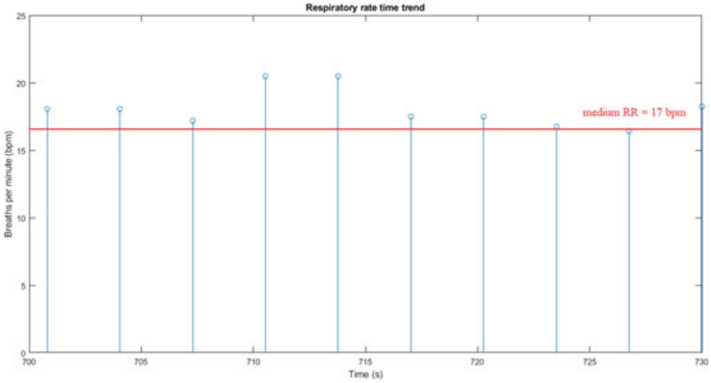

Fig. 6 Respiratory rate as a function of time

threshold at 0 of amplitude, above which the signal and the peaks can be considered as useful, we get a new signal, called *Breaths Signal*. In the hypothesis that the subject of the test breathes in a regular manner, in order to overcome the problem of the presence of double peaks or peaks too far from each other, when the cardiac period is not included in the normal range we can resort to one of the following mathematical approximations:

1. When peaks are too close to each other, they can be replaced by a unique peak positioned halfway between one peak and another;
2. Whether in the presence of peaks that are too close or too far apart, we can attribute to the cardiac period the value assumed in the previous time instant.

As done for the heart rate and the cardiac period, we plot the respiratory rate as a function of the time (Fig. 6).

Table 1 Characteristics of the subjects under test

	Subject 1	Subject 2	Subject 3
Age	55	53	22
Sex	M	F	F
BMI (Body Mass Index)	28 kg/m^2	27 kg/m^2	23 kg/m^2

4 "In Bed" Analysis

In this paragraph we describe the processing of the BCG signal, with the goal of analyzing some of its characteristics that vary according to the activity carried out by the subject, and in particular we will try, by using an adaptive algorithm, to recognize instant by instant which action is played by the subject.

For this purpose 3 healthy adult subjects, whose characteristics are described in Table 1, were submitted to the same test.

Four activities were carried out, in the following denoted as: REST, TALK, MOVE, EMPTY. The test, called "RGBK", consists in the succession of such activities:

- 1 min at rest in supine position (REST)
- 1 min talking in supine position (TALK)
- Supine to lateral position change (MOVE)
- 1 min at rest in lateral position (REST)
- 1 min talking in lateral position (TALK)
- Lateral to supine position change (MOVE)
- 1 min at rest in supine position (REST)
- Leaving the bed (MOVE)
- About 30 s of empty bed (EMPTY)

The developed algorithm consists of a preliminary calibration phase, followed by the actual activity recognition procedure. The calibration phase uses portions of the acquired signal to set the ranges in amplitude ad variance for the different activities carried out during the test; for example, to set the ranges for the "talk" activity, a portion of signal during which the subject was talking was taken, and from it both amplitude and variance ranges have been extracted. After the calibration phase, the signal is divided into small intervals and for each of them, according to its amplitude or variance, we assign the corresponding activity, based on the ranges found during the calibration phase. We finally plot in different diagrams the RGBK signal obtained by associating a different color with each activity in the following way:

- Empty → Red → R
- Rest → Green → G
- Talk → Blue → B
- Move → Black → K

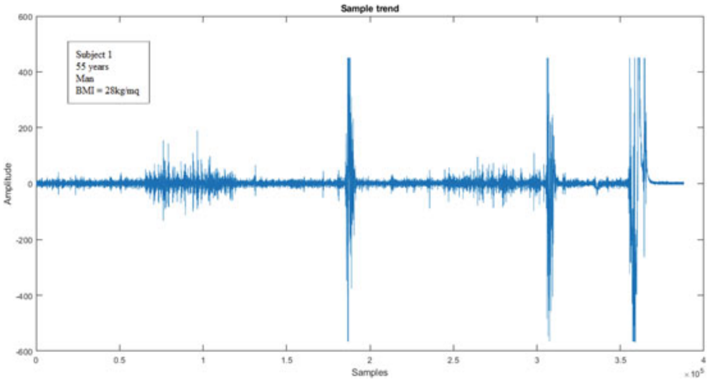

Fig. 7 RGBK signal for the subject 1. To obtain the value of the time in any instant, it is sufficient to divide the number of samples by 1000, i.e. the sampling frequency

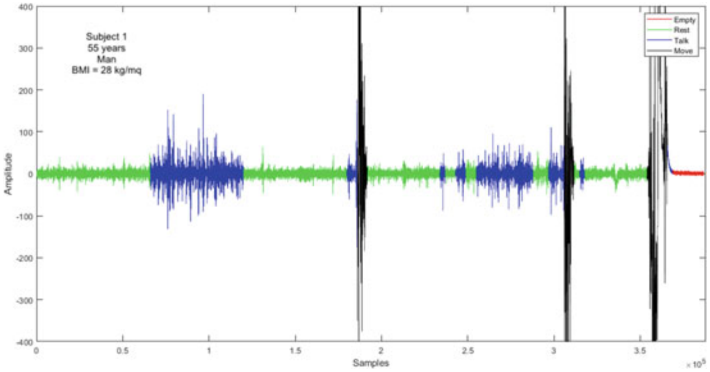

Fig. 8 RGBK signal for the subject 1 after applying the algorithm of recognition of the activities based on the variance of the signal

Figure 7 shows the RGBK signal relative to subject 1 before applying the activity recognition algorithm, while Fig. 8 shows the signal to which the discrimination of the activities based on variance has been applied. It is possible to observe that the algorithm is able to distinguish the various phases of the test quite precisely. The RGBK signals for the subject 2 and 3 after applying the activity recognition algorithm, based on the signal variance, are depicted in Fig. 9 and in Fig. 10.

As far as subjects 1 and 2 are concerned, it is possible to identify the different phases of the test (Figs. 8 and 9), while it is not possible to do the same with subject 3 (Fig. 10), since by looking at her graphs no differences between the REST activity and the TALK activity are identifiable. To justify this anomaly, two main hypotheses have been proposed:

1. In the examined case, the body mass index (BMI) could be determining for a correct recognition of activities since, with respect to subjects 1 and 2, subject 3

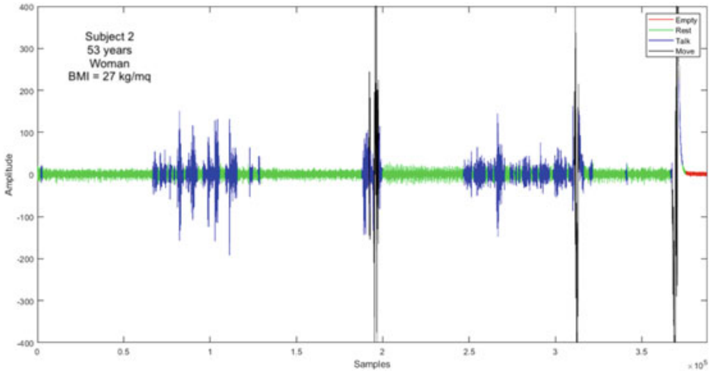

Fig. 9 RGBK signal for the subject 2 after applying the algorithm of recognition of the activities based on the variance of the signal

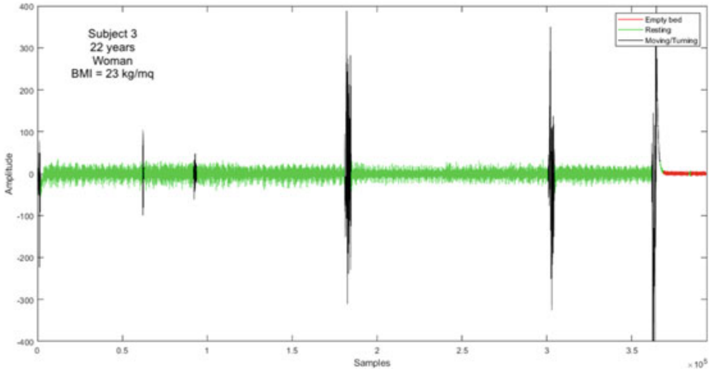

Fig. 10 RGBK signal for the subject 3 after applying the algorithm of recognition of the activities based on the variance of the signal

shows a lower value. As it was reported in [1], in fact, subjects with too high or too low BMI are usually not included in the tests, probably because they would produce unreliable data. A more concrete proof of this argument has been reported in [11], where a high BMI value has been found to have a detrimental effect on the signal. In this case, the BMI of subject 3 is the normal range, so that it is possible to extract the main vital parameters without difficulty, but it is probably too low to allow the algorithm to distinguish TALK activity from REST activity.

2. Subject 3 could have vocal characteristics that do not allow to recognize, using this algorithm, if he is speaking or not.

In order to confirm the discussed hypotheses, we depicted the spectrum of the signal portion relative to the TALK trait of subject 3 in Fig. 11, and we compared it with the spectra of subjects 1 (Fig. 12) and 2 (Fig. 13). Although the location of the TALK

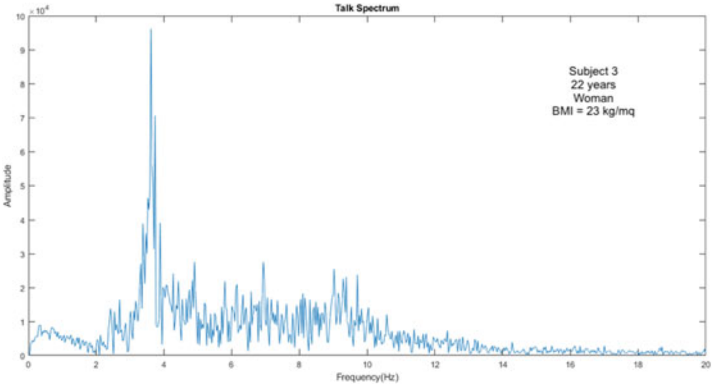

Fig. 11 TALK spectrum for the subject 3

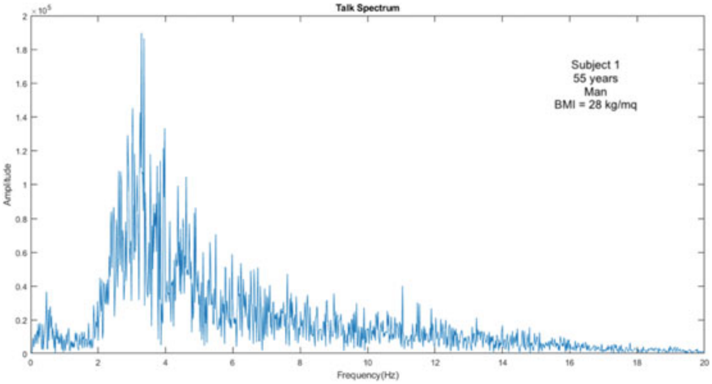

Fig. 12 TALK spectrum for the subject 1

portion in subject 3 it is not visually identifiable in Fig. 10, it is known a priori, having personally performed the tests.

Looking at the spectra of the three subjects we can draw some observations:

1. The maximum signal amplitude for subjects 2 and 3 (both women) is of the order of 10^4, while for subject 1 (man) it is of the order of 10^5. This allows to hypothesize that the subject 1 has a greater acoustic intensity (which is a plausible hypothesis since the subject is a man).
2. Another analogy, regarding the positioning of the peaks of the spectrum, is always present between subjects 2 and 3: in addition to a low-frequency peak due to respiration and to a peak around the 3.5 Hz typical of the BCG signal and present also in the subject 1 spectrum, there are 3 peaks placed at about 5, 6 and 9 Hz in both spectra of subjects 2 and 3. These data may suggest that subjects 2 and 3 have a comparable vocal range.

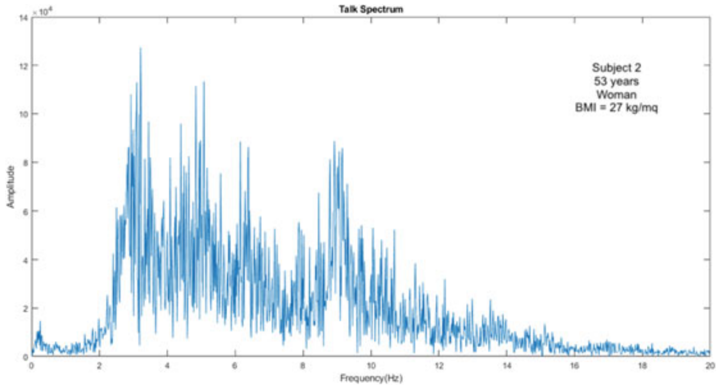

Fig. 13 TALK spectrum for the subject 2

3. As the spectra of subjects 2 and 3 are roughly similar, what might distinguish them, and which is not evident from the frequency content, is the tone of voice.

5 Conclusion

In this work we have presented the cardiorespiratory monitoring technique based on the BCG signal. This technique shows considerable advantages from the cost, comfort and versatility points of view. Moreover, it can be applied in the polysomnographic (PSG) examination, as it can replace the annoying electrodes for measuring the ECG used to derive the heart rate, and the chest belt used to derive the respiratory frequency from the signal coming from the strain gauges. It is a reliable and non-intrusive way to verify the so-called bed occupancy, or to keep under control, for example in hospitals or nursing homes, whether the patient is actually in bed or not. Finally, it can be used in the prevention of sleep apnoea, a very dangerous condition that has serious repercussions on health. It has been verified how the analysis of the BCG signal also provides indications on the quiet state of the subject during his stay in bed, thus allowing to extend the analysis from vital parameters to qualitative assessments on the subject’s well-being. The information obtained from BCG signal analysis represents the basis for an activity of sleep disorders identification based on a machine learning approach.

References

1. Sami N (2016) Nocturnal sleep quality and quantity analysis with ballistocardiography. Master’s thesis. Aalto University
2. Sharma RA et al (2018) Obstructive sleep apnea severity affects amyloid burden in cognitively normal elderly. A longitudinal study. Am J Respir Criti Med 197(7)

3. Osorio RS et al (2015) Sleep-disordered breathing advances cognitive decline in the elderly. Neurology 84(19). https://doi.org/10.1212/WNL.0000000000001566
4. Merihein Ulf—BCG Measurement in beds MURATA whitepaper
5. Nitesh MBM (2016) Data processing of ballistocardiogram signal using adaptive filter. Int J Innov Res Electr Electron Instrumen Control Eng 4(5). https://doi.org/10.17148/IJIREEICE.2016.4563
6. Kurumaddali B, Marimuthu G, Venkatesh.S M, Suresh R, Syam BS, Suresh V (2014) Cardiac output measurement using ballistocardiogram. Goh J (ed) The 15th international conference on biomedical engineering. IFMBE Proceedings vol 43, p 861
7. Omer TI, Pierre-Francois M, Kwang-Suk P, Marco Di R, Mozziyar E, Kouhyar T, Ramon C, John Z, Jens T, Irina F, Kim PG (2015) Ballistocardiography and seismocardiography: a review of recent advances. IEEE J Biomed Health Inform 19(4):1414–1427. https://doi.org/10.1109/JBHI.2014.2361732
8. Shao D, Tsow F, Liu C, Yang Y, Tao N (2016) Simultaneous monitoring of ballistocardiogram and photoplethysmogram using a Camera. IEEE Trans Biomed Eng 64(5). https://doi.org/10.1109/TBME.2016.2585109
9. Lydon K, Su BY, Rosales L, Enayati M, Ho KC, Rantz M, Skubic M (2015) Robust heartbeat detection from in-home ballistocardiogram signals of older adults using a bed sensor. Conf Proc IEEE Eng Med Biol Soc 2015. https://doi.org/10.1109/EMBC.2015.7320047
10. Manjula BM, Sharma C (2016) Ballistocardiography signal filtering using adaptive least mean square algorithm. In: Proceedings of IEEE international conference on recent trends in electronics, information & communication technology (RTEICT)
11. Almothana A, Frederico L Ulrich M (2019) Bed-embedded heart and respiration rates detection by longitudinal ballistocardiography and pattern recognition. Sensors 19:1451. https://doi.org/10.3390/s19061451

Analysis of Skeletal Muscles Contractility Using Smart SEMG-Based Socks

Lucia Giampetruzzi, Gabriele Rescio, Alessandro Leone, and Pietro Siciliano

Abstract Surface electromyography increasingly plays an important role for prevention, diagnosis and rehabilitation in healthcare field. In this context, the continuous monitoring of the electrical potentials produced by muscles appears to be effective to detect abnormal events. The recent progresses in surface electromyography technologies have allowed for the development of low invasive and reliable wearable devices. These devices promote long-term monitoring; however, they are often very expensive and not easy to be positioned appropriately. Moreover, they use disposable pre-gelled electrodes that can cause skin redness. In this work, to overcome these issues, a prototype of new smart socks has been realized, implementing reusable and high biocompatible hybrid polymer electrolytes. These electrodes provide a comfortable lower limb long-term monitoring avoiding a difficult daily repositioning by users. The realized socks are lightweight and integrates all electronic components for the pre-elaboration and the wireless data sending. The Gastrocnemius-Tibialis muscles were selected and analyzed due to their relevance for assessment of age-related changes in gait, sarcopenia pathology, postural anomalies, fall risk, etc. In particular, in this paper an evaluation on the risk of falling detection by the system was considered as a case of study.

Keywords Wearable device · Surface electromyography · Hybrid polymer electrodes · Smart socks

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1 Introduction

Recently, bio-signal measurements among which electromyography (EMG) and electroencephalography (EEG) have been increasingly demanded. In particular, EMG is a medical procedure that provide the acquisition of the electric potentials produced by the voluntary contraction of the skeletal muscle fibers. These potentials are bio-electric signals, acquired from the human body and then filtered to reduce the noise produced by other electrical activities of the body or inappropriate contact of the sensors, namely artifacts. Then the signals are processed in a control system to acquire information regarding the anatomical and physiological muscles' characteristics and to make a diagnosis.

The surface EMG (sEMG) can acquire signals by no invasive electrodes placed on the surface of skin, compared to the intramuscular technique. The sEMG signals are considered most useful as electrophysiological, for application in medicine as the assessment of age-related changes in gait, for diagnosis in Sarcopenia Pathology (SP), Amyotrophic Lateral Sclerosis (ALS) and Multiple Sclerosis (MS) or other neuropathies, postural anomalies, fall risk, etc. [8, 16, 17]. The effects of these diseases are mainly monitored through the response of EMG on the muscle strength/power performance in the lower limbs using medical wired stations or portable and wearable technologies [29]. Wearable devices have recently gained increased importance due to their reliability and no-invasive monitoring of health parameters, exercise activity, but also for the early detection of illnesses and/or disorders or to prevent dangerous events in the elderly healthcare [15].

Considering fall events among elderly, several automatic integrated wearable devices and ambient sensor devices capable of fall detection have been constructed [1, 3, 5, 20, 27]. Although these devices are remarkable, they are not able to prevent injuries resulting from the impact on the floor. To overcome this limitation advanced technologies should be developed on the timely recognition of imbalance and fall event, activating an impact protection system. The current solutions are oriented to evaluate the patient physical instability, primarily monitoring the users' body movements and their muscle behaviors [2, 6, 11, 17]. These studies suggest that the lack of balance causes a sudden modification on the EMG patterns brought about by reactive/corrective neuromuscular response. So, the imbalance detection systems based on EMG signals may represent a very responsive and effective strategy for fall prevention. In these kinds of analysis, generally, the wired probes or wireless devices integrate the gold standard for sEMG analysis: Silver/Silver Chloride (Ag/AgCl) wet (hydrogel) electrodes. These electrodes consist of a silver disc layer surrounded by a silver chloride hydrogel layer that improves the signal quality by lowering the impedance between the electrode and skin. However, these electrodes are unsuitable for a long-term monitoring because they cause skin irritation and they also dehydrate, producing high impedance and so providing the loss of signal quality [19] and consequently a high incidence of motion artifacts and noise. They are also relatively expensive depending on the cost of silver. Although the fabrication of comfortable and stable textile electrodes for long-term monitoring still represents an open research issue. Recently, several companies have developed electrodes that address hydrogel dehydration designing new electrodes made of new materials and polymer by combining viscoelastic polymeric adhesive to address the limitations of traditional electrodes, aiming to adhere and conform the electrodes to the skin [4].

In the paper, new wireless smart socks for the surface EMG signals acquisition were developed to increase the users' level of usability and acceptability. This aim was achieved with the integration into the device of all electronics components and biocompatible hybrid polymer electrolyte (HPe)-based electrodes for the EMG data acquisition and transmission. The device was designed to monitor the Gastrocnemius Lateralis (GL) and Tibialis Anterior (TA) muscles contractions. A low computational cost and low invasive hardware-software system for the lack of human balance detection is described by using the realized socks, suitable for the fall risk evaluation.

The hardware was realized customizing commercial devices for that purpose and a low computational cost machine learning paradigm was chosen for the evaluation of imbalance events.

2 Materials

To acquire the electromyography data coming from the GL and TA muscles a sensorized sock was realized. The device is mainly made of (a) hybrid polymer electrolytes (HPe) electrodes to contact the skin, (b) an electronic interface unit to read the signals coming from the electrodes, (c) an elaboration and wireless transmission unit. In Fig. 1 the overview of the smart socks it is reported.

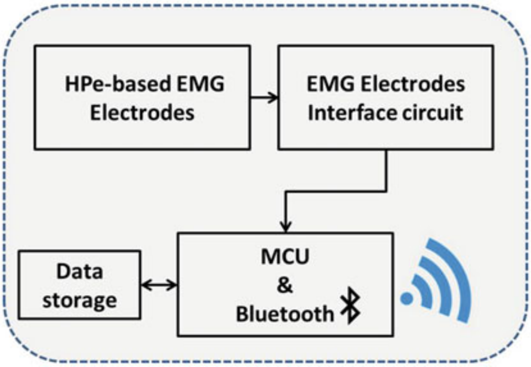

Fig. 1 Overview of the socks' hardware architecture

Fig. 2 HPe-based electrodes have been casting incorporating the clips, in the site where the Myoware Muscle Sensor board is placed

2.1 HPe-Based Electrodes Preparation and Implementation

The electrodes have been realized adopting the blending technique with a solution of Polyvinyl Alcohol (PVA) into a Carboxymethyl cellulose (CMC) solution. The two solutions were mixed at different ratio: 20:80, 40:60 and 50:50; while the best ratio has been resulted the 20:80 (PVA: CMC) as reported in literature [23, 24]. The polymer solutions were complexed with a 30 wt% of NH_4NO_3 in order to increase the biopolymer conductivity [25]. The CMC/PVA hybrid (80/20 wt%) as host solid biopolymer electrolytes complexed with NH_4NO_3 was casted into a mold containing the socks fabric and after the drying process, as described in literature [24], they resulted embedded into socks. An example of the system: socks-clip-HPe (made of 80:20 CMC/PVA blended) are shown in Fig. 2. The new electrodes made of CMC/PVA HPe could enhance the mechanical properties and the biological compatibility of the sensor system. In particular, CMC has been used in various medical applications including tissue engineering, drug delivery and wound dressings, as well as PVA has been employed in many medical fields [7, 22, 28]. The blending of CMC with PVA could result in highly effective hydrogen-affinity membranes reducing skin irritation and improving the signal detection [26, 31]. In the work a preliminary study was accomplished with the developed electrodes. Through the read-out circuit described in the following section, good signals quality was obtained. Further analyses will be needed for the electrodes mechanical and electrical characterization to realize reliable and robust electrodes adapt for long-term monitoring.

2.2 Data Acquisition and Transmission System

To read and amplify the signals coming from the HPe electrodes, the Myoware Muscle Sensor board interface, shown in Fig. 3, was sewed on the socks [13].

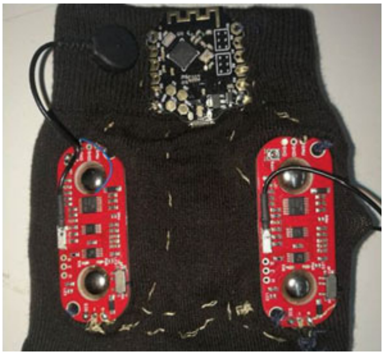

Fig. 3 Prototype of the smart socks

Myoware Muscle sensors are equipped with three electrodes; two of them must be placed on skin in the measured muscle area, and one on skin outside the muscle area, which is used as the ground point. Myoware device normally uses disposable pre-gelled electrodes, but through the variable gain of Myoware interface and the pre-elaboration step, described in the following section, it has been possible to obtain a high signal quality with the new realized electrodes. The Myoware Muscle Sensor can be polarized through a single voltage and it was designed for wearable devices. For the data transmission and elaboration unit the Bluno Beetle board was used [14]. It is lightweight, compact and integrates the low energy Bluetooth 4.0 transmission module. The board was sewed on the socks and connected to the Myoware device through conductive wires. Whereas, the whole system was supplied with a rechargeable Lipo battery of 3.7 V of 320 mA with dimension 26.5 × 25 × 4 mm and weight of 4 gr. It was placed and glued in the rear part of the Beetle board. In Fig. 3 is shown the realized prototype. Each electronic component was insulated through an Acrylic resin lacquer; in the future no-invasive packaging will be provided to make system washable. The total current consumption was measured to evaluate the lifetime of the 3.7 V battery. Based on the results the whole system consumes about 40 mA in data transmission mode. So, considering the used battery the system is able to monitor the lower limb muscles and to send data to a smartphone/embedded PC for about 8 h. Future improvements should be addressed to increase the system autonomy, optimizing the hardware and their power management logics. The prototype was realized by using an elastic sock to enhance the adhesion between the electrodes and the skin. The sensors were located on the socks in correspondence of the antagonist GL-TA Muscles. The algorithmic framework for the elaboration of the EMG signals, coming from the sensorized socks, was located and tested on an embedded PC, equipped with a Bluetooth connection.

3 Preliminary Results

To evaluate the electromyography signals coming from the device, five young healthy subjects of different ages (28.7 ± 7.1 years), weight (67.3 ± 8.5 kg), height (1.73 ± 0.3 m) and sex (3 males and 2 females) have simulated Activities Daily Livings (ADLs) and unbalance events, in controlled conditions. To acquire data, the socks were located so that the GL and TA muscles can be monitored, as shown in Fig. 4. In the zone where the probes were placed, the skin had been shaved and cleaned using an isopropyl alcohol swab to reduce impedance. Each actor performed about 40 simulated ADLs and 10 falls for a total of 211 ADLs and 54 falls. The acquired sEMG signals were sent to an embedded PC through the Bluetooth connection, for the data analysis. The imbalance events were simulated with the use of a movable platform designed and built to induce imbalance conditions until to the actors' fall. So, the data acquired have been used to develop and to test the computational framework of the system. In the primary phase of the data elaboration, the noise caused by movement artifacts were reduced through the band-pass filtering within a frequency range of [20–450] Hz. Moreover, for EMG-tension comparison, the signals were processed by generating their full wave rectification and their linear envelope [9]. The calibration was necessary to calculate the baseline of the signals and to reduce the inter-individual variability of sEMG signals between different users. The calibration phase was performed by users after the sEMG device is placed on the subject and through the calculation of Maximum Voluntary isometric Contraction (MVC) values for TA and GL muscles [17]. For the purpose of fall risk assessment, attention was focused on several low computational cost features, commonly used in the analysis of the lower-limb muscle activities [12, 18]. Based on the experimental results, the muscle Co-Contraction Indices (CCI) showed higher degree of discrimination using a sliding window of 100 ms. The CCI give an estimation about the simultaneous activation of the pair of muscles for each data point of the pre-processed data [12].

For the evaluation of performance and for the classification of the fall risk event, the low computationally cost Linear Discriminant Analysis (LDA) classifier was selected [10]. To assess the performance of the system the CCI features have been calculated for all ADLs and unbalance events simulated during the aforementioned acquisition

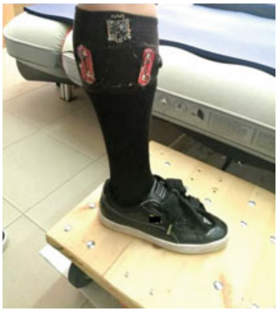

Fig. 4 The sEMG sensors mounting setup

campaign. The 70% of dataset was used to train the classifier, while the remain part was used to measure the performance in terms of sensitivity and specificity [30]. The measured values of the sensitivity and specificity are respectively 82.3% and 81.7%. These results were obtained considering 125 Hz sample rate. To evaluate the detection time, the average period between the moment when the unbalance condition is identified until the impact on the mat was analyzed. Based on the obtained results the system appears able to detect the fall risk about 750 ms before the impact on the mat. These results are close to those obtained from a similar analysis in which commercial, not very comfortable devices, were used [21]. This demonstrates the effectiveness of the realized wearable EMG-based system to detect fall in very fast way.

4 Conclusions

The paper deals with a preliminary study about a new and low invasive surface Electromyography-based smart socks for the monitoring of the antagonist GL-TA muscles. The system is suitable for the evaluation of several diseases related to the lower limb movements and activities such as age-related changes in gait, fall risk, sarcopenia pathology, amyotrophic lateral sclerosis and other peripheral neuropathies. To test the effectiveness of the system, the fall risk assessment was examined as a case of study. The classification has been performed through a low computational cost machine learning approach. Based on the results, relevant performance in terms of detection time, sensitivity and specificity have been monitored in controlled condition. The described analysis was carried out involving young healthy subjects, future work will be addressed to evaluate the system performance testing the socks with elderly subjects.

References

1. Andò B, Baglio S, Lombardo CO, Marletta V (2016) A Multi-sensor data fusion approach for ADL and fall classification. IEEE Trans Instrum Meas 65(9):1960–1967
2. Andò B, Baglio S, Marletta V (2016) A Inertial microsensors based wearable solution for the assessment of postural instability, ISOCS-MiNaB-ICT-MNBS, Otranto, Lecce, 25 29 June, 2016.
3. Andò B, Baglio S, Marletta V (2017) A neurofuzzy approach for fall detection. In: 23rd ICE/IEEE ITMC conference, Madeira Island, Portugal, 27–29 June 2017
4. Ansari SP, Anis A (2018) Conducting polymer hydrogels. Polym Gels. 2018. 467–486.
5. Bagalà F, Becker C, Cappello A, Chiari L, Aminian K, Hausdorff JM, Zijlstra W, Klenk J (2012) Evaluation of accelerometer-based fall detection algorithms on real-world falls. PLoS ONE 7:e37062
6. Blenkinsop GM, Pain MT, Hiley MJ (2017) Balance control strategies during perturbed and unperturbed balance in standing and handstand. Royal Soc Open Sci 4(7):161018

7. Capanema NSV, Mansur AAP, De Jesus AC, Carvalho SM, De Oliveira LC, Mansur HS (2018) Superabsorbent crosslinked carboxymethyl cellulose-PEG hydrogels for potential wound dressing applications. Int J Biol Macromol 106:1218–1234
8. Chung T, Prasad K, Lloyd TE (2013) Peripheral neuropathy: clinical and electrophysiological considerations. Neuroimaging Clin N Am 24(1):49–65
9. De Luca CJ, Gilmore LD, Kuznetsov M, Roy SH (2010) Filtering the surface EMG signal: movement artifact and baseline noise contamination. J Biomech 43(8):1573–1579
10. Englehart K, Hudgins B (2013) A robust, real-time control scheme for multifunction myoelectric control. IEEE Trans Biomed Eng 50(7):848–854
11. Galeano D, Brunetti F, Torricelli D, Piazza S, Pons JL (2014) A tool for balance control training using muscle synergies and multimodal interfaces. BioMed Res Int, 565370
12. Horsak B et al (2015) Muscle co-contraction around the knee when walking with unstable shoes. J Electromyogr Kinesiol 25
13. https://www.advancertechnologies.com
14. https://www.dfrobot.com
15. Kamišalić A, Fister I Jr, Turkanović M, Karakatič S (2018) Sensors and functionalities of non-invasive wrist-wearable devices: a review. Sensors (Basel, Switzerland) 18(6):1714
16. Joyce NC, Gregory GT (2013) Electrodiagnosis in persons with amyotrophic lateral sclerosis. PM & R: The J Inj, Funct, Rehabil 5(5 Suppl):S89-95
17. Leone A, Rescio G, Caroppo A, Siciliano P (2015) A Wearable EMG-based system pre-fall detector. Procedia Eng 120:455–458
18. Phinyomark A, Chujit G, Phukpattaranont P, Limsakul C, Huosheng H (2012) A preliminary study assessing time-domain EMG features of classifying exercises in preventing falls in the elderly. In: 2012 9th International conference on electrical engineering/electronics, computer, telecommunications and information technology (ECTI-CON), pp 1–4, 16–18 May (2012)
19. Posada-Quintero H, Rood R, Burnham K, Pennace J, Chon K (2016) Assessment of carbon/salt/adhesive electrodes for surface electromyography measurements. IEEE J Transl Eng Health Med 4, 2100209
20. Rescio G, Leone A, Siciliano P (2013) Supervised expert system for wearable MEMS accelerometer-based fall detector. J Sens 2013, Article ID 254629, 11 pages
21. Rescio G, Leone A, Siciliano P (2018) Supervised machine learning scheme for electromyography-based pre-fall detection system. Expert Syst Appl 100:95–105
22. Reza AT, Nicoll SB (2010) Characterization of novel photocrosslinked carboxymethylcellulose hydrogels for encapsulation of nucleus pulposus cells. Acta Biomater. 6:179–186
23. Roy N, Saha N, Kitano T, Saha P (2010) Novel hydrogels of PVP–CMC and their swelling effect on viscoelastic properties. J Appl Polym Sci 117(3), 1703–1710
24. Saadiah MA, Samsudin AS (2018) Electrical study on Carboxymethyl Cellulose-Polyvinyl alcohol based bio-polymer blend electrolytes. In: IOP conference series: materials science and engineering, vol 342, no 1. IOP Publishing
25. Saadiah MA, Samsudin AS (2018) Study on ionic conduction of solid bio-polymer hybrid electrolytes based carboxymethyl cellulose (CMC)/polyvinyl alcohol (PVA) doped NH_4NO_3. AIP Conf Proc 2030(1). AIP Publishing
26. Scilingo EP, Gemignani A, Paradiso R, Taccini N, Ghelarducci B, De Rossi D (2005) Performance evaluation of sensing fabrics for monitoring physiological and biomechanical variables. IEEE Trans Inf Technol Biomed 9(3):345–352
27. Siciliano P et al (2009) A networked multisensor system for ambient assisted living application. In: Advances in sensors and interfaces. IWASI, pp 139–143
28. Thomas LV, Arun U, Remya S, Nair PD (2009) A Biodegradable and biocompatible PVA–citric acid polyester with potential applications as matrix for vascular tissue. Eng J Mater Sci Mater Med 20:259–269
29. Wei Y, Liu Y, Peng PCQ (2007) Age-related sarcopenia: an electromyographic and mechanomyographic study. I: ISBS-conference proceedings archive, vol 1, no 1

30. Wu G, Xue S (2018) Portable preimpact fall detector with inertial sensors. IEEE Trans Neural Syst Rehabil Eng 16(2):178–183
31. Yang L et al (2019) Construction of porous sponge-like PVA-CMC-PEG hydrogels with pH-sensitivity via phase separation for wound dressing. Int J Polym Mater Polym Biomater. https://doi.org/10.1080/00914037.2019.1581200

Characterization of a PPG Wearable Sensor to Be Embedded into an Innovative Ring-Shaped Device for Healthcare Monitoring

Laura Fiorini, Filippo Cavallo, Mihail Martinelli, and Erika Rovini

Abstract Wearable sensor technologies have emerged as a revolutionary technique for real-time monitoring of physiological parameters, particularly for healthcare applications. To guarantee their use, the sensors should be embedded in everyday equipment improving their wearability. In this context, the MAX30102 wearable sensor was studied and characterized for the monitoring of the PPG signal acquired on the index finger. Heart rate (HR), heart rate variability (HRV), and oxygen saturation (SpO_2) measures were extracted from the PPG signal according to the pulse oximetry principles, by analysing the red and infrared signals detected by the LEDs embedded in the sensor. A valuation test was performed to compare the measures obtained by the MAX30102 with those achieved by two gold standard instruments used in clinical practices for cardiac and pulse oximetry measurements. The achieved results are promising, evidencing error rates lower than 2.5% for all the measures. The possibility to integrate such sensor in a ring-shaped device able to measure the vital parameters for health status monitoring can support the clinicians both in clinical and home settings for improving diagnosis, personalized treatments, and long-term monitoring.

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1 Introduction

Over the last two decades, wearable technologies, low-power electronics, Internet of Things (IoT) and communication systems are hugely improved. The demand for wearable devices has increased a lot in different fields of application, including sport and fitness, consumer electronics, games and entertainment, and particularly healthcare [1], where the use of wearable systems has become more and more common both in clinical and home settings for vital-signs monitoring [2]. Typically, wearable systems are wireless, with miniaturized sensors embedded in patches or equipment and they can be worn such as a watch, ring, and clothes to acquire data from wrist [3, 4], fingers [5], or chest [6]. These wearable sensors allow the measurement of motion and physiological parameters that can be stored, wirelessly sent to a database server, and consequently used to potentially help healthcare professionals on diagnosis, treatment, patient monitoring and prevention, also developing personalized treatment plans [7]. According to the World Population Ageing report, the population is progressively ageing, and the number of older persons is expected to double again by 2050 when it is projected to reach nearly 2.1 billion [8]. Thus, health and social care services have to be adapted to the complex care needs of an increasingly older population.

1.1 Wearable Sensors for Physiological Signals Monitoring

Wearable sensors able to measure physiological signals that can be useful for helping people in health status monitoring are recently increasing. According to the literature [9], heart rate and blood oxygen saturation are among the five traditional vital signs that have major importance to be measured to ensure clinical monitoring and allow to identifying potential health deterioration.

1.1.1 Heart Rate and Heart Rate Variability

For decades, physicians have used electrocardiograms (ECGs) to find heart-related diseases such as some forms of arrhythmias that can be caused by myocardial infarction and which in turn can lead to cardiac arrest. To avoid these consequences is required to detect the cardiac activity in the long-term and to treat all in an early stage. The ambulatory monitoring is not able to detect some rare, infrequent arrhythmias (e.g. arrhythmogenic right ventricular cardiomyopathy, long QT syndrome, hypertrophic cardiomyopathy), thus it is necessary to wear a wearable monitoring system that could not prevent normal daily activities. Some researchers have introduced system-on-chip technologies that are an integration of both analogue and digital signal processing units for ECG analysis. Izumi et al. [10] developed a system that incorporated a near field communication (NFC) module, a three-axis accelerometer, and an ECG processor chip. This chip obtains data, processes ECG and accelerometer signals and communicate with the smartphone. Another wearable ECG monitoring system were designed in a custom T-shirt and textile belts with embedded textile electrodes. These electrodes were made from silver-based conductive yarns, and they relied on body sweat, an electrolyte medium, that improves the conductivity of the skin–electrode interface and signal quality and to avoid the use of conducting gel that can have potential toxic and irritant effect on the skin on long-term [11].

Heart rate (HR) and Heart Rate Variability (HRV) are the two most common parameters extracted from ECG to monitor the cardiac activity. HR is a standard vital sign that represents the number of beats per minute and has become a routine measurement in healthcare as well as in fitness activities. HRV represents the variation of the heart rate, meant as the time interval between two consecutive peaks R in the typical ECG signal. HR and HRV can be measured both from the ECG or from the photo-plethysmography (PPG) even if the origin of these two physiological signals and their waveforms are quite different [12]. Pulse signal derived by PPG has been proposed as an HR-related measure that can substitute it. It is produced by the increase of volume of blood pushed into the vessel caused by the alternate contraction/relaxation of the heart that results in a palpable rhythmic expansion of an artery. Strength, amplitude and regularity of pulse are additional information that can be extracted from pulse signal respect to the HR [9].

The HRV is a reflex of the autonomic nervous system (ANS) that regulates heart rate, blood pressure, breathing, galvanic skin response, and digestion. The HRV is a human psychophysiological status indicator, so it is a useful and non-invasive parameter to identify ANS imbalances, like stress, poor sleep, unhealthy diet, and lack of exercise, and it is highly correlated to the cortisol level [13], which is a physiological biomarker for stress. HRV analyses have previously been used in different studies to detect stress during mental tasks [14], high workload [15], and car driving [16], as well as for emotion recognition purpose [17].

Low HRV can be an indicator of unhealthy ANS because there is no ability to switch gears, showing more resilience and flexibility; indeed, some researches have shown a relationship between low HRV and depression or anxiety like an individual with post-traumatic stress disorder (PTSD) [18]. Differently, high HRV is typical in people who have greater cardiovascular fitness, be more resilient to stress [19] and healthy, and in case of calm and positive emotions.

1.1.2 Blood Oxygen Saturation

Blood oxygen saturation can be measured from the PPG on the basis of pulse oximetry principles reading the peripheral oxygen saturation (SpO_2). The pulse oximetry is an alternative safe, inexpensive and non-invasive method to the traditional invasive arterial blood gas (ABG) analysis.

The PPG signal is a time-varying voltage signal related to the light absorbed by the human blood and it reflects changes in arterial blood volume [20]. The Lambert–Beer's law regulates the absorption of light by a substance where a monochromatic ray of light with I_0 intensity crosses a medium containing a light absorption substance, a part of this light is absorbed by the medium, a part is transmitted through the substance and the remaining part is reflected by the medium.

The transmitted light decreases exponentially along the way according to Lambert–Beer's law (Eq. 1):

$$I = I_0 e^{-\varepsilon(\lambda)cd} \tag{1}$$

where $\boldsymbol{I}$ denotes the intensity of light at the skin surface, $\boldsymbol{I_0}$ is the baseline intensity of light, and $\boldsymbol{e^{-\varepsilon(\lambda)cd}}$ models the arterial absorption, which depends on the extinction coefficient of the medium $\boldsymbol{\varepsilon(\lambda)}$ at the wavelength $\boldsymbol{\lambda}$, the substance concentration $\boldsymbol{c}$ that absorbs the light within the medium, and the arterial pulsating displacement $\boldsymbol{d}$. The transmittance $\boldsymbol{T}$ is the ratio between the intensity of light transmitted $\boldsymbol{I}$ and the baseline intensity of light $\boldsymbol{I_0}$ (Eq. 2):

$$T = \frac{I}{I_0} = e^{-\varepsilon(\lambda)cd} \tag{2}$$

Consequently, the absorbance A is defined as in Eq. 3:

$$A = -\ln(T) = \varepsilon(\lambda)cd \tag{3}$$

For pulse oximetry, it is assumed that the haemoglobin in the blood can be in two states only: the reduced state (Hb) and the oxyhaemoglobin state (HbO_2). Haemoglobin absorbance spectrum, indeed, changes when it bounds with oxygen, allowing the estimation of blood oxygen saturation according to the following relationship (Eq. 4):

$$SpO_2 = \frac{[HbO_2]}{[HbO_2] + [Hb]} \cdot 100\% \tag{4}$$

where $[HbO_2]$ represents the concentration of oxyhaemoglobin in the blood, while [Hb] is related to the deoxygenated haemoglobin concentration. Pulse oximetry, indeed, exploits the different light absorption spectra between Hb and HbO_2 using two different light wavelengths (i.e., $\lambda_1 = 660$ nm for the red light spectra, and $\lambda_2 = 880$ nm for near-infrared light spectra). The Hb has a higher absorption at 660 nm, whereas HbO_2 has a higher absorption at 880 nm [21].

There are two modes for measuring pulse oximetry: the transmittance or the reflectance mode. In the first case, the light-emitting diodes (LEDs) and the receiving photodiode are placed in the opposite side of the measurement site (e.g., the fingertip), and the light is absorbed from skin, bone, muscle in the body, thus it is attenuated at photodiode level. In the latter mode, differently, the LEDs and the photodiode are on the same side of the body site, offering greater flexibility of use [3].

The PPG signal is composed by the direct current (DC) component and the alternating current (AC) component. The DC component is related to the light absorption of the tissue, venous blood, and non-pulsatile arterial blood and it represents the offset of the signal. On the other hand, the AC component represents the pulsatile arterial blood and it is related to the amplitude of the signal. The SpO_2 depends on the modulation Ratio, which is calculated using the DC and AC components of both red (RED) and infrared (IR) signals according to the following equation (Eq. 5):

$$\text{Ratio} = \frac{\text{AC}_{\text{RED}}/\text{DC}_{\text{RED}}}{\text{AC}_{\text{IR}}/\text{DC}_{\text{IR}}}. \tag{5}$$

The Ratio is then converted to SpO_2 value through a linear relationship (Eq. 6), where A and B are parameters empirically identified by means of a calibration process (see par. 2.2.1):

$$\text{SpO}_2 = \text{A} - \text{B} \cdot \text{Ratio} \tag{6}$$

The normal range of oxygen carried by blood cells in healthy individuals is 95–100%. If the SpO_2 is $\leq$94%, the patient is hypoxic and needs to be treated quickly since insufficient oxygen supplies to the human body. Finally, $SpO_2 < 90\%$ represents a clinical emergency [22]. Monitoring of oxygen level is particularly important during sports activities, as well as for ambulatory monitoring in a clinical environment, and at home for long-term monitoring.

1.2 The Aim

Using PPG has some advantages but also technical limitations such as the incorrect position, partial inhibition and possible pain during a continuous acquisition with clip-fingertip pulse-oximeter. For this reason, a ring-shaped blood saturation monitoring system can be introduced as an alternative to the classical finger-tip pulse-oximeter probe being more comfortable and easy to adapt.

The aim of this work is to study and to test the ability of a prototype of a wearable physiological sensor system, to be integrated into an innovative ring-shaped device, to measure vital parameters such as blood oxygen saturation (SpO_2), heart rate (HR) and heart rate variability (HRV) extracted from the PPG signal. Additionally, the reliability of the measures is also investigated by comparing them with two gold standard devices. The ultimate goal of this wearable system is to integrate many types of sensors in a single power-saved device for physiological monitoring, which can be used daily, both in clinical and home settings.

2 Materials and Methods

In this paragraph the proposed system is described (Sect. 2.1), then a description of the two systems characterization was also proposed (Sect. 2.2). Finally, Sect. 2.3 reports a description of the analysis conducted to preliminarily validate the system thus to achieve the goal of the paper.

2.1 System Description

The module was developed by using an STM32-F103 board (STMicroelectronics), which is based on an ARM 32-bit Cortex™-M3 processor. The PPG sensor chosen is the MAX30102 (Maxim Integrated™, San Jose, CA, USA) that is controlled by means of an I^2C port. This sensor was selected because of its ultra-low power consumption, miniaturization, robust motion artefact resilience with a high Signal–Noise Ratio (SNR) and its use in similar application [23]. This sensor is placed on the first phalanx of a finger to detect HR, HRV, and SpO_2. The board size of 12.7 × 12.7 mm is compatible with its future integration in a ring-shaped sensor. During this work, the data were sent to a computer at a frequency of 100 Hz through a USB port, but in the next development, a wireless Bluetooth connection will be implemented.

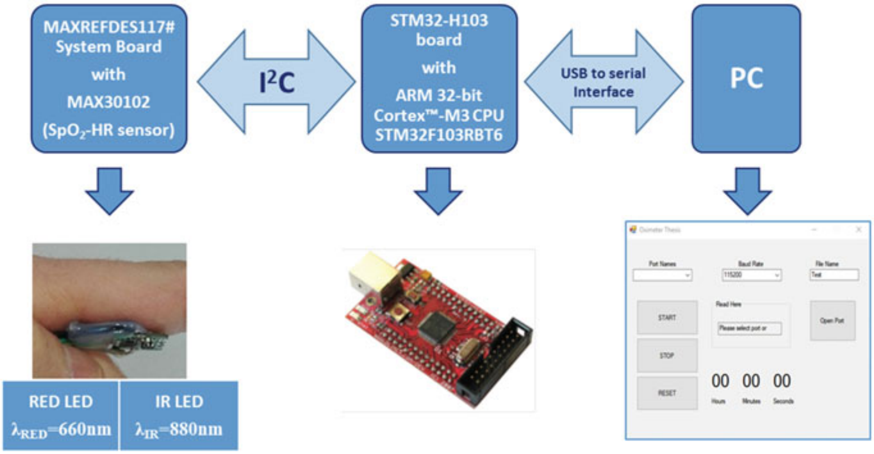
As concern the operative condition, the MAX30102 works in the reflective mode (i.e., LEDs and photodetector on the same side of the finger). The sensor is composed of two LEDs (i.e., red LED with $\lambda = 660$ nm and infrared LED with $\lambda = 880$ nm), that can be managed by ranging the current from 0 to 50 mA, and the pulse width from 69 to 411 μs. In this study, the LEDs pulse width was set to 69 μs and LEDs current to 50 mA. Additionally, in order to manage the data acquisition, the data storage and the communication with a PC, a custom application was developed in C# language in Visual Studio (Microsoft Corporation, Washington, USA) (Fig. 1).

2.2 Experimental Set-Ups

Two experimental set-ups were carried out. Firstly, a bench-test was performed to calibrate the SpO_2 signal acquired from our system; then the system was finally evaluated.

2.2.1 System Characterization

Prior to validating the system, it should be calibrated in order to correlate the coefficient Ratio with the SpO_2 value acquired from the gold-standard instrument thus to create an output-input relation between SpO_2 (output) and the PPG signal (input). In



Baud Rate 115200

File Name Test

Fig. 1 System Block diagram

this work, the OXY-5 GIMA was used as reference instrument since it is commonly used as professional wireless fingertip oximeter [24]. The SpO_2 measurement range is between 35 and 99%, whereas the SpO_2 resolution is equal to ±1%. The measurement accuracy is equal to ±2% within the SpO_2 operative range 75–99%.

The user was asked to wear the proposed system on the first phalange of the index finger and the OXY-5 on the medium finger. During this test, the user was asked to stay in a rest position for 7 min breathing slowly in order to decrease the SpO_2 level from 99% (a healthy normal level) to 92% (a hypoxic level still over the dangerous level). The data from the OXY-5 was recorded every 10 s. This calibration procedure was performed four times from a young healthy no-smoked subject aged 26 years old.

2.2.2 System Evaluation

The proposed system evaluation The BioHarness™ 3 (BH3) is a chest belt capable of measuring ECG at a frequency of 250 Hz, providing also HR and HRV at a frequency of 18 Hz; it was used for research purpose in similar applications [13, 17, 25]. Even if the BH3 is not a clinical gold-standard, according to Casaccia et al. [25], the accuracy in measuring the cardiac parameters starting from the values computed on-board by the device is high. Thus, this sensor was used in this study as reference and HRV values from BH3 were measured using the preprocessed data directly provided by the device.

Differently, data from OXY-5 were recorded each 10 s, as described in the previous paragraph (see par. 2.2.1).

A total of 8 healthy subjects (5 male and 3 female subjects, mean age ± standard deviation (SD) of 25.88 ± 3.92 years old) were enrolled for this test. Prior to starting

Fig. 2 The MAX30102 sensor is worn at first phalange level of index finger (similarly to a ring) whereas the commercial pulse oximeter OXY-5 is located on the medium finger-tip

the test, the users were asked to wear all the sensors at the same time. The proposed system and the OXY-5 were worn as depicted in Fig. 2, while the BH3 was appropriately worn on the chest. Then, the participants were asked to sit in front of a PC and to perform the 10-min test according to the following sequence:

1. **Relax phase**: subjects were asked to remain sitting with closed eyes for 1.5 min. No interaction between subjects and environment was allowed.
2. **Vision phase**: subjects were asked to watch a thriller film trailer for 2.5 min.
3. **Reading phase**: participants were asked to read loudly and as fast as possible for a total of 1 min.
4. **Apnoea phase**: subjects were asked to retain breath/breath slowly as long as possible for 3 min, thus to create a condition of mild hypoxia.
5. **Final relax phase**: subjects were asked to rest for 2 min with eyes closed in order to re-establish the normal physiological status.

All the trials occurred in a room with temperature and light conditions maintained constant for the entire duration. Then the data was retrieved and off-line analysed to compare the HRV, HR, and SpO_2 values simultaneously measured with the three devices over the five phases of the proposed protocol.

2.3 Data Analysis

The physiological data acquired during the two tests were analysed offline using Matlab® R2018a (MathWorks, Massachusetts, USA). The data from the MAX30102 was pre-processed. Firstly, a moving mean filter was applied to remove the trend of the signals and to correctly manage the baseline variation. Then, the values of the signal higher than the mean values plus three times the SD were removed by using the shape-preserving piecewise cubic spline interpolation. These outliers could be related to some pathologies in cardiac rhythm to the electrical conduction system - i.e.

the cardiac ectopy, ventricular extras systoles. Finally, the wavelet filter belonging to the Daubechies family (‘db-45’) was applied to smooth the signals and to highlight the peaks. Then, the IR-LED peaks and the RED-LED peaks were detected with the *findpeaks* Matlab function (Matlab R2018b).

Moreover, the Ratio of the direct current (DC) component and pulsatile alternating current (AC) component was computed as reported in Eq. 5 (see par. 1.1.2).

According to the relationship in Eq. 6 (see par. 1.1.2), the linear regression between the Ratio-values of MAX30102 and OXY-5 was computed for the calibration procedure, thus to link the Ratio-value with the SpO_2. Additionally, the coefficient of determination (R^2) and the root mean square error (RMSE) were calculated to evaluate the goodness of the implemented linear fitting.

As concern the system evaluation, the HR, HRV and SpO_2 were computed from the PPG signal. Particularly, the HR value was calculated by counting the peaks of the IR-LED signal over 60 s (t) (Eq. 7):

$$\mathrm{HR} = \frac{\#\mathrm{IR} - \mathrm{LED}_{\mathrm{peaks}}}{\mathrm{t}} \tag{7}$$

whereas, the HRV is measured as the mean time distance between two consecutive peaks in the IR-LED signal. HR and HRV were calculated with the IR-LED signal since it is more intense and more stable than the RED-LED one. As concern the gold standard measures, we used the ones measured directly by the devices.

HRV, HR and SpO_2 values were calculated for each phase of the protocol and for each subject. Then, the error rate (Eq. 8) and the absolute error (Eq. 9) were computed to compare and evaluate the performance of the proposed device.

$$\text{Error Rate} = \frac{(reference\ value) - (MAX30102\ value)}{(reference\ value)} \times 100\% \tag{8}$$

$$\text{Absolute Error} = |(reference\ value) - (MAX30102\ value)| \tag{9}$$

3 Results

The linear regression analysis reveals a good coefficient of determination ($R^2 = 0.80$) and a low RMSE value (RMSE = 1.14) between the Ratio values computed from the PPG signal and the SpO_2 values measured with the gold standard instruments (Fig. 3). Equation 10 reports the linear relation between the Ratio and the SpO_2 values empirically found from the calibration procedure:

$$\boldsymbol{SpO}_2 = 110.87 - 36.83 \cdot \boldsymbol{Ratio} \tag{10}$$

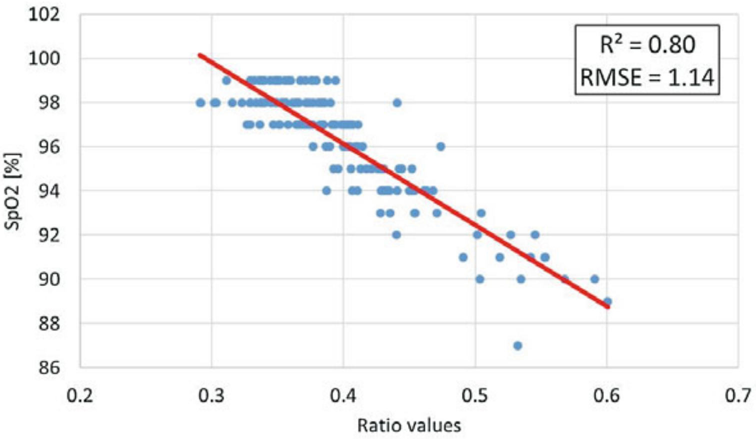


Fig. 3 Linear regression between the Ratio coefficient obtained from the PPG signal and the SpO_2 value measured with the OXY-5 GYMA

The evaluation results obtained from the analysis of HR, HRV and SpO_2 data are reported in Table 1 as the mean values and the SDs of the error rate and absolute error between MAX30102 sensor and the reference device.

Particularly, the HR values obtained from MAX30102 sensor are very similar to those obtained from the BH3 device as depicted in Fig. 4. Indeed, the error rate is below 1.44% in all phases except in the apnoea phase that it is equal to 2.54% (see Table 1).

Table 1 Means and standard deviations (SD) of HR, HRV and SpO_2 values of error rate and absolute error from all subjects divided into five phases

		Relax	Vision	Reading	Apnoea	Final relax
		Mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD
HR	Error rate [%]	1.44 ± 0.79	1.30 ± 0.97	1.35 ± 1.46	2.54 ± 2.25	1.28 ± 0.91
	Absolute error [bpm]	1.00 ± 0.55	0.99 ± 0.90	1.00 ± 1.00	1.82 ± 1.49	0.94 ± 0.68
HRV	Error rate [%]	0.32 ± 0.26	0.95 ± 1.33	1.35 ± 1.78	1.17 ± 1.37	0.93 ± 0.65
	Absolute error [s]	0.003 ± 0.002	0.007 ± 0.009	0.010 ± 0.013	0.010 ± 0.012	0.008 ± 0.006
SpO_2	Error rate [%]	1.70 ± 1.38	1.45 ± 1.17	1.02 ± 0.58	1.03 ± 0.91	1.78 ± 1.42
	Absolute error [%]	1.7 ± 1.4	1.4 ± 1.2	1.0 ± 0.6	1.0 ± 0.9	1.8 ± 1.4

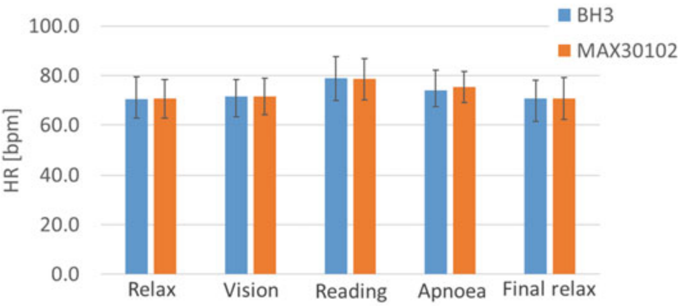


Fig. 4 Comparison of the HR values computed with the proposed device (MAX30102) and the BH3

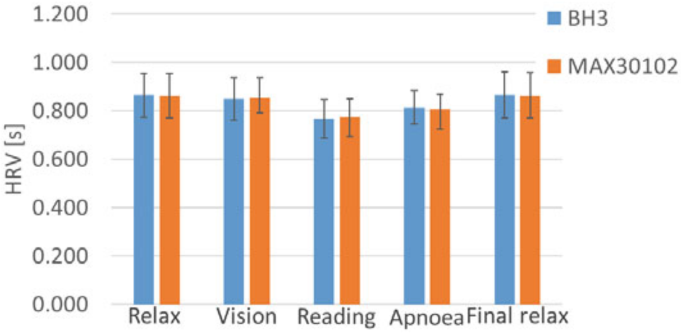


Fig. 5 Comparison of the HRV values computed with the proposed device (MAX30102) and the BH3

Also, the HRV comparison reports an error rate below 1.35% during all the five phases, and related absolute errors in the order of milliseconds. The high correlation between the measurements obtained with the two instruments is also evidenced in Fig. 5, where mean values and related SDs for HRV are reported.

As concern the comparison of SpO_2 values, the mean error rate is below 1.78% (Table 1) and the absolute error ranges between 1 and 1.8%. Figure 6 shows and compares the mean values of SpO_2 measured with the proposed system and the reference device.

4 Discussion

This work aimed at characterizing and testing a physiological sensor (i.e., MAX30102) able to measure the PPG signal from a finger for extracting and monitoring vital parameters, such as HR, HRV, and SpO_2. The preliminary results

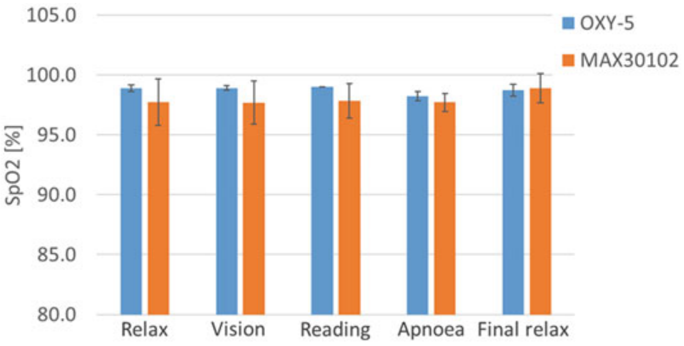


Fig. 6 Comparison of the SpO_2 values computed with the proposed device (MAX30102) and the OXY-5

presented in this paper are promising since the parameters extracted from the proposed system are comparable to those measured with the gold standard systems.

The obtained error rate is lower than 2.5% for all the measurements (Table 1) that is aligned with the state of the art. Indeed, in clinical studies, it was found that the accuracy for a single measurement of SpO_2 is 3–4% and for monitoring SpO_2 in a specific patient is about 2–3% [20]. It is worth to mention that measured HRV reports an excellent estimate error (average error rate equal to 0.94%), which is comparable with another similar work, which obtained an average normalized root-mean-square deviation (NRMSD) error equal to 2.05% [12]. Additionally, it is worth to underline that the system calibration obtained an R^2 coefficient equal to 0.8 that is comparable with another similar research [22].

The error in the measurements could be related to the light and sensor adherence, but also to the body movements that could influence the optical properties of local vessels because of the blood flow improvements. Expectably, such problems will be solved by integrating the sensor within the ring case that will be designed in order to maximize the contact area between the finger and the sensor, so reducing the amount of external light absorbed. Furthermore, the physiological measurements could be corrected by sensor fusion strategies using the MAX30102 and inertial sensors [26].

According to the preliminary results, the MAX30102 sensor has been embedded in a PCB layout and integrated into a ring-shaped sensor system where there are a microcontroller STM32, a Bluetooth module, some command buttons and a micro-B type USB port (Fig. 7). In order to reduce the motion artefact, an inertial measurement unit was also integrated into the ring. The idea to couple the measurement of physiological signals with inertial sensors lead towards a system capable of working in long-term activity monitoring with high precision and reliability. Such a system would allow the use both in clinical and home settings, to identify potential changes in people health status, including human psychophysiological assessment. Timely identification of vital parameters variations, indeed, could support the clinicians' actions on

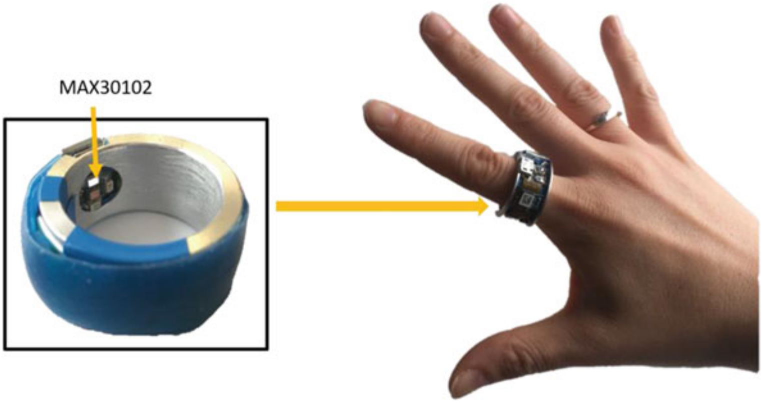


Fig. 7 MAX30102 integrated in a wireless ring-shaped device

diagnosis and treatment, developing also personalized therapy plans [27]. This application can be particularly useful for elderly and frail people that can require recurring monitoring of their physiological and motor status during their daily activities.

The main limitation of this study regards the reduced number of participants in the study, both for calibration and for validation tests. Future study should be planned to increase the number of participants obtaining a more heterogeneous dataset. Additionally, research efforts should be focused on the test of the ring-shaped device, optimizing the probe-finger coupling and the reduction of motion artefacts thus to obtain an innovative wearable physiological monitoring system. Furthermore, the acceptance of the system should be ensured, taking into account the users' needs that have to be investigated with particular attention when considering the application of the system for elderly and frail people.

5 Conclusion

The preliminary results obtained out of a comparison between our proposed system based on the MAX30102 sensor that measures SpO_2, HR and HRV parameters and two gold standard measuring the same features, namely BioHarness and OXY-5 GYMA were presented in this work. The obtained results revealed low error rate and low absolute errors yielded performance particularly comparable to the gold standards devices chosen as reference. This study is the first step to integrate the MAX30102 sensor into an innovative ring-shaped device with non-invasive sensing, local processing and feedback and communication capabilities to the user. Such system, able to measure the vital parameters of major importance for health status monitoring, can act as a reliable support system for clinicians that can use it both in clinical settings for improving the diagnosis as well as at home for long-term monitoring, favouring the development of personalized treatments.

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References

1. Collier R, Randolph AB, Collier R, Randolph AB (2015) Wearable technologies for healthcare innovation
2. Khan Y, Ostfeld AE, Lochner CM, Pierre A, Arias AC (2016) Monitoring of vital signs with flexible and wearable medical devices. https://doi.org/10.1002/adma.201504366
3. Lee H, Ko H, Lee J (2016) Reflectance pulse oximetry: practical issues and limitations ☆. ICT Express. 2:195–198. https://doi.org/10.1016/j.icte.2016.10.004
4. Fu Y, Liu J (2015) System design for wearable blood oxygen saturation and pulse measurement device 3:1187–1194. https://doi.org/10.1016/j.promfg.2015.07.197
5. Jeyhani V, Mahdiani S, Peltokangas M, Vehkaoja A (2015) Comparison of HRV parameters derived from photoplethysmography and electrocardiography signals. In: 37th annual international conference of the IEEE engineering in medicine and biology society, pp. 5952–5955. https://doi.org/10.1109/EMBC.2015.7319747
6. Liang T, Yuan YJ, Member S (2017) Wearable medical monitoring systems based on wireless networks: a review. IEEE Sens J 16:8186–8199. https://doi.org/10.1109/JSEN.2016.2597312
7. Turchetti BG, Micera S, Cavallo F, Odetti L, Dario P (2011) Technology and innovative services. IEEE Pulse 27–35
8. United Nations (2017) Department of Economic and Social Affairs, Population Division, World Aging Population 2017. https://doi.org/10.1049/el:20000788
9. Dias D, Cunha JPS (2018) Wearable health devices—vital sign monitoring, systems and technologies. Sensors (Switzerland) 18. https://doi.org/10.3390/s18082414
10. Izumi S, Yamashita K, Nakano M, Kawaguchi H, Marumoto K, Fuchikami T, Fujimori Y, Nakajima H, Shiga T, Yoshimoto M (2015) A wearable healthcare system with a 13.7 microA noise tolerant ECG processor. IEEE Trans Biomed Circuits Syst 9:733–742
11. Perego P, Standoli CE, Andreoni G (2015) Wearable monitoring of elderly in an ecologic setting: the SMARTA Project. https://doi.org/10.3390/ecsa-2-S3001
12. Pinheiro N, Couceiro R, Henriques J, Muehlsteff J, Quintal I, Goncalves L, Carvalho P (2016) Can PPG be used for HRV analysis? In: Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society EMBS, pp. 2945–2949. https://doi.org/10.1109/EMBC.2016.7591347
13. Betti S, Molino Lova R, Rovini E, Acerbi G, Santarelli L, Cabiati M, Del Ry S, Cavallo F (2017) Evaluation of an integrated system of wearable physiological sensors for stress monitoring in working environments by using biological markers. IEEE Trans Biomed Eng 9294. https://doi.org/10.1109/TBME.2017.2764507
14. Taelman J, Vandeput S, Spaepen A, Van Huffel S (2012) Influence of mental stress on heart rate and heart rate variability 37. https://doi.org/10.1007/978-3-642-23508-5
15. Orsila R, Virtanen M, Luukkaala T, Tarvainen M, Karjalainen P, Viik J, Savinainen M (2008) Perceived mental stress and reactions in heart rate variability—a pilot study among employees of an electronics company. Int J Occup Saf Ergon 14:275–283. https://doi.org/10.1080/10803548.2008.11076767
16. Picard RW, Healey JA (2013) Detecting stress during real-world driving tasks using physiological sensor. ProQuest Diss Theses 139. https://doi.org/10.1109/TITS.2005.848368
17. Fiorini L, Semeraro F, Mancioppi G, Betti S, Santarelli L, Cavallo F (2018) Physiological sensor system for the detection of human moods towards internet of robotic things applications. Front Artif Intell Appl 303:967–980. https://doi.org/10.3233/978-1-61499-900-3-967

18. Chalmers JA, Quintana DS, Abbott MJ-A, Kemp AH (2014) Anxiety disorders are associated with reduced heart rate variability: a meta-analysis. Front Psychiatry 5:80. https://doi.org/10.3389/fpsyt.2014.00080
19. Heart rate variability: a new way to track well-being—Harvard Health Blog—Harvard Health Publishing
20. Nitzan M, Romem A, Koppel R (2014) Pulse oximetry: fundamentals and technology update. Med Devices Evid Res 7:231–239. https://doi.org/10.2147/MDER.S47319
21. Lopez Silva SM, Dotor Castilla ML, Silveira Martin JP (2003) Near-infrared transmittance pulse oximetry with laser diodes. J Biomed Opt 8:525. https://doi.org/10.1117/1.1578495
22. Shao D, Liu C, Tsow F, Yang Y, Du Z, Iriya R, Yu H, Tao N (2016) Noncontact Monitoring of Blood Oxygen Saturation Using Camera and Dual-Wavelength Imaging System. IEEE Trans Biomed Eng 63:1091–1098. https://doi.org/10.1109/TBME.2015.2481896
23. Ma G, Zhu W, Zhong J, Tong T, Zhang J, Wang L (2018) Wearable ear blood oxygen saturation and pulse measurement system based on PPG. In: 2018 IEEE SmartWorld, ubiquitous intelligence and computing, advanced and trusted computing, scalable computing and communications, cloud and big data computing, internet of people and smart city innovation (SmartWorld/SCALCOM/UIC/ATC/CBDCom/IOP/SCI). IEEE, pp. 111–116. https://doi.org/10.1109/SmartWorld.2018.00054
24. Gima_Spa: Pulsoximetro da dito OXY-5, https://www.gimaitaly.com/prodotti.asp?sku=34282&dept_selected=620&dept_id=620
25. Casaccia S, Pietroni F, Calvaresi A, Revel GM, Scalise L (2016) Smart monitoring of user's health at home: performance evaluation and signal processing of a wearable sensor for the measurement of heart rate and breathing rate 4:175–182. https://doi.org/10.5220/0005694901750182
26. Jarchi D, Casson A (2016) Description of a database containing wrist PPG signals recorded during physical exercise with both accelerometer and gyroscope measures of motion. Data 2:1. https://doi.org/10.3390/data2010001
27. Nweke HF, Teh YW, Mujtaba G, Al-garadi MA (2019) Data fusion and multiple classifier systems for human activity detection and health monitoring: review and open research directions. Inf Fusion 46:147–170. https://doi.org/10.1016/j.inffus.2018.06.002

Multi Sensorial Stimulation Lab: A New Approach for Severe Dementia

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Abstract The MS-Lab project wants to implement a non-pharmacological method of multisensory stimulation aimed at reducing the sense of discomfort and improving the psycho-behavioral disorders typical of subjects with severe dementia, with the aim of improving the quality of life of patients, verifying effectiveness and safety

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of this method. This technological implementation is made possible by a wide and complex collaboration between organizations and companies with different skills. As described by practice and theory, appropriate sensory stimulation can lead to several improvements, such as: greater initiative of patients, greater vigilance, improvement in mood and interpersonal relations, greater attention and confusional state reduction. Moreover, positive effects could derive from the possible reduction of drugs and/or psychotropic drugs, with consequent reduction of pharmacological side effects and reduction of health costs, as well as decrease in the need for physical restraint. MS-Lab is experimenting a non-pharmacological therapy through a multisensory stimulation and intend to overcome some limits detected in this type of treatment, improving its effectiveness by supporting a framework designed as a complex system of input and output devices driven by an intelligent system able to modulate sensory stimuli according to the continuously measured biological parameters. The project also proposes to define a detailed protocol with an algorithm at the base of a dedicated software, in order to make this experience repeatable, producing data that can be freely used by experts, re-proposing it in a clinical contest or in any other environments to be defined ad hoc. Moreover, a multiplatform software layer will be designed and implemented to support Clinical Decisions (CDSS), supporting caregivers through suitable graphic interfaces on mobile devices, suggesting the most appropriate domains to be stimulated on the basis of current and past clinical parameters acquired from sensors' ecosystem. MS-Lab will be installed at "Casa Amata"—a nursing home located in Taviano (Le), Italy—and at "Casa Sollievo della Sofferenza" —an hospital and Research Institution located in S. Giovanni Rotondo (Fg), Italy— with the aim of conducting simultaneous and co-planned experiments through the proposed treatment able to represent the best answer to the end-user needs.

1 Literature Review

1.1 Healthcare Open Innovation Ecosystems

Healthcare Ecosystems are based on the interactions of individuals and organizations into a complex adaptive environment, where productive relationships need to be managed as part of a complex system and interactions among parts that can "produce valuable, new, and unpredictable capabilities that are not inherent in any of the parts acting alone" [37, p. 746].

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Healthcare ecosystems usually involve a wide number of actors (patients, doctors, nurses, companies and government bodies) that open their innovation processes in order to incorporate knowledge flows originated from or co-produced with external stakeholders—academia, research centers, industry, government, NGOs and public institutions [4, 16, 19, 22, 27].

In recent years, classical approaches in the field of innovation started to include a social dimension of these ecosystems, proposing the so-called "quadruple helix model" [30], where civil society become another cornerstone together to industry, university, and government, with an active role in all the innovation process.

In healthcare ecosystems, economic motivations for innovation are mediated by social motivations, introducing the concept of social innovation, defined as the identification of new ideas able to meet social needs, creating new relations and collaborations [34].

Here, some example of organizational models are described, starting from the assumption that healthcare ecosystem's actors can open up their innovation processes and enter in relationship with external organizations to transfer knowledge.

Two dimensions are described in the Open Innovation paradigm [10]: "Inbound" and "Outbound" Open Innovation [17].

- *Inbound Open Innovation* is the practice of leveraging technologies and discoveries of others, and it requires the establishment of inter-organizational relationships with an external organization with the aim to access their technical and scientific competencies.
- *Outbound Open Innovation* is instead the practice of establishing relationships with external organizations to which proprietary technologies are transferred for commercial exploitation.

Literature has documented the use of different organizational modes through which Inbound and Outbound Open Innovation can be put into practice [31] including networks in which participants retain their knowledge and collaborate informally [47], that are briefly described in Sect. 2.1.

1.2 Current Dementia Therapy

Dementia is a very serious and, unfortunately, frequent pathology, characterized by the progressive decline of intellectual functions, such as: memory, abstract thinking, critical capacity, language, spatial and temporal orientation, with maintenance of the state of vigilance (American Psychiatric Association).

This condition leads to the reduction and then to the loss of autonomy in the most elementary activities of daily life. Very often it involves serious relationship and behavioral problems, for example psychomotor agitation and aggression.

This clinical condition is also very frequent in old age and, only in Italy, there are more than one million of subjects suffering from dementia.

The most common forms of dementia are degenerative and vascular, but there are also other more rare typologies of dementia (due to vitamin deficiencies, thyroid dysfunctions, brain inflammation, brain infections, intracranial tumors, normal pressure hydrocephalus).

The costs of this disease, both on families and on the collectivity, are very high and considering that the prevalence of the disease is greater in old age and that the average age of the general population is increasing, a further expansion of this disease is expected, reaching triple values in the coming decades.

The growing interest of international organizations such as the World Health Organization, the Organization for Economic Cooperation and Development (OECD), the European Union support to the great importance of this issue [34].

For these reasons, the World Health Organization and the International Alzheimer Disease (ADI) in 2016 called "dementia" a world priority of public health.

Current therapies apply only at the degenerative status and consist of a few drugs reimbursed by the National Health System (like in Italy, but also in US) with several symptomatic effects.

These drugs act on some brain neuro-transmitters that are involved in cognitive processes: in particular, they have the ability to enhance cholinergic neurotransmission or to decrease glutamatergic neurotransmission, but these therapies are contraindicated in some subjects, offering few results and determining not negligible collateral effects.

1.3 The Snoezelen Method

Based on the previous pharmacological treatments, our attention turned to non-pharmacological treatments for dementia, with the aim of giving at least an alternative to medical therapies and to reduce spending charged to families and national health systems.

Different non-pharmacological methods are available, that can help in the management of demented patients: Cognitive training, Cognitive rehabilitation, Cognitive stimulation therapy, Snoezelen/multisensory stimulation, Reality Orientation, Reminiscence therapy, Validation therapy, Physical activity, Light therapy, Music therapy, Aromatherapy, Animal assisted-therapy, Doll therapy (modified from Takeda et al. [42]).

These methods apply on patients, but not on diseases and are not able to solve their severe clinical conditions.

An interesting non-pharmacological method is the "Snoezelen method", developed in the Netherlands in 70s. The method is based on the consideration that the main goal is to give to patients the necessary space and time, choosen for themselves.

The goal of Snoezelen is the patient (residents) relaxation with a reduction of pressure and tension experienced by the disabled in the housing groups, because of the constant pressure of the other residents with their peculiarities and possibly disturbing behaviour, like screaming, lashing out etc., that all can cause them tension and stress to hight degree.

Snoezelen is meant like a place where one can leave everything behind and find complete relaxation, based on the principle according to which "*nothing has to be done, everything is allowed*". During the Snoezelen treatment, the patient should be allowed to be himself and to do whatever he likes. The caregiver should therefore distance themselves from their own ideas and let the patient have their own way. For this reason the voluntary intention of the offer is particularly important. Those who do not like, do not have to take further part in Snoezelen [44].

The objectives of this method are rather ambitious and multiple: the most important is to promote relaxation and reduce behavioral disorders and, in particular, psychomotor agitation phenomena.

Some results of studies conducted with this methodology are interesting but not decisive or at least conclusive. Also a Cochrane review concluded for the non evidence of efficacy of multisensory stimulation with the Snoezelen method in subjects with dementia [14].

To overcome such issues we propose to implementing this method, with the help of an innovative technological support.

2 The Proposed Framework

Endogenous or exogenous stimuli can generate or promote in human beings (as also in other superior animals) behavioral reactions that are accompanied by non-behavioral manifestations, which go under the name of neurovegetative manifestations.

While behaviors can be more or less significantly inhibited by our will, neurovegetative manifestations are poorly controlled by the cerebral cortex.

Therefore often endogenous or exogenous stimuli determine a double response: the first non-inhibited neurovegetative, which manifests itself quickly and the second cognitive and behavioral one, which can be at least partially inhibited and which therefore tends to manifest itself later. The two responses (behavioral and neurovegetative) are correlated with each other and among the neurovegetative ones, ergotropic reactions can be considered (mediated by the orthosympathetic noradrenergic nervous system) and trophotropic reactions (mediated by the cholinergic sympathetic nervous system) as correlated and substantially anticipatory of behavior reactions respectively of activation and relaxation [6, 7, 11, 25, 32].

MS-Lab wants to check whether it is possible to exploit this time gap between the onset of neurovegetative manifestations and that of behavioral manifestations to interrupt the process of events that leads to activation (or sometimes apathy).

Our proposal therefore is to collect a series of information relating to neurovegetative parameters, such as: hearth rate (HR), peripheral oxygen saturation (SpO2), body temperature (BT), respiratory rate (RR), arterial blood pressure (ABP), patient's motor status, body impedance, that will be measured in real time during the treatment through miniaturized sensors to be applied to the patient [3, 8, 21, 26, 41].

Sensors should not annoy the patients and the biological parameters should be indicative of changes in the psychic state and predictive of behavioral changes. Then, these data will be used through a special software that will directly manage the device in use and will show them on a monitor display in the form of trends allowing the caregiver to modify the device to be used or the type of stimulus, in order to obtain the best behavioral effect on the patient.

It will therefore be possible to address the most appropriate stimuli both automatically and by the operator.

2.1 Players Interaction Model

Healthcare Ecosystems includes a variety of players with a wide range of interests, conflicting needs, priorities and influence. They can be classified as follows [9]:

- *Regulators*: Ministry of Health, National or Regional Committees who set regulatory guidelines;
- *Providers*: doctors, nurses and other health professionals who provide care in hospitals, doctor's surgeries, nursing homes, and others;
- *Payers*: statutory health insurance, private health insurance, and government agencies;
- *Suppliers*: scientific institutions, universities, pharmaceutical and medical technology companies, who develop new products and treatments; pharmacies and wholesalers, who mostly do resale;
- *Patients*: beneficiaries of care and source of valuable knowledge.

Specifically, patients in Healthcare Ecosystems can represent what Von Hippel [45] called the "lead users", i.e. users of a product that currently experience needs still unknown and who also benefit greatly if they obtain a solution to these needs. Patients gain their insights into how they solve a specific problem and declare their innovation needs. Patients as "lead users" are individuals who had experienced needs for a given innovation (product or process) earlier than the majority of the target market [45].

Literature identifies four categories of networks [46]:

(a) *Technology sector networks* are self-organized, driven by local stakeholders and local businesses with an interest in growing their performances. Market growth and profitability are their purposes.
(b) *Identity-based social networks* arise from a specific need expressed by a class of individuals, and then, are self-organized with a clear vision relating their mission, that is promoting individual benefits and success.
(c) *Government led networks* are created with the determinant role of public institutions, with the final aim to assure regional prosperity.
(d) *Civic and philanthropically enabled networks* are created on a voluntary basis through the involvement of community stakeholders.

According to the finality of this project, "*Identity based social networks*" model has been selected in order to manage information, roles and activities among the involved parties.

This model relates to Healthcare Ecosystems established with the specific mission of developing new products and services ready for the market. The main influent players are SMEs and large firms, in collaboration with universities and research centers. During exploration activities, knowledge flows could be established with non-R&D employees in the same firms. Because firms' main objectives consist in increasing profits, exploitation activities could let to new Intellectual Property (IP) or R&D projects with other active players. Intermediaries are third parties set up by a pool of companies, hospitals and research centers interested in improving their products through scientific collaborations. Examples of Identity-based social networks include ecosystems where mediation activities can be performed by organizations built with the mission of developing new products and innovative technologies, supporting a wide network of private and public entities for patentability analysis and commercial exploitation (Fig. 1).

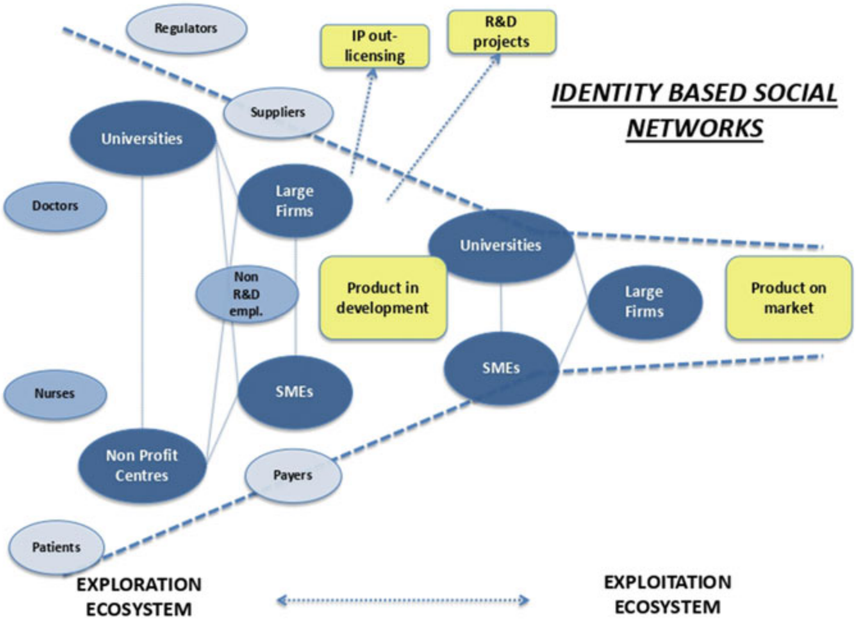

Fig. 1 The "Identity based social network" model [40]

2.2 The Technological Framework

The framework devices will share data and configuration settings by a central platform. This will be based on eResult's OMNIACARE, a multi-functional hardware and software system, specifically developed for the remote monitoring and assistance of frail users.

The OMNIACARE system is modular, and each element carries out certain specific functions, so that the system can adapt itself to different situations and environments in a dynamic manner. It is therefore possible to implement a higher or lower number of features, using or discarding specific elements without compromising the overall operation of the system in any way.

In the project context, OMNIACARE will be used as a software platform designed for a tidy and structured information management, under the form of a web application with a front-end consisting of dynamic pages accessible through web browsers. Starting from the data acquisition, even from external and heterogeneous sources, the platform will ensure efficient processing and management, fostering an automated and functional approach. It will allow interoperability among different systems and, being a software product endowed with very broad characteristics of configurability, scalability and robustness, is apt to act as a middleware integration layer.

2.2.1 Output Devices

The project involves the construction of a multi-sensory room with output devices representing real stimuli within which the patient accompanied by the caregiver can choose and decide how to use the environment itself.

It is the patient that will guide the start of the session and can decide which type of stimulus to approach.

The devices will allow visual, auditory, tactile and olfactory stimulation.

The staff will work in relation to one-to-one and the patient ho will undergo the therapy will be encouraged to experiment the sensory stimuli through output devices that will be made available within the room.

The use of these devices will not be structured or precisely sequential because no particular attentional or intellectual skills of the subjects are required.

The main objectives to reach through this system are:

- stimulate the exploration of the environment;
- establish positive relationships in daily care;
- promote the person well-being;
- supporting relationships with family members;
- facilitate communication and interaction;
- managing oppositional and mood behaviors;
- re-activation of the person;
- reduce non-adaptive behaviors and encourage positive behavior;
- facilitate communication and interaction;

- foster interpersonal relationships.

The stimulations can be unimodal (only auditory, only visual, only olfactive, only tactile) but more frequently multimodal (eg auditory, olfactory and visual at the same time, as to recreate the setting of a specific natural environment) allowing perceptional and emotional evolution. It is not appropriate to use different discordant or independent stimuli at the same time, because this can cause confusion and disorientation; the difficulties in interpreting and managing multiple non-concordant symptoms may be a source of malaise and psychomotor restlessness.

The output devices will therefore allow:

- visual stimulation, through the installation of optical fibers, films that can recall places of interest of the patient or places that favor relaxation of the same, interactive bubble tubes and colored lights;
- auditory stimulations, through the reproduction of sound films or simple-mind music;
- musical selection, through a preliminary listening of the habits of daily life of the patient (they may be, for example, sounds that recall the "noises" of the past life or songs of particular interest for the patient).

All these type of stimulations will therefore be provided through devices such as: video projector, audio equipment containing a selection—on the basis of preliminary interviews aimed to define the "favorite stimuli". In addition, a vibracustical bed will be installed, patented device able to transmit vibrations by means of a transducer applied directly to the bed surface. The vibrational acoustic bed is also equipped with a cable system for the amplification application directly on the subwoofer output.

Through the vibracustical bed, other senses can also be stimulated, including the touch. In fact, the realization of the mattress with spheres in expanded polystyrene will allow, together with the vibration emanating from it, to activate this sense, which will be stimulated also through texture on panels, padded chairs with balls and wraps, special sponges and brushes.

Finally, the sense of smell will be stimulated through the installation of evaporators with integrated relaxing music players, combined with LEDs that use the ultrasound technique, as well as through the use of perfumes emanating from real objects.

2.2.2 Devices Interfacing

As said previously, MS-Lab is based on the OMNIACARE platform, using a Central Server/Local Server concept. The Central Server is the main element of the system. User profiles, medical records, device configurations, patient interactions with actuators: all of such data reside on the Central Server. It also provides the web interface that operators and therapists use to interact with the system, in order to customize exercises and therapy for patients. It is endowed with the following robust inner characteristics:

- hierarchical data structure,

- web-based user interface,
- advanced data navigation, display and search,
- extensive data export functionalities,
- granular user privilege management,
- structured system event management,
- information traceability.
- The central server will collect and make available all data of patients in punctual and aggregate form, by a series of features:
- patient management (personal data, medical history, medical records, current therapies),
- charts for data monitoring (ECG curve, R-R interval, level of physical activity, heart rate, respiratory rate, …),
- comparative analysis of data and curves of vital signs,
- therapy management and stimulus provision,
- storytelling recording of therapy sessions in the multisensorial room,
- agenda setting and patient diary.

OMNIACARE offers a comprehensive list of comparative charts, including ECG curves on equivalent grid graph paper, where the x axis is scaled on 1 mm = 40 ms (25 mm/s). The platform is accessible via any Internet connection, using the most common browsers (Internet Explorer, Mozilla Firefox, Google Chrome …).

The Local Server is the element closest to the patient setting. It is essentially a data collector and gateway. It can launch and controls interaction nudges and stimuli, but most importantly, it acts as the hardware element that interfaces with detection sensors and external devices, managing all of the diverse communication protocols at once. The local server collects data from the devices and provides configuration data exchange to properly manage them. It also consolidates and conditions data and sends them to the central server, according to the established rules and timing, while at the same time providing warning or alerts in case of a detected anomaly [11, 20, 38].

2.2.3 Multiplatform Software Layer for Clinical Decisions Support (CDSS)

The MS-Lab framework uses also a Clinical Decision Support Systems (CDSS) tool.

CDSS [23, 36] are quickly becoming essential tools for healthcare providers as the volume of available data increases alongside their responsibility to deliver value-based care.

CDSS are designed to help sift through enormous amount of digital data to suggest next steps for treatments, alert providers to available information they may not have seen, or catch potential problems/issues such as dangerous interactions. Generally speaking, a CDSS is a piece of software which takes a set of input information about a patient's clinical situation (in our case coming from wearable sensors worn by the end-user as reported in the Input Devices Section described above during the cognitive stimulation process) and produces an output that can help practitioners to make decisions.

A CDSS is employed to reduce human error, to automate routine tasks, to address information overload, and to make the clinical guidelines available and accessible to the medical staff. In this context, the aim of the CDSS is related to the possibility of defining an automated logical structure that analyzes the behavioral and bio-humoral responses (respiratory frequency, skin impedance, mean arterial pressure, skin temperature, patient's motor state) of the end-user during the process of cognitive stimulation with a specific output device. The system is therefore able to relate the stimulus with the clinical response defining a cause-effect model, if present. Therefore, according to a customized Graphic User Interface defined for this purpose, the CDSS provides accurate indications to the clinical operator who oversees the process, in order to address the set of stimuli for which the end-user exhibits different bio-humoral parameters with respect to the normal ranges exhibited in the absence of the same stimuli. The whole process is aimed at providing customized indications based on the knowledge transferred to the specific end-user in order to practice cognitive stimulation therapies that have a positive impact on safety for all the involved subjects.

From the technological implementation point of view, statistical approaches (Bayesian Inference techniques) and learning schemes (Neural Networks) are implemented to define punctual metrics (referring to the specific session of cognitive stimulation) and global metrics (referring to the prior of the specific end-user). In particular, the bio-humoral signals, associated with multi-sensory stimulation, are analyzed in both time and frequency domains. In time domain, statistical and geometrical nonlinear approaches such as Poincaré plot analysis [39] are used to graphically represent correlation between physiological variabilities in time-series data. In frequency domain, parametric and nonparametric methods are used to estimate the power distribution over frequency of physiological signals, in particular those methods based on fractal dimension estimation [13] and on long short-term memory recurrent neural networks [24].

3 The Framework Validation Methodology

3.1 Patients Selection Criteria

The testing activity will validate or not the proposed method, allowing the continuation of that part of research and supporting the efficacy of multisensory stimulation as an alternative and non-complementary alternative non-pharmacological therapy.

Relating to the selection stage, 24/30 subjects with severe dementia will be recruited in the two involved centers: Casa Amata srl and Casa Sollievo della Sofferenza.

To guarantee the patients' safety, the Ethical Committee authorization—territorially competent—will be asked, through a detailed description of the study, in particular of the activities expected and possible benefits and risks for patients.

The main testing phases are described below:

1. The participation will be proposed to all the patients hosted at the Casa Amata nursing home and at "Casa Sollievo della Sofferenza" hospital. Who will accept will be subjected to neuropsychological test, through the MMSE "Minimentale Statement Examination" administered by a psychologist. Patients with an MMSE score lower than 10 are enrolled in the study. Randomization will follow, which will be carried out using a unique random number generator set to generate numbers from 1 to 30.
2. Randomly subdividing enrolled patients into two groups: "Experimental Group", which will undergo two weekly non-pharmacological therapy sessions for the duration of 16 weeks and a re-orientation session in the twentieth week (each session will have a duration of 30 min) and a "Control Group" that will be treated with ordinary occupational activities, in the same timescales envisaged for the Experimental Group.
3. Customization of the sessions: through the submission of the enrolled patients to a first evaluation / orientation session. This session is the basis of the recognition of the preferred stimuli, intended to be more appropriate during the subsequent sessions.
4. During the sessions, MS-Lab project will measure parameters like: mortality, cardio and cerebrovascular events, behavioral condition (true end-point). In addition, bio-humoral parameters (respiratory frequency, skin impedance, mean arterial pressure, skin temperature, motor state of the patient) will be measured for the integrated assessment of the state of stress during the session and the correlation of each of them will be analyzed with the end point.

3.2 Clinical and Biological Parameters

Inflammation may be an important mechanism underlying dementia. However, it is unclear if the inflammatory response is associated with the onset of may be the outcome of dementia.

The incidence of dementia was associated with an increase in cytokine levels, when other conditions that can accelerate inflammation occur, such as amyloid plaques and neurofibrillary tangles, depression [1], genetic conditions [18], infections [36], trauma, and vascular events [43], an immune sensitization may take place, worsening the cognitive impairment.

Dementia may lead changes in serum cytokine levels and inflammation, rather than resulting from elevated pro-inflammatory cytokines. It has been reported that patients with dementia, particularly at advanced stages, are at a higher risk for developing stroke and depression.

In a study by Kim et al. [29], incident dementia was significantly associated with increases in cytokine levels during the study period.

Our project, during the sessions, involves the measurement of parameters consisting of: mortality, cardio and cerebrovascular events, these data will act as a safety benchmark.

The bio-humoral parameters for the integrated assessment of the state of stress during the session will also be measured and the correlation of each of them with the endpoint will be analyzed.

The various assessments will be carried out at time 0 (before the start of the study), 8 weeks from the start of the study, 16 weeks (end of the study), follow up (twentieth week from the beginning of the study).

Moreover a study will be conducted in order to detect expression levels of a panel of serum/plasma markers on a cohort of patients subjected to multisensory stimulation. They include: fatty acid binding protein (FABP), beta 2 microglobulin (B2M), pancreatic polypeptide Y (PPY), soluble tumor necrosis factor receptor 1 (STNFR1), CRP, VCAM 1, thrombopoietin, α2 macroglobulin, eotaxin3, tumor necrosis factoralpha (TNFα) IFN-g, which is among the most important Th1 pathway cytokines, tenascin C (TNC), ILJ5, IL6, IL7, IL10, IL18, I309, FVII, thymus and activation regulated chemokine (TARC), serum amyloid A (SAA), and intercellular cell adhesion molecule 1.

The polycentric experimentation could acquire consistent samples and data. That will allow us to continue this research line, in order to disseminate this new therapeutic approach to formal and informal caregivers and, above all, to improve the quality of life of patients and families.

The clinical and biological parameters monitored will concern: mood, behavior and cognitive state, therefore behavioral, multidimensional and bio-humoral assessment. The behavioral assessment of the subject will be carried out through the NPI scale "Ucla Neuropsychiatric Inventory" and Cornell Scale for Depression in Dementia (CSDD) 11 while the bio-humoral scale will take place in real time during the sessions (thanks to the framework that the project will propose to implement) and will allow to evaluate the immediate improvements and, within each session, evaluate the achievement of the improvement peak, in order to reduce or lengthen the time of each session. Then the end user will proceed to the behavior-mental evaluation using NPI that will be associated to the evaluation of the bio-humoral parameters, according to the following protocol: (a) time 0 (before the beginning of the study); (b) 8 weeks from the start of the study; (c) 16 weeks (end of study); (d) follow-up (twentieth week from the start of the study).

This evaluation will allow us to verify any behavioral improvements achieved thanks to multisensory stimulation. The multi-dimensional evaluation will be performed through the following tests:

- functional status will be assessed through Activities of Daily Living (ADL) and Instrumental Activities of Daily Living (IADL) tests,
- the cognitive status will be evaluated through the Short Portable Mental Status Questionnaire (SPMSQ),

- the comorbidity will be examined through the Cumulative Illness Rating Scale Comorbidity Index (CIRS-CI),
- the statutory tax will be assessed through the Mini Nutritional Assessment (MNA),
- the risk of developing pressure sores will be examined by the Exton-Smith Scale (ESS),
- the number of drugs used will be registered, and
- the cohabiting status of the patients.

4 Conclusions

An implementation project of the Snoezelen method is expected to have considerable interest, both in those who are attempting to implement it, and in those who are aware of it and have a more practical than theoretical interest.

Several problems related to the implementation of the framework have been discussed by the project partners during the operational meetings, and will guide the project to reach the expected results. The main problems relate to the invasiveness of the sensors, which must also be used by agitated subjects. In this case, the main difficulty relates to the combination of miniaturization, non-invasiveness and reliability of these devices.

Furthermore it is pointed out that the realization of the project includes different stages of optimization of the stimuli proposed during the multisensory stimulation and therefore levels of complexity.

A higher level of complexity involves the creation of a software system with artificial intelligence capabilities that allows a particular personalization of the proposed stimuli. In particular, starting from the personal anamnestic data, supplemented by the neuro-vegetative data recorded in real time on the patient, the CDSS tool can offer the most advantageous stimuli, directly managed by a software able to control both the passage from one actuator to another (with mixed mode: directly operated or by means of an indication given to the operator), and the activity of the individual actuators.

The proposed methodology can increase benefits compared to the classic multisensory stimulation method, and in particular this method can be useful in decreasing behavioral disorders, in promoting relaxation, in favoring exploration of the environment, in promoting contacts and interpersonal relationships, in encouraging reactivation in the event of apathy, in improving the relationship between the patient and his family.

In order to reduce the project complexity, the system will not correlate the neurovegetative data, avoiding to and act directly on the actuators. By this way, the data collected by the sensors will be displayed on the screen so that the operator can take them into account and direct the patient towards a different type of stimulus if deemed more appropriate.

Therefore, MS-Lab intends to proceed gradually from the lower level of complexity to a greater level. In the first phase of this technological implementation of multi-sensory stimulation, a limited sensor with selected parameters will be used.

The resolution of all the technical problems that will emerge during the time will allow to tackle levels of increasing difficulties until the realization of the project in its most complete, complex and technologically advanced form.

In the case of success of this study, a second step is foreseen, expanding the survey to subjects with moderate dementia, with different psychiatric pathologies, including subjects in developmental age.

References

1. Akiyama H, Barger S, Barnum S, Bradt B, Bauer J, Cole GM et al (2000) Inflammation and Alzheimer’s disease. Neurobiol Aging 21:383–421
2. Almirall E, Casadesus-Masanell R (2010) Open versus closed innovation: a model of discovery and divergence. Acad Manag Rev 35(1):27–47
3. Appelhans BM, Luecken LJ (2006) Heart rate variability as an index of regulated emotional responding. Rev Gen Psychol 10(3):229–240
4. Ardito L, Messeni Petruzzelli A (2017) Breadth of external knowledge sourcing and product innovation: the moderating role of strategic human resource practices. Eur Manag J 35(2):261–272
5. American Psychiatric Association (1952) Manuale diagnostico e statistico dei disturbi mentali quinta edizione DSM V. Raffaello Cortina Editore, pp 687–746
6. Beauchaine T (2001) Vagal tone, development, and Gray’s motivational theory: toward an integrated model of autonomic nervous system functioning in psychopathology. Dev Psychopathol 13(2):183–214
7. Berntson GG, Cacioppo JT, Quigley KS (1991) Autonomic determinism: the modes of autonomic control, the doctrine of autonomic space, and the laws of autonomic constraint. Psychol Rev 98(4):459
8. Berntson GG, Cacioppo JT, Quigley KS (1993) Respiratory sinus arrhythmia: autonomic origins, physiological mechanisms, and psychophysiological implications. Psychophysiology 30(2):183–196
9. Bessant J, Künne C, Möslein K (2012) Opening up healthcare innovation: innovation solutions for a 21st century healthcare system. AIM Research, United Kingdom
10. Bianchi M, Cavaliere A, Chiaroni D, Frattini F, Chiesa V (2011) Organisational modes for open innovation in the bio-pharmaceutical industry: an exploratory analysis. Technovation 31(1):22–33
11. Cacioppo JT, Tassinary LG, Berntson GG (2007) Handbook of psychophysiology. Cambridge University Press, New York, NY
12. Casacci P, Pistoia M, Leone A, Caroppo A, Siciliano P (2015) Alzheimer patient’s home rehabilitation through ICT advanced technologies: the ALTRUISM project. In: Andò B, Siciliano P, Marletta V, Monteriù A (eds) Ambient assisted living. Bio-systems and biorobotics, vol 11. Springer, Cham
13. Chang S, Li SJ, Chiang MJ, Hu SJ, Hsyu MC (2007) Fractal dimension estimation via spectral distribution function and its application to physiological signals. IEEE Trans Biomed Eng 54(10):1895–1898
14. Chung JC, Lai CK (2002) Snoezelen for dementia. Cochrane Database System Rev (4)

15. Chesbrough H (2003) The logic of open innovation: managing intellectual property. California Manag Rev 45(3):33–58
16. Chesbrough H, Bogers M (2014) Explicating open innovation: clarifying an emerging paradigm for understanding innovation. In: Chesbrough H, Vanhaverbeke W, West J (eds) New frontiers in open innovation. Oxford University Press, Oxford, pp 3–28
17. Chesbrough H, Crowther AK (2006) Beyond high tech: early adopters of open innovation in other industries. R&D Manag 36(3):229–236
18. Cribbs DH, Berchtold NC, Perreau V, Coleman PD, Rogers J, Tenner AJ et al (2012) Extensive innate immune gene activation accompanies brain aging, increasing vulnerability to cognitive decline and neurodegeneration: a microarray study. J Neuroinflamm 9:1–18
19. Dahlander L, Gann DM (2010) How open is innovation? Res Policy 39(6):699–709
20. Davis MM, Freeman M, Kaye J, Vuckovic N, Buckley DI (2014) A systematic review of clinician and staff views on the acceptability of incorporating remote monitoring tech-nology into primary care. Telemed E-Health 20:428–438
21. Dawson ME, Schell AM, Filion DL (2007) The electrodermal system. In: Handbook of psychophysiology, vol 2, pp 200–223
22. Enkel E (2010) Attributes required for profiting from open innovation in networks. Int J Technol Manag 52(3/4):344–371
23. Farooq K, Khan BS, Niazi MA, Leslie SJ, Hussain A (2017) Clinical decision support systems: a visual survey
24. Faust O, Hagiwara Y, Hong TJ, Lih OS, Acharya UR (2018) Deep learning for healthcare applications based on physiological signals: a review. Comput Methods Programs Biomed 161:1–13
25. Goldstein S, Naglieri JA, Princiotta D, Otero TM (2014) Introduction: a history of executive functioning as a theoretical and clinical construct. In: Handbook of executive functioning. Springer, New York, NY, pp 3–12
26. Grossman P, Taylor EW (2007) Toward understanding respiratory sinus arrhythmia: relations to cardiac vagal tone, evolution and biobehavioral functions. Biol Psychol 74(2):263–285
27. Huizingh EK (2011) Open innovation: state of the art and future perspectives. Technovation 31(1):2–9
28. Szeto JYY, Lewis SJG (2016) Current treatment options for Alzheimer's disease and Parkinson's disease dementia. Curr Neuropharmacol 14:326–338
29. Kim JW, Stewart R, Kang HJ, Bae KY, Kim SW, Shin IS, Yoon JS, Kim JM (2018) Longitudinal associations between serum cytokine levels and dementia. Front Psychiatry. Nov 19; 9:606
30. Leydesdorff L (2012) The triple helix, quadruple helix, …, and an N-tuple of helices: explanatory models for analyzing the knowledge-based economy? J Knowl Econ 3(1):25–35
31. Lichtenthaler E (2004) Organising the external technology exploitation process: current practices and future challenges. Int J Technol Manag 27(2–3):255–271
32. McEwen BS (2008) Central effects of stress hormones in health and disease: understanding the protective and damaging effects of stress and stress mediators. Eur J Pharmacol 583(2–3):174–185
33. Mulgan G, Tucker S, Ali R, Sanders B (2007) Social innovation: what it is, why it matters and how it can be accelerated. https://eureka.sbs.ox.ac.uk/761/1/Social_Innovation.pdf. Accessed on 23 March 2017
34. Musen MA, van Bemmel JH (1997) Handbook of medical informatics. Bohn Stafleu Van Loghum, Houten, the Netherlands
35. OECD (2018) Care needed: improving the lives of people with dementia. In: OECD health policy studies. OECD Publishing, Paris
36. Perry VH, Cunningham C, Holmes C (2007) Systemic infections and inflammation affect chronic neurodegeneration. Nat Rev Immun 7:161–167
37. Plsek PE, Wilson T (2001) Complexity, leadership, and management in healthcare organisations. BMJ 323(7315):746–749
38. Raimondi G, Casacci P, Sancesario G, Scordamaglia B, Melchiorri G, Pistoia M (2017) Telemedicine for dementia-affected patients: the AAL-ACCESS project experience. In: Cavallo

F, Marletta V, Monteriù A, Siciliano P (eds) Ambient assisted living. ForItAAL 2016. Lecture notes in electrical engineering, vol 426. Springer, Cham

39. Satti R, Noor-Ul-Hoda Abid MB, De Rui M, Garrido M, Rauofy MR, Montagnese S, Mani AR (2019) The application of the extended Poincaré plot in the analysis of physiological variabilities. In: Frontiers in physiology, vol 10
40. Secundo G, Toma A, Schiuma G, Passiante G (2019) Knowledge transfer in open innovation: A classification framework for healthcare ecosystems. Bus Process Manag J 25(1):144–163
41. Society for Psychophysiological Research Ad Hoc Committee on Electrodermal Measures, Boucsein W, Fowles DC, Grimnes S, Ben-Shakhar G, Roth WT, Filion DL et al (2012) Publication recommendations for electrodermal measurements. Psychophysiology 49(8):1017–1034
42. Takeda M, Tanaka T, Okochi M, Kazui H (2012) Non-pharmacological intervention for dementia patients. Psychiatry Clin Neurosci 66(1):1–7
43. Tarkowski E, Rosengren L, Blomstrand C, Wikkelso C, Jensen C, Ekholm S et al (1997) Intrathecal release of proand anti-inflammatory cytokines during stroke. Clin Exp Immunol 110:492–499
44. Verheul A (2005) Fundamental philosophy of Snoezelen–historical backround, planning and concept. In: Mertens K, Verheul A (eds) Teoksessa Snoezelen–application fields in practise. ISNA, Germany and the Netherlands, pp 25–54
45. Von Hippel E (1986) Lead users: a source of novel product concepts. Manage Sci 32(7):791–805
46. Walshok ML, Shapiro JD, Owens N (2014) Transnational innovation networks aren't all created equal: towards a classification system. J Technol Trans 39(3):345–357
47. Williamson PJ, De Meyer A (2012) Ecosystem advantage. California Manag Rev 55(1):24–46

Smart Living Services

Technological Infrastructure Supports New Paradigm of Care for Healthy Aging: The Living Lab Ausilia

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Abstract Living labs are spaces where public and private stakeholders work together to develop and prototype new products, technologies and services in real environments embedded in the community or market place. This paper outlines the approach chosen by AUSILIA (Assisted Unit for Simulating Independent Living Activities), a living lab established in Provincia Autonoma di Trento in 2016 to develop an innovation model for taking care of the elderly or disabled patient by fusion of technology innovation and patient centered integrated care approach. AUSILIA goal is triple: i. to provide an innovative framework based on augmented virtual reality for occupational therapy in ageing and fragile individuals; ii. to help people who are losing autonomy and independence living at home reducing care burden; iii. warrant continuous innovation through the mixed contribution of the academy and private enterprise. The paper describes the specific solutions adopted for the three objectives, reporting an implementation example for each of them.

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1 Introduction

By 2050, the global population of older persons is projected to more than double its size in 2015, reaching nearly 2.1 billion. This phenomenon is leading to an exponential growth of chronically ill persons with disabilities at motor and/or cognitive level, accompanied by a progressive lengthening of life expectancy in chronic conditions. This will trigger a rapid increase in demand for care, while healthcare systems are dealing with depletion of resources. For these reasons, a major challenge is the development of low-cost and efficient solutions without compromising care, ensuring equity of access to healthcare services for everyone. This growing demand for qualified services related to ageing require a higher convergence of intents between all the possible stakeholders.

In this scenario the Provincia di Trento, in 2016, launched AUSILIA, a collaborative project involved the Local Health Trust (APSS) and a number of Engineering Department of the University of Trento, but open also to cooperation with private stakeholders, as health and care product and service developers. AUSILIA (Assited Unit for Simulation Independent Living Activities) is an innovative approach aimed to enable the personalization of care paradigm by identification of the best set of supportive technologies to help in recovery self-sufficiency and ensuring independent living at home [1]. AUSILIA has been realized at Villa Rosa hospital, an APSS premise located in Pergine Valsugana, Trento, Italy. Based on the strict collaboration of clinical and engineering professionals it leverages on the availability of an apartment with a specifically designed home automation system, a reconfigurable gym, and an engineering laboratory. The smart apartment and the gymnasium are equipped to monitoring patients daily life and testing of architectural, ergonomic and technological solutions. With a surface area of approximately 66 m^2, the apartment has one kitchen-living room (Fig. 1), one bedroom and one bathroom. It has been partially refitted to satisfy the needs of persons with physical, sensory and cognitive difficulties while performing basic Activity of Daily Living (ADL) as for example toilet hygiene, bathing, showering, dressing, self-feeding, etc., and "instrumental" ADL (e.g.. cooking, housekeeping, etc.) [2]. The aim is to allow the patient to live in the structure for a medium-short period (typically from 1 to 4 days) in a fully realistic environment where he can learn the use of a set of architectural solutions and assistive technologies potentially suited to his needs evaluating their use at home.

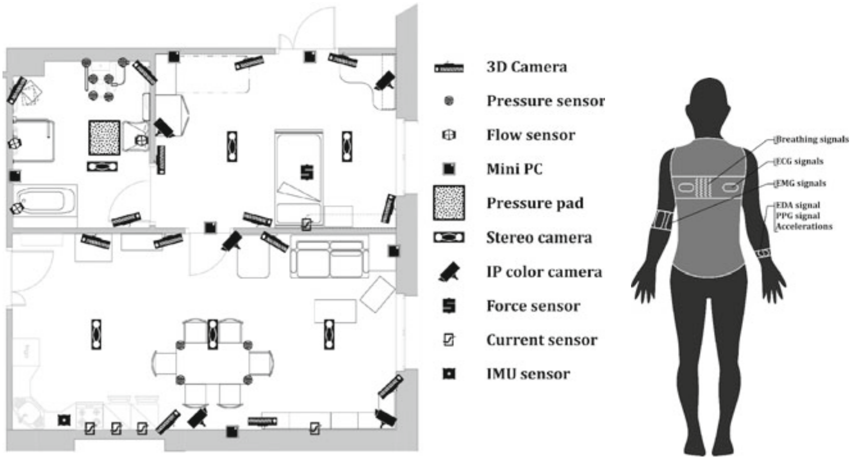
Located in a zone of approximately 372 m^2, the Gymnasium is a flexible space equipped with dedicated functional areas for the evaluation of the users abilities while performing ADL. The main parts are the Bathroom Area, the Kitchen Area, the Door Area, the Handles Area and the Stairs Area. They are equipped with elements of variable configuration. In addition, the gym is integrated with standardized items (e.g.. Ramps, Slide Slope, Steps, Flooring Area, etc.) for the evaluation of the mobility related skills of the user [3]. The main function of trial gymnasium is to allow the assessment of patients abilities within ad hoc domestic spaces where different and re-configurable Ambient Assisted Living (AAL) technologies can be tested in order to find the best fitting configuration for their comfort.

Fig. 1 The kitchen area of the smart apartment of AUSILIA

The above described complementary setting aimed to help people who have experienced deterioration in their health and/or have increased support needs to relearn the skills required to keep them safe and independent at home. Additional marked point of AUSLIA is the continuous technological updating to warrant state of the art and sustainable assistive solutions. Thus, it results crucial for the living lab the link with third parties involved in production and delivery of assistive devices and personal care services. In this paper these triplicate challenges (1. Occupational Therapy; 2. Independent living at home; 3. Sustainability of AUSILIA model) of AUSLIA living lab will be described reporting explicative examples.

1.1 ICT Infrastructure

A distributed infrastructure of sensors and cameras was designed and included in these environments. The objective was the measurement of interactions among the monitored patient and the environment, furniture and objects. Additionally, following the paradigm of the Body area Network, [4] a set of wearable sensors were employed to monitor physiological parameters useful in assessing stress and fatigue levels of the patient [5]. These wearable sensors are a Smartex T-Shirt which provides the breath rate and the sweat level of the patient, an Empatica E4 which provides the hearth rate and a Myo sensor which provides measurements on the muscular activity of the forearm, useful in understanding the capabilities of the patient in manipulating objects (the measurement is correlated to the force applied by the hand in grasping/



(a) (b)

Fig. 2 Sensors distribution in AUSILIA smart apartment for monitoring ambient related physiological status and subjects movements

holding/moving an object). The Interaction-related sensors are instead composed of accelerometers, Punctual Pressure sensors and Pressure matrices. The accelerometers are fastened to different objects, the objective is the measurement of manipulation capabilities by analyzing tremors and trajectories (for short tracks) imposed by the patient while performing actions related to a specific object (toothbrush, glass, razor, etc.). Punctual Pressure sensors are placed under the seats to measure the distribution of the weight of the patient, his stability (in space and time) and evaluate if the patient applies forces while standing from a chair. Pressure matrices are installed to measure the stability of the patient while standing and performing tasks related to his activity in front of designated positions (f.e. sink, mirror, kitchen). Moreover, a series of stereo cameras (14) and some IP cameras (5) have been installed within the environments to monitor, offline and in real-time, the interactions with the sensorized objects and to evaluate the patients' actions in order to objectify the clinical evaluation as we will see later. An example of these distributed infrastructure is shown in Fig. 2, where it can be seen the apartment plant and an example of how the wearable sensors are worn.

1.2 MQTT Broker

The distributed sensors infrastructure above described is orchestrated by a MQTT-based system architecture [6]. The MQTT (MQ Telemetry Transport protocol) protocol uses a broker core component to allow publishers and subscribers in the system to communicate in a bidirectional, asynchronous message forwarding fashion, with

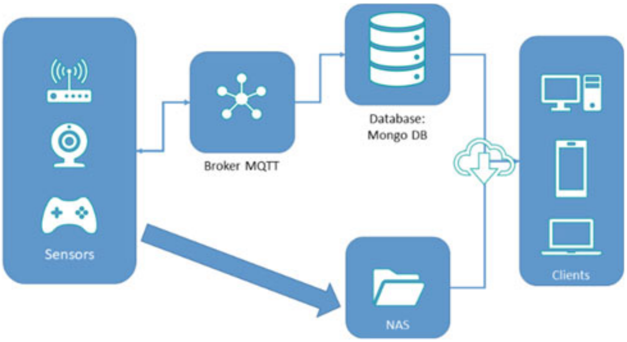


Fig. 3 The block schema of the ICT recording infrastructure of AUSILIA

different levels of Quality of Service (QoS). An explanatory scheme of the role of the broker together with the publish/ subscribe mechanism in the AUSILIA infrastructure can be seen in Fig. 3.

In the AUSILIA infrastructure, each relevant piece of information coming from each sensor is archived in a Network Attached Storage (NAS) and can be accessed through a Mongo DB database. The MQTT broker can communicate with the database in order to fetc.h the position of each datum in the NAS, in order to allow the subscribers to have access to it or for the publishers to write in it.

1.3 *Identification and Tracking*

As described a network of synchronized IP cameras is used to save video snapshots of the patients activities, which could be exploited in the future to build an automatic activity recognition system. Anyway to filter out only relevant information from all the sensors in the system in order to optimize memory usage in the NAS, it was necessary to find a solution for patient identification and re-identification among the different cameras. We exploit Redmon et al.s method [7] for real-time object detection to fetc.h the 2D position of each person in the environment from each camera "c ∈ C." Then, we exploit the infrared information coming from the stereo cameras in order to identify the patient, which is the only one not wearing high-visibility pieces of clothing. For each bounding box b_c detected by the AUSILIA detector, we filter out and count the number of pixels with reflection value ρ_{b_c} over a threshold T and assume that the patient is seen by cameras $c \mid \rho_{b_c} \in \min_{\forall c \in C}(\rho_{b_c})$.

2 Augmented Virtuality for Occupational Therapy

With respect to the standard pathway (see below), mainly based on the direct observation of the patient by the therapist, the novelty brought in AUSILIA comes from the technological infrastructure included in the environment. This constitutes an aid for the therapist in observing the actions performed by the monitored patient during his independent living inside the apartment, or the execution of specific tests in the gymnasium. First of all, that enables the therapist to be delocalized from the action, minimizing his influence on the patient. Second, the combination of measurements and data aggregation process enables a more objective assessment of (a) (hidden) interactions among the patient and the environment (applied forces, the distribution of the body weight, precision of the movements and so on) and (b) the monitor of his physiological status (fatigue, stress, effort). The data collected in this manner, and their visualization through Augmented Virtuality, offer a much more precise and objective method to analyze actions. These can be seen again and again using dedicated interfaces, removing the time constraint, but also including multiple data in the scene at the same time. Than enhances the perception of what the patient did, empowering the capabilities of the therapist in noticing details and behaviors that may result difficult to be perceived in a direct, single and mainly visual driven, observation. Furthermore, the capabilities in storing multi-physical data enables the comparison of similar actions but achieved in different operative conditions, for examples using different assistive solutions, or before and after a rehabilitative treatment. The effectiveness of the process and the improvements for the patient can be in this way assessed objectively, resulting in optimized prescriptions, a shorter hospitalization time, reduced costs for the community and a potential better quality of life for the patient thanks to a better match between his needs and identified technological aids.

2.1 AUSILIA Pathway

The generation of personal plan of care, based on high and consolidated standards of care, is the basic principle of AUSILIA clinical paradigm. Therefore, after an initial phone screening which aims to gather first indications, the individual with a disability undergoes a physiatrist assessment followed by an interview with an occupational therapist to determine the individual competencies and define his/her primary needs and that of his/her caregiver. This is carried out using the Canadian Occupational Performance Measure (COPM). It is standardized semi-structured interview that allows the therapist to identify the activities most important to the individual, thus activities which he/she wants to do, needs to do or is expected to do, but cant do, doesnt do or isnt satisfied with the way he/she does. Hence, the individual defines, in order of priority, the daily activities problematic that he/she would like to perform more independently. At the end of the interview, the person is asked to rate their level of performance and satisfaction regarding these activities on a 10-point scale [8].

Subsequently, an initial observation of the ADL identified as a priority is performed, using the clinical assessments described below. Furthermore, the patient wears an undershirt that measures heart frequency, respiratory frequency, and respiration/sweating while the registration and sensor systems installed in the apartment, register and archive data and video clips, also in 3D, that can be subsequently reanalyzed. After this initial observation and assessment, the health care personnel complete an Initial Individual Reablement Project that is shared with the individual as well as his/her caregiver, which foresees that the individual, alone or with a caregiver, lives in the AUSILIA apartment for some time, which can range from 1 to 4 days. During this stay the individual and his/her caregiver perform their normal daily routines: prepare lunch, eat, tidy up the kitchen, rest, read, watch tv, go to the bathroom, perform personal hygiene, take a shower/bath and more.

In this manner the person can experiment the spaces, furniture, devices and assistive technology in an ecological environment. While they are performing these activities the individual and potentially also his/her caregiver wear the undershirts mentioned above. When a personalized solution for the individual cannot be realized in the apartment, it is actualized "ad hoc" in the various configurable areas of the gymnasium. Daily activities data and images are registered to assist in identifying the most appropriate solution. At the end of the AUSILIA pathway the interdisciplinary team can reexamine the more significant moments of the individuals stay in AUSILIA and make more objective the proposals made in the Final Individual Reablement Project, which provides precise indications regarding modifications of spaces, elimination of barriers, introduction of proactive support [9] or adaptive aids/technology/ together with a hypothesis of costs, contributions and deliverability by the public health board.

The team remains available to accompany the individual during the realization phase of the project and performs a follow-up at 3, 6, and 12 months.

2.2 Software Interfaces for Occupation Therapy

Two software interfaces were designed for the therapist to access recorded data: (a) a Web Dashboard and (b) an Augmented Virtuality Interface. The first, designed to be accessible from remote (web-based), provides an overview of the activities performed in the apartment. Here are presented the measurements in the form of plots and temporal trends. The latter, optimized to visualize specific actions and the associated set of measurements all in once, exploits virtual reality headset to provide an immersive feeling to the therapist in the observation of the data.

2.2.1 Web Dashboard

We developed a web-based, secure dashboard with the help of the clinicians and tailored to their needs, to allow the users to be able to actively use the system and interpret al.l the data coming from the different sensors. By using an interactive

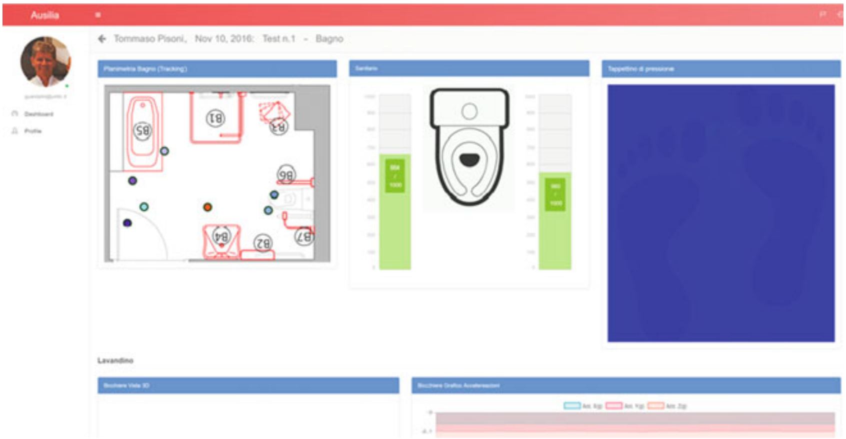


Fig. 4 Dynamic, web-based visualization of different kinds of data as extracted from the environmental sensors

software lifecycle model, the clinicians are allowed to continuously ask for new features integration into the interface or different visualizations for different data kinds. The dashboard provides the control on all performed activities, dividing them accordingly to the room or to the time in which they took place. As example, Fig. 4 shows the organization of the interface for the bathroom and related measurements.

2.2.2 Augmented Virtuality Interface

A custom designed User Interface (UI) was created to visualize in detail specific actions recorded in the apartment. This is usually accessed after an initial screening with the previous interface, identifying the time span and the room to visualize.

As presented in [10, 11], the interface foresees the data aggregation and contextualization by showing synchronous measurements [12] directly in place in which these were collected. A virtual copy of the apartment was created, and inside such environment the 3d point cloud and other measurements are displayed.

As showed in Fig. 5, multiple sensory elements are exploited for monitoring patient posture and movement as well as ambient interactions and physiological status. Data are presented both in visual and auditive media. The UI offers the possibility of controlling time and space, allowing in this sense the navigation of the observer inside these domains: by moving into unlimited point of views, and by playing the same dataset over and over, in slow motion, fast forward or by freezing the reproduction at a specific frame.

The therapist can interact with the data using a physical joystick (HTC Vive) that is also shown inside the UI. He can enable or disable measurements and plots, can interact with them by drag-and dropping a cursor to fast forward the reproduction of the frames accordingly to the data displayed. That represents a key feature since

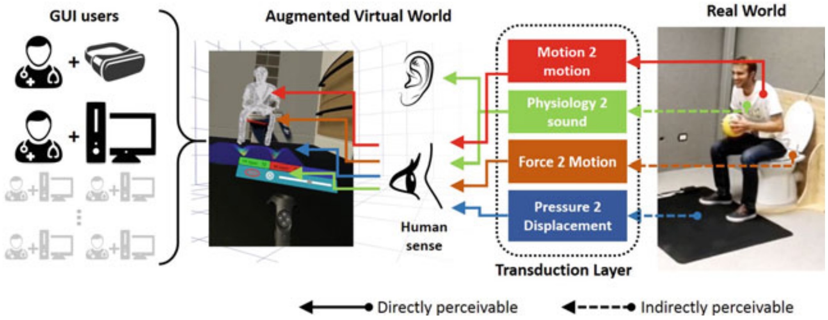


Fig. 5 Schematic representation of the sensory structure included in the User Interface to display and represent multi-physical data

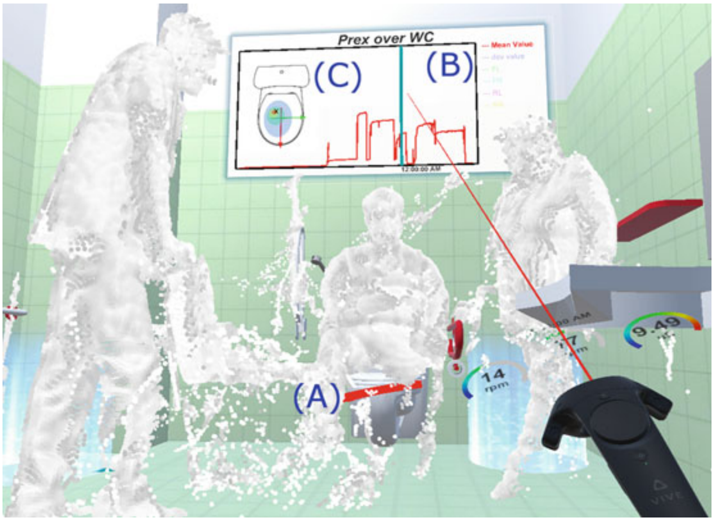


Fig. 6 Example of the user interface showing the data in the form of: a 3d point cloud, physiological parameters, and environmental measurements. The last can be shown as: **a** objects, **b** charts, and **c** schematic representation

it enables an easier recognition of particular events, usually marked by noticeable changes in the measurement trends in time.

Figure 6 reports an example in which 3 different visualization types that are available at UI level [11]: as augmented physics (A), trend over time (B) and average value (C). For this specific case, the distribution of the body weight, related to the self- balance capabilities of the patient, are presented as an objective information to the therapist, helping him in assessing if the transfer from the wheelchair to the toilet seat was achieved properly, and safely, or not.

3 Ausilia Clinical Assessment and Scales

At the end of the observation phase, composed by direct observation, a period in the apartment, gym and the successive clinical analysis by mean of the aforementioned interfaces, the clinical assessment is carried out using the Performance Quality Rating Scale (PQRS). This scale analyses the completeness and quality of the observed occupational performance. It is a 10-point observation-based rating scale, with 1 indicating that no activity criteria is met, and 10 indicating that all activity criteria are met with good quality. It can be used with any activity and provides an objective measure of actual performance. It is the generic rating scale, with good inter-rater reliability (0.71–0.77), and high test-retest reliability (>0.80) [13]. Each activity is described using motor and process skills with their relative descriptors of efficacy, safety, assistance and effort [14].

At the end of the pathway, the COPM and PQRS will be administered a second time, and qualitative description documented again to allow a before/after comparison.

A fundamental passage in the AUSILIA pathway is the follow-up, as it allows the team to verify the appropriateness of the technological and architectural solutions proposed and their impact on the quality of life and autonomy of the individual and his/her family.

4 The Customized Design of AUSILIA

The purpose of the functional areas, both those available in the smart apartment and those reproduced in the gymnasium, is to obtain parameters, data and information in order to support the designer appointed to adapt or redesign the home of the AUSILIA patient. To obtain information and new knowledge in terms of spaces, furniture, aids and technologies, is a remarkable support for the customized design of the different domestic areas [15]. The customized design can be developed for different levels of interventions and solutions that are variable according to the specific needs of the user. It can: (a) relate to the design of one single environment and/or of the entire dwelling/building in which the AUSILIA patients living spaces are located; (b) be represented by a simple supply of aids and/or technologies aimed at supporting in the performance of the users ADL (Activities of Daily Living). It is undeniable that both aids and technologies must however be integrated into environmental units that are barrier free and appropriately furnished and equipped.

The Door Area, an environment characterised by two external translating low walls and two parallel internal fixed vertical walls inside of whom three of the main internal door opening systems are installed (Fig. 7), represents a clear example of the AUSILIA assessment method. In this Area the user can test the following doors: single-leaf, sliding door and roto-translating, including their different handing and width. Thanks to the external translating walls it is also possible to evaluate the

Fig. 7 The *Door Area* of the gymnasium of AUSILIA

required manoeuvring spaces according both to the door kind and to the specific mobility aid (e.g.. manual wheelchair, power assist wheelchair, walking aids, etc.). The provided technological infrastructure for the Door Area will allow to collect and analyse the data of the trial-test in order to define the user centred solution for each single AUSILIA patient. Different type of door handles can be tested in another dedicated area of the Gymnasium called Handles Area.

The structures of the AUSILIA Living Lab (Fig. 8) have been designed to be modified and integrated over time in order to enhance the research activity on new issues and to meet the needs of a wider range of users. AUSILIA will encourage the study of new technologies and design solutions for the home. The collected data might also be used to develop new guidelines for the designers and to support new studies related to a possible upgrade of the current regulatory provision and standards on the accessible design.

5 Economic Sustainability of Ausilia

Going towards the full implementation and activation of Ausilia living lab and connected services potentially spreadable on the territory, it becomes fundamental to make an analysis of economic sustainability. This shall be composed by two different perspectives: sustainability for the structure that will have to provide the service, in a general context of decreasing available resources and increasing needs and demand; on the other hand, sustainability for the user/patience that eventually should imple-

Fig. 8 The structures of the AUSILIA Living Lab in the Gymnasium

ment in his house the assisting living technologies, with cost at his load. Considering the amount of money that these technologies could cost, the aim of this second aspect is to find a way to financially support whichever user that might not be able to bear the expense.

Consequently, the economic analysis will have to define:

(a) the fully operating costs of AUSILIA Laboratory;
(b) the quantity and the type of services and other outputs on the basis of the potential demand. Services and other outputs will have to be estimated with reference to the epidemiological data relating to Trento Province and the surrounding geographical areas;
(c) the consequent reduction of other types of social health services currently provided within the Trento Province boundaries;
(d) the effectiveness of the intervention, both in terms of social inclusion, and of improvement of citizens life.

A second objective of the project consists in the production of a report mapping the current instruments of economic support to people with motor or cognitive disabilities on the provincial territory. The intent of this second objective is to verify if some of these already actives economic instruments could be used also for the scope of Ausilias user (in house installation of assisting living technologies).

This is the mandate of the Research Fellowship of the Department of Economic and Management within Ausilia project, that is becoming operative since end of February 2019.

5.1 Business Model Canvas

In order to have a clear overview of the project, of its costs and outputs, and considering the several potential collaborations that AUSILIA could generate with both public and private stakeholders, and to find out the best configuration for these collaborations, it has been decided to start designing a business model of AUSILIA project [16].

Among the various possibilities to model a business, the business model Canvas has been chosen for three main reasons:

1. Thanks to its visual way and simple frameworks, enables team-discussion and easier communication of fundamental economic topics, through a quick building-up of shared language, so important in a interdisciplinary team, such as the one in AUSILIA;
2. Consent to have an overall view of the main elements with a glance; in order to verify, set and ensure solid coherence between the elements of the projects;
3. Because of previous points and the flexibility that can provide, the Canvas model is currently the most famous business model, used to describe and project not only profit businesses, but also services, non-profit organizations and in general every kind of organized, continuous activity that wants to create and share value.

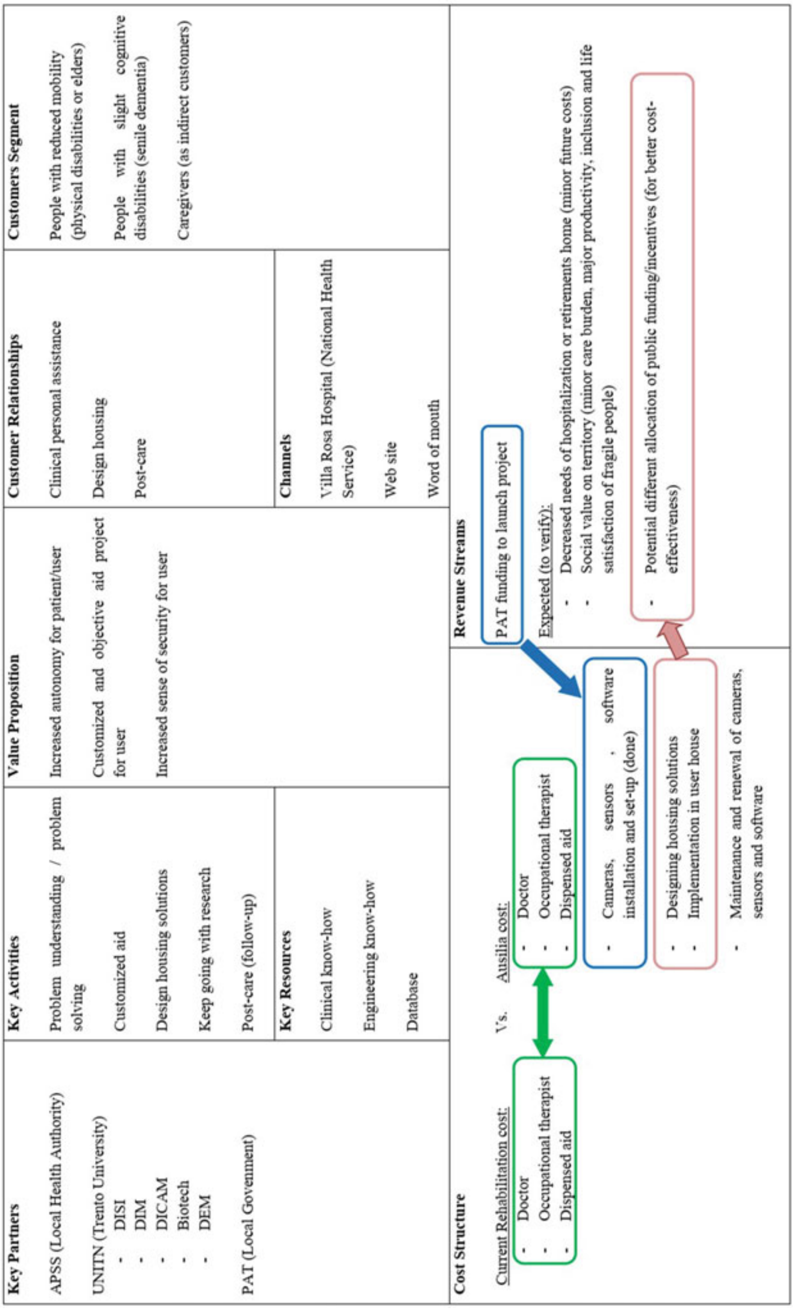
In Fig. 9, we reported an early demonstrative analysis of Canvas economic analysis performed for the AUSILIA case.

6 Conclusions and Future Applications

The AUSILIA paradigm represent a turning point for the actual challenge of ageing society with increasing demand of care and needs of assistance to foster independent living of patients suffering from impairing conditions.

The combination of a evidence based clinical paradigm for occupational therapy and on the edge technologies, as ambient and subjects sensoring and augmented virtuality, along with particular care in providing architectural modulating solutions are the main pillars of the AUSILIA living lab. In this paper we briefly illustrated the pursued clinical and technological strategies and the ongoing analysis for evaluating impact and long-term sustainability of the initiative.

We believe that sharing our experience and our vision can factitively contribute to the development of new approaches to demographic challenge, assuring the best assistive and caring solutions for ensuring for as long as possible autonomy and independence for citizens who age with sustainable and quality services.



Key Partners

APSS (Local Health Authority)

UNITN (Trento University)
- DISI
- DIM
- DICAM
- Biotech
- DEM

PAT (Local Government)

Key Activities

Problem understanding / problem solving

Customized aid

Design housing solutions

Keep going with research

Post-care (follow-up)

Key Resources

Clinical know-how

Engineering know-how

Database

Value Proposition

Increased autonomy for patient/user

Customized and objective aid project for user

Increased sense of security for user

Customer Relationships

Clinical personal assistance

Design housing

Post-care

Channels

Villa Rosa Hospital (National Health Service)

Web site

Word of mouth

Customers Segment

People with reduced mobility (physical disabilities or elders)

People with slight cognitive disabilities (senile dementia)

Caregivers (as indirect customers)

Cost Structure

Current Rehabilitation cost:
- Doctor
- Occupational therapist
- Dispensed aid

Vs.

Ausilia cost:
- Doctor
- Occupational therapist
- Dispensed aid

- Cameras, sensors, software installation and set-up (done)

- Designing housing solutions
- Implementation in user house

- Maintenance and renewal of cameras, sensors and software

Revenue Streams

PAT funding to launch project

Expected (to verify):
- Decreased needs of hospitalization or retirements home (minor future costs)
- Social value on territory (minor care burden, major productivity, inclusion and life satisfaction of fragile people)

- Potential different allocation of public funding/incentives (for better cost-effectiveness)

Fig. 9 Business Model Canvas of Ausilia—patient/user focus

References

1. Pisoni T, Conci N, De Natale FG, De Cecco M, Nollo G, Frattari A, Guandalini GMA (2016) Ausilia: assisted unit for simulating independent living activities. In: 2016 IEEE international smart cities conference (ISC2). IEEE, pp 1–4
2. Frattari A, Dalprá M, Bauer B, Luchetta L (2017) Design of an assisted unit for simulating independent living activities. In: Sustainability and innovation for the future, proceedings of 41st IAHS world congress on housing, pp 1–10
3. Frattari A, Dalprá M, Bauer B (2018) The gymnasium of the ausilia project for independent living of persons with disabilities. In: Proceedings of 42nd IAHS world congress on housing, Naples (Italy),10–13rd April 2018, pp 1–10
4. Valente M, Nollo G (2017) Wireless body area networks: a new paradigm of personal smart health. In: IEEE smart cities initiative—trento white paper
5. Zanetti M, Faes L, De Cecco M, Fornaser A, Valente M, Guandalini G, Nollo G (2018) Assessment of mental stress through the analysis of physiological signals acquired from wearable devices. In: Italian forum of ambient assisted living. Springer, pp 243–256
6. Andrich R, Gower V, Caracciolo A, Del Zanna G, Di Rienzo M (2006) The dat project: a smart home environment for people with disabilities. In: International conference on computers for handicapped persons. Springer, pp 492–499
7. Redmon J, Divvala S, Girshick R, Farhadi A (2016) You only look once: Unified, real-time object detection. In: Proceedings of the IEEE conference on computer vision and pattern recognition, pp 779–788
8. Law MC, Baptiste S, Carswell A, McColl MA, Polatajko H, Pollock N (1998) Canadian Occupational Performance Measure: COPM. CAOT Publ. ACE
9. D'Agostini J, Bonetti L, Salee A, Passerini L, Fiacco G, Lavanda P, Motti E, Stocco M, Gashay KT, Abebe EG et al (2018) An augmented reality virtual assistant to help mild cognitive impaired users in cooking a system able to recognize the user status and personalize the support. In: 2018 workshop on metrology for industry 4.0 and IoT. IEEE, pp 12–17
10. De Cecco M, Fornaser A, Tomasin P, Zanetti M, Guandalini G, Ianes PG, Pilla F, Nollo G, Valente M, Pisoni T (2017) Augmented reality to enhance the clinicians observation during assessment of daily living activities. In: International conference on augmented reality, virtual reality and computer graphics. Springer, pp 3–21
11. Fornaser A, De Cecco M, Tomasin P, Zanetti M, Guandalini G, Gasperini B, Ianes P, Pilla F, Ghensi R (2018) Augmented virtualized observation of hidden physical quantities in occupational therapy. In: 2018 international conference on cyberworlds (CW). IEEE, pp 423–426
12. Fornaser A, Tomasin P, De Cecco M, Tavernini M, Zanetti M (2017) Automatic graph based spatiotemporal extrinsic calibration of multiple kinect v2 tof cameras. Rob Auton Syst 98:105–125
13. Martini Rose, Rios Jorge, Polatajko Helene, Wolf Timothy, McEwen Sara (2015) The performance quality rating scale (pqrs): reliability, convergent validity, and internal responsiveness for two scoring systems. Disabil Rehabil 37(3):231–238
14. Fisher AG (2009) Occupational therapy intervention process model. A model for planning and implementing top-down, client-centered, and occupation-based interventions, pp 15–22
15. Frattari A, Dalprá M, Bauer B, Luchetta L, Chiogna M (2017) Soluzioni abitative innovative per vivere attivamente e in modo autonomo a casa: la sfida del progetto ausilia. In: Proceedings of ColloquiATe 2017: demolition and reconstruction?, Ancona (Italy), 28–29 settembre 2017, pp 550–561
16. Osterwalder A, Pigneur Y (2010) Business model generation: a handbook for visionaries, game changers, and challengers. Wiley

Cognitive Buildings for Increasing Elderly Fire Safety in Public Buildings: Design and First Evaluation of a Low-Impact Dynamic Wayfinding System

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Abstract The progressive population ageing increases the participation of autonomous Elderly to the community life and their presence in public buildings. Such complex spaces are generally characterized by high occupants' density, with different users' types (including elderly) that additionally own a scarce familiarity with the emergency layout. Emergency safety levels (i.e.: fire) are significantly affected by man-environment interactions, especially for the hosted autonomous Elderly. Here, they tend to choose well-known paths, while group behaviours can provoke overcrowding and, hence, an increasing of the evacuation time. Cognitive Buildings can solve this issue, because they can suggest to people how to behave in relation to the monitored surrounding conditions. This study proposes a Cognitive Wayfinding System (Co-WayS) to be applied in such scenarios, with a low impact level. Co-Ways is composed by: individuals' badges for their wi-fi tracking; building components including wi-fi tracking system and electrically-illumined signs (to dynamically address correct paths to evacuees); central processing unit to solve a density-based guidance algorithm for sign activation. Co-WaysS addresses the egress paths depending on monitored queueing conditions. A first validation in a significant public building is performed through egress drills. When using Co-WayS, the evacuation time decreases (−28%) while correct path choices (+17%) and individuals' sign confidence (+58%) increases, with respect to standard signage.

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1 Introduction

The population average age is progressively increasing by provoking a sensible rising in the number of Elderly: only in Italy, from 2007 to 2017, the number of individuals with 65 years and more has been increased of about 2 millions, by leading to an incidence of this age class of 22.3% in respect to the overall National Population.[1] In such a scenario, allowing the Elderly to remain independent and socially included in their daily life is a key challenge. Ambient Assisted Living (AAL) solutions could solve this issue by supporting a person's daily life in both normal and risk (emergency) conditions, and increasing the individual's social connection and independence also into old age [1–3].

To this end, the Built Environment (both indoor and outdoor scenarios) should be designed to include intelligent and Cognitive Building-oriented systems (i.e. implemented in their Building Components and devices) with the aim to [4–6]: (1) detect human activities and behaviours within the situational context of the Built Environment (and so the environmental conditions), by preferring low-impact (for the hosted users and for the Built Environment) solutions; (2) recognize behavioural patterns and users' needs; (3) provide support to the users by means of direct assistance to them (i.e., to autonomous occupants) or by invoking external aid.

Such AAL solutions can ensure independent fruition of the Built Environment by the autonomous Elderly, by hence increasing their quality of life [1, 7, 8]. In this sense, Elderly safety is one of the most challenging topics, especially in relation to possible emergency conditions that they can cause particular stresses to them and so possible additional threads [2, 3, 9].

This work applies this concept to autonomous Elderly's safety issues in buildings, by focusing on the first critical phases of an emergency: the building evacuation process. In fact, the evacuation process for them is critical, especially in case of complex buildings like public ones [2, 3]: in addition to critical conditions due to high occupants' density and the possibility that spaces are not well designed for Elderly's use, such occupants can have scarce familiarity with emergency layout and procedures. These circumstances can lead them to adopt improper and risky behaviours also in terms of evacuation choices and direction (i.e. missed identification of the "best" evacuation path") [2]. To solve these issues, this study proposed a Cognitive Building-oriented System for their support in the evacuation process, which suggests occupants how to behave and where to move in relation to the monitored surrounding conditions. The system is tested by means of a wide-scale drill in a significant public building, by actively involving the Elderly in the experiments.

The structure of the paper firstly offers the literature background adopted to develop the Cognitive Building-oriented System and to set up the experiments (Sect. 2). According to the methodological outline (Sect. 3), results provide the proposed system architecture and its preliminary validation in a significant case

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[1] Source: ISTAT, 2016 https://www.istat.it/it/files/2017/03/Indicatori-Demografici.pdf (in Italian - last access: 01/04/2019).

study application, by comparing egress drills conditions with and without the system itself (Sect. 4).

2 Literature Overview

The current lifestyle of the Elderly makes them frequent public spaces with a possible high density of occupants which are in their informal care networks, such as museums, city halls, 3rd age universities [8]. Allowing autonomous Elderly to be independent in such Architectural Spaces use will additionally help healthcare assistants and other staff members to focus their attention on not-autonomous individuals, by increasing the overall Elderly participation to the community social life and then the life quality for all of them.

To support them in these buildings also in emergency and evacuation conditions, it is essential to focus on three main topics: the general paradigms to be adopted to developing Built Environment-integrated solutions for Elderly's support in such architectural spaces; the factors affecting their safety in emergencies; the solutions that can be adopted to improve their safety during the emergency.

2.1 Paradigms for Built Environment-Integrated Solutions

Cognitive Building-oriented approach [4] moves towards such goal, in proactive and reactive manners [6]. In fact, it firstly analyzes the data collected by the sensors implemented in the building (including the ones on the hosted occupants), and it learns how users behave according to joint man-environment interactions models. Then, it automatically predicts possible critical scenarios and preventively acts (proactive), or it detects incoming anomalous situations and then adapts the implemented components to manipulate the current situation (reactive) thus proceeding to the possibility of implementing alarm signals and improvement measures.

Different paradigms can be merged in this approach to improve their capabilities, and mainly [10–14]:

- Internet-of-Thing (IoT) criteria to effectively interconnect the embedded devices by sharing data, model to analyze them, and computational resources to be used (i.e. also to provide local low-level computations);
- user-centered and behavioural design-based approaches to actively include users' behaviour modeling and understand their effective needs against different environmental drivers, especially in relation to most vulnerable users' categories (i.e. Elderly). In such a way, it could be also possible to develop interactive solutions that can suggest people how to properly behave;
- supporting digital technologies for environment representation, data sharing and storage, by using e.g. Building Information Modeling techniques, also to improve

the management of the facilities in relation to the users' changing needs (i.e. different kind of Elderly hosted within the building).

2.2 Safety-Affecting Factors for Elderly in Buildings

Elderly's safety in public buildings is generally affected by [2, 3, 15–20]:

- low level of familiarity with spaces and safety strategies to be adopted (including the evacuation plan), because of occasional fruition of the buildings itself. By this way, emergency wayfinding activities can be oriented towards well-know spaces (i.e. the path used to enter the building), by leading to risky overcrowding conditions;
- sensory, perceptual, cognitive and communication abilities, as well as motor skills, that can worsen in emergency conditions (e.g. delays in reaction and evacuation start) and, mainly, in case of high occupants' densities and overcrowding (e.g. additional reduction of evacuation speed in groups because of Elderly with lower motion speeds);
- social identification effects, that can affect group choices in the evacuation process (including direction and evacuation target) and lead individuals to support each other by provoking possible group evacuation delays (e.g. people remain in risky conditions to help the Elderly);
- intrinsic features of space layout, that can be not designed to be easily used by them in relation to their motion abilities (especially in case of historic buildings).

As a result, possible evacuation delays and wrong choices (including the ones in wayfinding activities) can expose the Elderly to additional risks. In particular, in case of fires in buildings, they can be affected by serious consequences because of smokes (including irritants), carbon monoxide and fire (burns) exposure [21]. In such conditions, the occupants' safety depends on a rapid building evacuation: this goal can be achieved by suggesting the "best" paths and exits to all the evacuees who can autonomously move, through guidance systems [2, 17].

2.3 Solutions to Support the Elderly in Evacuation

Literature works show the effectiveness of wayfinding signage systems in egress time reduction [2, 18, 22, 23]. In general terms, signage systems can be distinguished between collective (placed in the built environment, so as that more than one individual can be supported by them) or individual (each occupant is supported by his/her personal devices, e.g. a smartphone) [12]. Moreover, they can be:

- "passive" [2, 18, 24]—the evacuation direction addressed by the sign is predetermined; they are the common "standard" evacuation signs currently included in the buildings according to the current fire regulation. They can be reflective, photoluminescent or luminous;

- “active” [12, 22, 23, 25, 26]—the evacuation direction addressed by the sign dynamically varies depending on the surrounding conditions thanking to a combined sensor-control-actuator system. They are composed of luminous signs connected with a common network to the control unit.

“Active” signage systems move towards a Cognitive approach, since they address the “best” paths to evacuees in terms of environmental conditions (e.g.: fire and smokes) and/or human motion and egress process by monitoring check-points conditions. In particular, the individuals’ motion is monitored by using personal devices such as badges or electronic devices, CCTV control systems or motion detection devices [12, 22, 26]. Then, these data are used as input by the central control unit, which runs a software control that, step-by-step, assesses the best evacuation paths according to the defined evacuation route calculation algorithms [12].

Different path selection algorithms can be adopted, starting from a route graph of building spaces/paths, such as [12, 22, 27]: threshold-based to evidence blocked paths; Dijkstra’s algorithm-based on evacuation path risk; travel distance or evacuation time-based. The guidance algorithm could also take advantage of supervision systems (by means of a safety staff member) or of (quasi) real-time evacuation simulators, which use the input monitored data to evaluate the egress process timing and evolution [22].

Finally, the directional information assessed by the central control unit is displayed to occupants by means of electrical-illumined signs, by including directional and prohibition information [12, 22]. Previous drills demonstrated how “continuous” evacuation signs (at least 1 directional sign per 5 m of paths) can improve the evacuation speed, especially for Elderly, in respect to punctual solutions (on doors, directional changes, etc.) [2, 18]. Sound alarms can be also included in order to help people with visual impairments [26].

However, the effectiveness of wayfinding signage systems are also related to “group phenomena”, due to social-shared identity within the hosted individuals or among a “group leader” [16, 19, 20]. Such phenomena affect the whole duration of the evacuation, during both the pre-movement time (i.e. people spend time waiting for other groups members before starting the evacuation) and the motion process. During the evacuation motion, people in the same social group (e.g. family) prefer to move together towards the evacuation target, by sharing the same evacuation direction and adjusting their motion speed to the ones of the other group members. Studies also point out the support given to the most vulnerable individuals (i.e., elderly) within the same group, by also provoking “Coming-and-going” behaviours along the evacuation time to reach or to wait for those individuals [20]. Such behaviours are relevant in public spaces and public buildings, for the interaction between different groups and the creation of macro-groups sharing the same evacuation target. It could be also possible to identify a leader within the evacuation group, which is generally responsible for wayfinding activities for their followers (the group) [19, 20, 25].

"Active" wayfinding signage systems could take advantage of such phenomena to monitor group activities.

"Active" wayfinding signage systems were provided for different public buildings (e.g. train and underground stations, theatres, offices, multi-storeys buildings)[12, 22, 26], and commercial systems have also been developed.[2] Anyway, real-world experiments carried out to evaluate the system effectiveness are still limited in terms of involved number of participants, and, mainly, in terms of elderly participation [22, 26].

3 Phases, Materials and Methods

The current work is organized according to the following two phases:

1. definition of the Cognitive Wayfinding System (Co-WayS), by taking advantages of previous literature researches, and mainly focusing on occupants' evacuation behaviour (i.e. group behaviours) detection. Both behavioural-based (Sect. 3.1) and technological (Sect. 3.2) requirements are shown;
2. experimental drills in a significant case study to evaluate how Co-Ways can improve the evacuation process with respect to the current scenario conditions (standard evacuation signage systems). The case study, the tests methodologies and the Key Performance Indicators (KPIs) adopted for drills results comparison are described in Sect. 3.3.

Drills were performed by involving 49 volunteers, by including autonomous Elderly, as follows: 10 to 24 years-old = 10%; 25 to 38 years-old = 60%; 39 to 52 years-old = 10%; 53 to 75 years-old = 20%). All people involved in the test confirmed having a normal or corrected-to-normal vision, and had no motion impairments. All people also confirmed to be unfamiliar with the architectural spaces used in the test.

3.1 Behavioral-Based Requirements for Co-WayS Definition

In this study, the attention is focused on the individuals' motion as key factor for the "best" path choice. According to a Density-based approach for the "best" path identification [12], the Cognitive Wayfinding System (Co-WayS) should check possible overcrowding conditions in specific areas. Such factor affects the evacuation time by provoking evacuation slowing down or even pushing phenomena between evacuees,

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[2] E.g.: EVACLITE Dynamic and Adaptive Emergency Evacuation Signage: https://www.evaclite.com/ (last access 20/04/2019); Q. Li, T. Plocher, Time-dependent classification and signaling of evacuation route safety, US 7,683,793 B2, 2010 https://www.google.com/patents/US7683793 (last access 20/04/2019).

and then related individuals' injuries, regardless of the considered disaster conditions (e.g. fire, earthquake, general-purpose, terrorist acts) [12, 26].

Firstly, group motion behaviours are considered according to common fruition conditions of public buildings. The Elderly and the other occupants generally prefer entering the building in groups [2] and, according to the social shared identity phenomena described in Sect. 2, they try to gather together also during the evacuation process [16, 20]. Co-WayS can take advantage of this evacuation behaviour, by considering the optimization of the motion monitoring through a related sensor associated with the group leader, instead of each component [19, 25]. The monitoring device given to the group leader is associated with the group dimension. Although the possible simplification of this operational choice, the proposed solution can: (1) reduce the number of monitoring devices to be used by improving the computation timing; (2) lead to a consistent representation of the phenomena especially in case of small groups; (3) encourage evacuees to stay close during the whole process by avoiding "coming-and-going" behaviors and reduce individual-individual interactions along egress paths.

Secondly, the group motion can be monitored by mainly considering specific areas of the Built Environment (called "*control areas*") like geometrical bottlenecks (doors; intersections between corridors, and between corridors and staircases), that can be seriously affected by overcrowding conditions. Co-WayS should count the number of people in such areas to evaluate the occupants' density within them [persons/m^2]. A certain evacuation path could be "unavailable" when the pedestrians' density at the related entrance "*control area*" is higher than 3 persons/m^2 [12]: in this condition, hazardous physical contacts among people can occur and the evacuation flows slows down. When all the possible routes are marked as unavailable, the one with the lower pedestrians' density can be considered as opened.

Finally, Co-Ways has to address the "best" evacuation paths to pedestrians:

- moving along a path or inside a room, by using "continuous" wayfinding signs. The presence of constant directional information can speed up the motion process also for the Elderly, as shown by previous works (up to +54%) [2, 18, 26];
- arriving near a decision point by including doors, by using green/red lights or not marked/red X-marked signs to define the direction to choose/to avoid [12, 22, 23]. Such elements allow individuals to choose the proper evacuation direction.

Electrically-illumined signs can be used to be visible both in lighting and blackout conditions, by placing them also near to the floor (at least along the path) to be visible also in smoke conditions [12, 26].

3.2 Co-WayS Technological Requirements

Co-Ways should adopt wireless communication to detect the individuals' positions and to support the evacuees through the signs. By this way, it ensures rapid application and adaptation, system modularity and improved efficiency of the communication network also in emergency conditions [25, 26].

Hence, group monitoring was performed by using a Wireless Mesh by Apio (https://www.apio.cc/eng/platform/apio-mesh; last access 18/04/2019), that uses the IEEE 802.15.4 (2.4 GHz) standard. In particular, the Apio Gateway was connected to the Apio Dongle to ensure the mesh operation and the connection with the Apio General devices. These were used as monitoring nodes for both the ones with a known (reference nodes, placed in the building in fixed positions) and unknown (blind nodes, given to the individuals) position. The main system controller (hosting the path selection algorithms) connected to the gateway was a Raspberry Pi (operating system ApioOS). In this system, the location engine estimates the blind node position by using the value of Received Signal Strength Indicator (RSSI) [dBm] between the Apio General devices. Preliminary tests are carried out in the drill environment (described in Sect. 3.3) to define the values of RSSI depending on the distance between fixed and movable nodes, to classify critical values for counting the number of individuals inside each *control area*. Tests were carried out by moving a blind node, for 20 times, along a 10 m-long linear path, with a speed of 1 m/s, which is consistent with evacuation speed by previous works [2, 15]. Average RSSI-distance couples were calculated, and results should can be acceptable only if they showed a monotonously decreasing trend. Linear regression was also performed.

Finally, the electrically illumined signs are connected to Gateway by wireless communication. Depending on the path selection algorithm results, the status of the signs is changed. The dimension of the sign (i.e. directional arrows) can be assessed by means of correlation between the dimension and the identification distance. For instance, according to UNI EN 1838:2013 (current standard for evacuation signage in Italy), the identification distance l [m] of each directional sign for internally illumined elements is calculated as $d = 200h$, where h [m] is the sign (arrow) height.

3.3 Evacuation Drills

Co-WayS is applied to a significant scenario: a classroom in the Faculty of Economics at the Università Politecnica delle Marche, placed in Ancona. The classroom can represent a general indoor public space with possible high density of occupants, frequented by Elderly, like 3rd age universities, small theatre or city hall, and where the attention of the occupant attention is directed on a single focal point [8, 12]. The building fire safety requirements on wayfinding signage and emergency plan are designed according to the National Regulation (i.e. D.M. 81/2008). Figure 1 shows the scenario application layout, by also defining the conditions of the stepped classroom where the participants were placed at the evacuation starting (i.e. the position of the participants).

Two building exits are considered in the experiments, as sketched by Fig. 1: the entrance door U_E (Fig. 1A); the fire compartment door U_A, placed at the first floor (it can be considered as a building exit since it leads to another fire compartment where

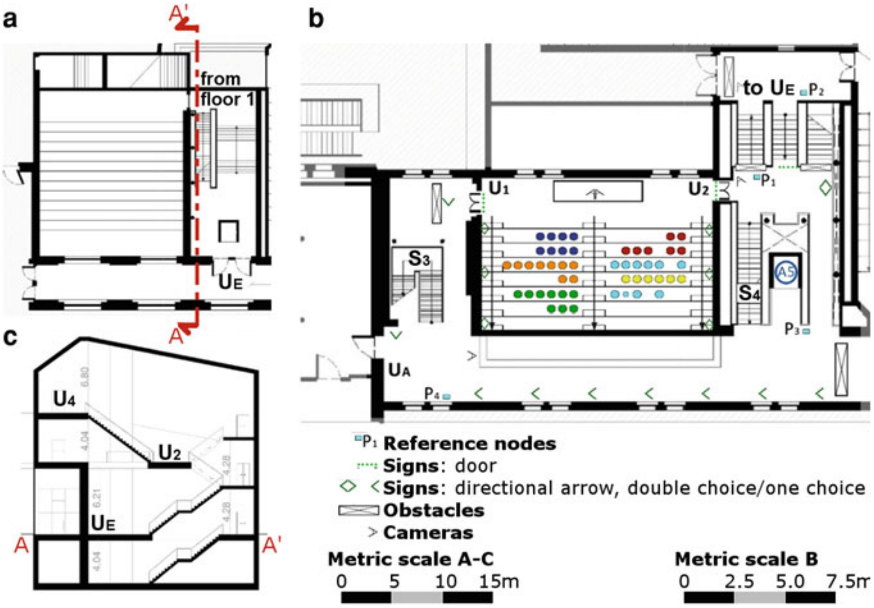

Fig. 1 The scenario characterization: **a** ground floor layout; **b** first floor layout, by including symbol explanation (dots are the individuals' positions in both the tests; each colour refers to a group); **c** section view of the building

people could be considered as safe, and then to the outdoor by means of a secondary evacuation staircase). Furthermore, the stepped classroom has 4 exits: two downside door U_1 and U_2 (directly on the first floor, as shown in Fig. 1B) and two upside door U_3 and U_4 (connected to the first floor by means of dedicated staircases S_3 and S_4 in Fig. 1B). Figure 1C resumes the related section view for the building.

Figure 2 shows the evacuation paths according to the building emergency plan: standard reflective signs are punctually placed at the door and at the intersection between corridors and between corridors and staircases, to point out the evacuation direction define in the plan. Table 1 resumes the possible main paths that can be used to exit the classroom and reach one of the exits. It can be noticed that the main evacuation path links the room to the fire compartment door U_A instead of to the entrance door U_E, by exiting the room from U_1 or U_3. Figure 1 also shows the position of Co-WayS elements (including signs) in the test environment. Video cameras were placed inside the classroom and at the intermediate doors/paths intersections, and at the exits, to monitor the drills. Either the tests (without and with Co-Ways application) were performed during a short seminary in order to reproduce real cases conditions. The test without Co-WayS (original scenario) were performed before the one with Co-WayS implementation. Since no information about evacuation paths was given to the participants when entering the building (as in normal fruition conditions), this choice could support the fact that people were not affected by the knowledge of secondary evacuation paths [12].

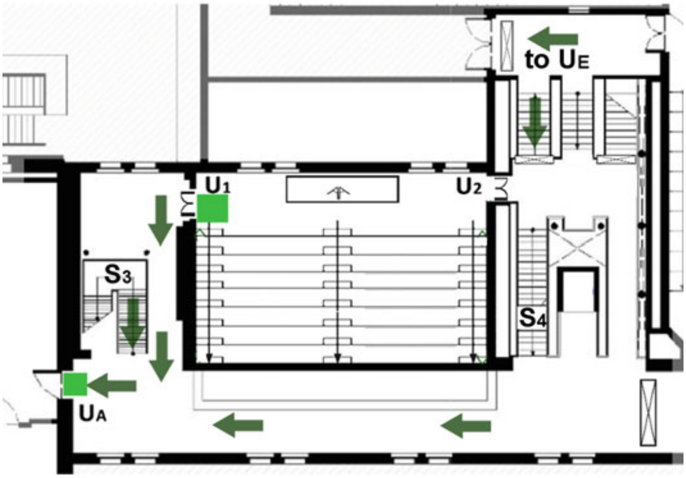

Fig. 2 Evacuation plan (arrows are the paths) implemented in the original scenario. Standard signs are placed at the door (green squares) and at paths intersection. The metric scale is the displayed by Fig. 1b

Table 1 Possible paths to be used by stepped classroom occupants. – means none. Elements codes refer to Fig. 1 localization. CO-WayS control areas are also stressed. Paths 3 and 5 are the paths considered in the emergency plan (original scenario, without Co-WayS application)

Path code	Classroom exit	Staircase to first floor	Intermediate point	Exit	Control area in Co-wayS
1	U_2	–	P_1 then P_2	U_E	P_1 then P_2
2	U_4	S_4	P_1 then P_2	U_E	P_1 then P_2
3	U_1	–	P_4	U_A	P_4
4	U_2	–	P_1 then P_3 then P4	U_A	P_1 then P_3
5	U_3	S_3	P_4	U_A	P_4
6	U_4	S_4	P_1 then P_3 then P4	U_A	P_1 then P_3

In the two tests, the whole sample entered the university building in groups by the main entrance, and then they occupied the seats in the room on the first floor. Individuals' positions were randomly chosen by each group, by considering that all the group members had to seat close one to each other, and by taking account a homogenous distribution for the room. Occupants' positions during the first drill (without Co-WayS) were exactly replicated in the second drill (with Co-Ways), as shown by Fig. 1.

During the seminary, the fire alarm rang and the voice alarm announced: "Please, the evacuation drill is started. The audience is invited to not hurry and to exit the building by following the wayfinding systems". Each evacuation drill ended when the last occupant reached the considered exits in Fig. 1 (U_A or U_E). After each drill, persons were asked to fill out a questionnaire. Questions concern the evacuation way-finding system appreciation (according to a likelihood scale 0 to 4: for all the participants "Did you find the system helpful in evacuation choices?", and, for Elderly, "Was the sign visible and easy to be understood?") and the individuals' perception on group motion assumption (yes or no response; "Did you perceive that you move together with your group?").

Video cameras were used to monitor the evacuation conditions in each drill from a qualitative (adopted behaviours, by focusing on the main Elderly-related ones in relation to the group; use of evacuation signs) and quantitative (individuals' and groups path selection, number of exited occupants against the time, group evacuation time) standpoint. Adopted approximation was 1 s for the evacuation time-related quantities. Since the effectiveness of continuous wayfinding signs on individuals' choices and speed were assessed by previous works [2, 18], Key Performance Indicators (KPIs) used to assess the evacuation conditions were focused on the overall effects of Co-WayS on the evacuation conditions, by outlining: evacuation paths choices (e.g. exits usage) [persons], overall evacuation time [s], evacuation flows at the exits (by using linear regression on the number of exited occupants against the time; the flows are the coefficient multiplying the x variable) [persons/s]. For each of these quantities *A* (including questionnaires results), percentage differences *dA* [%] were calculated between Co-Ways supported (subscript *Co-WayS*) and original (subscript *Orig*) scenario according to Eq. 1:

$$dA = \frac{A_{Co-WayS} - A_{Orig}}{A_{Orig}}[\%] \tag{1}$$

4 Results

According to Sect. 3 phases, results are organized in two parts: (1) Co-WayS definition and implementation to the case study (see Sect. 4.1); (2) evacuation drill results in the original scenario conditions and in case of Co-WayS application, by comparing the two systems according to Sect. 3.3 KPIs, and analyzing the individuals' confidence in respect to the Co-WayS, through questionnaires to the involved volunteers (see Sect. 4.2).

4.1 *Co-WayS Definition and Implementation in the Case Study*

Co-Ways is composed as shown by Table 2. The main device is a wearable one for each group (hold by the group leader) in the environment, which is the blind node of

Table 2 Co-Ways components characterization

Components	Main task	Main requirements
Reference node	Interaction with the blind node; known position	At least one for each “control area” entrance
Blind node	Interaction with the reference node	One for device, given to the individual (i.e. leader of the group, while entering the building)
Gateway	Ensure the communication between the system elements	At least one, to create a unique mesh for building/building part
Main controller	Estimation of the number of blind nodes (by using the RSSI value) for each “control area”; evacuation path solving	One for building/building part
Wayfinding sign (door)	Addressing paths to be used and paths to be prohibited	One for door/control area access, by using LED-strip portals (green/red light)
Wayfinding sign (directional arrows)	Pointing out the direction along a path	At least 1 per 5 m of path (continuous wayfinding signs)

the localization system (Apio General). The blind node is delivered when the group enters the building, by associating the related number of people in a database.

When the alarm rings and the evacuation starts, the main controller collects the positions of the blind nodes. It uses the Density-based solving algorithm described in [12], which address open paths with less than 3 person/m^2 in the entrance *control area*. The group is considered to be in the control area when the related RSSI value is higher than a certain experimental threshold. Figure 3 shows the average RSSI values against the distance between blind and reference node in the considered testing scenario. For each distance, the percentage RSSI-related standard deviation is lower than 10%. Experimental pairs confirm a monotonously decreasing trend of data, which can be associated with the following linear regression: *RSSI [dBm]* $= -2.9$ *dBm/m* $*$ *distance [m]* $+$ *40 dBm* (R^2 of about 0.5). In the drills, the frequency of sampling for RSSI values was set equal to 1.5 s. According to the dimension of the scenario in Fig. 1, a control area of about 4 m of radius (centered on the reference node) is considered, so as to: avoid the overlapping between the nearest control areas; ensure at least 2 position localization inside the *control area* also in case the evacuees move at high speed (about 2 m/s); measuring, at least, the identification of 3 groups of about 10 individuals inside the *control area* in critical conditions, except for physical obstacles (3 persons/m^2). This choice also fits with confident Fig. 3 results, by taking advantages of the significant decreasing of RSSI between 2 and 3 m. Hence, all the blind nodes with RSSI $\geq$ 30 dBM in relation to a specific reference node were considered inside the related *control area*.

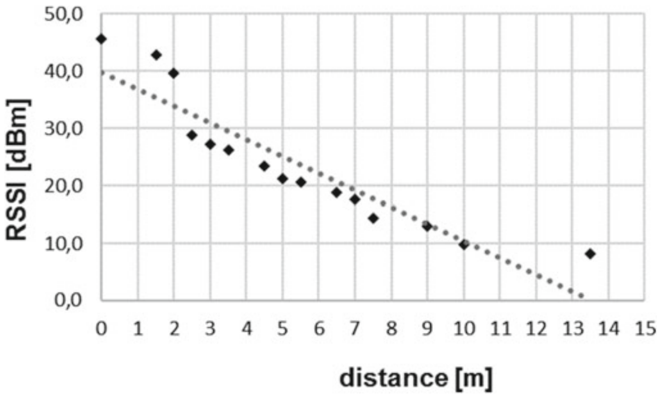

Fig. 3 RSSI against the distance between the blind and the reference node. Points are experimental pairs (average values), the dotted line is the adopted linear regression

Fig. 4 View of the Co-WayS application in the testing scenario: **a** stepped classroom (directional sign and, on the top, the U3 door sign); **b** door sign (prohibited access, red; to be used, green); **c** along the corridor (directional arrows)

Co-WayS reference nodes and signs are implemented as shown by Fig. 1b. The reference nodes are assigned to the *control areas* described in Table 1, so as to define if a path can be open or not. Finally, Fig. 4 shows some relevant views of the Co-WayS signs application in the building (by using RGB LED strips, Lm/LED: 12, Lm/m:800, 60 LED/m). The directional arrows are 17 cm high to be seen at about 30 m of distance (maximum length of a corridor within the building), according to Sect. 3.3 requirements. LED strips at the door are 1 m long.

4.2 Drill Evacuation Results

In general terms, the use of Co-WayS improves the emergency conditions according to the defined KPIs. In fact, it firstly allows an overall reduction of the egress time of about 15 s, that means -28% in percentage terms, as shown by Fig. 5. In both the drills results, it is possible to distinguish two evacuation parts: the first one related to

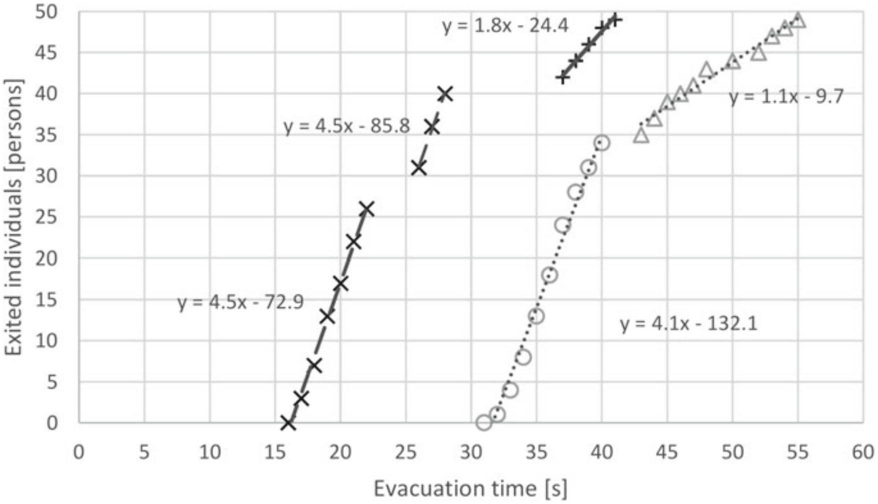

Fig. 5 Number of exited individuals versus the evacuation time for the original scenario (light grey pairs: circles refers to U_A exit and triangles to U_E exit) and the Co-WayS scenario (black pairs: X refers to U_A exit and + to U_E exit). Linear regression for each group of individuals is offered to evidence people moving in groups, and the related equation is offered (R^2 always greater than 0.97): here, the flows are the coefficient multiplying the x variable [persons/s]

the use of U_A related paths (people who arrived first, or rather before about 40 s in the original scenario, and before about 27 s in the Co-WayS scenario) and the second one related to the use of U_E related paths. Choosing to move towards U_E implies higher evacuation times, mainly because of the path length. Anyway, the evacuation flows at each exit improve while using the Co-WayS, as shown by the linear regression in Fig. 5, according to Sect. 3.3 definition: the flows increase of + 63% for U_E (from 4.1 to 4.5 persons/s) and +10% for U_A (from 1.1 to 1.8 persons/s).

These results can be obtained because of the optimization of the evacuation path use by means of their control in terms of density at related bottlenecks (*control areas* in Table 1). Meanwhile, the use of U_A (which is connected to the recommended evacuation path) is increased of +17% in Co-WayS use conditions in comparison to the original scenario (from 27 to 40 persons using U_E and the related paths).

Figure 6a shows the paths used in the original scenario drill for each group. Paths identified by the codes 1, 3 and 5 were used (see Table 1). Hence, the evacuation plan is partially followed by the individuals. In general terms, the occupants moved towards the nearest classroom exit, regardless of the overall evacuation layout. Then, they move towards the nearest identifiable exit. In particular, the choice of using U_E related paths (path code 1 in Table 1) can be related to the familiarity with the entrance route in combination to group phenomena (social-shared identity combined to leader–follower effects) [19]. All the Elderly follow their group leader by adopting this behaviour. The groups similarly arrived at the doors, so only two linear regression are noticed in Fig. 5.

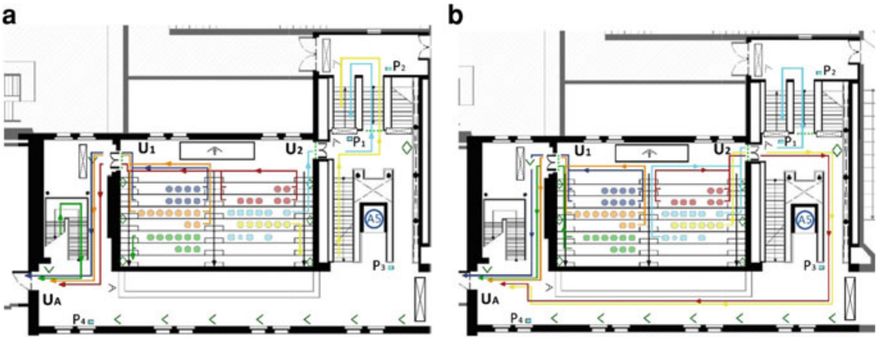

Fig. 6 Evacuation paths followed by the groups in: **a** original scenario conditions; **b** Co-WayS scenario. The initial group members' positions are the colored dots; each color is associated to a different group, and the related path has the same color

Figure 6b shows the paths used in the Co-WayS drill for each group. In this condition, most of the occupants used paths 3 and 4, while path 1 was used only by a group (see Table 1). In this conditions, the "cyan" group members arrived at the decisional point after "red" and "yellow" groups, as shown by the RSSI values over the evacuation time in Fig. 7, concerning the control area P_1 (which refers to U_2, compare to Table 1). Meanwhile, path 4 reaches critical conditions of density at the *control area* P_3 because of the arrival of "red" and "yellow" groups. Hence, path 4 is considered as blocked and the signs changed their status, by suggesting the "cyan" group to move towards path 1 and U_E.

Finally, questionnaires results to the involved individuals evidenced an increased satisfaction towards the Co-WayS with respect to the standard signs. About the question "Did you find the system helpful in evacuation choices?", the modal value for the likelihood-scale vote was 2 for standard signage (31% of people; vote 4: 25% of people) and 4 for Co-WayS (83% of people). The 75% of Elderly also stated that

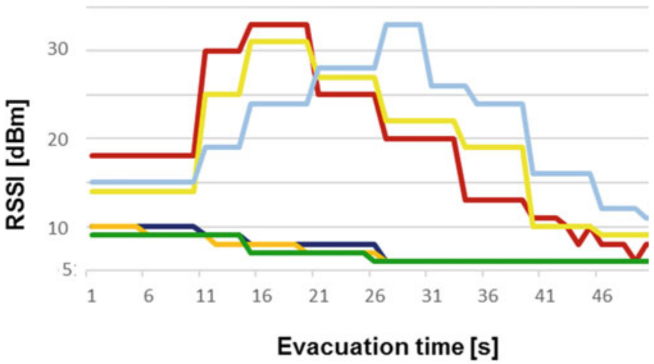

Fig. 7 RSSI values for the control area P_1, by evidencing the previous arrival of "red" and "yellow" groups in respect to the "cyan" one. The group colors are the same of Fig. 6

Co-Ways was visible and easy to be understood (vote 4), while only 50% stated the same for the standard signage. Finally, 89% of the individuals perceived to move together with their group in the original scenario, feeling themselves safe within their group. This value rises to 95% for Co-WayS use. The safety perception based on group motion assumption increases too.

5 Conclusions

In case of emergency in buildings, the safety of people is connected to their possibility to exit the building as quick as possible, by using the "best" evacuation path. Wayfinding activities are essential in this term for all the individuals who can autonomously move. The identification of the "best" evacuation path can reduce the overall time and so to prevent hazardous conditions to occupants (e.g.: prolonged exposure to toxic smokes; burns; risky crowding conditions). Vulnerable people, such as Elderly, should be considered with particular attention in this sense, especially when they are placed in an unfamiliar built environment. Public buildings represent for Elderly a critical scenario since they are additionally characterized by complex layout and high occupant densities.

To this assistance purpose, wayfinding systems can enhance the safety conditions for the occupants, including the Elderly. Anyway, they should be able to address the "best" evacuation direction depending on the effective evacuation conditions of the various building parts. Cognitive Building-oriented solutions can face this issue since they are able to monitor the conditions of the architectural space (referring to: building environment, disaster effects spreading in it, occupants' behaviours) to understand their related performance levels (referring to safety) and support individuals' choices by directly interacting with them (i.e. addressing the "best" path or which "safe" behaviours should be adopted). Moreover, they are integrated within the building components and take advantages of sensors placed in the environment to ensure the occupants' assistance.

This work proposes a Cognitive Wayfinding System (Co-WayS) to support evacuation tasks according to the effective users' needs and behaviours. The proposed system firstly detects the occupants' positions to evidence possible risky conditions for them (i.e. overcrowding leading to unacceptable pushing phenomena and to evacuation slowing down). The detection takes advantages of spontaneous gathering behaviours of people in evacuation, and so it is performed by assigning a detection element for each group of individuals in the building. Data on the localization of groups are collected by a central solving unit, and the main controller uses a density-based guidance algorithm to select the fastest and less crowdy paths. Electrically illumined signs with a dynamic status are connected to the controller, and they dynamically address the path to be followed according to the algorithm results. Signs are placed at the directional changes (i.e. doors), along corridors and stairs. The proposed system is also easy-to-apply and easy-to-remove, as well as it is modular.

The application of the system in a representative case study is offered in order to verify the proposed system effectiveness with respect to current wayfinding signage. Wide-scale drills involving the Elderly are performed. Results show how evacuation the time significantly decreases while occupants are guided by the proposed system, because the path choice (and so the related exits flows) is optimized. Advantages are essentially due to the adoption of the density-based algorithm, which reduces the motion time by leading people to move towards the clearest paths. The same results descend from both motion quantities evaluation and analyses on questionnaires to attendees, especially to the Elderly, who pointed out a very high appreciation of the system in terms of visibility and intelligibility. The system effectiveness is demonstrated although each individual's localization is checked according to his/her belonging group. The possibility to monitor each occupant would surely improve the system reliability but computational issues should be solved to ensure the (quasi) real-time system operation, especially in case of large and complex buildings.

Study outcomes recommend applying such intelligent wayfinding systems to existing buildings to help occupants during the evacuation (especially autonomous older ones). For instance, they could be installed in hospitals and Care Homes to reduce the possible evacuation interferences between autonomous and not-autonomous (i.e. assisted by healthcare assistance and safety staff members) Elderly. Anyway, further studies should extend the validity of the results, by using different spaces configurations (e.g. individuals placed in different parts of a building) and by massively involving silver age individuals. Moreover, it could be combined also to alarm solutions which could be able to guarantee the alert of occupants and their support also at the begin of the emergency (i.e. to reduce the pre-movement phase). Finally, the inclusion of additional control of the conditions of the architectural spaces within the system, i.e. disaster-induced effects during the time (e.g. smoke production), would better prepare the "path" selection algorithm to risky environmental factors.

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References

1. Monekosso D, Florez-Revuelta F, Remagnino P (2015) Ambient assisted living [Guest editors' introduction]. IEEE Intell Syst 30:2–6. https://doi.org/10.1109/MIS.2015.63
2. Bernardini G, Quagliarini E, D'Orazio M, Santarelli S (2017) How to Help elderly in indoor evacuation wayfinding: design and test of a not-invasive solution for reducing fire egress time in building heritage scenarios. In: Cavallo F, Marletta V, Monteriù A, Siciliano P (eds) Ambient assisted living. ForItAAL 2016. Springer, Cham, pp 209–222

3. Tancogne-Dejean M, Laclémence P (2016) Fire risk perception and building evacuation by vulnerable persons: points of view of laypersons, fire victims and experts. Fire Saf J 80:9–19. https://doi.org/10.1016/j.firesaf.2015.11.009
4. Escherich K, IBM Watson IoT cognitive buildings. https://www.buildingcontrol.dk/artikler/EscherichBuildingControl.pdf
5. Chen Z, Jiang C, Xie L (2018) Building occupancy estimation and detection: a review. Energy and Buildings 169:260–270. https://doi.org/10.1016/j.enbuild.2018.03.084
6. Machado A, Maran V, Augustin I et al (2017) Reactive, proactive, and extensible situation-awareness in ambient assisted living. Expert Syst Appl 76:21–35. https://doi.org/10.1016/j.eswa.2017.01.033
7. Siegel C, Dorner TE (2017) Information technologies for active and assisted living—influences to the quality of life of an ageing society. Int J Med Inf 100:32–45. https://doi.org/10.1016/j.ijmedinf.2017.01.012
8. Camarinha-Matos LM, Ferrada F, Oliveira AI et al (2014) Care services provision in ambient assisted living. IRBM 35:286–298. https://doi.org/10.1016/j.irbm.2014.08.001
9. Folk L, Gales J, Gwynne S, Kinsey M (2016) Design for elderly in fire situations. Interflam 2016. https://doi.org/10.13140/RG.2.1.1853.5924
10. Ahmadi-Karvigh S, Becerik-Gerber B, Soibelman L (2019) Intelligent adaptive automation: a framework for an activity-driven and user-centered building automation. Energy Build 188–189:184–199. https://doi.org/10.1016/j.enbuild.2019.02.007
11. Hong T, Yan D, D'Oca S, Chen C (2017) Ten questions concerning occupant behavior in buildings: the big picture. Build Environ 114:518–530. https://doi.org/10.1016/j.buildenv.2016.12.006
12. Bernardini G, Azzolini M, D'Orazio M, Quagliarini E (2016) Intelligent evacuation guidance systems for improving fire safety of Italian-style historical theatres without altering their architectural characteristics. J Cult Herit 22:1006–1018. https://doi.org/10.1016/j.culher.2016.06.008
13. Tang S, Shelden DR, Eastman CM et al (2019) A review of building information modeling (BIM) and the internet of things (IoT) devices integration: Present status and future trends. Autom Constr 101:127–139. https://doi.org/10.1016/j.autcon.2019.01.020
14. Li R, Lu B, McDonald-Maier KD (2015) Cognitive assisted living ambient system: a survey. Digit Commun Netw 1:229–252. https://doi.org/10.1016/j.dcan.2015.10.003
15. Shi L, Xie Q, Cheng X et al (2009) Developing a database for emergency evacuation model. Build Environ 44:1724–1729. https://doi.org/10.1016/j.buildenv.2008.11.008
16. von Sivers I, Templeton A, Künzner F et al (2016) Modelling social identification and helping in evacuation simulation. Saf Sci 89:288–300. https://doi.org/10.1016/j.ssci.2016.07.001
17. Gwynne SMV, Boyce KE (2016) Engineering Data. SFPE Handbook of Fire Protection Engineering. Springer, New York, New York, NY, pp 2429–2551
18. Jeon G-Y, Hong W-H (2009) An experimental study on how phosphorescent guidance equipment influences on evacuation in impaired visibility. J Loss Prev Process Ind 22:934–942. https://doi.org/10.1016/j.jlp.2009.08.008
19. Ma Y, Yuen RKK, Lee EWM (2016) Effective leadership for crowd evacuation. Phys A 450:333–341. https://doi.org/10.1016/j.physa.2015.12.103
20. Bañgate J, Dugdale J, Adam C, Beck E (2017) A review on the influence of social attachment on human mobility during crises. In: Proceedings of the international ISCRAM conference 2017–May
21. Purser DA (2017) Effects of pre-fire age and health status on vulnerability to incapacitation and death from exposure to carbon monoxide and smoke irritants in Rosepark fire incident victims. Fire Mater 41:555–569. https://doi.org/10.1002/fam.2393
22. Galea ER, Xie H, Deere S et al (2017) Evaluating the effectiveness of an improved active dynamic signage system using full scale evacuation trials. Fire Saf J. https://doi.org/10.1016/j.firesaf.2017.03.022
23. Olander J, Ronchi E, Lovreglio R, Nilsson D (2017) Dissuasive exit signage for building fire evacuation. Appl Ergon 59:84–93. https://doi.org/10.1016/j.apergo.2016.08.029

24. NFPA 101: Life Safety Code
25. Tabirca T, Brown KN, Sreenan CJ (2009) A dynamic model for fire emergency evacuation based on wireless sensor networks. In: Eighth international symposium on parallel and distributed computing. IEEE, pp 29–36
26. Ran H, Sun L, Gao X (2014) Influences of intelligent evacuation guidance system on crowd evacuation in building fire. Autom Constr 41:78–82. https://doi.org/10.1016/j.autcon.2013.10.022
27. Cho J, Lee G, Won J, Ryu E (2014) Application of Dijkstra's algorithm in the evacuation system utilizing exit signs. In: International symposium on automation and robotics in construction and mining (ISARC)

Probabilistic Logic Reasoning in Multi-agent Based Smart Home Environment

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

Abstract The dynamic nature of the ambient assisted living (AAL) environments coupled with vague inhabitant voice commands may result in ambiguous, incomplete, and inconsistent contextual information about the state of the home and its inhabitants. Ultimately, these lead the AAL system into uncertainty, which is common in smart home environments due to inaccurate sensor readings or due to the existence of unobserved variables for privacy reasons. Aiming at tackling some of these challenges, this paper applies a probabilistic logic based reasoning technique into a multi-agent based smart home architecture. Accordingly, the study shows how the probabilistic reasoning technique enables the agents to reason under uncertainty. Further, it discusses how intelligent agents enhance their decision-making process by exchanging information about missing data or unobservable variables using agent interaction protocols. In addition, the paper presents the proof-of-concept implementation and preliminary experimental evaluation of the proposed smart home system architecture. In general, the study demonstrates that the combination of multi-agent system (MAS) technologies and probabilistic logic programming can help in building a smart home reasoning system, which is capable of performing well under vague inhabitant commands and missing information in partially observable environments.

Keywords Smart homes · Reasoning under uncertainty · Multi-agent systems

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1 Introduction

The term *"smart home"* refers to a residence equipped with technologies that facilitate monitoring of residents, promote independence and increase the quality of life [8]. Smart home systems have been widely applied to home energy management [1], health-care [10], and comfort centered services [17]. To effectively deliver these services, the smart home system needs to perceive the state of the residence through sensors, and automatically adapt the living environment to its inhabitants' preferences through actuators. The automatic adaptation process of the living environment is mainly determined and controlled by the reasoning system, which is considered to be the brain of the smart home system. Precisely, the primary role of a smart home reasoning system (SHRS) is to make appropriate decisions towards achieving the comfort and efficiency goals of the inhabitant and their environment.

Recent investigations in SHRSs identified reasoning under uncertainty and incomplete knowledge as the major challenges of these systems. Specifically, [13] underlined that uncertainty is inevitable in ambient assisted living environments as sensors may read inaccurate data or due to the existence of unobserved variables for privacy reasons. Further, the dynamic nature of the environment and vague human communications may result in ambiguous, incomplete and inconsistent contextual information, which ultimately lead the system into uncertainty. However, little attention has been paid to address these challenges.

The present article aims to tackle some of these challenges by proposing a probabilistic multi-agent system architecture for reasoning in the AAL environments. For this, it utilizes the notion of intelligent agents and a probabilistic logic programming technique. On the basis of these technologies, the paper defines multiple intelligent agents and discusses their purposes and operations. Mainly, it illustrates how the agents perform reasoning under uncertain situations, using an ambiguous inhabitant command as a scenario. Finally, the feasibility of the proposed MAS architecture is demonstrated using a proof-of-concept (PoC) implementation.

The rest of the paper is organized as follows: Sect. 2 gives an overview of the related works. Section 3 briefly introduces the ProbLog language and agent interaction protocols. In Sect. 4, we present our multi-agent system architecture and discusses the probabilistic reasoning process using a simple scenario. Section 5, evaluates the proof-of-concept implementation of the proposed system presenting the experimental settings and the preliminary test results. And, Sect. 6 concludes the paper.

2 Related Research

Over the years, several studies have exploited the basic advantages of intelligent agents to model smart home environments and to automatically control their overall operations. For instance, [15] introduced a multi-agent system architecture to provide health care services in the AAL environment. The core of the system is a belief-desire-intention (BDI) agent, which represents the reasoning module of the overall architecture. Similarly, [14] proposed ThinkHome, a smart home architecture composed of a knowledge base and a multi-agent system. ThinkHome is populated by various specialized BDI agents, which are responsible for solving different problems by utilizing ontological reasoning methods. Further, [1] modeled the home environment as a MAS, and utilized contract based negotiation protocol for power management in home automation domain. Each of these contributions showed the advantages of modeling an AAL environment in terms of MAS, however, none of them consider issues related to uncertainty while presenting their reasoning modules. On the other hand, the MavHome architecture [5], which is a hierarchy of collaborative rational agents, was designed to meet the overall goals of a smart home environment. In MavHome each agent is composed of four cooperating layers: Decision, Information, Communication, and Physical. The decision layer is built by combining different machine learning algorithms, including Markov decision process. However, the contribution barely discusses issues related to uncertainty and methods to handle them in AAL environments.

Some other studies attempted to tackle uncertainty related challenges in the AAL environment using probabilistic graphical models. For instance, [12] utilized Multi-Entity Bayesian Networks to present a reference model for the AAL system that deals with uncertainty. However, the contribution is more tailored to the detection and prediction of unwanted situations than decision-making under uncertain conditions. Likewise, [20] discussed a smart home reasoning scenario which incorporates uncertainty reasoning using a rule-based system and Bayesian networks. And, [4] presented a framework to build a home automation system reactive to voice commands. In which, Markov logic network (MLN) is used to build the decision-making module of the system, and the uncertainty of the decision model was learned from data. Further, the authors integrated and tested their proposed system in a real-world environment, and presented some interesting results. However, both of the aforementioned works did not structure their solutions as a MAS, thus did not benefit from the advantage of autonomous agents. Further, MLNs are known to require a non-trivial effort by experts to properly model uncertainties in terms of weights [3]. Taking this into account, [19] utilized ProbLog for complex activity recognition in the smart home domain but again did not discuss a reasoning system as a whole.

Having these in mind, the present paper utilized the combination of MAS and probabilistic logic programming techniques to tackle uncertainty related issues in AAL environments. Specifically, in this paper, the smart home system is modeled in terms of collaborative intelligent agents, and probabilistic reasoning is utilized to give the agents an ability to make a decision under an uncertain situation.

3 Background

This section briefly introduces the probabilistic logic programming technique and the agent interaction protocols utilized in this paper.

3.1 ProbLog

ProbLog is a probabilistic extension of Prolog, and like Prolog, its program consists of a set of definite clauses. However, in ProbLog every clause c_i is annotated with the probability p_i that it is true, and these probabilities are mutually independent with each other [6]. That is $P(A \cap B) = P(A)P(B)$. Listing 1 shows a simple ProbLog program,[1] in which the first clause indicates the fact burglary is true with probability 0.3 and false with probability 0.7. And the second clause indicates, if burglary is true, then alarm will be true as well with 0.9 probability.

```
0.3::burglary.
0.9::alarm:-burglary
```

Listing 1: Simple ProbLog program

Unlike Prolog, where one is interested in determining whether a query succeeds or fails, in ProbLog we are interested in computing the probability that it succeeds. Below, the equations for computing the success probability of a ProbLog query are cited and summarized from [6] and [19].

Given a ProbLog program $T = \{p_1 : c_1, ..., p_n : c_n\}$. The probability of a world ω, that is a certain instance of the program, is defined as follows:

$$P(\omega|T) = \prod_{c_i \in \omega} p_i \prod_{c_i \in \omega_T \setminus \omega} (1 - p_i) \tag{1}$$

where $\omega_T \setminus \omega$ describes the set of clauses that were not instanced in ω but are part of T, i.e. the set of false ground probabilistic atoms. Then, the success probability of a query q in the ProbLog program T is computed as follow:

$$P(q|\omega) = \begin{cases} 1, & \exists\theta : \omega \models q\theta \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

$$P(q, \omega|T) = P(q|\omega).P(\omega|T) \tag{3}$$

---

[1] This program is a shortened form of an example provided in the official website of ProbLog.

$$P(q|T) = \sum_{\omega \subseteq W} P(q, \omega|T) \quad (4)$$

In short, the probability that a ProbLog query q succeeds is the sum of the probabilities of those worlds where q can succeed.

3.2 Agent Interaction Protocols

In a MAS environment, it is essential to have a standard agent interaction mechanism, that allows agents to collaborate and coordinate with each other in order to achieve their goals. Hence in our proposed MAS architecture, we utilized the FIPA Request Interaction Protocol (IP) [11] and Contract Net Protocol (CNET) [18]. IP allows one agent, the *Initiator*, to request another agent, the *Participant*, to perform an action. The Participant processes the request and makes a decision whether to *accept* or *refuse* the request. Once the request has been agreed upon, the Participant must communicate a *failure*, an *inform-done* or *inform-result* messages for the initiator agent [2]. Likewise, CNET is a market-based protocol which allows the Manager agent to have some task performed by one or more other Contractor agents. In both IP and CNET, at any time an agent can be an Initiator/Manager, a Participant/Contractor or both.

4 The Multi-Agent System Architecture

Home is a place where one lives. Commonly, it is composed of several rooms, dedicated for the specific activities of daily living. As shown in Fig. 1, our proposed multi-agent system architecture follows this logical structure of the home environment. Specifically, a group of collaborative intelligent agents manages each room of the smart home. These agents specialize in the specific tasks of the home automation system (such as monitoring the brightness or the air conditioning of the room) and collectively control the comfort and efficient operation of that specific room. In addition, these agents collaborate with other agents, which resides in another room of the home, to achieve the overall goals of the smart home system. In order to realize this architecture, we propose four kinds of room-level agents: *Device, Service, Reasoner, and Negotiator* agents. In general, this kind of architecture allows to benefit from the basic advantages of intelligent agents such as autonomy, social ability, reactivity, and pro-activeness. It enables to modularize the smart home system into autonomous, collaborative and distributed components, which provide well-tailored services based on their location in the home. Further, the architecture allows to design a highly customizable and fault tolerant smart home system. Below the purposes and functioning of the aforementioned agents are discussed.

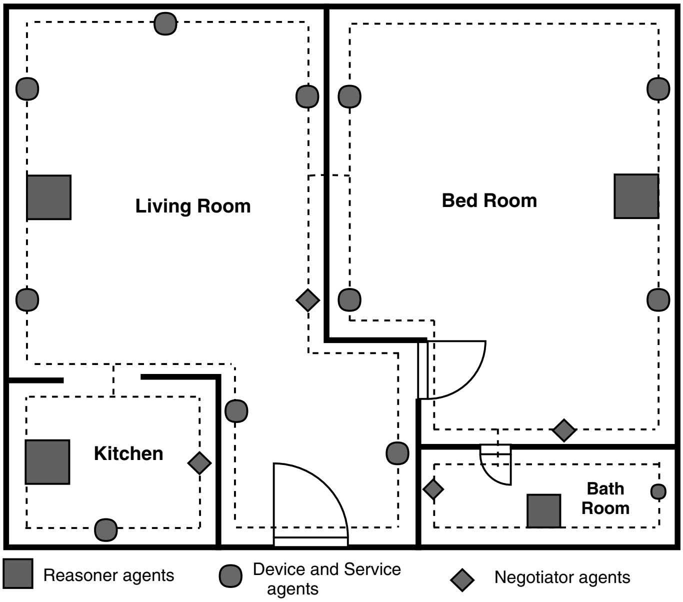

Fig. 1 The smart home floor plan

4.1 Device Agents

In the proposed architecture, a device agent (DA) controls the overall operation of a smart home device (i.e a sensor or an actuator) or group of devices. A DA which is responsible for controlling a specific sensing device(s), continuously monitors the changes in the environment and combines low-level sensor readings with other data in the home to generate high-level contextual information about the state of the home or its inhabitant. For instance, a device agent which controls room temperature, monitors a group of temperature sensors in that room and generates contextually meaningful information (e.g.. *warm, cold* …) by processing the sensor data with the season of the year, time of the day, type of the room etc. In addition, device agents are also able to determine their degree of belief (*Bel*) for the generated contextual information (e.g.. *Bel(warm)* = *0.9*). Here, a degree of belief can be understood as a number in the range of [0, 1], that represents the measure of the agent's confidence in the generated context based on all available evidence. In order to combine separate pieces of information and determine its *Bel* about the newly derived context, a DA may use evidential theories such as Dempster-Shafer theorem [16] or other probabilistic approaches.

On the other hand, a device agent which controls the operation of an actuator(s) put into consideration the current situation of the home and its inhabitants, while executing a user command or during a self-adaptation process. For instance, when operating an electrical device the agent should check the real-time electric prices, and schedule the operation for off-peak hours if the outcome of the operation is not urgently required. This ensures the efficient execution of the command on the targeted smart home device and renders high-quality services in a cost effective way possible.

4.2 Service Agents

Service agents (SA) are general purpose agents which provide house level information, that is not specific to a single room or space in the home environment. Global information, which can be acquired from external data sources (such as weather data, and real-time electricity price) and information from other smart home software components (such as activity recognition and person localization systems) can be coupled into services agent and integrated into the proposed multi-agent system architecture. Like device agents, SAs are also able to determine and share their degree of belief about their produced information.

4.3 Reasoner Agents

In the proposed MAS architecture, each room is equipped with a reasoner agent (RA), which is responsible for the automatic control of the room environment and its adaptation to the inhabitant's needs. The decision-making unit of this agent is designed based on a probabilistic logic programming technique called ProbLog. This technique allows the design of a hybrid reasoning system, which benefits from the advantages of both symbolic and statistical artificial intelligence methods. As a result, along with other assets of hybrid systems, RA possesses the ability to act under uncertainty and perform well with erroneous sensor data and ambiguous user commands. In addition, ProbLog enables to learn the structure and parameters of the probabilistic rules from data and to model the system using human-readable and easily modifiable rules. Besides, these agents are designed to cope with unavailable, conflicting and inconsistent sensor data by actively collaborating with other agents in the system.

Algorithm 1 details the overall operation of an RA when it receives a user command or detects a change in the home. When an RA receives a user command, first it determines the smart home service associated with it (e.g.. the user command "*turn on the light*" can be associated with the smart home service "*light*"). Following this, it discovers a list of device and service agents which provide relevant information to the requested service, and then it identifies the device agent which controls the behavior of that specific smart home service (lines 2-3). Subsequently, it will send an information request about the current state of the inhabitant and its environment to the data provider agents (line 4). Whereas, when a DA receives an information request, it determines the value of the requested information and its degree of belief about it (e.g.. *useractivity="cooking", Bel=0.99*), and send back a reply for the reasoner agent. However, some of the data provider agents may fail to provide the requested information on time or may fail to reply at all due to sensor failure or other problems. Moreover, RA may discover some inconsistencies or conflicts in the collected data (lines 5-6). In this kind of situations, RA will request its negotiator agent to interact with other negotiator agents in the system and gather the missing data from similar data provider agents in other rooms of the smart home (line 7). When the interaction process ends, the negotiator agent will transfer the result to the reasoner agent, which will use the data to improve its level of uncertainty or resolve conflicts, so that it makes the most appropriate decision (lines 8–9). When RA receives all information, it will check again if some data are still missing (lines 10–11), if so, it will use default values for these data (lines 12–13). Here, the default values of a sensor can be determined from the values of other sensors in the environment, and the current contexts of the home. After resolving the missing information, RA will build the ProbLog model and checks if it has the ability to run it locally (lines 16–17). RA's ability to solve a ProbLog model is determined by the local availability of a ProbLog engine and computational resources required to solve the model. If RA has reasoning ability, it solves the ProbLog model locally (line 19), that is determining the success probabilities of all the associated commands related to the user request and the situation of the home. Afterwards, it picks the command with the highest probability, that is the command considered to give maximum user satisfaction in the current state of the home. Whereas, if RA does not have reasoning ability, it will request the negotiator agent in the same room to delegate the reasoning task for other RAs in the system (line 21). If the negotiator agent fails to find another RA willing to solve the model, RA will take the default command for the user request (line 26). Otherwise, it will use the result of the interaction, which is a command with the highest success probability to serve the user request (line 24). Finally, RA will send the control command for the devices controller agent (line 29). Section 4.3.1 briefly describes the underlying decision-making process of this agent, using a simple scenario, and Fig. 2 depicts the sequence diagram of the agents' interaction in the scenario. The function and operation of the negotiator agent are discussed in the next section.

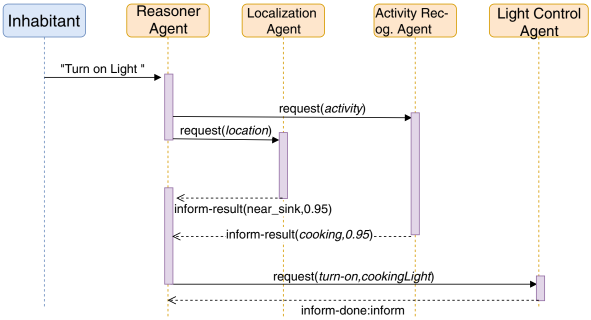

Fig. 2 Sequence diagram representing the interactions between the agents

Algorithm 1: RA's reasoning algorithm

```
input : userRequest
service ⟵ determineRequestedService(userRequest);
dataProviderAgents ⟵ discoverDataProviders(service);
devicesControllerAgent ⟵ discoverDevicesController(service);
sensorData ⟵ collectSensorData(dataProvidersList);
missingData ⟵ getMissingData(service, sensorData) ;
if not empty missingData then
    sendInformationRequest(negotiator, missingData);
    missingData ⟵ receiveData(negotiator);
    sensorData.merge(missingData);
    missingData ⟵ getMissingData(service, sensorData) ;
    if not empty missingData then
        missingData ⟵ getDefaultValues(missingData);
        sensorData.merge(missingData);
    end
end
probLogModel ⟵ buildProbLogModel(sensorData, service);
ableToReason ⟵ ableToReasonLocally();
if ableToReason then
    controlCMD ⟵ solveProbLogModel(probLogModel);
else
    sendReasoningTaskRequest(negotiator, probLogModel);
    result ⟵ receiveReasoningResult(negotiator);
    if result.status = SUCCESS then
        controlCMD ⟵ result.data ;
    else
        controlCMD ⟵ getDefaultCommand(service, sensorData);
    end
end
sendCommand(devicesControllerAgent, controlCommand);
```

4.3.1 Scenario: Dealing with Ambiguous User Command

Suppose the kitchen has four kinds of lights (*i.e. ceiling, sink, dining and cooking lights*) and the inhabitant stands near the kitchen-sink (*loc = "near-sink", Bel = 0.95*) while preparing her dinner (*act = "cooking", Bel = 0.95*). Meanwhile, she issues a voice command *"turn on the light"* to the system, without specifying the exact light she wants the system to turn on. This kind of ambiguous user commands are one of the major sources of uncertainty in smart home environments, and hereinbelow we will use this scenario to illustrate how the reasoner agent function under such circumstances.

To simplify the discussion let us again assume that, RA controls the lighting of the room only based on the inhabitant's current location and activity. That is, the system turns on the *cooking, sink, dining or ceiling light*, when the inhabitant is around the kitchen cabinet and preparing food, around the sink and washing plates, on the dining table and eating, or anywhere in the room and tidying up respectively. The current location and activity of the inhabitant are also separately utilized to control the lighting of the room, with distinct probability values (*Pr*). That is, activity-based light control (*Pr = 0.7*) is assumed to give better user satisfaction compared with location-based control (*Pr = 0.5*). Further, for any *"turn on the light"* command, it is also assumed to be fair, if the RA turns on the ceiling light with *Pr = 0.5*. Listing 2, shows the ProbLog representation of the aforementioned scenario. The parameters of the probabilistic clauses can be mined from a dataset using a probabilistic rule learner tool such as ProbFOIL [7], or manually designed by a knowledge engineer. The parameters of the rules and facts in listing 2 are from the assumptions made in this scenario.

```
0.95::loc(near_sink).
0.95::act(cooking).
0.90::cookingLight:- act(cooking), loc(cooking_area).
0.70::cookingLight:- act(cooking).
0.50::cookingLight:- loc(cooking_area).
0.90::sinkLight:- act(washing), loc(near_sink).
0.70::sinkLight:- act(washing).
0.50::sinkLight:- loc(near_sink).
0.90::dinningLight:- act(dinning), loc(dinning_table).
0.70::dinningLight:- act(dinning).
0.50::dinningLight:- loc(dinning_table).
0.90::ceilingLight:- act(tidyingup).
0.50::ceilingLight.
```

In light of the above scenario, when RA receives the voice command, it first determines the set of possible worlds based on the current activity and location of the inhabitant. The possible worlds are the list of commands, whose logical formulas evaluated as true. And, as shown in Fig. 3, *cooking light, sink light and dining light* commands are all each in one possible world, which is represented as solid line rectangles in the figure. Subsequently, the agent determines the success probabilities of each possible worlds using Eq. 1, and sum up the probability values of each command using Eq. 4. Finally, it executes the command with a larger total sum probability value

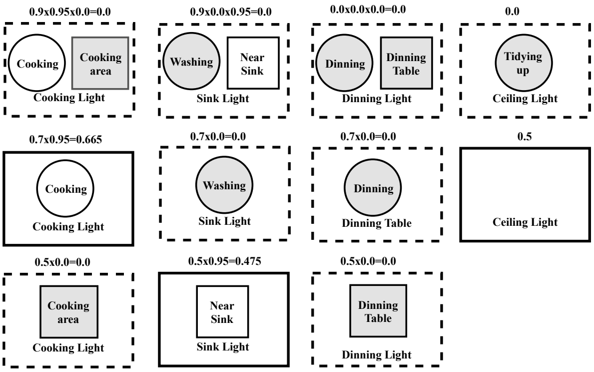

Fig. 3 All worlds for the turn on the light command

(i.e. *"cookingLight"*, with *0.665* success probability). For the process of determining the possible worlds and their success probabilities, the reasoner agent fully relies on the ProbLog solver.

4.4 Negotiator Agents

In the proposed MAS based smart home architecture, each room has a negotiator agent (NA), which is in charge of handling the collaboration process between agents of different rooms. Specifically, NA enables other agents in the system to exchange information about the state of the environment they are operating in. Further, when reasoner agents are not able to solve their decision-making problem due to computational resource limitation, the negotiator agent enables them to share their reasoning tasks (i.e. determining the success probability of a query) with other reasoner agents in the system. In practice, this agent is designed based on the FIPA Request Interaction and Contract Net Protocols, thus at different times, it acts as the *initiator* or *participant* of an information exchange process, or it acts as the *manager* or *contractor* of a negotiation process over reasoning tasks. As the primary focus of this paper is tackling some of the major causes of uncertainty in the smart home environments: that are *missing information, partial observability, and ambiguous user commands*, this section only discusses the information exchange processes between the intelligent agents, and leaves the discussion about the negotiation process over the distribution of reasoning tasks for future works.

NA plays the initiator role when it receives an information request message from the reasoner agent in the same room. As the Request Interaction Protocol initiator, the negotiator agent first looks for other negotiator agents in the house, who are registered to provide the information that the RA requested. Afterward, it will send a *request* message with the submission deadline, for all the information provider agents. Upon receiving the information from each of the participants (i.e. *inform-result* message), it will determine the best reply based on some criteria or combines separate replies to derive one, and communicates the final result for the reasoner agent. For instance, if RA is interested in the total number of people in the house after each participant NA communicated the number of people in their respective rooms, the initiator NA will sum the values, or if the requested information is room temperature, RA will determine the statistical mean value.

Likewise, NA plays the participant role, whenever it receives an information request message from another agent of the same type. Accordingly, based on the availability of a device agent in the same room, that is able to provide the requested information, the negotiator agent will accept or reject the request by sending *agree* or *refuse* messages respectively. If it accepts, it will send a *request* message for the information provider device agents. At last, when it receives the data from all device agents, it will process and communicate the result for the initiator NA. This process should help the reasoner agents to cope with sensor failures and perform well in partially observable environments.

5 Preliminary Evaluation

A Proof-of-concept implementation of the proposed multi-agent system architecture is done using the Java Agent DEvelopment Environment (JADE) framework [2] and ProbLog Python library. JADE is an open-source FIPA compliant middleware for developing multi-agent systems. It provides a ready-to-use and easy-to-customize MAS development platform, efficient agent communication mechanisms, effective agent life-cycle management, support for agent mobility, yellow and white page services, and a GUI for debugging and monitoring MAS application [2]. ProbLog is available as an online tool on the web and for download. The offline version offers both command line access to inference and learning and a Python library for building statistical relational learning applications [9]. For the purposes of giving the probabilistic reasoning ability for the reasoner agents in our system, we integrated the ProbLog Python library into the JADE MAS platform.

5.1 Experimental Setup

For the PoC implementation, we simulated the four-room smart home architecture presented in Fig. 1. In which, agents of each room run inside a JADE container hosted on a single board computer and connected with each other through a local area network. The MAS hosted in each node is composed of one Reasoner, one Negotiator, one JADE Directory Facilitator, and four Device and Service agents, that are Inhabitant Activity Recognition, Inhabitant Localization, Luminosity sensor, and Light service controller agents. The device and service agents are designed to randomly generates synthetic sensor data from their respective predefined set of values. For the purposes of heterogeneity, we host two of the rooms in Raspberry PI 3 Model B+ nodes (quad-core A53 (ARMv8) 64-bit @ 1.4GHz, 1GB SDRAM, Gigabit Ethernet, Raspbian OS), and the other two in Intel Galileo boards (single core i586 CPU @ 400 MHz, 256 MB DRAM, 100 Mb Ethernet, Yokto Linux OS). As the latest version of Yokto does not support Python 3, which is a prerequisite to run a ProbLog engine, the two rooms which are hosted in the Galileo boards were without the ability to solve ProbLog model, thus need to delegate their reasoning tasks to other reasoner agents in the system. In general, this setup allows us to measure the CPU time needed by the RA to reason locally on the Raspberry PI nodes, and the CPU time needed by the RA to negotiate and solve the ProbLog model on another node in the system. Further, to make a comparison of the reasoning time in the two hardware configurations, the latter case was tested both on the Raspberry Pi (with no local reasoning ability) and Galileo boards. In this evaluation, scenario one and its ProbLog model (presented in Fig. 2) is utilized. Figure 4 depicts the experimental setup used to run the tests and evaluate the proposed multi-agent system.

Fig. 4 The experimental setup

5.2 *Tests and Results*

To measure the CPU time that an RA requires to reason, we run two groups of experiments. First, we measure the CPU time that an RA requires to perform the entire reasoning process locally on a Raspberry PI node. Second, we measure the CPU time that an RA requires to delegate and solve the ProbLog model via the negotiator agent, both on the Raspberry PI and Galileo nodes. Further, we conducted four distinct tests for each of the aforementioned two experiments, by incrementally changing the number of locally unavailable (missing) information required to reason from zero to three. We run all the tests 100 times and recorded the mean and standard deviation of the reasoning time. Tables 1 and 2 summarize the results of the experiments, and Figs. 5, 6 and 7 present comparable results of each run.

As can be seen in Table 1 and Fig. 6, the reasoner agent which run on the Raspberry PI node required a relatively small amount of time to reason locally compared with the

Table 1 CPU time (ms) of reasoning locally versus over negotiation with varying missing information (MI), on Raspberry PI 3 nodes

Raspberry PI	No. of missing information			
	None	One	Two	Three
Reasoning locally	597.2 ± 17	617.9 ± 17	618.2 ± 23	650.2 ± 17
Reasoning over negotiation	674.9 ± 28	727.6 ± 34	716.13 ± 32	729 ± 28

Table 2 CPU time (ms) of reasoning via negotiation with varying missing information (MI), on Raspberry PI 3 versus Galileo nodes

Board	No. of missing information			
	None	One	Two	Three
Raspberry	674.9 ± 28	727.6 ± 34	716.13 ± 32	729 ± 28
Galileo	828 ± 60	920 ± 71	925.3 ± 42	900.5 ± 41

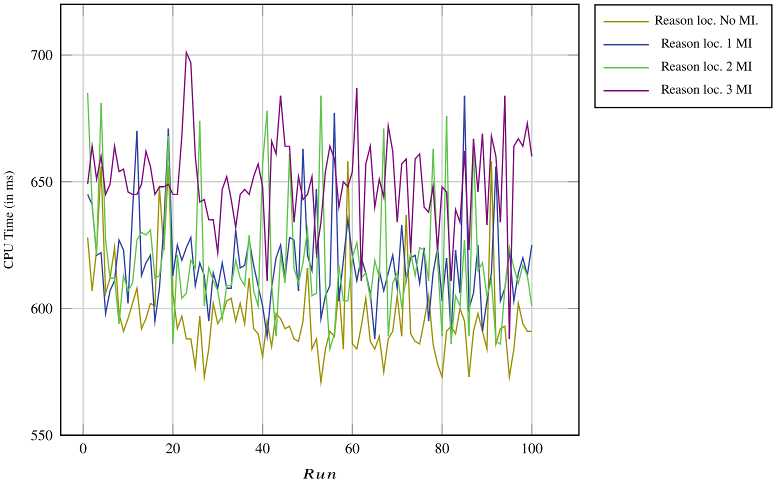

Fig. 5 Reasoning locally on the Raspberry PI nodes

one which needs to delegate the reasoning task to another reasoner agent. This is due to the negotiation process and the message exchange between the agents involved in it. Whereas, as shown in Fig. 7, the difference in reasoning time between the Galileo and Raspberry PI nodes is relatively big. Intuitively, this is due to the difference in the computational capacity of the two boards. In addition, in this experiment, we also noticed that the time required to collect missing information (MI) from other device agents in the system is nearly constant.

In general, from the proof-of-concept implementation and preliminary experiments, we observed the practicality and feasibility of the proposed MAS based smart home architecture. First, it was observed that the probabilistic inference technique allows the reasoner agent to reason with ambiguous user commands and partial information. Second, collaborative MAS architecture enables the agents to cope well in partially observable environments. In addition, the MAS architecture makes it possible to design heterogeneous, highly customizable, robust and modular system.

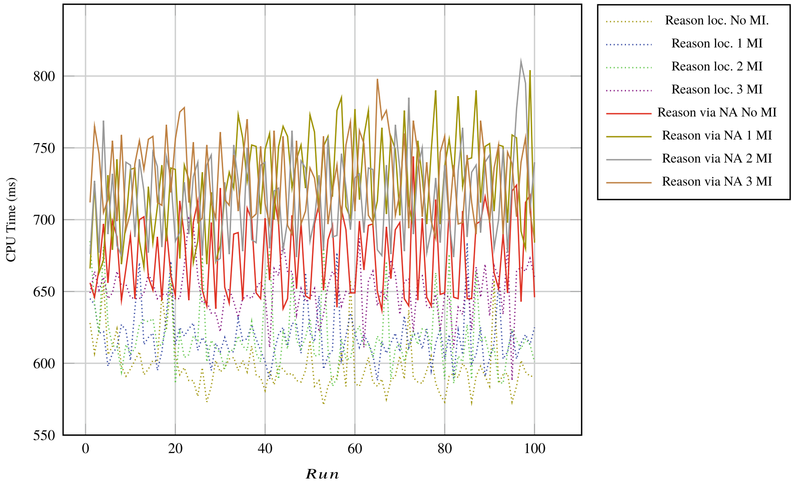

Fig. 6 Graphical comparison of reasoning locally and over negotiation on Raspberry PI nodes

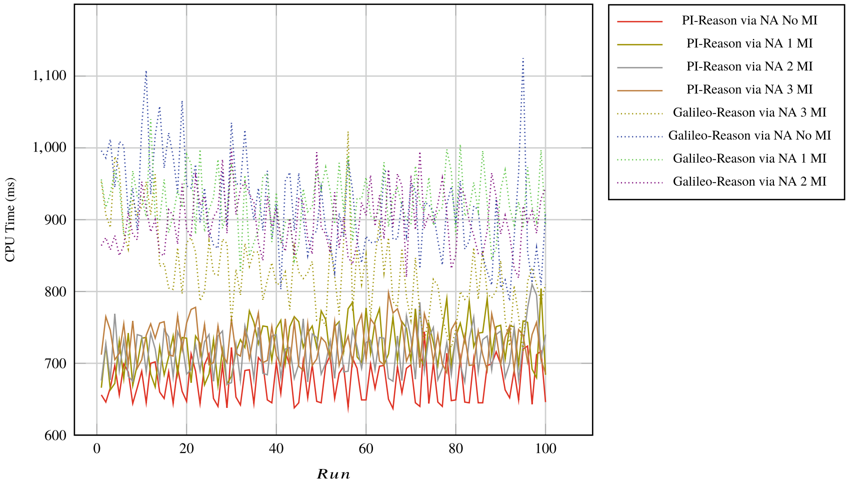

Fig. 7 Graphical comparison of reasoning over negotiation on Raspberry PI and Galileo nodes

5.3 Threats to the Validity of the Experiments

Being a preliminary study on the application of probabilistic logic reasoning in multi-agent based smart home system, the proposed experiments do inevitably suffer from threats to validity. Therefore, future works will address the identified limitations.

First, the core ProbLog model used in the experiments is based on the scenario discussed in Sect. 3, so a model with few probabilistic logic clauses is not a computational challenge both for the proposed system and the integrated ProbLog solver.

Second, all the device and service agents used in our PoC implementation are simulated, consequently, the data generation time of these agents was almost negligible. Therefore, to draw a strong conclusion about the reasoning time of the agents a more complex ProbLog model and real sensors data need to be used.

6 Conclusions and Future Works

Prior works widely applied multi-agent systems to model AAL environments. However, most of them have not considered issues related to uncertainty reasoning, while presenting their decision-making components. Contrarily, few others tackled these challenges using probabilistic graph models, but either they have not discussed SHRSs as a whole, or they have not utilized the advantages of MAS to support the decision-making process in the AAL environments. With this in mind, in this study, we proposed a probabilistic multi-agent system architecture for reasoning in smart homes, based on a probabilistic logic programming technique called ProbLog and multi-agent system technologies. Accordingly, we illustrated how the probabilistic reasoning technique enables the intelligent agents to reason under uncertain situations. Further, we discussed how the agent interaction protocols enhance the decision-making process by allowing the agents to exchange information about missing data or unobservable variables between the agents. Therefore, this study showed that the integration of MAS and probabilistic logic programming can help in building a reasoning system for AAL environment, which is capable of performing well under vague inhabitant commands, missing information, and in partially observable environment.

Most notably, this is the first study to our knowledge which integrates the ProbLog reasoning engine into a multi-agent system framework and, to utilize it for tackling uncertainty issues in smart home environments. In general, our PoC implementation and experimental analysis suggest that this approach appears to be effective in counteracting uncertainties in the reasoning systems of these complex and dynamic environments. However, some limitations are worth noting. First, the proposed system is a work in progress, it is implemented as a PoC implementation, but not evaluated exhaustively. Second, some operations of the proposed system, especially the service and device agents are presented based on several assumptions. Third, the structure and parameters of the probabilistic logic rules are designed based on the subjective knowledge of the authors, yet can be learned from data. Finally, the application and advantage of CNET protocol for the distribution of the reasoning task are not discussed in detail. Therefore, future work will address these limitations and evaluate the proposed system thoroughly.

References

1. Abras S, Ploix S, Pesty S, Jacomino M (2008) A multi-agent home automation system for power management. In: Informatics in control automation and robotics. Springer, pp 59–68
2. Bellifemine F, Bergenti F, Caire G, Poggi A (2005) JADE—A Java agent development framework. In: Multi-agent programming. Springer, pp 125–147
3. Bruynooghe M, Mantadelis T, Kimmig A, Gutmann B, Vennekens J, Janssens G, De Raedt L (2010) ProbLog technology for inference in a probabilistic first order logic. In: ECAI. ACM, pp 719–724
4. Chahuara Pedro, Portet François, Vacher Michel (2017) Context-aware decision making under uncertainty for voice-based control of smart home. Expert Syst Appl 75:63–79
5. Cook DJ, Youngblood M, Das SK (2006) A multi-agent approach to controlling a smart environment. In: Designing smart homes. Springer, pp 165–182
6. De Raedt L, Kimmig A, Toivonen H (2007) ProbLog: a probabilistic prolog and its application in link discovery. In: IJCAI. Hyderabad, pp 2462–2467
7. De Raedt L, Thon I (2010) Probabilistic rule learning. In: International conference on inductive logic programming. Springer, pp 47–58
8. Demiris G, Hensel BK (2008) Technologies for an aging society: a systematic review of "smart home" applications. Yearbook Med Inform 17, 33–40
9. Dries A, Kimmig A, Meert W, Renkens J, Van den Broeck G, Vlasselaer J, De Raedt L (2015) ProbLog2: probabilistic logic programming. In: Joint European conference on machine learning and knowledge discovery in databases. Springer, pp 312–315
10. Falcionelli N, Sernani P, Brugués A, Mekuria DN, Calvaresi D, Schumacher M, Dragoni AF, Bromuri S (2018) Indexing the event calculus: towards practical human-readable Personal Health Systems. Artif Intell Med
11. FIPA Request Interaction Protocol Specification. (2002) http://fipa.org/specs/fipa00026/SC00026H.html Cited 10 May 2019
12. Machado A and Maran V, Augustin I, Lima JC, Wives LK, de Oliveira JPM (2016) Reasoning on uncertainty in smart environments. In: Proceedings of the 18th international conference on enterprise information systems. SCITEPRESS-Science and Technology Publications, Lda, pp 240–250
13. Mekuria DN, Sernani P, Falcionelli N, Dragoni AF (2018) Reasoning in multi-agent based smart homes: a systematic literature review. In: Italian forum of ambient assisted living. Springer, pp 161–179
14. Reinisch C, Kofler MJ, Iglesias F, Kastner W (2011) Thinkhome energy efficiency in future smart homes. EURASIP J Embedded Syst 2011, 1
15. Sernani P, Claudi A, Palazzo L, Dolcini G, Dragoni AF (2003) Home care expert systems for ambient assisted living: a multi-agent approach. In: Proceedings of the workshop on the challenge of ageing society: technological roles and opportunities for artificial intelligence, Turin, Italy
16. Shafer G (1976) A mathematical theory of evidence. Princeton University Press
17. Si H, Kawahara Y, Morikawa H, Aoyama T (2005) A stochastic approach for creating context-aware services based on context histories in smart home. Cognitive science research papers, vol 577. University of Sussex, p 37
18. Smith RG (1980) The contract net protocol: high-level communication and control in a distributed problem solver. IEEE Trans Comput 12, 1104–1113
19. Sztyler T, Civitarese G, Stuckenschmidt H (2018) Modeling and reasoning with ProbLog: an application in recognizing complex activities. In: 2018 IEEE international conference on pervasive computing and communications workshops (PerCom Workshops). IEEE, pp 259–264
20. Xiao B, Chen L, Liu M, Cao Y, Yang Y (2015) Design and implementation of rule-based uncertainty reasoning in Smart House. In: 2015 IEEE 16th international conference on communication technology (ICCT). IEEE, pp 441–448

How Would Do that? An Agile Elicitation Technique to Explore Users' Spontaneous Gestural Commands

Valeria Orso, Alice Bettelli, Luca Zamboni, and Luciano Gamberini

Abstract Hand gestures are an essential component of our behavior and are often considered a valuable way for Ambient Assisted Living solutions. Gestural commands are particularly helpful in hectic home environments, like the kitchen, where we often have greasy hands. Yet, gestures can be challenging to learn and recall especially for non-tech savvy users. The adoption of a user-centered approach to select the gestural commands typically allows to generate postures and moves that are easier to perform and remember. Following this approach, we report on an agile and cost-effective elicitation study based on a virtual prototype that was conducted to design a set of gestural commands to operate the lighting system embedded into an extraction hood. Spontaneous gestures by 30 participants were video recorded and categorized through computer-supported structured video analysis. Our findings indicate the feasibility of the proposed approach with able-bodied users and open to the involvement of physically and cognitively challenged individuals.

1 Introduction

Ambient Assisted Living (AAL) solutions aim to empower cognitively- and physically-challenged individuals to increase their autonomy in managing everyday activities. More specifically, one of the major goals of AAL is to actively compensate for the impairments of its inhabitants [2]. To facilitate the interaction between frail users and advanced systems, frequently Natural Users Interfaces (NUI) have been implemented. Several assistive interventions have addressed the kitchen environment, which is typically a crowded place, where many activities need to be coordinated, which can be challenging for users with limited mobility or impoverished cognitive skills [19]. Being able to control some functions of the appliances with

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touch-less commands can be very convenient, especially for physically challenged users. In this context, hand gestures qualify as a valuable interaction means for operating the computers embedded in our environment [14, 20]. As human beings, we spontaneously make an extensive use of speech and gestures for communicating with each other, for signifying objects and for interacting with the environment [27]. Indeed, gesture-based interfaces implemented in the home environment were found to effectively increase the autonomy of users with motor and linguistic impairments [3]. Differently, from other situations, mid-air gestural interaction in the household and at the presence of familiar people is well accepted [12]. Despite their naturalness and acceptability, gestural commands can be challenging to learn and recall, especially when they are designed based only on the technical constraints of the interface, and for non-tech savvy users [9, 15]. To overcome this issue, co-creation or user-centered approaches are followed, yet often they require expensive facilities, thereby limiting their exploitation [7]. In the present research we aimed to assess the feasibility of using an elicitation method based on a virtual prototype simulation for facilitating end users in proposing the touch-less gestural commands for controlling specific functions of the lighting system embedded in an extraction hood. Users' spontaneous gestures were video-recorded from different perspectives and analyzed offline to identify the most frequent gestural commands. The present work contributes to the research on gesture elicitation by showing the effectiveness of using an agile and cost-effective method based on rear projection to stimulate end users in prompting gestural commands.

2 Touch-Less Based Gestural Commands

Gestural interaction has been experimented in various forms, for instance mediated by hand-held devices (e.g., [25]), as direct touch-based gestural commands (e.g., [23]) or as touch-less gestures (e.g., [11]). Commands based on touch-less hand gesture enable immediate and direct control and has several advantages over mediated interactions [3]. Firstly, it allows the user to access information in total sterility, because there is no contact with surfaces. Secondly, information is accessible from a distance, enabling also people with physical impairments to control the devices afar. Finally, it facilitates the exploration of big data, because it involves no movement constraints and allows the direct manipulation of information [20, 27]. However, such interaction mode comes with limitations. The actions available to the user can hardly be made visible to her/him [14, 18]. In addition, providing meaningful feedback regarding the correctness of the commands prompted is difficult—yet crucial—in this context, raising issues regarding the suitability of the feedback that is provided by the interface [20]. Finally, despite their flexibility and potential intuitiveness [26], gestural interactions are strongly related to the application in use, the cultural practices and social acceptability [12, 21, 27]. As a consequence, designing a gestural vocabulary mainly driven by technological constraints, the so-called Technology Based Gestural Vocabulary, can result in meaningless commands that are difficult to perform, to learn and recall, especially for beginners and users with special needs [9, 17, 24]. It is, therefore, crucial to consider the characteristics of the target users and of the context of use when designing a gestural interface [7]. To this end, many researchers have involved users in the process of defining the set of gestural commands, which is referred to as Human Based Gesture Vocabulary [17].

2.1 Devising User-Based Gestural Commands

For the average user prompting a gestural command from scratch can be hard and in some cases such a request can even sound weird. To facilitate users to grasp the actual meaning of the experimental request, a number of diverse techniques have been proposed and experimented. A basic strategy for involving users consists of the mere instruction to prompt a gesture for activating a given function. Choi and collaborators [5] instructed participants to imagine themselves in a smart home and then to perform a gesture for each of the commands verbally described by the experimenter. Similarly, Ruiz [24] provided participants with the sets of tasks listed in a paper sheet and required them to read out loud each task and to make the gesture while verbalizing their thoughts. To complement gesture elicitation and help users not to strictly focus on the technology, a scenario is often introduced. Sorathia and collaborators [25] read participants a scenario exemplifying the functions for which they were asked to prompt a gesture. Participants' outputs were then video recorded and analyzed offline. Nielsen and colleagues [17] proposed a four-step method, in which, after the functions are selected by researchers (Phase 1), participants are presented a scenario, and then asked to propose the gestures, which are video-recorded (Phase 2). In the third phase, researchers extract the gestures by analyzing the videos, and finally they were tested with users (Phase 4). A multiple-step approach was applied also by Neßelrath [16] to devise the gestural commands for operating a smart home environment. After being presented a scenario, users were first asked to paint and describe each gesture. Finally, participants were asked to rank the expected difficulty of each of the gesture proposed. To identify gestural input for controlling music playback, Löcken [13] introduced a Wizard of Oz approach: participants prompted a gesture toward a computer screen and an experimenter activated that function. Afterwards, the gesture set was selected by the authors and users assessed its complexity. Similarly, Akers [1] asked participants to generate a gesture for exploring and controlling neural pathways and to illustrate the meaning of that gesture before the wizard would executed it. The Wizard of Oz approach was adopted also by Connell [6] with a group of children to find a set of gestures for playing a game. Again, kids were first shown the function, then they were asked to prompt a gesture to make that event happen again. After their move, the function was played again to provide a feedback. Anastasiou and collaborators [2] run a Wizard of Oz study to investigate the gestural and vocal commands that users would employ to operate an automatic wheelchair within a living lab, highlighting that participants tended to produce gestures mostly to adjust the outcomes of vocal commands.

An adaptation of the Video Card Sorting method was applied by Brereton [4]. Short video fragments illustrating people engaged in different working situations were played. In a following discussion, participants compared the gestures identified and analyzed the role they could have in the design of gestural input devices. Mid-air gesture interaction proved to be a convenient way for interacting also with augmented reality (AR) applications. Dudley [8] investigated the use of bare hands for drawing AR sketches. Pham [22] presented users with various AR 3D models of different environments and showed them the “before” and “after” states of the model. Participants were then asked to perform the gestural command that according to them would be more appropriate to change the model from the initial to the final state. The size of the model was found to affect the gestures prompted by users. Similarly, Cárdenas and colleagues [7] proposed to develop a virtual simulation of a living lab to elicit users’ gestures. However, the virtual environment implemented has not been tested with end users yet.

3 The Case Study

In the present study, we considered the case of a lighting system embedded into an extraction hood to be controlled by touch-less hand gestures. In particular, the functions of the lighting system were the following:

- switching the light on;
- switching the light off;
- moving the spotlight rightwards;
- moving the spotlight leftwards;
- increasing the size of the spotlight;
- decreasing the size of the spotlight;
- increasing the light brightness and
- decreasing the light brightness.

3.1 Implementation and Equipment

When confronted with the unconstrained request of showing the gesture they would prompt for activating a given function, participants may fail to comprehend the real meaning of the request, especially when they are not tech-savvy [13]. Furthermore, in ordinary ideas elicitation techniques, e.g., brainstorming, it may be difficult for both users and designers to imagine the gesture to activate a function and the expected effects on the interface [1]. In the present case study, the situation was even more complex, because not only the gesture-based interface was unfamiliar for users, but also the majority of the functions examined were unknown to them. To help participants conjure up the situation to which they should refer, a virtual simulation of the prototype was developed using Flash CS5.5. The virtual simulation consisted of the

Fig. 1 The virtual simulation of the extraction hood with the stove top

representation of a hood and the stove top. The simulation included a horizontal black bar depicting the detection area of the interface. In addition, a spotlight appeared on the stove top to simulate the light of the hood (Fig. 1). The experimenter could play the switching on and off of the light, the movement of the spotlight, and could modulate the level of brightness of the light and the spotlight size. The virtual simulation was rear projected on a dedicated white screen (2.5 m height by 2.1 m width), using an Epson EH-TW3600 projector, which enabled a real-size visualization of the hood. Three video cameras (Sony Handicam HDR-XR155E) were employed for recording users' interaction and the screen projection was also video-recorded. The four video streams were synchronized automatically using a 4-channel Edirol mixer.

3.2 Setting

The experiment took place in a laboratory room. The dedicated room was arranged with a white canvas for the rear projection, a projector and three cameras for recording users' actions (Fig. 2). One camera (Number 1 in Fig. 2) provided a wide shot, which yielded a clear view of the wider movements made by participants. Another camera was placed on the right side of the screen at an approximate height of 1.40 m and provided a clear view of the participant's hands (Number 2 in Fig. 2). A third camera was placed on the left-hand top corner of the screen at an approximate height of 2 m and provided a framing from above (Number 3 in Fig. 2). The virtual simulation projected on the screen was also recorded and the four video frames were synchronized (Video recording station, Number 4 in Fig. 2). The projector was placed 2 m behind the screen (Number 5 in Fig. 2). During the entire experimental session, the experimenter sat out of participants' view, occupying the position indicated by

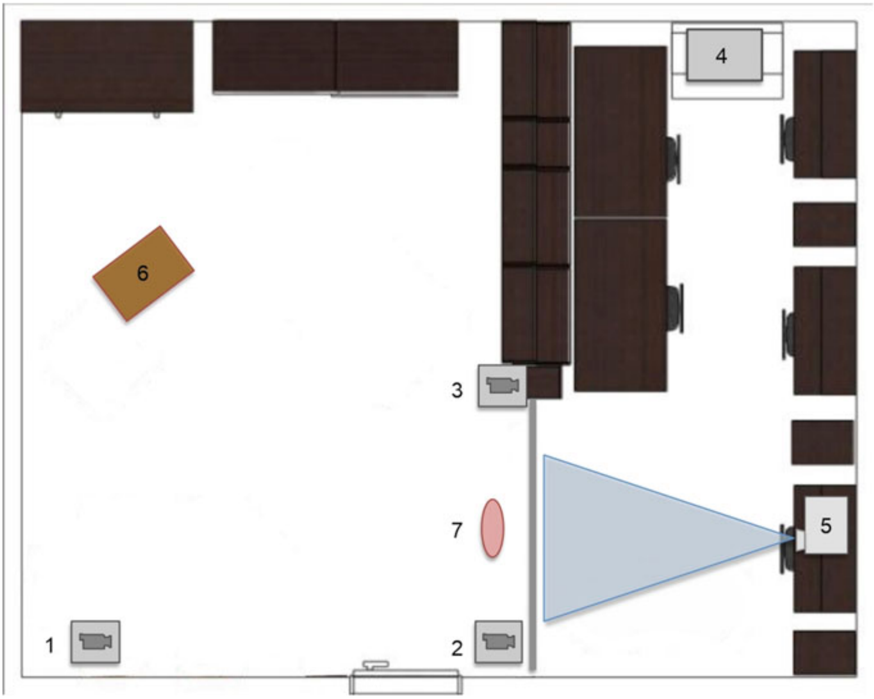

Fig. 2 A representation of the experimental setting. The spots numbered 1, 2 and 3 show the locations of the video cameras. Spot number 4 corresponds to the mixer workstation. Spot 5 represents the video projector. Spots number 6 and 7 display the experimenter and the participant's locations respectively

the spot Number 6 in Fig. 2. Participants stood in front of the screen (Number 7 in Fig. 2). Such setting allowed users to stand in front of a natural size (60 cm width and 150 cm height) simulation of a hood and to interact with it.

3.3 *Experimental Procedure*

On the day of the test, the participants were welcomed in the laboratory and received a brief introduction regarding the activity. After they had given informed consent to take part in the experiment, the activity started. The participants were invited to move on a predefined spot in front of the rear projection screen. We adopted a guessability approach, so the experimenter read aloud the instructions, informing the participants that they would have to prompt a gesture for each of the functions they would observe. For each function examined, participants were first instructed to watch carefully the animation on the screen, then the experimenter played the animation representing a specific function, i.e., the referent. When the animation ended, the experimenter shortly described what had just happened and asked the participant to make the gesture they would spontaneously do to activate that specific function. Since our aim was to have participants focusing only on the generation of spontaneous gesture, rather than on the feasibility of the solution proposed, after they have prompted the gesture no feedback was provided, similarly to Sorathia and colleagues [25]. As mentioned earlier, a total of eight functions were addressed: (1) switching the light on; (2) switching the light off; (3) moving the spotlight rightwards; (4) moving the spotlight leftwards; (5) increasing the size of the spotlight; (6) decreasing the size of the spotlight; (7) increasing and (8) decreasing the brightness of the light. The functions were required in a counter-balanced order, to prevent ordering effects. In addition, participants were given no usage scenario as a reference. Finally, participants had to fill in a brief questionnaire assessing their previous experience with touchscreens and gestural interfaces. Furthermore, they were asked to list the devices they thought had influenced the gestures they did.

3.4 Participants

A sample of 30 users (15 females) was recruited in the present experiment. The average age was 32.2 years ($SD = 14.20$). All of the participants but two were right handed, one was left-handed and one was ambidextrous. None of them had previous experience with touch-less interfaces. All participants reported to have an extraction hood in their kitchen and to use it regularly when cooking. Participants were recruited by word of mouth and received no compensation for taking part in the experiment.

3.5 Analysis

Following Gamberini and collaborators [10], the video-recordings obtained during the experimental trials were analyzed offline using of the software The Observer XT 11 by Noldus, which allows a systematic coding of all the events occurring in a video. The events selected for coding were (a) the shapes of the hand(s) and (b) the movements employed to perform each gesture.

4 Results

We first present the different hand shapes emerged followed by the frequency with which each shape emerged. Next, the gestures are categorized based on the direction of the movement they followed. The frequency with which each movement appeared is then related to the function examined. Finally, for each function considered a consensus score is reported.

4.1 Hand Shapes

Firstly, the hand shapes proposed by participants were categorized considering whether the gesture prompted involved the whole hand or only the fingers. In total, eight categories of gestures were recognized (Fig. 3), half of them included gestures prompted with the fingers, and the other half comprised the gestures made with the hand. Each category is described below:

Finger pointing, where the gesture is prompted with only one finger stretched and pointing toward a specific area of the interface.

Thumb-index, where the gesture is prompted using the thumb and index finger and the user mimics to move a leverage placed on the interface.

Pinch, where the gesture is prompted with the thumb and index finger and the user imitates the pinch-like gesture usually employed for zooming in and out on touch-screens.

Snapping, where the user snaps the fingers in front of the interface.

Vertical hand, where the gesture is prompted with all the fingers stretched and the palm facing the interface.

Hand upright, where the gesture is prompted with all the fingers stretched and palm facing upwards.

Semicircular hand, where the gesture is prompted with the fingers shaping the letter “C”.

Wave, in which the gesture is prompted with all the fingers stretched and the palm facing the interface together with a wide movement of the arm.

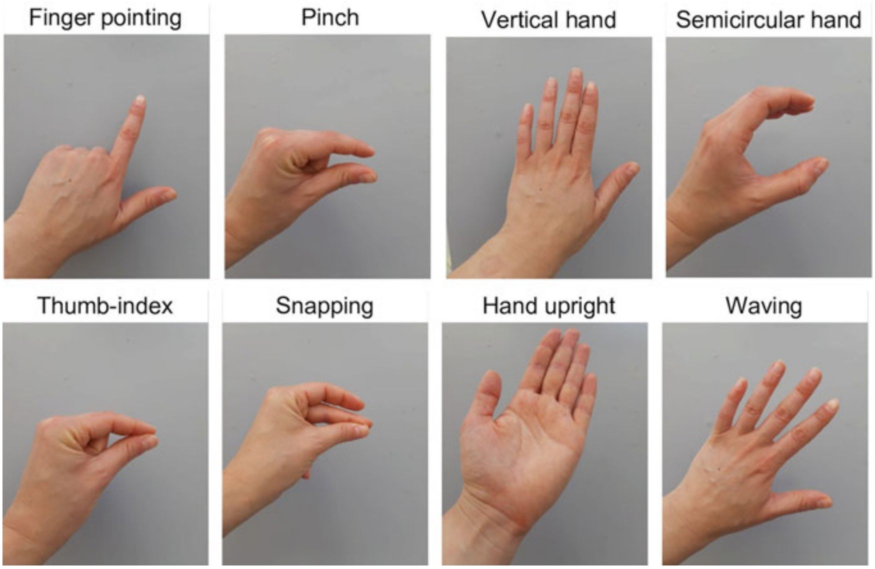

Fig. 3 A representation of the hand shapes emerged

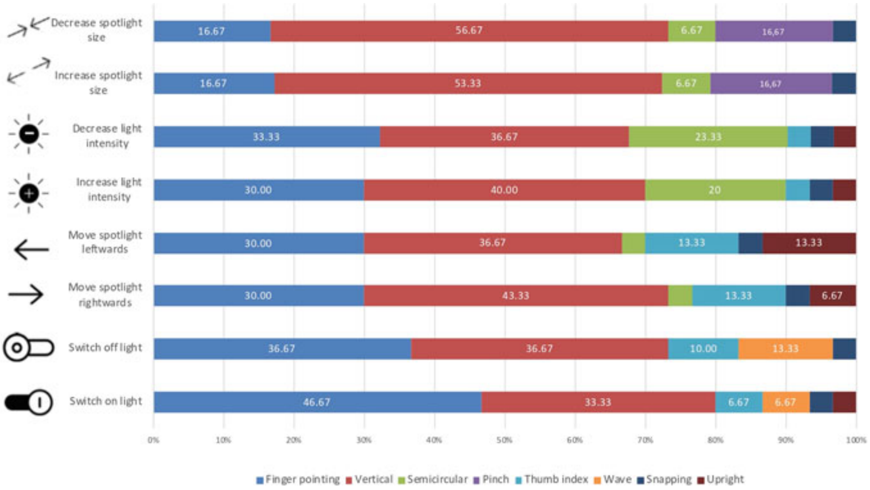

Fig. 4 A summary of the frequency of the hand postures emerged, where no label is reported the value is 3.33%

Overall, the most frequent hand shape emerged was the *Vertical hand*, which was chosen by more than one third of the sample for all the functions required (Fig. 4). Notably, more than 50% of the sample made a gesture with all the fingers stretched and the palm facing the interface (*Vertical Hand*) for both increasing and decreasing the size of the spotlight. The second most frequent hand shape among all the functions considered was *Finger pointing*, which was recurrent especially for switching on and off the light. Interestingly, a gesture in the category *Semi-circular hand* was prompted by more than the 20% of the participants for modulating the intensity of the light and to a much lesser extent to modulate the size of the spotlight (6.67%). In the attempt to modulate the size of the spotlight, the 16.67% of the sample prompted a gesture in the category Pinch. *Thumb-index* hand shape was employed above all for moving the spotlight (13.33%) and for switching the light on and off. Gestures in the category *Hand upright* emerged to move the spotlight rightwards and leftwards (respectively, 6.67% and 13.33%), for switching on the light and for modulating the intensity of the light (3.33% in all the cases). *Waving* the hand toward the interface was made only for switching on and off the light (6.67% and 13.33% respectively).

4.2 Hand Chosen

In the majority of the cases, participants prompted the gesture with their right hand. This was true for switching the light on and off, respectively the 90% and the 83.33%, for moving the spotlight leftwards (90%) and rightwards (60%) and for increasing and decreasing the brightness (80% in both cases). Differently, for modulating the size of the spotlight, the sample split: around the 50% of users employed the right hand, while the other half used both hands.

5 Movements

The gestures that participants prompted were further analyzed to determine whether they were static or dynamic, and whether the direction of the movements was consistent for each of the functions considered. Four categories of movements were identified (Fig. 5):

Static gestures, after approaching the interface, the gesture is prompted without any movement;

Horizontal movements, the gesture is prompted by moving the hand(s) horizontally along the interface;

Vertical movements, the gesture is prompted by moving the hand(s) over the vertical plane of the interface, that is to say upwards or downwards;

Rotational movements, the gesture made simulated the rotating action made on a knob.

Overall, participants seemed to favor static gestures over motion gestures, especially for switching on and off the light (respectively, 83.33% and 66.66%), for increasing (46.67%) and decreasing (50%) the intensity of the light and for modulating the size of the spotlight (40% for both the requests of increasing and decreasing). Mainly, the motion gestures were prompted with a horizontal movement, especially for moving the spotlight to the right and to the left (83.33% in both cases) and for modulating the size of the spotlight (40% in both cases). Interestingly, rotational movements emerged for modulating the intensity of the light (23.33% for

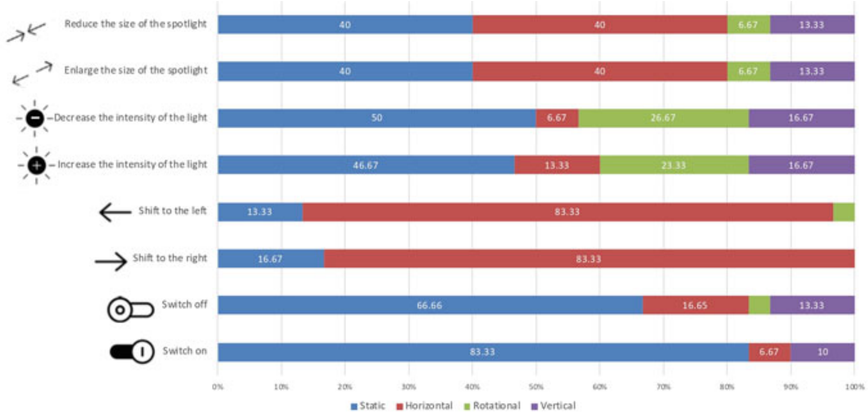

Fig. 5 A summary of the frequency of the dynamic and static gestures, where no label is reported the value is 3.33%

increasing the intensity and 26.67% for reducing it), for modulating the size of the spotlight (6.67%) and, to a lesser extent, for switching off the light and for shifting the spotlight leftwards (3.33% in all cases). Finally, vertical movements emerged for modulating the intensity of the light (16.67% for both increasing and reducing the brightness), for modulating the size of the spotlight (13.33% for both functions) and for switching on (10%) and off the spotlight (13.33%).

5.1 Agreement of the Gesture

Following Ruiz and colleagues [24], an agreement score for each task was calculated considering the hand shapes and the movements identified. The agreement score is calculated by summing up the squared ratios of the subset of identical gestures emerged and the size of the sample for each function considered.

$$A = \sum_{p_i} \left(\frac{|p_i|}{|p_t|} \right)^2$$

where, t is a task in the set of all tasks T, P_t is the set of proposed gestures for t, and P_i is a subset of identical gestures from P_t. The range for A is [0, 1].

Overall, the agreement scores were low, ranging between 0.18 and 0.32. More specifically, we found that the functions of switching on and off the spotlight had the highest agreement score (0.32 in both cases), followed by shifting the spotlight rightwards (0.24) and leftwards (0.20) and the modulation of the size of the spotlight (0.24 for increase and 0.23 for decrease). The lowest rate of consensus was for the modulation of the intensity of the spotlight, 0.18 for the increase and 0.20 for the decrease.

5.2 Perceived Influence of Previous Experience

In the questionnaire administered after the experiment, the majority of respondents ($n = 17$) reported that they have been influenced from their previous experience in the gestures they prompted. In particular, for switching the light on, four participants recognized that they were influenced by the mechanism embedded into their own extraction hoods. The surface gesture for zooming in and out on touch-screen devices (tablets and smartphones) affected the commands proposed by 11 users for modulating the size of the spotlight. Similarly, three participants reported that they have been influenced by the surface gestures they usually perform on tablets and smartphones for moving the spotlight. In shifting the spot-light, one participant also reported the influence of his/her own extraction hood. One participant affirmed that was the trackpad to influence him/her in modulating the brightness, and one that was the tablet. Finally, one user reported a general influence of their use of touchscreens devices.

6 Discussion

In the present research, we investigated the spontaneous gestural commands users would prompt for controlling the lighting system of an extraction hood. The functions addressed were unusual for a kitchen lighting system (e.g., modulating the size of the spotlight) and we expected participants to struggle to represent them and pair an appropriate gestural trigger. To overcome these issues, a virtual prototype of the system was developed. We purposefully built an agile and basic simulation of the interface to serve as a proof of concept to be adjusted to portray future advancements of the prototype. Still, the simple animation of basic graphical elements was evocative enough to inspire participants to prompt specific controlling gestures. Despite there was a widespread preference for a specific hand posture, i.e., the open hand, we have to acknowledge that the agreement scores that we found were generally pretty low. This finding is in line with previous research [9] and can be explained, at least in part, by the unfamiliarity of the functions selected for the study: the best-known functions, i.e., switching on and off, received the highest agreement scores. However, also the lack of evident affordances on the interface may have played a role: users had no evident cues to shape their mental models. In addition, we found that participants tended to link the width of gestures they prompted with the scale of the intended effect: the larger the expected result, e.g., increasing the size of the spotlight, the more participants were likely to either perform the gesture using both hands or to extend it to the arms. Our observation expands previous findings by Pham [22], who showed that it was the scale of the simulated model to affect the gesture spontaneously prompted by participants. Taken together our findings suggest the feasibility of using an agile virtual simulation to generate gestural ideas. In addition, the proposed approach is flexible enough to support the adjustment of the projected simulation to meet frail individuals' needs, e.g., lowering the stove top to be accessible to wheelchairs users. Therefore, we plan to extend it and involve also physically challenged users. Finally, future studies will compare the consistency of the gestures emerged when interacting with a real prototype with those emerged when interacting with the virtually simulated prototype.

7 Conclusion

In the present paper we reported on the deployment of a virtual simulation of a prototype as a facilitating means for users to propose the gestural commands for controlling the lighting system embedded in an extraction hood. The unconstrained nature of the task and the purposeful lack of evident affordances, led to a set of relatively heterogeneous gestures. Nevertheless, the flexibility and cost-effectiveness of the proposed approach make it a valuable tool to be used as a proof of concept also with physically and cognitively challenged individuals.

References

1. Akers D (2006) Wizard of Oz for participatory design: inventing a gestural inter-face for 3D selection of neural pathway estimates. In: CHI'06 extended abstracts on human factors in computing systems. ACM, pp 454–459
2. Anastasiou D, Jian C, Zhekova D (2012) Speech and gesture interaction in an ambient assisted living lab. In: Proceedings of the 1st workshop on speech and multimodal interaction in assistive environments. Association for Computational Linguistics, pp 18–27
3. Bhuiyan M, Picking R (2009) Gesture-controlled user interfaces, what have we done and what's next. In: Proceedings of the fifth collaborative research symposium on security, E-Learning, Internet and Networking (SEIN 2009), Darmstadt, Germany. 25–29.
4. Brereton M, Bidwell N, Donovan J, Campbell B, Buur J (2003) Work at hand: an exploration of gesture in the context of work and everyday life to inform the design of gestural input devices. In: Proceedings of the fourth Australasian user interface conference on user interfaces 2003-Volume 18. Australian Computer Society, Inc., pp 1–10
5. Choi E, Kwon S, Lee D, Lee H, Chung MK (2014) Towards successful user interaction with systems: Focusing on user-derived gestures for smart home systems. Appl Ergon 45(4), 1196–1207
6. Connell S, Kuo P, Liu L, Piper AM (2013) A Wizard-of-Oz elicitation study examining child-defined gestures with a whole-body interface. In: Proceedings of the 12th international conference on interaction design and children. ACM, pp 277–280
7. Cárdenas M, Gómez Sanz J, Pavón J (2018) Testing Ambient assisted living solutions with simulations. In: IFIP International conference on testing software and systems. Springer, pp 56–61
8. Dudley JJ, Schuff H, Kristensson PO (2018) Bare-handed 3D drawing in augmented reality. In: Proceedings of the 2018 on designing interactive systems conference 2018. ACM, pp 241–252
9. Ferron M, Mana N, Mich O (2019) Designing mid-air gesture interaction with mobile devices for older adults. in: perspectives on human-computer interaction research with older people. Springer, pp 81–100
10. Gamberini L, Spagnolli A, Prontu L, Furlan S, Martino F, Solaz BR, Lozano JA et al (2013) How natural is a natural interface? An evaluation procedure based on action breakdowns. Pers Ubiquit Comput 17(1), 69–79
11. Grguric´ A, Mošmondor M, Kušek M, Stocklöw C, Salvi D (2013) Introducing gesture interaction in the ambient assisted living platform universal. In: Telecommunications (ConTEL), 2013 12th international conference on. IEEE, pp 215–222
12. Hsieh Y, Jylhä A, Orso V, Gamberini L, Jacucci G (2016) Designing a willing-to-use-in-public hand gestural interaction technique for smart glasses. In: Proceedings of the 2016 CHI conference on human factors in computing systems. ACM, pp 4203–4215
13. Löcken A, Hesselmann T, Pielot M, Henze N, Boll S (2012) User-centred process for the definition of free-hand gestures applied to controlling music playback. Multimedia Syst 18(1):15–31
14. Marquardt N, Greenberg S (2012) Informing the design of proxemic interactions. IEEE Pervasive Comput 11(2):14–23
15. McAweeney E, Zhang H, Nebeling M (2018) User-driven design principles for gesture representations. In: Proceedings of the 2018 CHI conference on human factors in computing systems. ACM, p 547

16. Neßelrath R, Lu C, Schulz CH, Frey J, Alexandersson J (2011) A gesture-based system for context–sensitive interaction with smart homes. In: Ambient assisted living. Springer, pp 209–219
17. Nielsen M, Störring M, Moeslund TB, Granum E (2003) A procedure for developing intuitive and ergonomic gesture interfaces for HCI. In: International gesture workshop. Springer, pp 409–420
18. Norman DA (2010) Natural user interfaces are not natural. Interactions 17(3), 6–10
19. Orso V, Gullà F, Menghi R, Ceccacci S, Cavalieri L, Germani M, Gamberini L (2017) A digital cookbook for elderly people: investigating interface concept. In: Proceedings of the international conference on interfaces and human computer interaction, pp 159–166
20. O'hara K, Harper R, Mentis H, Sellen A, Taylor A (2013) On the natural-ness of touchless: Putting the interaction˙ back into NUI. In: ACM Transactions on Computer-Human Interaction (TOCHI), vol 20, no 1, p 5
21. Panger G (2012) Kinect in the kitchen: testing depth camera interactions in practical home environments. In: CHI'12 extended abstracts on human factors in computing systems. ACM, pp 1985–1990
22. Pham T, Vermeulen J, Tang A, MacDonald Vermeulen L (2018) Scale impacts elicited gestures for manipulating holograms: implications for AR gesture design. In: Proceedings of the 2018 on designing interactive systems conference 2018. ACM, pp 227–240
23. Ringel Morris M, Huang A, Paepcke A, Winograd T (2006) Cooperative gestures: multi-user gestural interactions for co-located groupware. In: Proceedings of the SIGCHI conference on Human Factors in computing systems. ACM, pp 1201–1210
24. Ruiz J, Li Y, Lank E (2011) User-defined motion gestures for mobile inter-action. In: Proceedings of the SIGCHI conference on human factors in computing systems. ACM, pp 197–206
25. Sorathia K, Jain M, Amrit M, Mokashi Punekar R, Srivastava S, Rajput N (2015) Gesture selection study for a maternal healthcare information system in rural Assam, India. J Usability Stud 11(1), 7–20
26. Stern HI, Wachs JP, Edan Y (2008) Optimal consensus intuitive hand gesture vocabulary design. In: Semantic Computing, 2008 IEEE
27. Wachs JP, Kölsch M, Stern H, Edan Y (2011) Vision-based hand-gesture applications. Commun ACM 54(2), 60–71

VOICE Actuated Control Systems (VACS) for Accessible and Assistive Smart Homes. A Preliminary Investigation on Accessibility and User Experience with Disabled Users

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Abstract Recently, mobile and in-home Voice Actuated Control Systems (VACs) have become affordable and reliable, allowing the control of several IoT devices from a distance. Individuals with motor impairments could benefit from VACS installed in smart domestic environments to operate home appliances and other devices. The

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present paper explores the potentials of using such systems in terms of accessibility and user experience by involving a group of individuals with motor disabilities and mild speech impairments. Participants were invited to directly try out the voice-controlled assistant by operating different smart devices (e.g., lights, fan) in a friendly living-room like environment. Results show that all participants were able to perform the proposed tasks after a brief practice section and few failures, and that the interaction experience was well received by participants.

Keyword Voice actuated control systems · Voice user interfaces · Voice-controlled assistants · Motor disability · Smart devices · Disabled users · Accessibility · Smart home

1 Introduction

Voice Actuated Control Systems (VACs) and their Voice User Interfaces (VUIs) are becoming increasingly accessible in our everyday lives. Thanks to technological advancements, voice recognition units can reliably identify speech entities in near-real time [1]. Moreover, the drop of their cost [2] has made VACs and VUIs a common way to interact with a wide range of technologies, e.g., in-vehicle assistants, smartphone, and smart home technologies. Several major companies have developed voice-controlled home-based assistants which exploit VUIs (e.g., Google Home or Amazon Echo). These systems offer users hands-free voice control and allow to perform a variety of different activities, such as asking for information, playing video and music, and operating smart home appliances.

While in many studies voice-controlled home-based assistants have been evaluated with able-bodied users, the experience of disabled users has been overlooked so far. Nevertheless, people with motor disabilities could benefit from the interaction with voice-controlled home-based assistants, because no motor interaction is involved. For example, users with limited mobility could control door locks, thermostats, and home's lighting by issuing voice commands [3–5]. Thus, these systems may improve the autonomy of people with motor disabilities and, in general, positively affect their quality of life.

The aim of the present study is to assess the feasibility of using a voice-controlled home assistants (i.e., Google Home) with a group of participants with motor disabilities and in some cases slightly impaired speech production.

1.1 VACSs and Individuals with Disabilities

People suffering from motor disabilities can present a wide range of secondary deficits, including speech impairments. The degree of speech impairment is variable and the clinical picture is different for each patient. In general, the language production can show abnormalities in terms of phonatory, articulatory, or prosodic aspects [6]. Although people with motor disabilities may benefit from the use of VACs, the coexistence of motor and language deficits raises some issues about accessibility of these patients to these systems. Indeed, speech impairment can hamper accessibility to VACs [7].

Since VACs are relatively new, especially voice-controlled home-based assistants, few studies investigated how speech impairment can affect accessibility to these systems. Rudzicz and colleagues [8] explored speech interactions with personal assistive robots in a group of older adults with Alzheimer Disease. The authors showed how the linguistic difficulties of patients, namely the non-continuous speech, represented a barrier of accessibility to the use of speech-based assistants. Similarly, Pradhan and colleagues [9] observed that one of the main accessibility problems in people with physical disabilities concerned the speech interaction. In this work, authors observed that some users with speech problems reviewed speech-based assistants as inaccurate in speech recognition. In particular, users could not pronounce clearly or loudly enough the command, and the device timed out before the user could complete the command.

Taken together, these studies highlight how speech problems can negatively impact accessibility of voice-controlled home-based assistants in users with disabilities. Of interest, previous studies developed voice-controlled systems designed on the needs of individuals with speech impairments. Hawley and colleagues [10] described a prototype, installed on a laptop, of a speech-based environmental system (to control TV, radio, and a lamp) for individuals with severe dysarthria. The authors showed promising results, even if the designed system required very long training (namely a 6-week period) to increase its response accuracy. In a more recent research [11], another prototype was developed but still the time needed for the training phase was very long (2–4 weeks).

In this paper, we present an experiment that involved individuals with motor and mild speech deficits.

2 The Study

The present study reports on a preliminary evaluation that aimed to evaluate the feasibility of an affordable voice-controlled home-based assistant (i.e., Google Home) for individuals with motor disabilities and deficit in speech production. More specifically, two sessions have been run so far, each one week apart. The session lasted about 2 h and a half and was conducted by an expert moderator and one assistant. Four participants with motor disabilities accompanied by two professional assistants were involved in each session.

2.1 Participants

A total of 8 participants (*M* age = 40.5, *SD* = 7.56; F = 4) were involved in the study. They were all individuals with motor disabilities (N = 7, needed a wheelchair) and had mild issues in speech production. The medical history of participants showed ascertained motor and language impairments.

2.2 Setting and Equipment

The experimental sessions took place in a living laboratory. The room was furnished with a large table, two smart lamps, a fan connected to a smart plug, and a large TV screen connected to Google Chromecast. All the devices were connected to Google Home (Inc.), which allowed to control several functions.

2.3 Tasks

Several realistic tasks were arranged, which involved the following devices: smart lamps, a fan connected to a smart plug, and a smart TV. Participants were asked to activate a series of functions using the Google Home system (e.g., changing the color lamp, turning on/off the fan, selecting a song from Spotify). Furthermore, other tasks concerned different activities which involved only Google Home (e.g., asking the weather forecast). A detailed list of considered devices and commands is showed in Table 1.

2.4 Procedure

On the day of the test, participants were welcomed at the premises of the Human Inspired Technology Research Center (University of Padova) and were debriefed on the purpose and unfolding of the activity. We conducted the study in two different sessions that lasted about 2 h and a half each. An expert moderator and one assistant conducted the sessions. In each session, four participants and two professional assistants were involved. During the experimental sessions the atmosphere was kept friendly and informal, not to stress participants. Before starting the session, participants gave their informed consent. Afterwards, an experimenter introduced the Google Home device and explained how to operate it by providing several practical examples. Participants were instructed how to properly convey the commands. In particular, they were told that, after activating Google Home using the "Hey Google" command, they had to wait for the light feedback to show before pronouncing the

Table 1 List of devices and commands participants were asked to perform during the session

Device	Command
Smart lamps	Turning on/off
	Changing colours
	Changing light intensity
Fan	Turning on/off
TV (Netflix)	Selecting movies,
	Pausing
	Playing
TV (YouTube)	Selecting videos
	Increasing/decreasing volume
TV (Spotify)	Selecting songs
	Increasing/decreasing volume
Google Home	Asking the latest news
	Asking the weather forecast
	Setting an alarm

actual command. Participants were invited to try out some sample commands, in order to ensure that they had understood the instructions. After this preliminary phase, every user was invited to carry out a set of tasks. To keep the sessions friendly and prevent participants the feel- ing of being in a ‘testing situation’, the sequence of tasks was alternated across participants. In case difficulties in speech recognition arose, in order to avoid frustration, participants were gently encouraged and supported by the moderator to try again. At the end of each session, a set of questions was asked to collect participants’ opinions regarding their experience. A brief interview was run, including questions regarding: an overall evaluation of the interaction with the device; preferences regarding the different controls and the location in their homes for Google Home; and which other smart devices they would like to control by means of this device. Meanwhile, the other trained observer was responsible for taking notes while monitoring participants’ interactions and spontaneous comments.

2.5 Results

The Google Home system was well received by all participants. Indeed, the responses showed a generally positive opinion of the interaction with such a device. Overall, participants were able to accomplish the proposed tasks. In some cases, they had to attempt several times in order to be able to properly give the specific commands to Google Home. Indeed, sometimes users did not wait the light feedback on the Google Home device before starting speaking, so the device did not process the commands. In other instances, users waited too long and the system was not capable of elaborate the message. In both cases, Google Home was providing an error message "I'm sorry, I do not know how to help you".

Considering the general evaluation of the systems, users assigned at least 8/10 or more than the maximum possible score of the scale to the device (e.g., P04: "I mark Google Home 20 out of 10"). In regard of the preferred functions, some of the respondents reported the music control (N = 4/8) and the majority were interested in being able to turn on/off the lights (N = 7/8). Participants would like to have the opportunity of utilizing this speech-based interface mainly in the living room (N = 6/8) and in their bedrooms (N = 8/8). The majority of the respondents expressed the desire to have Google Home also at their home (N = 6/8). Finally, participants mentioned several other devices that they would like to control using Google Home (e.g., P06: "to control the computer"; P03: "changing the environmental temperature", "opening/closing the blinds").

3 Discussion

The aim of this study was to assess the feasibility of using one voice-controlled home-based assistant (i.e., Google Home) in a group of participants with motor disabilities and co-existing speech production impediments. People with motor disabilities could benefit from these devices, as long as their speech abilities are partially preserved. Unfortunately, speech production abnormalities frequently coexist with motor impairments and those few studies that investigated this topic show that speech production impediments hamper accessibility to voice-speech assistants [8, 9]. Contrary to this premise, one of the most important results of this study concerns the fact that, although our participants were characterized by a peculiar clinical picture with motor and speech problems, everyone was able to operate the voice-controlled home-based assistant. This encouraging outcome suggests that within a certain degree of speech impairment, these devices may be accessible to people with motor disabilities. Our results are in line with a previous study by Ballati and colleagues [12] that verified to which extent patients with dysarthria could be understood by three virtual assistants, namely Siri, Google Assistant, and Amazon Alexa. The study reported a percentage of speech recognition accuracy around 50–60%, without differences between the systems. However, they did not involve human patients.

In the present study, we overcome this limitation by recruiting human participants. Our results show that almost all the participants were able to carry out the commands correctly. This success could be given by the fact that the interaction between the participant and the device was guided by the experimenter [13]. Indeed, the solely feedback provided by Google Home "I'm sorry, I do not know how to help you" it is not sufficient to make the users understand if the device has not understood the message or that it is intrinsically not able to accomplish that specific task. Therefore, at least in a first phase in which the disabled user is instructed, the presence of a caregiver could be crucial to close the gap between disabled users and voice-controlled home-based assistant. The second result regards the quality of experience reported by participants. In general, participants reviewed the system enthusiastically. The Google Home system was well received by all participants. Indeed, the responses showed a generally positive opinion of the interaction with the device. This result reveals that in an assisting living context, voice-controlled home-based assistants could be well accepted by users with physical disabilities. To conclude, results of this study encourage to further develop voice-controlled home-based assistants, especially keeping in mind the needs of people with physical disabilities [14]. To improve accessibility of people with disabilities, future voice-controlled systems could exploit supplementary modalities, for example, the combination of speech and gesture modalities [15]. In addition, future studies should also consider the integration between VACs and voice control wearable devices, after a proper user acceptance evaluation [16]. The integration of these systems may allow disabled people to control remote devices everywhere and break down physical barriers that these people face every day. Furthermore, the installation of these systems in ambient-assisted living scenarios (e.g., co-housing solution and nursing home) could improve quality of life and safety in disabled people [17]. Definitely, these devices could represent an important opportunity that can be leveraged by many disabled people to support them achieve daily routines and overcome everyday challenges.

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References

1. Andolina S, Orso V, Schneider H, Klouche K, Ruotsalo T, Gamberini L, Jacucci G (2018) Investigating proactive search support in conversations. In: Proceedings of the 2018 designing interactive systems conference. ACM, pp 1295–1307
2. Noda K (2018) Google Home: smart speaker as environmental control unit. Disabil Rehabil Assist Technol 13(7):674–675
3. Rudzionis V, Maskeliunas R, Driaunys K (2012) Voice controlled environment for the assistive tools and living space control. In: 2012 federated conference on computer science and information systems (FedCSIS). IEEE, pp 1075–1080
4. Busatlic B, Dogru N, Lera I, Sukic E (2017) Smart homes with voice activated systems for disabled people. TEM J 6(1):103
5. Domingo MC (2012) An overview of the Internet of Things for people with disabilities. J Netw Comput Appl 35(2):584–596
6. Duffy JR (2013) Motor speech disorders-E-book: substrates, differential diagnosis, and management. Elsevier Health Sciences
7. Brewer RN, Findlater L, Kaye JJ, Lasecki W, Munteanu C, Weber A (2018) Accessible voice interfaces. In: Companion of the 2018 ACM conference on computer supported cooperative work and social computing. ACM, pp 441–446
8. Rudzicz F, Wang R, Begum M, Mihailidis A (2015) Speech interaction with personal assistive robots supporting aging at home for individuals with Alzheimer's disease. ACM Trans Access Comput (TACCESS) 7(2):6

9. Pradhan A, Mehta K, Findlater L (2018) Accessibility came by accident: use of voice-controlled intelligent personal assistants by people with disabilities. In: Proceedings of the 2018 CHI conference on human factors in computing systems. ACM, p 459
10. Hawley MS, Enderby P, Green P, Cunningham S, Brownsell S, Carmichael J, Palmer R (2007) A speech-controlled environmental control system for people with severe dysarthria. Med Eng Phys 29(5):586–593
11. Hawley MS, Cunningham SP, Green PD, Enderby P, Palmer R, Sehgal S, O'Neill P (2013) A voice-input voice-output communication aid for people with severe speech impairment. IEEE Trans Neural Syst Rehabil Eng 21(1):23–31
12. Ballati F, Corno F, De Russis L (2018) Hey Siri, do you understand me?: virtual assistants and dysarthria. In: Workshop proceedings of the 14th international conference on intelligent environments (IE 2018)
13. Derboven J, Huyghe J, De Grooff D (2014) Designing voice interaction for people with physical and speech impairments. In*:* Proceedings of the 8th Nordic conference on human-computer interaction: fun, fast, foundational. ACM, pp 217–226
14. Reyes-Cruz G, Fischer J, Reeves S (2019) An ethnographic study of visual impairments for voice user interface design. arXiv:1904.06123
15. Anastasiou D, Jian C, Zhekova D (2012) Speech and gesture interaction in an ambient assisted living lab. In: Proceedings of the 1st workshop on speech and multimodal interaction in assistive environments. Association for Computational Linguistics, pp 18–27
16. Spagnolli A, Guardigli E, Orso V, Varotto A, Gamberini L (2015). Measuring user acceptance of wearable symbiotic devices: validation study across application scenarios. In: International workshop on symbiotic interaction. Springer, Cham, pp 87–98
17. Gamberini L, Fabbri L, Orso V, Pluchino P, Ruggiero R, Barattini R, Sozza A (2018) A cyber secured IoT: fostering smart living and safety of fragile individuals in intelligent environments. In: Italian Forum of Ambient Assisted Living. Springer, Cham, pp 335–342

Smart Cities: A New Relationship Between People and Technologies

Laura Burzagli

Abstract Smart cities are often presented as an efficient, effective and unitary vision of the application of new technologies for city management, especially in term of services, which are provided to the users in different sectors. The concept and the activities relating to smart cities are strictly connected with activities relating to Living Environments and even more with the context of Ambient Active Living. This sector focus mainly on creating support services, adaptable to the user's different characteristics. The relationship between these two sectors is here introduced, in order to point out the elements to be considered for a more correct design of smart cities, which take into the appropriate consideration different aspects of human beings and their behaviour.

1 Introduction

Smart cities are often presented as an efficient, effective and unitary vision of the application of new technologies for city management. Therefore, they offer great benefits to the citizens, especially in term of services, which can be are provided to the users in different sectors. At general level, smart cities can be defined as "systems of systems", or systems that structure and integrate different functionalities for a more efficient overall use. The concept is complex and manifold; a large number of specific and structured definitions and descriptions are present in literature [1]. There are also various perspectives of analysis, ranging from the level of the architecture of the infrastructures, to the level of the applications sectors, such as energy, rather than the transport and management of buildings, up to the level of public administration, which involves socio-economic aspects too. These are only a few examples, without exhausting the list. Numerous activities are currently underway, including the CNR DIITET proposal for "a prototype of an urban environment provided with a new generation of innovative ICT services and technologies to improve energy

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and resource efficiency, environmental sustainability, emergency response, climate resilience, social cohesion and quality of life of citizens” [2].

In this new urban vision, a technological perspective often represents the starting point to structure in a more rational, sustainable, efficient and effective way the citizens’ services, in all areas of their life, from transport to work, from domestic life to health care, from energy management to environmental sustainability.

2 Users and Smart Cities

The concept and the activities relating to smart cities are strictly connected with the context of Living Environments and even more with the context of Ambient Active Living. This sector focus mainly on creating support services, adaptable to the user’s different sensory, motor and cognitive characteristics. These personalized services cannot be the result of the aprioristic automation of some processes. On the contrary, they require the adoption of a wider user profile, as opposite to stereotype that is often used at the technological level in the design of complex systems. The concept of a widened user profile is not new, since appeared in ICT in the ’80s. Anyway, when this new and wider user profile was introduced, services had precise requirements. Since the focus was on human–computer interaction accessibility, a specific functionality was identified, with its related accessibility problems, and specific solutions were studied, according to different users’ profile.

Furthermore, the distinction between the physical level and the information level of the systems was clear. The interaction was limited to the one or the other area. For example, for a person with sight problems it was sufficient to create a screen reader for the access to information, thus defining a level of interaction limited to the person-device. This did not make the problem less complex from the technological point of view, but clearly defined its boundaries. Similarly, in order to overcome the obstacle of the stairs at architectural level it was often sufficient to create an access ramp, where, even in this case, the level of interaction was well defined, at physical level.

The solution was however addressed to the single user, or to the group of people with the same specific problem, without considering the social level, i.e. interpersonal interactions and relationships [3].

In the context of smart cities, this model of human–machine interaction is no longer valid.

The model used so far is limited and inadequate in the new context of smart cities, where the individual and group (or social) dimensions are strictly interconnected, and where the physical dimension and the virtual or cybernetic dimension are no longer separate part of the system. In the transition from the interaction between person and device to the interaction between people and environment (a physical and social environment), in the transition towards a unified and organized management of services and information, both the design of users’ services and the smart cities activities which involve citizens requires a new discussion.

2.1 Smart Cities Definitions Including Services

One of smart cities definition, which better present this relationship between citizens and smart cities is provided by Hitachi [4], which identifies for the city two distinct infrastructures, strictly connected to a more general infrastructure, which covers areas larger than single cities:

1) Urban infrastructure, which is based on the geographical and physical characteristics of individual cities. The sectors of the urban infrastructure layer include energy, water, mobility, communications, and waste. These are closely integrated with the more general infrastructure layer.
2) Service infrastructure, which contains city's facilities and other services including medicine and healthcare, education, administration, and finance. This layer can be considered from a citizen's perspective as being the layer in which they obtain services, and from a city manager's view as the layer in which services are provided to citizens.

2.1.1 A New Role for the Person in Smart Cities

This "two-levels" definition highlights that the smart city can be assimilated to and Cyber-Physical Social System (CPSS), a concept developed in the industrial field, but that helps to correctly define the new scenario of the environment of life [5–7].

The relationship between citizen and smart cities highlights a new, more articulated way of considering the user within the system. In this context, the person loses the dimension of a simple user of the services, and becomes an active part of the system, for example as a producer of information, in both an active and passive way. In a passive way since most of data produced by the users, (for example with any transaction on the personal mobile), contribute to the amount of data which are processed in the public systems of recommendations (according to appropriate conditions for privacy). In an active way, first because she can provide information also directly to public system, (for example sending detailed information about traffic jam is a direct contribution to a city Transport Information System). Secondly because, since human behaviour is not automatic, different way to react to public services, for example to traffic recommendations, also influences the efficiency of services [8, 9].

3 New Aspects of Users' Services

In order to rethinking the users' service design in the framework of smart cities, it is essential to rethink also some basic concepts. We introduce here two examples about personalization and collective intelligence.

3.1 A New Idea for Personalization of Services

For the final user a great importance assumes the concept of service personalization. If we examine this concept in the framework of smart cities, we have to understand if, when and how new elements do arise in this process, in comparison with the same concept applied in the past [10]. Even if the main objective comes from the user (preferences, interests and above all needs), it is necessary to take also in account also all the constraint presented by the environment. An interesting perspective is offered by the literature [11]. The key point is represented by the different parameters, which represent the optimization function. In a smart city this process of optimization contains multiple coexisting goals. Each user lives in a physical space, and not alone, but together with many other people. Therefore, the behaviour is conditioned by both these elements. This implies that in the personalization process, many are the variables to be considered. Not only the user and the IT application, but also the space, the relationship with other people, and the context. The optimization function is much more complex.

3.2 A New Perspective for Collective Intelligence

In the context of users' services, another important concept is represented by collective intelligence. An example of application in the field of e-Inclusion was given by [12]. A more recent perspective is presented in the context of CPS [13]. An accurate analysis carried out by those authors put in evidence three main aspects. Firstly, CPSS is a system-of-systems, with the integration of social software or crowdsourcing platforms. The review highlights a lack of methods to explore and analyse the design of data integration, dissemination and actuation phases especially for human interaction.

Secondly, there is a variety of definition for CPSS, such as for smart cities, and consequently for its 'social' aspect. These different perspectives of social involvement "*range from humans simply being the users of the system to humans being involved*", [13], which is the most appropriate use of collective intelligence systems.

Thirdly, concepts such as privacy, data security, and architectural design methods are not yet introduced in most studies, even if they represent a basic aspect of this social problem. An accurate activity is required and represents one of the elements to be investigate in the future.

4 Future Work

Many questions still emerge in this regard, for both the system and the user.

For the system:

What is the level at which the automation barrier is placed?

Which is the most appropriate user model to be adopted?
How does the user operate within the system?

For the user:

Which are the criteria that foster its acceptability and collaboration?
What should the user know about the choices and mechanisms of the machine (system) to increase confidence in it?

5 Conclusions

While the concept of smart cities is becoming increasingly widespread, its connection with the services, which support people in their daily activities, is much less defined. The adoption of the smart city concept for our Living Environments and above all for the design of services in these environments requires an accurate analysis of the mechanisms of interaction between the general infrastructure and the level of each user or groups of users. A first analysis about this comparison is here presented and a few elements of interest, such as about personalization, are here discussed. Only an appropriate trade-off between these aspects can guarantee efficient services and satisfied users. Indeed, the system does not work only because the "machines" make it work, but because the whole process in which the person is included is efficient and effective.

References

1. Cassandras CG (2016) Smart cities as cyber-physical social systems. Engineering 2(2):156–158. https://doi.org/10.1016/J.ENG.2016.02.012
2. https://www.diitet.cnr.it/smart-city/
3. WHO (2001) ICF international classification of functioning, disability and health. World Health Organization, Geneva
4. Hitachi's Vision of the Smart City. https://www.hitachi.com/rev/pdf/2012/r2012_03_all.pdf
5. Sowe SK, Zettsua K (2015) A conceptual framework for modelling human involvement in cyber-physical social systems: leveraging STT information in heterogeneous data. In: EJC 2015 proceedings
6. Sowe SK, Simmon E, Zettsu K, de Vaulx F, Bojanova I (2016) Cyber-physical-human systems: putting people in the loop. IT Professional 18(1):10–13
7. Cassandras CG (2016) Smart cities as cyber-physical social systems. Engineering 2:156–158
8. Dressler F, Sommer C (2010) On the impact of human driver behaviour on intelligent transportation systems. In: 2010 IEEE 71st vehicular technology conference, Taipei, pp 1–5
9. Andrisano O et al (2018) The need of multidisciplinary approaches and engineering tools for the development and implementation of the smart city paradigm. Proc IEEE 106(4):738–760
10. Fink J, Kobsa A, Nill A (1996) User-oriented adaptivity and adaptability in the AVANTI project. In: Designing for the web: empirical studies
11. Yilma BA, Naudet Y, Panetto H (2018) Introduction to personalisation in cyber-physical-social systems. In: On the move to meaningful internet systems: OTM 2018 Workshops Print ISBN:

978-3-030-11682-8. Electronic ISBN: 978-3-030-11683-5. https://doi.org/10.1007/978-3-030-11683-5

12. Burzagli L, Emiliani PL (2013) Collective intelligence for inclusion. In: Stephanidis C, Antona M (eds) Universal access in human-computer interaction. Applications and services for quality of life. UAHCI 2013. Lecture notes in computer science, vol 8011. Springer, Berlin, Heidelberg
13. Sabou M, Musil A, Musil J, Biff S (2018) Collective intelligence aspects of cyber-physical social systems: results of a systematic mapping study. In: Proceeding of ACM collective intelligence 2018, Zurich, July 7–8, 2018

Biomedical and Robotic Solutions

Humanoid Robotics for Patients with Sarcopenia: A Preliminary Study on Interaction Features

Claudia Porfirione and Francesco Burlando

Abstract A significant growth of the population of senior citizens is estimated to be observed in the coming years, leading to the onset of socio-sanitary issues. Therefore, it is important to design tools that facilitate active ageing and prevent the occurrence of physical frailty in older people, making seniority a valuable resource rather than an issue of concern. Technology represents an efficient tool to take on such task, as it facilitates the replicability of human-centered trials. In particular, humanoid robotics have proven to be effective applied to weak users, notably in the treatment of people with cognitive disorders, both children (e.g. autistic) and older patients (e.g. Alzheimer). Humanoid robots could represent efficient tools in the design of trials to promote active ageing, since the latter are able to guide elderly people through exercises, to monitor proper execution and to give a real-time human-like feedback, with a consequent involvement of the users. Such high-level of engagement characterizes that kind of interactions, called Human-Humanoid interactions, which should be invested of the same importance of morphological and technological aspects during the design phases. In this paper we provide an overview of some humanoid robots which have been used over the last years in the revolutionary robotics field, providing a comparison of the principal interaction features in relation to what kind of user every robot was designed for.

Such preliminary study will serve as a basis to define the most appropriate aesthetic/behavioural features required in the design of a humanoid robot for the prevention of sarcopenia.

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1 Introduction

The European Union estimates that a significant growth of the population of senior citizens will be observed in the coming years. Such increase will rise social costs for the active population, which will decrease in the meanwhile.

With regard to clinical issues that affect older people, it can be stated that frailty is one of the most significant disease, as it can determine the occurrence of obesity, depression, risk of falls, and many others [1]. Frailty is a disorder that usually emerges from the sixtieth year of life, due to the loss of physical and psychological abilities, and involving loss of muscle tone, mass, and strength. The incidence of this latter condition, known as “sarcopenia”, is expected to dramatically increase in the next 30 years [2].

Physical activity is essential for preventing physical and cognitive decline. Therefore, tools that facilitate active ageing are expected to prevent socio-sanitary issues and help in making seniority a valuable resource rather than an issue of concern.

Technology represents one of the more efficient tools to take on such task, as it facilitates the replicability of human-centered trials. In particular, there is a technology field in which several studies have been carried out in recent years and that seems very promising for the future of research: humanoid robotics.

A study carried out by the Architecture and Design Department of the University of Genoa is investigating the use of a humanoid robot, Pepper, as a tutor in training sessions for elderly in order to prevent sarcopenia. In this paper we analyse and compare proprieties and features of different humanoid robots, in order to highlight which of them are suitable for the design of a humanoid robot to be used in the prevention of sarcopenia.

2 Humanoid Robotics

Humanoids are robots which are chiefly humanlike in their morphology and behaviour. Eaton [3] outline a detailed taxonomy for n + 1 separate levels of embodied humanoid.

0 Replicant. Looks exactly like a human being in terms of physical aspect and behavior.

1 Android. Very close to human morphology and behavior. Difficult to distinguish from a human.

n − 3 Humanoid. Close to a human with high levels of intelligence and dexterity. However, there is no possibility of mistaking the robot for a human being.

n − 2 Inferior Humanoid. Has the broad morphology of humans and a reasonable intelligence but may be confined mainly to a limited task set.

n − 1 Human-Inspired. Looks quite unlike a human but has the broad morphology of humans. It may have bipedal capabilities or be wheeled. Limited intelligence and dexterity.

n Built-for-Human. Looks nothing like a human but it is able to operate in most human-centered, designed environments [4].

3 Humanoid Robotics Application

Generally speaking, humanoid robots can find application in different contexts, such as:

- Work dangerous for humans
- Works which humans normally find unpleasant or tedious
- Home assistance
- Care of weak users
- Entertainment

Since many robots in scientific fictions look like humans, in the collective unconscious robots are humanoids by default. Actually, thanks to advancing technology, there has been the trend to design robots increasingly humanlike, triggering the so-called uncanny valley effect [5].

However, with regards to the first two categories described above, a robot designed to operate in industrial workspace should not be humanlike for any practical purpose. Nevertheless, we are seeing an increasing trend of anthropomorphic design of CoBots. It seems clear that at least some humanoids features are always preferred in the design of a machine bond to work at the side of a human.

In respect of the home assistance field, apart from virtual assistants like Amazon Alexa or Google Home, humanoid shapes are unavoidable for a humanoid robot aimed at helping people in physical tasks. In fact, in this case both the environment and the tools are human-centered designed. The width of a corridor, the height of a stair, the size and shape of chairs and tables are all designed by referring to ergonomic standards. Therefore, it should be more economical and reasonable to use humanoid robots whose design is based on these standards than to re-design environments and tools [6]. Moreover, caregiving and entertainment represent areas in which humanoid robotics proves to be more efficient due to the high level of engagement with the user [7].

4 Humanoid Robotics for Sarcopenia Prevention

As stated before, humanoid robotics has been successful in interacting with weak users for entertainment purposes [8]. Moreover, studies have shown that humanoid robots are able to increase the users' propensity for imitation [9].

With regard to the healthcare area, humanoid robots have proven to be particularly successful when employed in the treatment of people with cognitive disorders, either in the case of children (e.g. autistic [10, 11]) or older patients (e.g. Alzheimer [7]).

Based on these data, it can be assumed that humanoid robotics could represent an efficient tool in the design of trials to prevent sarcopenia. Since physical activity plays a key role in active ageing, such trials could consist of sessions of physical activity tutored by a humanoid robot. The robot will be able to guide users through exercises, to monitor proper execution, and to give a real-time, human-like feedback.

These aspects are related to Human–Robot Interaction (HRI), which is the key for the success of every application of Humanoid Robotics. Indeed, we can, de facto, consider robots as technological industrial products with the highest possible level of interaction (if we assume human–human interaction as the best interaction possible). Thus, we assume that the design of such interaction should have the same importance of morphological and technological aspects.

Therefore, the design of a humanoid robot requires a highly interdisciplinary approach, with contributions from such different fields as engineering and industrial design, psychology and medicine, philosophy and ethics. The role of the designer is to take into account interactions as the key factor in every choice during the development of a humanoid robot.

5 Brief Overview of Selected Humanoid Robots

In this section we provide an overview of some humanoid robots which have been used over the last years in the revolutionary robotics field. Because of the large and ever-growing number of humanoid robots under development and in use, we will focus mainly on robots available on the market, plus some interesting case studies.

In the table (Table 1) we analyze the main properties and features of twenty humanoid robots divided by price range: less than 2000 €, between 2000 € and 20,000 € and more than 20,000 €. Humanoid robotics is a relatively new and unregulated field, therefore, instead of spotlighting a precise range, it is likely to be more useful to focus on the entire panorama of products, looking for features in common between robots from different price ranges. Additionally, the infographic (Table 2) provides an overview of the main interaction features in relation to what kind of user every robot was designed for.

6 Conclusion

The analysis has highlighted some interesting cues for the design of a humanoid robot for patients with sarcopenia. First, it appears that white is the most common colour used for the covers. Some other colours are used for the inserts. It is found that grey and light blue are the most common second colours for robots designed

Table 1 Main properties and features

Name	Manufactures	Country	Price (€)	Year[a]	Height (cm)	Weight (kg)	Special features
Pando	Leju Robot	CHN	300	2018	35	1,5	Cartoon-like
Little Sophia	Hanson Robotics	HKG	300	2019	35	–	Human-like woman face
Kirobo Mini	Toyota	JPN	350	2017	10	0,2	Cartoon-like
Alpha 1 Pro	Ubtech	CHN	650	2016	40	1,6	Cartoon-like
Aelos	Leju Robot	CHN	700	2018	34	1,6	Cartoon-like
Walker	Ubtech	CHN	1000	2019	140	77	
Ipal	Avatarmind	CHN	2000	2015	103	12,5	
R1	IIT	ITA	3500	2019	145	50	
Zeno	Robokind	USA	4600	2007	56	–	Human-like face
Iuro	ACCREA	POL	5000	2012	169	200	
Nao	Softbank Robotics	JPN	7000	2004	58	4,3	Children-like
Poppy	Inria	FRA	8800	2012	85	3,5	3d printed
Sanbot	Qihan Technology	CHN	9000	2016	92	19	
Robotis OP3	Robotis	KOR	11,000	2017	51	3,5	
Pepper	Softbank Robotics	JPN	20,000	2014	120	28	
Asimo	Honda	JPN	15,000	2000	130	48	
Atlas	Boston Dynamics	USA	200,000	2013	150	75	
iCub	IIT	ITA	250,000	2009	104	22	Children-like
Romeo	Softbank Robotics	JPN	250,000	2019	146	36	
Talos	Pal Robotics	ESP	900,000	2016	175	95	

[a] Year of the first production

without a precise category of end-users. In the industrial field orange is also often used, if we consider co-bots that are not in this analysis.[1]

With regard to robots designed for children or weak users, there is evidence of a wider use of colours as blue and red, and specifically pink for products targeted to girls. Moreover, robots designed for children seem to be inspired more closely by

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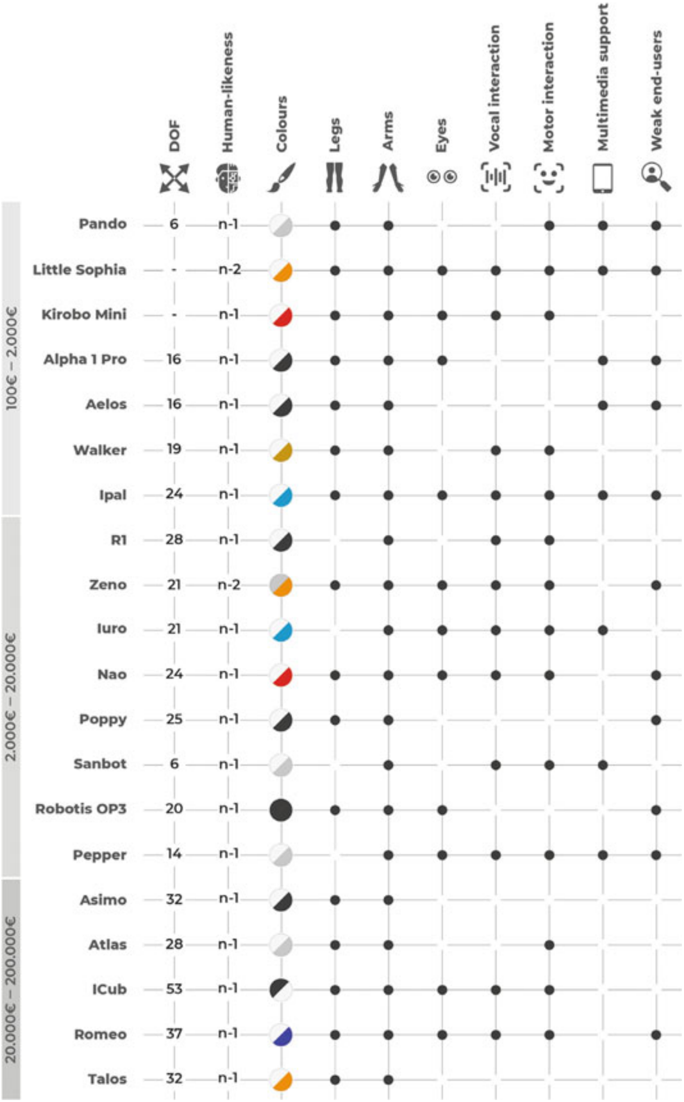
[1] Reference is made to co-bots by companies as Hanwha, Kuka and Aubo.

Table 2 Interaction features



		DOF	Human-likeness	Colours	Legs	Arms	Eyes	Vocal interaction	Motor interaction	Multimedia support	Weak end-users
100€ – 2.000€	Pando	6	n-1	⚪	●	●			●	●	●
	Little Sophia	-	n-2	🟠	●	●	●	●	●	●	●
	Kirobo Mini	-	n-1	🔴	●	●	●	●	●		
	Alpha 1 Pro	16	n-1	⚫	●	●	●			●	●
	Aelos	16	n-1	⚫	●	●				●	●
	Walker	19	n-1	🟡	●	●		●	●		
	Ipal	24	n-1	🔵	●	●	●	●	●	●	●
2.000€ – 20.000€	R1	28	n-1	⚫		●		●	●		
	Zeno	21	n-2	🟠	●	●	●	●	●		●
	Iuro	21	n-1	🔵		●	●	●	●	●	
	Nao	24	n-1	🔴	●	●	●	●	●		●
	Poppy	25	n-1	⚫	●	●					●
	Sanbot	6	n-1	⚪		●		●	●	●	
	Robotis OP3	20	n-1	⚫	●	●	●				●
	Pepper	14	n-1	⚪		●	●	●	●	●	●
20.000€ – 200.000€	Asimo	32	n-1	⚫	●	●					
	Atlas	28	n-1	⚪	●	●			●		
	ICub	53	n-1	⚫	●	●	●	●	●		
	Romeo	37	n-1	🟣	●	●	●	●	●		●
	Talos	32	n-1	🟠	●	●					

cartoon characters than by human morphology. Therefore, a distinction can be made between human-like robots (normally called humanoids) and cartoon-like robots.

For what concern the limbs, arms seem to be essential to ensure a perception of the robot as a humanoid. The same importance is not given to legs, although this may be due to technological reasons instead than aesthetic choices.

Contrary to what we might have expected, it appears that a human-like face is not an essential feature. Many designers chose to have lights and screens as a replacement for eyes, mouth, eyebrow or the entire face. It is well known that people tend to see human face in inanimate objects. Maybe this ability is so well-developed that is not necessary to pursue a high level of human-likeness in the design of the head of a humanoid robot.

An additional device as a tablet placed on the chest of the robot turns out to be a useful feature, as well as the possibility of connecting the robot with a mobile app.

With regard to size, robots designed for children or, generally, with recreational purposes are often shorter than 1 m. Humanoid robots designed for elderly are usually taller than 1 m but still shorter than those who are not designed for a specific end user.

It is interesting to note that, with respect to the taxonomy set out above, delineated by Eaton [3], almost all humanoid robots taken into account belong to the $\mathbf{n-1}$ level. However, the level of human likeness is very different among them. Therefore, it would be appropriate to outline a sub-division of the $\mathbf{n-1}$ level.

The possibility of having vocal and physical interactions depends mostly by the budget of software development, so it can be argued that the higher is the price of the robot, the better is its capability of interaction. Since costs are always a key variable, the right solution is generally the one that maximizes goal achievement without wasting economic resources.

This overview has provided useful findings for the design of a humanoid robot for the prevention of sarcopenia. Nevertheless, the actual deployment of the robot will dictate the design choices. As the prevention of frailty needs physical activity, it can be expected that such robot will become a sort of trainer for old people. A trial led by *the Architecture and Design Department* of the *University of Genoa* and the *Hospital of national importance and high specialization Galliera* of Genoa is investigating the use of the humanoid robot Pepper as a tutor for physical activity sessions with sarcopenic and pre-sarcopenic users.

Future studies will investigate how the robot behaviour, and other features like volume of speech and speed of movement, can affect the human-humanoid interaction.

References

1. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T, ... Schols J (2019) Sarcopenia: revised European consensus on definition and diagnosis. Age Ageing 48(1):16–31. https://doi.org/10.1093/ageing/afy169
2. Ethgen O, Beaudart C, Buckinx F, Bruyère O, Reginster JY (2017) The future prevalence of Sarcopenia in Europe: a claim for public health action. Calcif Tissue Int 100(3):229–234. https://doi.org/10.1007/s00223-016-0220-9
3. Eaton M (2015) Evolutionary humanoid robotics. https://doi.org/10.1007/978-3-662-44599-0
4. Brooks RA, Aryananda L, Edsinger A, Fitzpatrick P, Kemp C, O'Reilly U-M et al (2004) Sensing and manipulating built-for-human environments. Int J Humanoid Rob 1(01):1–28
5. Mori M, MacDorman KF (2012) The Uncanny Valley [From the Field]. IEEE Rob Autom Mag 19(2):98–100. https://doi.org/10.1109/MRA.2012.2192811

6. Kajita S, Hirukawa H, Harada K, Yokoi K (2014) Introduction to humanoid robotics. Retrieved from https://www.springer.com/us/book/9783642545351
7. Valentí Soler M, Agüera-Ortiz L, Olazarán Rodríguez J, Mendoza Rebolledo C, Pérez Muñoz A, Rodríguez Pérez I, ... Martínez Martín P (2015) Social robots in advanced dementia. Front Aging Neurosci 7. https://doi.org/10.3389/fnagi.2015.00133
8. Martinez-Martin E, del Pobil AP (2018) Personal robot assistants for elderly care: an overview. In Costa A, Julian V, Novais P (eds) Personal assistants: emerging computational technologies, pp. 77–91. https://doi.org/10.1007/978-3-319-62530-0_5
9. Oberman LM, McCleery JP, Ramachandran VS, Pineda JA (2007) EEG evidence for mirror neuron activity during the observation of human and robot actions: toward an analysis of the human qualities of interactive robots. Neurocomputing 70(13):2194–2203. https://doi.org/10.1016/j.neucom.2006.02.024
10. Giannopulu I, Terada K, Watanabe T (2018) Communication using robots: a perceptionaction scenario in moderate ASD. J Exp Theor Artif Intell 30(5), 603–613. https://doi.org/10.1080/0952813X.2018.1430865
11. Damiani P, Grimaldi R, Palmieri S (2013) Robotica educativa e aspetti non verbali nei Disturbi Specifici di Apprendimento. 1:1211–1220. Retrieved from https://iris.unito.it/handle/2318/134850#.XG_jvOhKjOg

Preliminary Study of Brain-Inspired Model for Multimodal Human Behavior Detection in Social Context

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Abstract In a near future, robots will permeate our daily life; indeed, they have the potential to proactively support the senior citizen in tedious and different daily tasks (i.e. cleaning, gaming, walking activity, promote socialization). However, to efficiently cooperate with human-beings, robots should have enhanced human–robot interaction capabilities. This work addresses the challenge of designing a robotic model by simulating the modality human beings interact with each other. The first objective of this work concerns the identification of the social cues which correctly describe the user's emotional and engagement state during the interaction. Based on selected descriptors, a perceptual system has been proposed to detect elderly's behavior in a social context. The proposed architecture is inspired to the human brain structure as concern the functionalities modules and analogies in the modules' location. The proposed perceptual system aims at transforming raw data coming from three kinds of sensors (camera, microphone, and laser) into behavioral patterns by mimicking the abstraction evolution which characterizes the consciousness process of the human brain.

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1 Introduction

As fertility declines and life expectancy rises, the proportion of the population above a certain age rises as well. This phenomenon, known as population aging, is occurring throughout the world. The population aged 60 or above is growing at a rate of about 3 percent per year. Currently, Europe has the greatest percentage of the population aged 60 or over (25%) [1]. For this reason, several global initiatives focus on defining solutions for satisfying the needs of the aging population in order to prolong independent living. Indeed, most elderly people prefer to live independently in their homes as long as possible, as this leads to a richer social life and it is paramount to maintaining established habits [2].

In this context, Social Assistive Robots (SAR) can play an important role in the promotion of quality of life by integrating activities with independent-living older adults [3]. Using robots as home-health aids is one promising solution to support older adults' needs. If we want to integrate a social robot for a long-term period in a house, one of the main goals of the robot is to create stimulating and engaging interactions in which a user actively participates for an extended period of time.

One strategy is to provide the robot with social intelligence. Thanks to this ability, the robot recognizes the current social behavior of the user and it is able to adapt its behavior so that to enhance the interaction in a polite and pleasant manner [4]. It highlights the importance of developing an automated assessing of user's social behaviors.

The attitude of a person towards social interaction is expressed by a set of social signals which conveys information about mental state, feelings and other personal traits (i.e. eye gazing, postures, voice quality) [5]. In human–human interaction, the listener automatically assesses the emotional and engagement state of the speaker. This human inherent ability in a social context is the effect of specific processes happening at the level of the brain, as described by Theory of Mind [6].

The challenge is how to develop a computational model that can simulate the modality human beings interact with each other. The first objective of this work is the identification of the social cues that are meant to describe the user's behavior during interaction. Among all, the ones listed in this work have been chosen as the most representative descriptors of the human emotional and engagement state. Secondly, this work aims at modelling a perceptual system able to recognize human social behavior. The importance of this system is twofold. Firstly, by recognizing human behavior online, the robot can act accordingly performing the most appropriate behavior (i.e. the perceptual system represents the sense block in the sense-plan-act loop which characterizes any human–robot interaction system). On the other side, the perceptual system can be used to assess human feedback on the sequence of actions performed by the robot.

The proposed system has been modeled in a brain-inspired way. It implies that our perceptual system aims at transforming raw data coming from the sensory equipment into behavioral patterns by mimicking the abstraction process occurring in the human brain. The proposed perceptual model re-creates the flow of information exchanged by the thalamus and brain cortex areas to infer the social behavior of the user.

The paper is structured as follows. Section 2 reviews the current state of the art of brain-inspired systems. Section 3 summarized the neuroscientific findings that guided the development of the proposed architecture. Section 4 details the social cues of interest and the description of the system. Discussion and conclusions are listed in Sect. 5.

2 Related Works

Biological systems provide a new source of inspiration for developing intelligent and autonomous robots. Biological principles coming from plants or animals models are becoming widely used in the design of robots that can sense, think, walk, swim, crawl, or fly [7]. The innovative structures developed with this emerging field allow achieving intelligence, flexibility, stability, and adaptation for emergent robotic applications, such as manipulation, learning, and control [7]. In this context, human brain activity is also used as an inspiration model for robotic control architectures.

Neuro-robotic models are conceptualized as networks that produce and combine information [8]. The information captured by the sensory channel from the environment or other neurons is integrated and distributed along with the artificial neural network [9]. Neurophysiological insights were used to develop artificial architectures. According to the task the robot needs to perform, specific functionalities of the brain areas are replicated by neuro-robotic models. Several examples are reported in Table 1.

Computation models of the thalamus and limbic system are implemented to replicate a range of cognitive processes such as emotional feedback, selection of appropriate actions and memory in robotic platforms. In this context, the functionality of the thalamus consists in pre-processing the stimuli collected from the environment. The raw representation of the collected data is then elaborated at a higher level by the sensory cortex. Both areas communicate with other brain-inspired modules (i.e. amygdala) to infer the relative emotion, given the condition generating it, as shown in [10] and [11]. The flow of information from the thalamus to the limbic system is frequently mimicked not only to recreate some emotions, as in [10] and [11], but also to assess user's engagement state in human–robot interaction. The work described in [12] shows a complete architecture that allows a robot to recognize the level of attention of children and to react accordingly. The robotic model has been developed by mimicking thalamus, limbic system, and prefrontal cortex's functionalities. The only limitation of the system described by [12] is that the child behavior assessment is performed by detecting one social cue, the postural gesture.

To detect human behavior, multiple social cues need to be identified [5]. Multiple social signals imply multiple sensors mounted over the robot. Due to the complexity of information flow during the perception phase, our work proposes a brain-inspired perceptual system able to identify the behavior of the user from the multimodal data

Table 1 Overview of brain-inspired applications

References	Robot task	Robot	Input signals	Brain areas
[10]	Emotional learning	None	Visual and audio data. Exchange of information between brain areas	Thalamus, sensory cortex, orbitofrontal cortex and amygdala
[11]	Artificial fear generating	None	Environmental data	Sensory system, amygdala system, hippocampal system and working memory
[16]	Goals generation	NAO	Visual data (colors and shape of objects)	Amygdala-thalamus-cortical circuit at its functional level
[12]	Joint attention detection	Robotis Bioloid humanoid robot	Visual data (child's posture)	Amygdala, hypothalamus, hippocampus and basal ganglia
[13]	Person recognition	Pioneer 3DX (P3-DX)	Environmental data, visual data (body and face of the user) and biometric features	Hierarchical structure of the sensory cortex and replication of the spatial–temporal binding criteria

collected during the interaction. Concerning the work described in [13], our model does not replicate the brain structures at the level of neuron configurations, but the modules composing our system mimic functionalities of the brain areas involved. In details, computational models of the thalamus and brain cortex are implemented.

We propose a brain-inspired model which includes insights of the Theory of Mind to improve the human–robot interaction. Theory of Mind is commonly referred as the inference mechanism of identifying the mental state (i.e. emotions, intentions, beliefs) of a person, which is automatically performed by the human brain in social situations [14, 14]. Theory of Mind can be replicated artificially by combining the identification of multiple social cues defined in the Social Signal Processing (SSP) field [5], as proposed by the authors of [15]. This approach opens two challenges. The first issue is related to the identification of social cues which are more representative of the human mental state. The sources of information of our perceptual system are images, audio and laser data. Consequently, specific social cues have been selected according to each modality of perception. The second challenge is relative to the way the social signals should be combined so that to express the user's behavior. Our work focuses on two specific aspects of social behavior: emotional and engagement state. Each aspect is encoded by specific patterns, expressed by a sequence of multimodal data. Thanks to this structure, the proposed brain-inspired system can assess the current social behavior of the user in real-time.

3 Neuroscientific Background

In the following, we delineate the most significant functionalities of brain areas mimicked by our perceptual system.

3.1 Thalamus

The thalamus is the biggest group of neurons, which is encompassed in the diencephalon and it represents the antechamber of the brain. It receives inputs from several systems, such as the sensory, the motor, and the limbic systems, but also from the reticular formation. The fibers that carry this information outreach different nuclei in the thalamus, which, in turn, send these fibers to a very discrete portion of the ipsilateral brain cortex, except for the thalamic-reticular nucleus. This nucleus is the only thalamic nucleus with an inhibitory activity, and it does not project directly to the brain cortex. The thalamic networks represent the first preprocessing station of information and the first structure related with the integration of this information, and their neural activity is related with the consciousness state of the subjects, indeed thalamic neurons own two different fashion to fire; tonic firing, related with awake state, and burst firing, related with drowsiness and sleep state. The thalamic networks represent an important stop station also for descending fibers, which travel in the opposite direction from the Central Nervous System (CNS) to the Peripheral Nervous System (PNS) [17].

3.2 Brain Cortex

Human brain cortices are several and they accomplish for different goals. Particularly, concerning the aim of this work, sensory and associative cortices will be taken into account. Sensory cortices are the brain areas responsible to the processing of sensory information, such as hearing, touch, vision, proprioception, and others. Information gathered from human sensory organs travel from the PNS to the CNS passing throughout the thalamus nuclei, since they reach primary sensory cortices. Each sensorial modality refers to a specific neural substrate, which elaborates the sensorial inputs at a low level of complexity and integration. After that, the information travels towards others sensory cortices, belonging to the same sensorial modality, which cooperates among them analyzing different aspects of the sensorial inputs, assembling them, to reach a higher level of integration and complexity. Subsequently, the information is sent towards associative areas, in which it is merged with other types of information. At this step, the information is not strictly related to the unimodality nature of the stimuli. It is shaped by an increasing level of abstraction and complexity. These areas are not related to a specific sensorial modality, quite the opposite, they handle the integration of several types of information together, to accomplish a higher level of processing. That represents one of the prerequisites to create consciousness [18].

4 Brain-Inspired Perceptual System

This work proposes reverse engineering of the human brain functionality to improve human–robot interactions.

In the designing phase, a set of social cues representative of the human behavior has been selected based on the findings highlighted by the SSP research field [5]. The chosen social cues belong to three input modalities: image, audio, and laser. It is the explanation behind the installation of the camera, microphones, and laser scan over the robotic platform.

In the implementation phase, the ability of the brain to process stimuli from the environment is mimicked by the interconnection of three modules: thalamus, sensory cortex and associative cortex. The functionality of each module shows analogies with the abilities of the corresponding human-beings' neural structure. Besides, the flow of information across the modules is characterized by an increasing level of abstraction, which extends structure complexity and recalls the "convergence-zone" described by Damasio [19].

The overall architecture of the system is shown in Fig. 1. The first module coincides with a lower level of abstraction (thalamus). In this layer, raw data collected during the interaction are preprocessed to reshape them. The medium level of abstraction corresponds with the second module (sensory cortex), where the system processes the reshaped data to extract social cues defined in the design phase. At the higher level of abstraction (associative cortex), the social signals are merged together to be descriptors of a particular social behavior. Descriptors are conveniently combined to perform the automatic assessment of human behavior online.

4.1 Social Cues

Data recorded by the sensors mounted over the robot are used to detect social cues. Social cues are descriptors of the behavioral state of the user during the interaction. Among the social cues described in [5], this work focuses on the following ones.

1. Posture and body movements: since it is assumed unconsciously, body posture represents honest information to assess the engagement of the user during the interaction [20]. In this work, the identification of inclusive and non-inclusive postures is performed. In details, the features of interest consist of body orientation and interpersonal distance between the user and the robot. The quantity of motion performed by the user during the interaction expresses the current

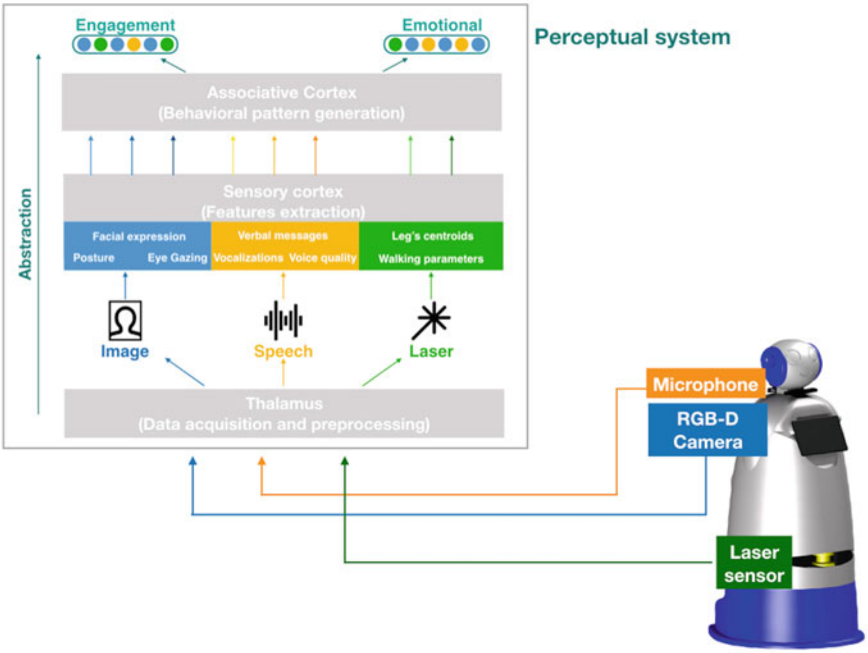

Fig. 1 Architecture of the proposed brain-inspired perceptual system

emotional state. Based on Darwin's discoveries [21], specific changes in arm movements and walking parameters (i.e. gait) express social affective states. For example, frequent changes of posture and high quantity of motion are usually related to embarrassment [22]. The recognition of the body postures and counting of their occurrences aims at assessing the engagement level of the user in the social context.

2. Facial expressions: they directly communicate the affective state of a person [23]. In details, facial expressions allow the identification of six emotions: fear, sadness, happiness, anger, disgust, and surprise.
3. Head orientation: it is described by the eye-gazing. It is the key component of the joint attention mechanism in the human–human interaction. By focusing on a certain object, one person keeps the eyes in the direction where the object is located and automatically bring the other person to look at the same direction (joint attention) [24]. Besides, when two people are engaged in eye contact, the interaction is perceived more likable [25]. Eye gazing provides an insight on the engagement level of the user and a feedback on the attention captured by the robot during the interaction [12].
4. Verbal messages: this category of social cues includes repetition, incomplete words, amount of silence during the interaction. The repetition of words in a small amount of time can be connected to a particular cognitive state of the user

(i.e. confusion) or it can be used as an input to modify the current behavior of the robot. The presence of incomplete words during the dialog can be an evidence of cognitive decline. In this context, the absence of speech is an important indicator to understand not only the role of the user in the interaction (speaker or listener) but also to evaluate the current emotional and engagement state [5].

5. Voice quality: it is described by a set of prosodic features of the speech signal to detect the emotional state of the user [26]. Tempo, energy and pitch are the prosodic features of interest. Tempo is defined as the speaking rate detected in the signal, i.e. the number of phonetically relevant units. Together with the information carried by energy feature, tempo is an emotional descriptor [27]. Pitch provides insights relative to the personality traits, such as lack of hesitations [27].
6. Vocalizations: they encode the emotion of the person speaking. Identifying two groups of vocalizations is possible. Linguistic vocalizations include small words (i.e. “ehm-ehm”, “ah-ah”) which occur more often when a person is feeling difficulty for the situation [28]. Non-linguistic vocalizations belong to the non-verbal sounds like sobbing, crying, laughing and they are more representative of the overall emotional state of the user.

4.2 Data Acquisition and Pre-processing

The model has been developed to enrich the interaction of the elderly user with ASTRO robot. ASTRO is a service robot designed to assist an elderly person with mobility needs. The first version of this robot was developed under ASTRO mobile project [29] and it was refined under ACCRA project [30]. ASTRO is based on the Scitos G5 robotic platform (Metralabs GmbH, Germany). Concerning safety, SCITOS G5 is equipped with a bumper and a couple of emergency-stop buttons to the stop motor. About Human–Machine-Interface (HMI) two touch screens for direct access to the services were mounted on the front and on the back side of the robot. External sensors were integrated into the system to extend the sensing abilities of ASTRO.

On the front, the platform is improved with an additional laser (Laser Sick 300) for the perception of the surrounding environment and the detection of walking parameters. SICK 30B-2011BA is a 2-dimensional laser sensor for area scanning. The light source of the sensor is a pulsed light laser diode (infrared) of wavelength 785 nm with laser class 1 safety. The scan area is 270° semicircle with an angular resolution of 0.5°. Scans are performed at a frequency of 12,5 Hz. The detection distance range is 30 m. These sensors can acquire a different type of information.

The ORBBEC Astra Pro[1] camera is mounted on the front of ASTRO to collect visual data from the environment and from the user. It is an RGB-D camera which provides, at the frame rate of 30 fps, RGB images with a resolution of 1280 × 720 pixels and depth images with a resolution of 640 × 480 pixels. One of the main

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[1] https://orbbec3d.com/.

Table 2 Summary of social cues

Behavioral aspect	Social cue	Features	Sensor
Engagement state	Body posture	Body orientation	Camera
		Interpersonal distance	Laser
	Head orientation	Eye gazing	Camera
Emotional state	Expression	Facial expression	Camera
	Voice quality	Tempo	Microphone
		Energy	Microphone
		Pitch	Microphone
Engagement and emotional state	Quantity of motion	Arm movements	Camera
		Walking parameters	Laser
	Verbal messages	Repetitions	Microphone
		Incomplete words	Microphone
		Amount of silence	Microphone

features of the Astra Pro camera is the range it can cover. The range of the camera covers up to 8 m of distance. The camera integrates two built-in microphones, which can be used to record the surrounding sound and user's speech.

Multidata recording is handled by the thalamus module which collects the incoming signals and pre-processes them in terms of synchronization and filtering. Furthermore, the thalamus module reshapes the collected data accordingly to the requirements of the feature extraction's algorithms of the sensory cortex module. The detection of the aforementioned social cues is performed by integrating appropriate sensors and implementing dedicated machine learning algorithms over the robotic platforms. Table 2 summarizes the relation between social cues, the sensor used to collect corresponding raw data and the aspect of the human behavior they are more representative of.

4.3 Features Extraction

The second module is composed of the set of feature extraction techniques, each of them aims at detecting a certain cue from the incoming signals. This module consists of three blocks. Mimicking the functionality of the sensory cortex, which processes unimodal signals in the human brain, each block composing the second module takes as input one interaction modality. In details, an image for the visual modality, a speech signal for the audio modality and a laser data for the motion modality.

On the image data, the following feature extraction techniques are applied.

- Pose estimator: to detect the posture of the user during the interaction. It consists of a skeleton tracker which extracts the 3d position of joints and compare the current joint configuration with a set of given meaningful poses. The methods developed by [31] allows the identification of joint poses in real-time with high accuracy without taking as input depth information. It can accelerate the perception process.
- Facial expression recognizer: to recognize the emotional state of the user when the face is visible from the robot perspective. Among all the available algorithm, a face detector based on Viola and Jones algorithm ([32]) is used to detect the face in the image. The face profile is then sent to a cloud face expression recognition API (i.e. Microsoft Face API) to select the emotion with the higher confidence level.
- Eye gazing estimator: to evaluate the engagement state of the user in interaction and to guide the attention of the robot towards the direction the user is looking at. Eye gazing estimator relies on the 2D data coming from the camera by using the more reliable technique among the ones described in [33].

On the speech signal, the following feature extraction algorithms are applied.

- Verbal messages detector: to identify the repetition of specific words and count the number of incomplete words, automatic transcription of dialog can be used to identify the repetition of specific words of interest. Given the speech-to-text output, the assessment of the number of times sequence of words are repeated can be performed. On the other hand, the recognition of incomplete words is out of the current development due to the challenges related to it. The presence of silence in the speech can be recognized by applying a Voice Detection Activity (VAD) algorithms. They allow the machine to distinguish from an audio frame containing silence from another with data.
- Voice quality estimator: to calculate the prosodic features (tempo, energy, and pitch), the tools listed in [5] can be combined;
- Vocalizations recognizer: it can be built over an automatic speech recognizer to identify specific linguistic elements ("uhm", "ehm", "ah-ah") and certain sounds expressing emotional states of the user. Automatic speech recognition algorithm (i.e. Google Speech API, Microsoft Speech API) can be used to detect specific words of interest.

On the laser data, the following feature extraction techniques are applied.

- Leg's centroid detector: this technique permits the computation of the interpersonal distance between the user and the robot. The distance is an indicator of the established relationship between the user and the robot (proximity feature) [5].
- Walking parameter recognizer: to evaluate the quantity of motion of the user. The quantity of motion expresses the feelings towards the social situation. The walking

parameter detected in this work is the gait parameter, which is computed terms of velocity and acceleration of the walking performance in front of the robot.

Most of the techniques described above rely on pre-trained models available on the Cloud. The novelty of this work is to combine them successfully by parallelizing the procedures. Due to the high workload, the strategy adopted to perform the feature extraction online is to process the data on Cloud so that to reduce the amount of running processes on the robotic platform. Furthermore, the pre-trained models strictly depend on the data they are trained on. Since in most of the cases the models are trained on datasets composed by young people's features, the models will be re-trained on a larger dataset including elderly data.

4.4 Behavioral Pattern Generation

The term behavior refers to (human) actions associated with emotions, personality, and psychological state [34]. In this work, the behavior of the user is analyzed in two different aspects: engagement in the conversation and emotional perception of the situation, which are representative of the current mental state of the user. The two aspects characterize the prototypical nature of human behavior in a social situation. The strategy adopted in this work is to combine the unimodal attributes extracted by the sensory cortex based on the behavioral aspects they represent the most. The idea is to represent the behavior as a tensor of multimodal data.

To automatically exploits the complementarity and redundancy of multiple modalities, an artificial neural network model is implemented to construct a joint mutual representation [35]. By using a joint representation, it is possible to compute similarities between the features in the representational space which reflects the similarities in the corresponding semantic concepts [36], that in this work are the behaviors. The neural network for multimodal representation is fed by the features of each modality. The architecture is composed of individual neural layers (one for each modality) alternated by hidden layers, which project the features into the joint space [35].

As shown in Table 2, it is possible to identify features that are more likely to be a meaningful descriptor of a particular behavior (i.e. the interpersonal distance and body posture of the user are meaningful descriptors of the engagement aspect). Tensor composed by the features belonging to a certain behavioral aspect can be used as training data of the neural network. Even if neural networks require a large amount of training data, they provide superior performances in joint representations tasks [35].

5 Discussion and Conclusion

Our work represents a new strategy for human behavior recognition in human–robot interaction. Since human being is a social animal and it can handle a social situation in a fast and appropriate way, the idea is to develop a multimodal perceptual module inspired to the human brain. Concerning previous works, the proposed architecture is composed by a confined number of modules organized in a hierarchical structure, influenced by findings of Theory of Mind. Furthermore, the hierarchical structure underlines the abstraction process developed to transform raw data into meaningful behavioral descriptors. This work provides a solution to the proper features selection and descriptors to capture human social signals by combining insights coming from social signal processing. By automatic assessing of human behavior, the system contributes to the implementation of a robotic social intelligence.

A limitation of the proposed system is relative to the absence of decision-making, planning, and acting modules. A possible approach is to re-create them in a brain-inspired way and to provide a complete interaction system. For example, the decision-making process can be included by adding an orbital prefrontal module, able to select the most appropriate robot's response based on the detected human behavior.

Another limitation regards the lack of availability of datasets to train the features extraction models. To make the system working for elderly users, the learning models should be trained on them. One possibility to overcome this issue is to organize an ad-hoc experimental session to collect raw data of interest. By increasing the features datasets, it is possible to increase the training dataset also fed into the behavioral pattern generation model. It will lead to a more reliable recognition system.

As specified above, the aim of this work is to describe a novel perceptual model for human behavior recognition based on selected social cues, expressed by the user involved in the interaction. This work details the theorical background and the insights behind some designing choices. As future works, we will organize specific experimental sessions to test the proposed architecture, developed by using the approaches described in this paper. Besides, we will like to improve the system by enhancing the abstraction process. Future development involves the abstraction of social signals into social actions so that to have a system able to detect the social role [37] and the intentions of a person. It is possible to reach this aim by integrating the perception module with a memory structure continually updated with robot's experiences.

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References

1. United Nations Department of Economic and Social Affairs Population Division: E02 World Population Prospects The 2017 Revision: Key Findings and Advance Tables. World Popul. Prospect. 2017 (2017) https://doi.org/10.1017/CBO9781107415324.004
2. Cortellessa G, Fracasso F, Sorrentino A, Orlandini A, Bernardi G, Coraci L, De Benedictis R, Cesta A (2017) Enhancing the interactive services of a telepresence robot for AAL: Developments and a psycho-physiological assessment. In: Lecture Notes in Electrical Engineering. https://doi.org/10.1007/978-3-319-54283-6_25
3. Tapus A, Mataric MJ, Scassellati B (2007) Socially assistive robotics [Grand challenges of robotics]. IEEE Robot Autom Mag 14:35–42. https://doi.org/10.1109/MRA.2007.339605
4. Kaiser FG, Glatte K, Lauckner M (2019) How to make nonhumanoid mobile robots more likable: employing kinesic courtesy cues to promote appreciation. Appl Ergon 78:70–75. https://doi.org/10.1016/j.apergo.2019.02.004
5. Vinciarelli A, Pantic M, Bourlard H (2009) Social signal processing: survey of an emerging domain. Image Vis Comput 27:1743–1759. https://doi.org/10.1016/j.imavis.2008.11.007
6. Frith U, Frith CD (2003) Development and neurophysiology of mentalizing.https://doi.org/10.1098/rstb.2002.1218
7. Fukuda T, Chen F, Shi Q (2018) Special feature on bio-inspired robotics.https://doi.org/10.3390/app8050817
8. Tononi G, Sporns O (2003) Measuring information integration. BMC Neurosci 4. https://doi.org/10.1186/1471-2202-4-31
9. Sporns O (2007) What neuro-robotic models can teach us about neural and cognitive development. Neuroconstructivism Perspect Prospect 2:179–204. https://doi.org/10.1093/acprof:oso/9780198529934.003.0008
10. Balkenius C, Morén J (2001) Emotional learning: a computational model of the amygdala. Cybern Syst 32:611–636
11. Raymundo CR, Johnson CG, Vargas PA (2015) An architecture for emotional and context-aware associative learning for robot companions.https://doi.org/10.1109/ROMAN.2015.7333699
12. Dağlarlı E, Dağlarlı SF, Günel GÖ, Köse H (2017) Improving human-robot interaction based on joint attention. Appl Intell 47:62–82. https://doi.org/10.1007/s10489-016-0876-x
13. Al-Qaderi MK, Rad AB (2018) A brain-inspired multi-modal perceptual system for social robots: an experimental realization. IEEE Access 6:35402–35424. https://doi.org/10.1109/ACCESS.2018.2851841
14. Premack D, Woodruff G (1978) Does the chimpanzee have a theory of mind? Behav Brain Sci 1:515–526. https://doi.org/10.1017/S0140525X00076512
15. Wiltshire TJ, Warta SF, Barber D, Fiore SM (2017) Enabling robotic social intelligence by engineering human social-cognitive mechanisms. Cogn Syst Res 43:190–207. https://doi.org/10.1016/j.cogsys.2016.09.005
16. Franchi AM, Mutti F, Gini G (2016) From learning to new goal generation in a bioinspired robotic setup. Adv Robot 30:795–805. https://doi.org/10.1080/01691864.2016.1172732
17. Jones EG (2012) The thalamus. Springer Science & Business Media, Berlin
18. Cacioppo JT, Tassinary LG, Berntson G (2007) Handbook of psychophysiology
19. Damasio AR (1989) The brain binds entities and events by multiregional activation from convergence zones. Neural Comput 1:123–132. https://doi.org/10.1162/neco.1989.1.1.123
20. Scheflen AE (1964) The significance of posture in communication systems. Psychiatry 27:316–331. https://doi.org/10.1080/00332747.1964.11023403
21. Darwin C, Prodger P (1998) The expression of the emotions in man and animals.https://doi.org/10.1017/CBO9780511694110
22. Costa M, Dinsbach W, Manstead ASR, Ricci Bitti PE (2001) Social presence, embarrassment, and nonverbal behavior. J Nonverbal Behav 25, 225–240. https://doi.org/10.1023/A:1012544204986

23. Ekman P (1993) Facial expression and emotion. Am Psychol. https://doi.org/10.1037/0003-066X.48.4.384
24. Emery NJ (2000) The eyes have it: the neuroethology, function and evolution of social gaze. Neurosci Biobehav Rev 24:581–604. https://doi.org/10.1016/S0149-7634(00)00025-7
25. Mason MF, Tatkow EP, Macrae CN (2005) The look of love: gaze shifts and person perception. Psychol Sci 16:236–239. https://doi.org/10.1111/j.0956-7976.2005.00809.x
26. Scherer KR (2003) Vocal communication of emotion: a review of research paradigms. Speech Commun 40:227–256. https://doi.org/10.1016/S0167-6393(02)00084-5
27. Scherer KR (1979) Personality markers in speech. In: Social markers in speech. Cambridge University Press
28. Glass CR, Merluzzi TV, Biever JL, Larsen KH (1982) Cognitive assessment of social anxiety: development and validation of a self-statement questionnaire. Cognit Ther Res 6:37–55. https://doi.org/10.1007/BF01185725
29. Cavallo F, Limosani R, Fiorini L, Esposito R, Furferi R, Governi L, Carfagni M (2018) Design impact of acceptability and dependability in assisted living robotic applications. Int J Interact Des Manuf 12. https://doi.org/10.1007/s12008-018-0467-7
30. D'Onofrio G, Fiorini L, de Mul M, Fabbricotti I, Okabe Y, Hoshino H, Limosani R, Vitanza A, Greco F, Giuliani F, Guiot D, Senges E, Kung A, Cavallo F, Sancarlo D, Greco A (2018) Agile Co-creation for robots and aging (ACCRA) project: new technological solutions for older people. Eur Geriatr Med 1–6. https://doi.org/10.1007/s41999-018-0106-7
31. Cao Z, Simon T, Wei SE, Sheikh Y (2017) Realtime multi-person 2D pose estimation using part affinity fields. In: Proceedings of the IEEE conference on computer vision and pattern recognition (CVPR). pp 7291–7299. https://doi.org/10.1109/CVPR.2017.143
32. Viola P, Jones M (2001) Robust real-time object detection. Int J Comput Vis 4, 34–47
33. Admoni H, Scassellati B (2017) Social eye gaze in human-robot interaction: a review. J Human-Robot Interact 6:25–63. https://doi.org/10.5898/jhri.6.1.admoni
34. Vrigkas M, Nikou C, Kakadiaris IA (2015) A review of human activity recognition methods. Front Robot AI 2. https://doi.org/10.3389/frobt.2015.00028
35. Baltrušaitis T, Ahuja C, Morency LP (2019) Multimodal machine learning: a survey and taxonomy.https://doi.org/10.1109/TPAMI.2018.2798607
36. Srivastava N, Salakhutdinov RR (2012) Multimodal learning with deep boltzmann machines. Adv Neural Inf Process Syst 2222–2230. https://doi.org/10.1109/CVPR.2013.49
37. Lan T, Sigal L, Mori G (2012) Social roles in hierarchical models for human activity recognition. In: IEEE conference on computer vision and pattern recognition. pp 1354–1361. https://doi.org/10.1109/CVPR.2012.6247821

An Obstacle Avoidance Strategy Using an Indoor Localization System

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Abstract In this paper an assistive device for the mobility support of the elderly and people with impairments is presented. The device is a Smart Walker developed for the Assistive Technology context, within the framework of the NATIFLife project. The hardware architecture of the system, the algorithm implemented for both static and dynamic obstacles avoidance and the experimental results are reported.

1 Introduction

The trend towards a gradual demographic aging of the population has been confirmed by several studies. With reference to European Union, a study by Eurostat [1] shows how the proportion of elders to working age population is gradually reducing, while the number of pensioners is growing, due to a substantial reduction in birth rates and the increase in life expectancy.

One of the consequences of demographic aging is the growth of the share of elderly people living alone. This implies the need to provide more support to guarantee independence and autonomy of life to this category of people. On the other hand, there are some safety issues since elderly people are more vulnerable to domestic accidents. In fact, the cases of domestic accidents occurring to people aged between 65 and 80, represent the 80% of the total [2]. Moreover, falls are the main cause of accidental injuries [3]. Fall-related injuries can have a substantial impact on the lives of the elderly, as they can lead to both a decrease in motor skills and to a considerable increase in health care costs.

The availability of technological solutions capable of contributing to the improvement of the safety, health and quality of life of the elderly represents an enabling step towards implementation of new social assistance models. The main idea of such

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models is to decentralize part of the social-assistance activities from healthcare facilities to the users' residences. According to the definition provided by the World Health Organization, assistive devices and technologies are those whose primary purpose is to maintain or to improve an individual's functioning and independence to facilitate participation and to enhance overall well-being. They can also help prevent impairments and secondary health conditions [4].

Many research efforts by the authors have been focused, in recent years, on the development of reliable solutions for Activities of Daily Living (ADL) monitoring and for the recognition and classification of critical events to the user, such as falls [5–9].

In this paper, part of the research activities developed within the NATIFLife project "A Network of Assistive Technology for an Independent and Functional Life" are presented [10]. The project is funded by the INTERREG V-A Italy Malta Cooperation Programme and involves the Universities of Catania and Malta, and several public entities and enterprises located both in Sicily and Malta [11]. The Project aims at providing effective technological solutions to the needs of independency and autonomy of elderly and people with impairments. Its main objective is the development of an innovative framework of assistive technology in the domestic environment, supporting elderly and people with disabilities, by a joint, cross-border action between research, industrial, institutional and social stakeholders.

In particular, a smart walker, i.e. an assistive device for mobility support, will be presented here. The main features and functionalities which make such a walker *smart* rely on the solutions provided within the framework of the NATIFLife project.

2 Related Work

Several research activities have investigated the enhancement of commercial walkers through actuators, sensors and high-level functionalities. In the related literature, such improved walkers are typically referred to as *smart walkers* [12]. These devices are usually classified according to their autonomy, shared-control degree, sit-to-stand support, monitoring of the user's status, and wheel actuation. Walkers with actuated wheels ease the mobility of the user, by navigating in the environment. On the other hand, passive walkers guide the users by means of brakes acting on the wheels, while the user is still responsible for the motion. Some examples are available in the literature on such a brake-based approach [13, 14], however they usually adopt expensive servo motors for the brakes and costly obstacle detection systems.

3 The Proposed Solution

An obstacle avoidance solution has been implemented on a commercial walker. Such a solution can handle both static and dynamic obstacles. Static obstacles are managed

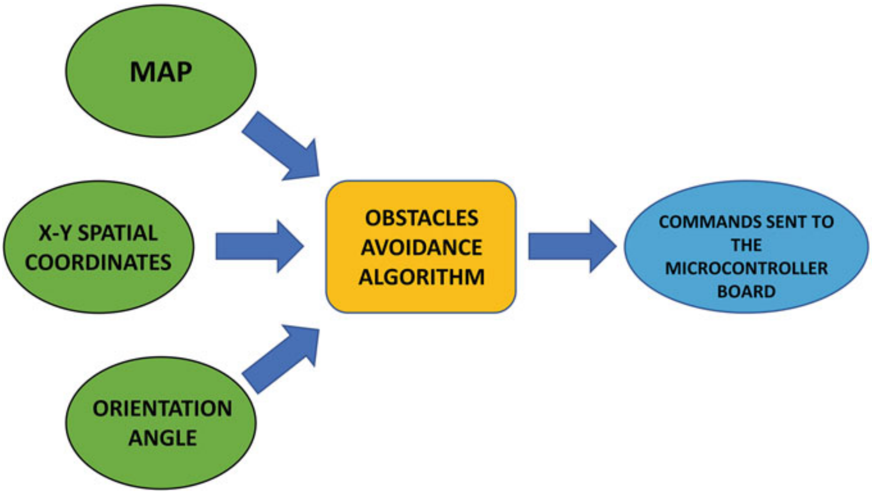

Fig. 1 Input and output of the control algorithm for static obstacles

by a control algorithm requiring three inputs, as schematically shown in Fig. 1, and they are:

- The 2-D binary map of the operating environment, including obstacles and free areas;
- The 2-D coordinates of the walker within the map;
- The orientation angle of the walker.

The map must be provided a priori and, in our case, has been manually realized. This is the main limitation of the current version of our work.

Whenever the algorithm identifies an obstacle within the minimum allowed distance from current position and orientation within the map, it sends a command to a microcontroller board in order to actuate the braking system, in order to steer the elder walking to avoid the collision.

Dynamic obstacles (i.e. not present in the map) are detected through three Time-of-Flight (ToF) ranging sensors (one frontal, one towards the right and one towards the left). Whenever an obstacle is closer to the minimum safety distance, a suitable control signal is triggered also in this case to actuate the braking system.

The main novelties in our solution are the low-cost hardware implementation and the monitoring of the elderly status.

4 Hardware Architecture of the System

The algorithm for the static obstacle avoidance is executed by a Raspberry Pi 3, a popular single-board low-cost low-power computer. The map of the environment is

Fig. 2 The Smart Walker developed

pre-loaded into the computer mass memory. The walker heading is obtained using a board called Sense Hat, an expansion board for the Raspberry Pi 3, which integrates a set of heterogeneous sensors and devices, including a LED display, which allows the user to view the data detected through icons or messages, and an Inertial Measurement Unit (IMU), that integrates an accelerometer, gyroscope and magnetometer in a single chip. It also includes some environmental sensors such as a barometric pressure sensor, a temperature sensor and a humidity sensor. Furthermore, a 5-button joystick is present, which can be used as an input device.

The 2-D coordinates are provided by the indoor location system described in [15], through a wireless sensor network based on the ZigBee-IEEE 802.15.4 protocol. An XBee module has been used to interface the Raspberry Pi to the localization system. Such system is a solution belonging to the NATIFLife framework.

The control board integrated in the walker is a NUCLEO-L476RG board, which is equipped with a low-power ARM Cortex M4 STM32L476RGT6 microcontroller. Raspberry Pi and Nucleo board communicate through a serial channel. The two servomotors MG946R Towerpro are driven independently by PWM signals provided by the Nucleo Board. These signals switch the servo from the free to hold position of the two wheels' brakes. The result is an on-off control approach. The integrated system obtained is shown in Fig. 2.

5 Obstacle Avoidance Algorithm

Once position and orientation of the walker are known, the static obstacle avoidance algorithm probes the map to detect the presence of obstacles in the surrounding environment and, if needed, to avoid them.

In order to do this, the algorithm calculates the distances to the obstacles in the map (static objects or walls) over an arc of 181 degrees in front of the walker. The

Table 1 Threshold command control

Distance_left	Distance_front	Distance_right	Brake activation
0	0	0	None
0	0	1	Left
0	1	0	Both
0	1	1	Left
1	0	0	Right
1	0	1	None
1	1	0	Right
1	1	1	Both

arc is then divided into three equal sectors and the algorithm verifies for each sector if the distance from the obstacles is lower than a given threshold. Depending on the output of this check, the control action on the braking system is established. The three control variables, Distance_Left, Distance_Front and Distance_Right, shown in Table 1, represent the presence of obstacles respectively in the left, front and right sectors in the arc. The values of 1 and 0 indicate respectively the presence or absence of obstacles within the threshold distance. The basic principle is to produce (through the brakes) a difference in the speed of rotation of the two rear wheels, thus resulting in a steering of the walker. If the presence of an obstacle requires that the walker should stop, the control algorithm blocks both wheels.

The same approach is used with the ranging data acquired by the three ToF sensor to avoid unexpected or dynamic obstacles, with an equivalent consequent actuation of the brakes.

6 Results

Experimental tests carried out in the laboratory have shown that the developed system improves the ability to identify obstacles and therefore to avoid them automatically and intuitively. Then volunteers performed pilot tests for the qualitative usability assessment of the proposed smart walker.

The integration between data provided by ToF laser sensors and localization system greatly improves the ability of the system to avoid collisions with obstacles and consequent potential falls.

Moreover, the monitoring functionality of the smart walker, like the one provided by the NATIFLife infrastructure, allows exploiting potential advantages coming from processing data to observe the status of the elderly.

As a future development, we plan to carry out a wider and quantitative testing campaign on the platform.

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References

1. Population Structure and ageing, Statistics Explained, Eurostat. https://ec.europa.eu/eurostat/statistics-explained/index.php/Population_structure_and_ageing
2. Lee VMS et al (1999) Home accidents in elderly patients presenting to an emergency department. Accid Emerg Nurs 7(2):96–102
3. Gudnadottir M et al (2018) Accidental injuries among older adults: an incidence study. Int Emerg Nurs 40(9):12–17
4. World Health Organization, Assistive devices and technologies. https://www.who.int/disabilities/technology/en/
5. Andò B. et al (2014) An advanced tracking solution fully based on native sensing features of smartphone. In: 2014 IEEE sensors applications symposium (SAS), 2014. Queenstown, pp 141–144
6. Andò B et al (2016) A multisensor data-fusion approach for ADL and fall classification. IEEE Trans Instrum Meas 65(9):1960–1967
7. Andò B et al (2017) A NeuroFuzzy approach for fall detection. In: 2017 International Conference on Engineering, Technology and Innovation (ICE/ITMC), June 27–29, 2017. Madeira Island, Portugal, pp 1312–1316
8. Andò B et al (2018) A RFID approach to help frail users in indoor orientation task. In: 2018 IEEE sensors applications symposium (SAS), 2018. Seoul, pp 1–4
9. Andò B et al A measurement strategy to assess the optimal design of an RFID-based navigation aid. IEEE Trans Instrum Meas
10. https://natiflife-project.eu/
11. https://www.italiamalta.eu/en/pc-interreg-v-a-italia-malta.html
12. Martins M, Santos C, Frizera A, Ceres R (2015) A review of the functionalities of smart walkers. Med Eng Phys 37(10):917–928
13. Hirata Y, Hara A, Kosuge K (2007) Motion control of passive intelligent walker using servo brakes. IEEE Trans Rob 23(5):981–990
14. Fontanelli D, Giannitrapani A, Palopoli L, Prattichizzo D (2015) A passive guidance system for a robotic walking assistant using brakes. In: 2015 54th IEEE conference on decision and control (CDC). IEEE, pp 829–834
15. Andò B, Baglio S, Lombardo CO (2014) RESIMA: an assistive paradigm to support weak people in indoor environments. IEEE Trans Instrum Meas 63(11):2522–2528

Human-in-the-Loop Approach to Safe Navigation of a Smart Wheelchair via Brain Computer Interface

Lucio Ciabattoni, Francesco Ferracuti, Alessandro Freddi, Sabrina Iarlori, Sauro Longhi, and Andrea Monteriù

Abstract Assistive robots operate in complex environments and in presence of human beings, as such they are influenced by several factors which may lead to undesired outcomes: wrong sensor readings, unexpected environmental conditions or algorithmic errors represent just few examples. When the safety of the user must be guaranteed, a possible solution is to rely on a human-in-the-loop approach, e.g. to monitor if the robot performs a wrong action or environmental conditions affect safety during the interaction, and provide a feedback accordingly. The proposed work presents a human supervised smart wheelchair, i.e. an electric powered wheelchair with semiautonomous navigation capabilities of elaborating a path planning, whose user is equipped with a Brain Computer Interface (BCI) to provide safety feedbacks. During the wheelchair navigation towards a desired destination in an indoor scenario, possible problems (e.g. obstacles) along the trajectory cause the generation of error-related potentials signals (ErrPs) when noticed by the user. These signals are captured by the interface and are used to provide a feedback to the navigation task, in order to preserve safety and avoiding possible navigation issues modifying the trajectory planning.

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1 Introduction

Human robot cooperation and interaction have experienced a significant growth in the last years to support people with reduced motor skills, both from the academia and industrial point of view. In particular, real time feedback from the user to the robot is an emerging requirement, with the main goal of ensuring human safety, better than a common sensory set equipping the robot can ensure. In cooperative tasks, a prompt feedback from the human to the robot allows to handle possible environmental factors that can change and affect the cooperative performance, and possibly mitigate the effects of unexpected factors, as investigated in the literature [1–5]. Wrong sensor readings, unexpected environmental conditions or algorithmic errors are just some of the factors which can expose the users to serious safety risks. For these reasons, it is fundamental that the human operator is included within the robot control loop, so that she/he can modify the robot's decisions during human-robot interaction if needed [6]. Different works, such as [7, 8], have investigated these kind of applications by considering real-time feedbacks about the surrounding environment as well as robot control architecture and behavior via electroencephalographic (EEG) signals. In several different robotic applications, the human electroencephalogram encodes internal states, which can be detected online in single trial and can be used to improve robotic behavior, e.g., smoother interaction, in rehabilitation tasks and user workload adjustments [9]. During previous researches [10, 11], a cursor movement was used to evoke the correct or erroneous potentials. Such a research reported the 80% of accuracy in detecting the Error-related Potentials (ErrPs), leading to a reduction of decoding error from 30% to less than 9%. As a consequence, the classification accuracy increased from 70% to almost 80% by using the online ErrP-based correction. Another research [12] supports the feasibility of the ErrPs use by the combination of BMI (Brain-Machine Interface) signal to decode the action commands, while the ErrP decoding to correct the erroneous actions. The consequent offline analysis showed an improvement into the decoding of movement-related potentials, thanks to the introduction of ErrP classification. The average recognition of the ErrP was about the 80%, showing a significant reduction of the global error rate in discriminating movements.

The aim of the present paper is to develop a human-in-the loop approach for addressing accurate autonomous navigation of an assistive mobile platform, while simultaneously accounting for unexpected and undetected errors via human correction. In detail, a specific assistive mobile robot is investigated adding the possibility of modifying its pre-planned navigation when it receives a message from the human operator. The robot is a smart wheelchair, capable of performing semiautonomous navigation, while human-robot communication is performed via Brain Computer Interface (BCI): this device is especially useful for people who have very limited mobility and whose physical interaction with the wheelchair must be minimal. In detail, when the user notices the presence of an obstacle not detected by the sensors installed on the wheelchair, then the ErrP signals generated in his/her brain are recorded by the BCI system, as investigated in [13]. The ErrPs are evoked potentials recorded when the subject recognizes an error during a pre-planned task, and described by a variation in the brain signal within 500 ms after the erroneous response. Consequently, an alert message is sent to the mobile robot in order to redefine the navigation task at the path planning level. The possibility for the user to participate to the human-robot cooperation task allows to face all those environmental changes that the system may not be able to manage, as well as to correct possible erroneous robot decisions due to software and/or hardware problems. The size and shape of any undetected object, its distance from the wheelchair, together with the relative speed, as well as EEG signal classification and communication speed, all play an important role and should be given great consideration.

The paper is organized as follows. The proposed approach is introduced in Sect. 2 mainly focusing on the robot trajectory planning and the EEG methods for human-robot interaction. The hardware of the system is described in Sect. 3, while Sect. 4 discusses preliminary results of the proposed approach. Conclusions and future improvements end the paper in the last Sect. 5.

2 Proposed Approach

Assistive robots, employed to support the mobility of impaired users, are usually equipped with several sensors, especially to detect possible obstacles on the way. However, in some cases, these sensors can not correctly detect objects (e.g., holes in the ground, stairs and small objects are often missed by laser rangefinders). The proposed idea is that of including the human observation within the robot control loop, by recording ErrP signals to detect possible changes, and sending a feedback to the robot. The proposed human-in-the-loop approach is sketched in Fig. 1. The ROS ecosystem was used as a base to build the proposed solution, due to its flexibility and wide range of tools and libraries for sensing, robot control and user interface. Description of the core modules of the proposed approach are given in the following subsections.

2.1 Robot Navigation

The main goal of the navigation algorithm is to determine the global and local trajectories that the robot follows to move to a desired point, defined as *navigation goal*, from the starting position, considering possible obstacles not included in the maps [14]. The navigation task performed by the smart wheelchair is mainly composed by three different steps: localization, map building [15] and path planning [16]. Each step is introduced in the following.

- *Localization*: the estimation of the current robot position in the environment; the localization method is based on the AMCL (Adaptive Monte Carlo Localization),

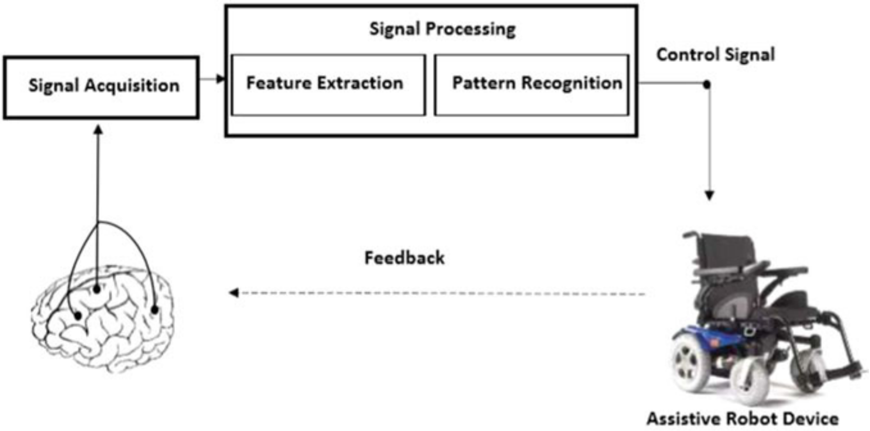


Fig. 1 Scheme of the proposed system that involves the human ErrP signal within a closed-loop strategy

which exploits recursive Bayesian estimation and a particle filter to determine the actual robot pose. The Monte Carlo algorithm is used to map the odometry estimation acquired after the mapping phase [17]. When the smart wheelchair moves, it records changes in the environment. The algorithm uses the "*Importance Sampling*" method [18], a technique that allows to determine the property of a particular distribution, starting from samples generated by a different distribution with respect to that of interest. The localization approach by Monte carlo can be resumed into two phases. During the first one, the algorithm predicts the generation of n new positions and each of this is randomly generated from the samples determined in the previous step. In the latter, the sensorial recordings are included and weighted in the pool of samples as it happens with the Bayes rules in the Markov localization.

- *Mapping*: the representation of the environment where the mobile robot operates, which should contain enough information to let the robot accomplishes the task of interest; it mainly relies on the laser rangefinder, positioned on a fixed support at the base of the smart wheelchair and able to measure the distance in the space and to delineate the profile of a possible obstacle, drawing the environment map.
- *Path Planning*: the choice of the path to reach a desired goal location, given the robot position; it takes into account possible obstacles detected by the laser rangefinder. The applied navigation algorithm is the Dynamic Window Approach (DWA) [19]. The velocity space of the robot is limited by the configuration of the obstacles in the space and by its physical characteristics. The obstacles near the robot impose restrictions on the translation and rotation velocities. All the allowable velocities are calculated by a function that evaluates the distance from the nearest obstacle to a certain trajectory and gives a score choosing the best solution among all the trajectories.

All the steps described above are performed via ROS modules: the wheelchair software is basically composed of ROS packages and nodes, which acquire data from the sensor sets, elaborate the information and command the wheels accordingly. A description of these functionalities can be found in [20].

2.2 EEG-Based Feedback

In the proposed humal-in-the-loop approach, the wheelchair operator can interact with the robot when he/she observes a problem during the navigation task (e.g., the wheelchair is about to fall into something unexpected, such as a hole or an obstacle not detected by the laser rangefinder). In detail, the system allows the operator to send a signal to the robot in order to change the predefined path. This interaction requires the addition of software packages to the navigation modules, whose aim is to build the link between the BCI and navigation stack of the smart wheelchair. The new packages implement the following steps:

1. subscribe or listen to the BCI for the trigger;
2. create the obstacle geometry;
3. pose the obstacle within the built map;
4. request a new iteration of the path planning algorithm.

When a trigger from the BCI is received, then a new unexpected obstacle is virtually created and positioned within the map built. In this way, the path planning module can elaborate a new way to the goal, taking into account the newly introduced obstacle.

The BCI software is used to collect the ErrP signals and specific algorithms are implemented to recognize them. The ErrP wave and its shape is detectable at almost 500 ms from the error recognition by the user and it is defined by a huge positive peak, preceded and followed by two negative peaks as in Fig. 2. Consistently to the literature, the error potentials are most prominent in the central electrodes, i.e. Cz, Fz and Pz, as occurs in similar researches in the most cases.

As already stated in Sect. 1, authors of [12] supported the feasibility of the ErrPs use by the combination of Brain-Machine Interface signal to decode the action commands while the ErrP decoding to correct the erroneous actions. This approach has been reproduced in the present study, simulating the presence of obstacles in the path, originally chosen by the smartwheelchair, in order to use the generated ErrP signals, recorded by the BCI system, to give a feedback and try to avoid the obstacles.

2.3 Navigation: EEG Feedback Integration via ROS Nodes

The integration between the smart wheelchair navigation and the EEG feedback was realized by the creation of dedicated ROS nodes. The ROS navigation stack takes information from odometry and sensor streams and outputs velocity commands to

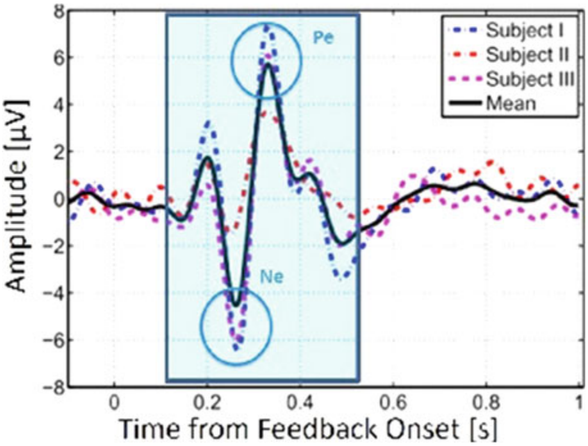


Fig. 2 Example of typical ErrP wave shape [1]

send to the smart wheelchair. The best way to apply a correction action on the wheelchair trajectory is by creating imagery obstacles on the map layer. The navigation stack changes dynamically the cost map, by using sensor data or by sending point cloud. In particular, a new software package has been created which allows a link between the BCI and the navigation task.

The implemented package is able to:

- subscribe and listen continuously to the robot position;
- transform the robot pose from the robot frame to the map frame;
- subscribe/listen to the BCI for the trigger;
- create the obstacle geometry and position it on the map;
- convert it to ROS point clouds.

Then, the point clouds are published in the ROS navigation stack where the local and global cost map parameters are modified. The implementation of the nodes architecture is represented and detailed in Fig. 3, while the flowchart of the algorithm is introduced in Fig. 4.

3 Experimental Setup

In this section both the smart wheelchair and the BCI used for building a prototype of the proposed system are presented. A scheme of the system setup is reported in Fig. 5 in order to show how the different sensors and components of the system are connected to each other. Please note that the proposed approach can be generalized to other hardware as well (i.e., different BCI systems, mobile robots or robotic arms).

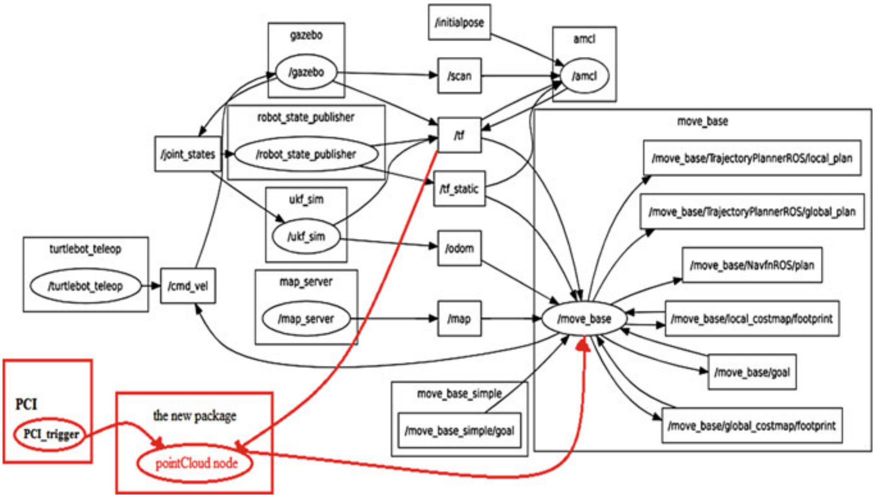


Fig. 3 Wheelchair package integrated with the new suggested solution in red colour

3.1 Smart Wheelchair

The mobile robot used for this study is based on the *Quickie Salsa* R^2, an electric powered wheelchair produced by Sunrise Medical company. Its compact size and its low seat to floor height (starting from 42 cm) gives it flexibility and grant it easy access under tables, allowing a good accessibility in an indoor scenario. The mechanical system is composed of two rear driving wheels and two forward caster wheels; these last are not actuated wheels, but they are able to rotate around a vertical axis. The wheelchair is equipped with an internal control module, the OMNI interface device, manufactured by PG Drivers Technology. This controller has the ability to receive input from different devices of SIDs (Standard Input Devices) and to convert them to specific output commands compatible with the R-net control system. In addition, an Arduino MEGA 2560 microcontroller, a Microstrain 3DM-GX3-25 inertial measurement unit, two Sicod F3-1200-824-BZ-K-CV-01 encoders, an Hokuyo URG-04LX laser scanner and a Webcam Logitech C270 complete the smart wheelchair equipment. The encoders, inertial measurement unit and the OMNI are connected to the microcontroller, while the microcontroller itself and the other sensors are connected via USB to a computer running ROS. Signals from the Sicod and Microstrain devices are converted by the Arduino and sent to the ROS localization module. The information provided by the Hokuyo lase scanner is used by the mapping module and by the path planning module for obstacle avoidance. Once a waypoint is chosen by the user, the path planning module creates the predefined path: this can be then modified by a trigger coming from BCI signal as described before.

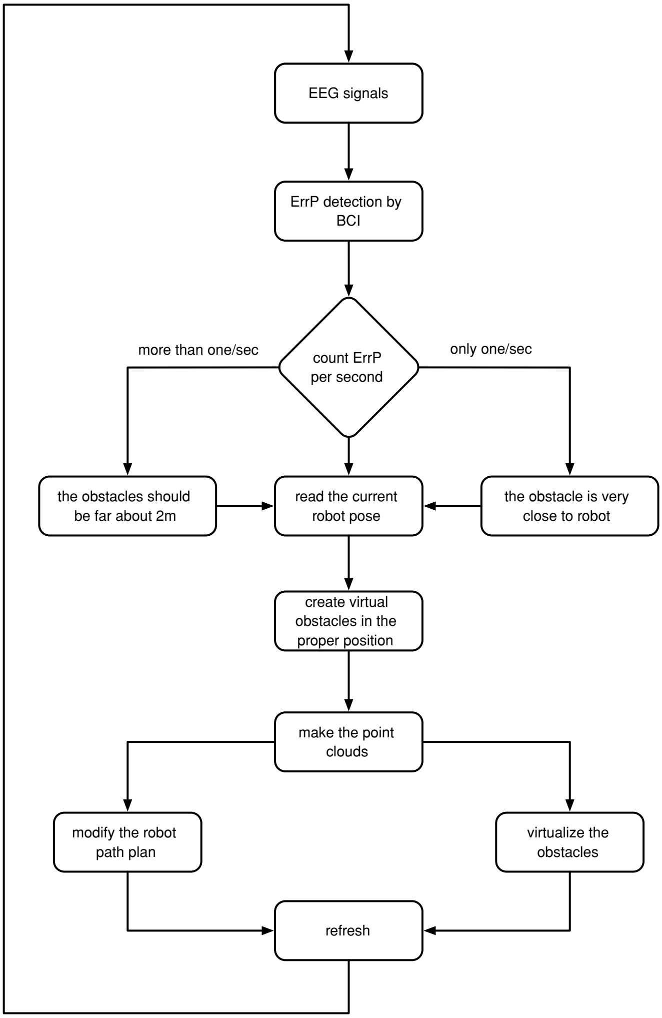


Fig. 4 The implemented algorithm flowchart. The creation of an obstacle on the virtual map is strictly connected with the generation of the ErrP signal recorded by the BCI

3.2 BCI

The EEG data used to classify the ErrP signal were acquired using a BCI system, constituted by a cap with 8 electrodes, and an amplifier, normally used due to the weakness of the brain signals. The adopted equipment is composed by:

- g.GAMMAcap, equipped with different kind of active/passive electrodes, specifically for EEG recordings. The disposition of the electrodes follows the International 10–20 System;

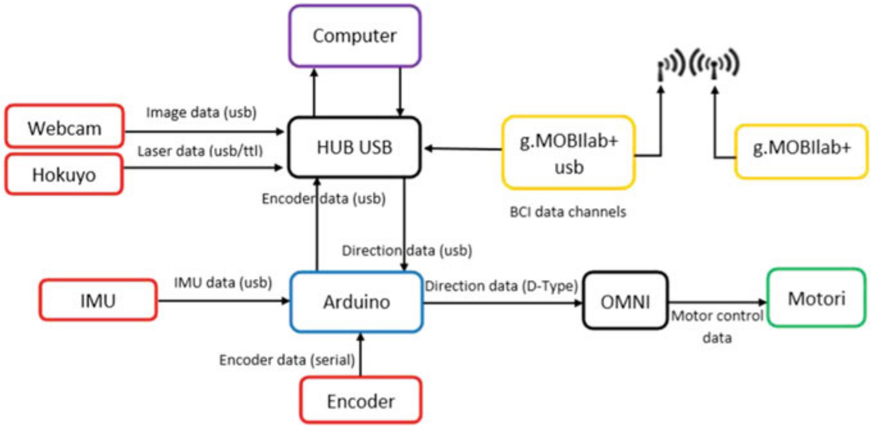
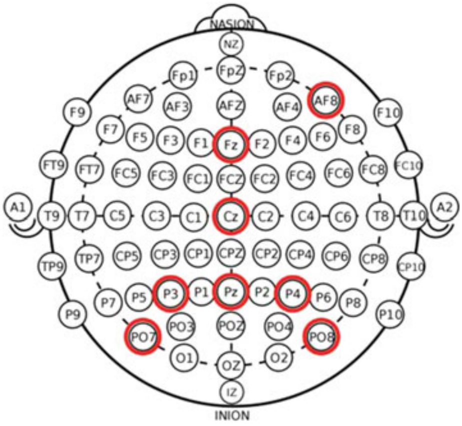


Fig. 5 In the scheme all the sensors and devices involved in the robot planning and in the EEG acquisition and analysis are reported

Fig. 6 The 8 selected electrodes are positioned as represented on the cup scheme circled with red colour



- g.MOBIlab + ADC, that collects data from a g.MOBIlab+ device, a tool for recording multimodal biosignal data on the laptop or PC, namely an amplifier which transmits the data wirelessly via Bluetooth 2.0;
- the software BCI2000.

The device supports 8 analog input channels digitalized at 16 bit resolution and sampled at a fixed 256 Hz sampling rate, which guarantees data quality and an high signal-to-noise ratio. The selected eight electrodes are AF8, Fz, Cz, P3, Pz, P4, PO7 and PO8 and they are positioned according to the representation in Fig. 6. The amplifier has a sensitivity of ±500 μV.

4 Preliminary Results

The system has been preliminary tested by simulating the smart wheelchair in the open-source 3D robotics simulator Gazebo, together with its sensor set, and using a real BCI for triggering the feedback signal from the user. We focus only on step (1) of the "EEG-based feedback" described in Sect. 2.2. As such, the trials were performed in two phases, namely the training of participants for the ErrP detection, and the test in a simulator environment, where the wheelchair moves and the user reacts to the appearance of a simulated obstacle.

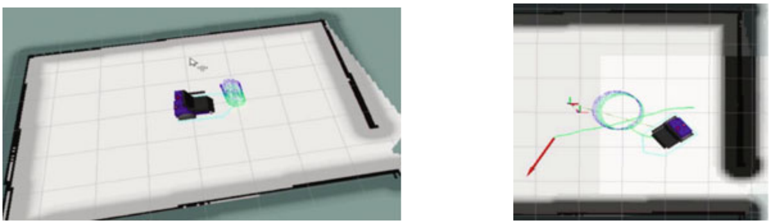
4.1 BCI Training

The experimental trial was composed by two different phases. The first related to the participants training for the ErrP detection, and the other related to the robot task simulation in a simulator environment. The defined protocol for the participant training consisted of a short video with a pointer that flowed horizontally on the screen, from the left to the right, whose goal was to reach the final destination, defined as a red X. After that, the recorded ErrP signals were classified in order to recognize the generated ErrP when the subject observed the obstacles appearance in the 3D simulated scenario, i.e. Gazebo, on the way of the smart wheelchair trajectory. The video also randomly showed pointers which did not arrive to the expected goal: this "error" evoked the ErrP, considering the wrong position interpretation with respect to the human intent. Three participants were enrolled and received the previous described training before the acquisition. The preliminary results in this training phase allowed to recognize the ErrP signals applying a logistic classifier [21] that distinguishes between target and non target stimuli. The average percentage of classification obtained was of 85% for not target stimuli and of 75% for the target ones.

4.2 Simulation Testing

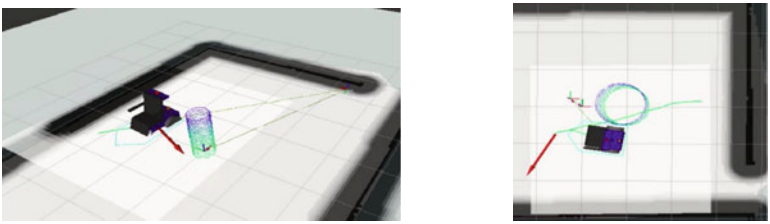
After the training, the subjects became "virtual users" of the smart wheelchair: equipped with the BCI system, they were positioned in front of a PC where a virtual wheelchair was moving in the simulated environment (Gazebo robot simulation). After choosing the end point and generating the predefined path, new obstacles were positioned on the screen. The recorded ErrP signals were classified in order to recognize the generated ErrP when the subjects observed the obstacle appearance.

At the moment, the ErrP signals, generated by each user, were recorded and recognized by the system and a message was written in a ROS node, interacting with the navigation system of the smart wheelchair in order to communicate the



3D representation of the environment in Gazebo when the obstacle is introduced.

2D representation of the local and global trajectories when the obstacle is introduced.



3D representation of the environment in Gazebo after the ErrP feedback.

2D representation of the local and global trajectories after the ErrP feedback.

Fig. 7 3D (left) and 2D (right) representation of the obstacle avoidance triggered by the ErrP signal registration

necessity of recalculating the path. During the ErrP acquisition phase, the velocity of the wheelchair has been decreased, and once a message was obtained, the wheelchair was stopped in order to have time to elaborate the new path planning (see Fig. 7).

5 Conclusion

The study investigates the use of ErrP signals in a closed-loop system, proposing a human-in-the-loop approach for path planning correction of assistive mobile robots. In particular, this study supports the possibility of a real-time feedback between the smart wheelchair and the BCI acquisition system, allowing the user to actively participate to the control of the planned trajectory, avoiding factors in the environment which may negatively affect user safety. This kind of interaction promotes the user intervention in robot collaborative task: the user must not only choose where to go or which object to take, but can also monitor if the task is correctly realized and provide a feedback accordingly. This approach could be a desirable solution for a user everyday's life, especially those users who have limited physical capabilities to control the wheelchair. The presence of the user in the closed-loop system promotes his/her involvement in the human-robot interaction allowing a direct participation and control on the task execution.

So far, only the BCI trigger has been developed and tested in a ROS simulated scenario, but all the architecture system has been developed with the creation of ROS node to interface the BCI system and the smartwheelchair as described in Sect. 2. Even if the results are at a preliminary stage, the system is able to recognize the ErrPs generated by the presence of obstacles on the path of the smartwheelchair and send a feedback to avoid the obstacle.

Future works include the definition of a policy to recalculate the path and avoids wheelchair stops once the trigger has been activated, and tests in an experimental environment. Moreover, it is necessary to involve more people in the study both for the classification of the ErrP signals and to improve the time necessary to recognize the object on the trajectory of the smart wheelchair. A fast communication of the feedback from the BCI system results to the smartwheelchair is one of the most important aspect for the feasibility and the usability of the proposed system.

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References

1. Salazar-Gomez AF, DelPreto J, Gil S, Guenther FH, Rus D (2017) Correcting robot mistakes in real time using EEG signals. In: 2017 IEEE international conference on robotics and automation (ICRA), pp 6570–6577
2. Iturrate I, Montesano L, Minguez J (2010) Single trial recognition of error-related potentials during observation of robot operation. In: Annual international conference of the IEEE engineering in medicine and biology 2010, pp 4181–4184
3. Iturrate I, Chavarriaga R, Montesano L, Minguez J, Millan JDR (2012) Latency correction of error potentials between different experiments reduces calibration time for single-trial classification. In: 2012 annual international conference of the IEEE engineering in medicine and biology society, pp 3288–3291
4. Zhang H, Chavarriaga R, Khaliliardali Z, Gheorghe L, Iturrate I, Millan JDR (2015) EEG-based decoding of error-related brain activity in a real-world driving task. J Neural Eng 12:1–10
5. Foresi G, Freddi A, Iarlori S, Monteriù A, Ortenzi D, Proietti Pagnotta D (2019) Human-robot cooperation via brain computer interface in assistive scenario. Lecture notes in electrical engineering, vol 540. Ambient Assisted Living, Italian Forum 2017, pp 115–131
6. Iturrate I, Antelis JM, Kubler A, Minguez J (2009) A noninvasive brain-actuated wheelchair based on a p300 neurophysiological protocol and automated navigation. IEEE Trans Robot 25:614–627
7. Behncke J, Schirrmeister RT, Burgard W, Ball T (2018) The signature of robot action success in EEG signals of a human observer: decoding and visualization using deep convolutional neural networks. In: 2018 6th international conference on brain-computer interface (BCI), pp 1–6
8. Mao X, Li M, Li W, Niu L, Xian B, Zeng M, Chen G (2017) Review article progress in EEG-based brain robot interaction systems. Comput Intell Neurosci 2017:1–25
9. Kim SK, Kirchner E, Stefes A, Kirchner F (2017) Intrinsic interactive reinforcement learning using error-related potentials for real world human-robot interaction. Sci Rep 7
10. Millan JDR (2005) You are wrong!—Automatic detection of interaction errors from brain waves, pp 1413–1418
11. Millan JDR (2008) Error-related EEG potentials generated during simulated brain computer interaction. IEEE Trans Bio-Med Eng 55:923–929

12. Artusi X, Niazi I, Lucas MF, Farina D (2012) Performance of a simulated adaptive BCI based on experimental classification of movement-related and error potentials. IEEE J Emerg Select Top Circuits Syst 1:480–488
13. Ferracuti F, Casadei V, Marcantoni I, Iarlori S, Burattini L, Monteri A, Porcaro C (2019) A functional source separation algorithm to enhance error-related potentials monitoring in noninvasive brain-computer interface. Comput Methods Programs Biomed 191:105419
14. Cavanini L, Cimini G, Ferracuti F, Freddi A, Ippoliti G, Monteri A, Verdini F (2017) A QR-code localization system for mobile robots: application to smart wheelchairs. In: 2017 European conference on mobile robots (ECMR), pp 1–6
15. Cavanini L, Benetazzo F, Freddi A, Longhi S, Monteriù A (2014) SLAM-based autonomous wheelchair navigation system for AAL scenarios. In: 2014 IEEE/ASME 10th international conference on mechatronic and embedded systems and applications (MESA), pp 1–5
16. Bonci A, Longhi S, Monteriù A, Vaccarini M (2005) Navigation system for a smart wheelchair. J Zhejiang Univ Sci A 6:110–117
17. Radmard S, Croft E (2011) Approximate recursive Bayesian filtering methods for robot visual search
18. Nordlund P, Gustafsson F (2001) Sequential monte Carlo filtering techniques applied to integrated navigation systems. In: Proceedings of the 2001 American control conference (Cat. No.01CH37148), vol 6, pp 4375–4380
19. Ogren P, Leonard NE (2005) A convergent dynamic window approach to obstacle avoidance. IEEE Trans Robot 21:188–195
20. Ciabattoni L, Ferracuti F, Freddi A, Longhi S, Monteriù A (2017) Personal monitoring and health data acquisition in smart homes. In: IET human monitoring, smart health and assisted living: techniques and technologies, pp 1–22
21. Peng CYJ, Lee KL, Ingersoll GM (2002) An introduction to logistic regression analysis and reporting. J Educ Res 96:3–14

Classification of Cardiac Tones of Mechanical and Native Mitral Valves

Giovanni Dimauro, Danilo Caivano, Marco Matteo Ciccone, Giovanni Dalena, and Francesco Girardi

Abstract Mechanical heart valve dysfunction can develop in as little as a few weeks, often causing a heart attack or serious complications. Investigating the altered acoustic characteristics of the cardiac tones in a mechanical valve may allow the early identification of valve malfunction. Nowadays, it is essential to equip a transplanted patient with innovative tools capable of monitoring his state of health at home and, in this case, the state of operation of the mechanical valves of his heart. This study is a step towards the early identification of valve malfunction. Here, basic acoustic features will be identified and tested, showing their effectiveness in discriminating the sound of a native mitral valve from a mechanical one. This study differs significantly from other studies since it is based on the new digital stethoscope eKuore-PRO®. The experimental results are interesting. The sensitivity is 100%, the accuracy is 95%, and the specificity is 93.3%, indicating that these features can discriminate the two types of valves effectively, and above all, that it is worth investigating whether they can timely and effectively predict mechanical valve malfunction.

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1 Introduction

To date, a perfect prosthetic heart valve has not been produced, and many serious problems, such as thrombosis, affect mechanical heart valves. State-of-the-art stethoscopes allow, through auscultation, the detection of tone variations when the valve defect is already in an advanced stage, that is, when the defect compromises the functionality of the valve and puts the patient's life in danger. An early diagnosis of thrombosis is expensive due to both the cost of diagnostic equipment and operators. Therefore, a growing interest aims to improve low-cost, noninvasive methods to evaluate the functionality of prosthetic heart valves.

This study is part of a project that aims to provide an electronic stethoscope with the ability to signal the onset of alterations of a mechanical prosthetic valve. This way, by using or self-using an affordable device, it allows the patient to frequently test the valve sound and be alerted early in case of dysfunction. The information obtained by such a device would allow one to anticipate and search for the causes that determine these alterations, allowing for the possibility to act through a pharmacological way and not an invasive one after the valve prosthesis gets damaged.

Research is currently directed to patients with aortic and mitral mechanical valves, as some studies [1] have shown that these types of valves present with evident changes in sound vibrations when they switch from being fully functional to when they begin to show the first signs of dysfunction. Briefly explained, the mechanical valve prostheses, under normal conditions, produce a clicking metallic sound, which is muffled in cases of anomalies. For this reason, we decided to analyze the audio digital signals derived from auscultations to identify these types of prosthetic malfunctions.

This paper focuses on the segmentation of the cardiac tones to find and analyze a group of S1 tones and extract the features capable of discriminating the sound of a mechanical mitral valve from the sound of a native one. Many studies evaluate native and prosthetic heart valves by analyzing heart sounds, and the suitability of the spectral analysis has already been tested and confirmed in many papers [2–6].

In [7] classification of the fundamental heart sounds using continuous wavelet transform (CWT) scalograms and convolutional neural networks (CNN) was investigated. Classification between the first and second heart sound of scalograms produced by the Morse analytic wavelet was compared for CNN, support vector machine (SVM), and k-nearest neighbors (kNN) classifiers. Classification of the CNN features outperformed local binary pattern features using both SVM and kNN classifiers. The results indicate that there is significant potential for the use of CWT and CNN in the analysis of heart sounds. In [8] normalised spectral amplitude of 5 s duration phonocardiogram segments was determined by fast Fourier transform and wavelet entropy by wavelet analysis. For each of these, a simple single feature threshold-based classifier was implemented and the frequency/scale and thresholds for optimum classification accuracy determined. Spectral amplitude and wavelet entropy features were then combined in a classification tree. The feasibility of accurate classification without segmentation of the characteristic heart sounds was demonstrated. Classification accuracy is comparable to other algorithms but achieved without the complexity of segmentation. Chen in [9] focuses on the heart sound recognition based only on acoustic characteristics with the objective to investigate whether reliable S1 and S2 recognition performance can still be attained under situations where the duration and interval information might not be accessible. A deep neural network (DNN) method is proposed and the K-means algorithm is applied to cluster the Mel-frequency cepstral coefficients derived from heart sound signals. The method achieved high precision, recall, and F-measure scores with more than 91% accuracy rate. In [10] it is shown that by combining Linear Predictive Coding coefficients with a classifier built upon combining Support Vector Machine and Modified Cuckoo Search algorithm, an improvement in the performance of the diagnostic system, in terms of accuracy, complexity, and range of distinguishable heart sounds, can be made. The developed system achieved accuracy above 93% for all considered cases including simultaneous identification of twelve different heart sound classes.

While other studies are based on various tools designed and built for their specific research, in this study, data were collected via the eKuore-PRO® device [11]. This device is an electronic CE-branded stethoscope. It acquires the heart sounds and returns them in digital format to a mobile device connected to its wireless network, thus allowing us to easily collect the dataset.

In the next sections, we will show some features and algorithms suitable for discriminating the sound of a native mitral valve from a mechanical one. Of course this is a preliminary step towards the aim of providing an electronic stethoscope with the ability to signal the onset of alterations of a prosthetic valve.

This paper is structured as follows: in section two, the features and the algorithms used here will be explained, while in the third section, we show the experimental phase and discuss the conclusion and future developments of this work.

2 Features and the Algorithms Used for Valve Classification

The segmentation of the heart digital sound is accomplished through the Ensemble Empirical Mode Decomposition (EEMD) that is based on the Empirical Mode Decomposition (EMD), a method of breaking down a signal without leaving the time domain. It can be compared to other analysis methods such as the Fourier transforms and wavelet decomposition. The result of the EMD is a set of functions called the Intrinsic Mode Functions (IMFs) that describe the signal [12, 13]. In EMD, the problem that a single IMF either is formed by signals of widely different scales or that a similar scale signal resides in different IMFs frequently occurs, thus losing significance to the IMF. To solve this problem, the EEMD method has been proposed. In this method, an ensemble mean is taken from the IMFs extracted from multiple applications of the EMD on the original data method, with the addition of different series of white noise. The added noise occupies the entire temporal space and the parts of the signals are automatically projected on appropriate scales of reference established by the white noise, thus eliminating the problem of the EMD mentioned above [14].

To find the temporal location of the cardiac tones, the kurtosis values have been used here. Kurtosis is a measure used in statistics and represents the characteristic of the shape of the distribution that measures the thickness of the tails of a distribution as described previously [15]. Kurtosis can be used in the processing of audio signals thanks to its ability to detect deviations from the Gaussian curve caused by changes in the waveform observed in the occurrence of the tones in a cardiac signal. The kurtosis coefficients are estimated along a time window. These coefficients show peaks at the beginning and at the end of the heart tones.

In this study, in order to get the sound features, it was necessary to obtain the Power Spectral Density (PSD), which describes how the power of the signal is distributed over the frequencies [16]. Additionally, we used the Welch method [17] because it reduces the variance and noise of data, ensuring more reliable results as the heart sound data usually have much noise [2]. The Welch method divides the original signal into windows of equal size arranged in such a way where a fraction of the signal overlaps the next and the previous one by a specified amount. Thus, every window is equal to the "upper half" of the previous window and the "lower half" of the next one, except for the first and the last windows. In this study, we used a window overlap of 50%. A window function [17] is then applied to these segments, and in this case, the Hamming function was chosen. In Fig. 1 we report an example of how data are influenced by this process. On each of the windows, the Fast Fourier Transform (FFT), which allows the transition from the time domain to the frequency domain, was subsequently calculated, obtaining the PSD of every window. Then, the average of all the PSD windows was calculated to obtain the final PSD as a result of the Welch method. As is shown later, the method presented here considers as relevant

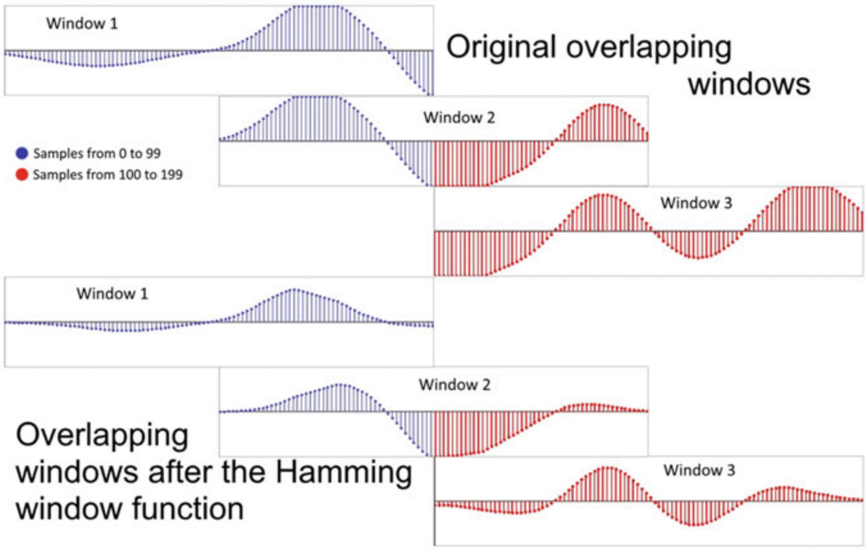

Fig. 1 Graphical representation of the Hamming windows

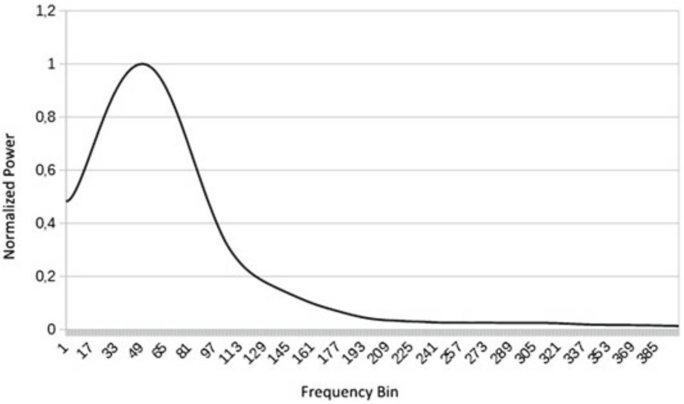

Fig. 2 A signal graph resulting from the Welch algorithm

the power distribution and not its absolute values, and the PSD power is normalized (see Fig. 2). This leads to the reduction of the influence on the signal strength due to factors that are external to the phenomenon and that must be analyzed (for example instrumentation, operator experience, etc.), rendering this information misleading. Based on the power spectral distribution of the signal, 5 features are extracted and are the frequency showing the highest power in the peak, the bandwidth of the peak, the distribution of the power along the entire PSD, the distribution of the power along the peak, and the distribution of the power along the tail.

The first feature is correlated with the sound height, i.e., the sound of a mechanical valve is more acute than that of a native valve, making the value of this feature higher in patients with a valve prosthesis. The second feature is related to the damping factor of the heart sound, which describes how the power decays in the peak, i.e., a higher value of the bandwidth means a slower decay. The last 3 features indicate how much the sound is noisy; in fact, mechanical valve sounds appear to be noisier, making the values of those features higher in the cardiac sounds of patients with a prosthetic valve implant.

To verify if the extracted features are actually able to discriminate the sound of a native valve from that of a mechanical valve, the K-means classification algorithm was used [18]. Our data will be classified into two clusters: native valve sounds and mechanical valve sounds, each according to its features.

The silhouette coefficient of the clusters was calculated to evaluate how well the data were classified. This is a measure of how similar an object is to its own cluster, known as cohesion, or how it compares to other clusters, known as separation. The silhouette value ranges from -1 to $+1$, where a high value indicates that the object is well matched to its own cluster and poorly matched to neighboring clusters. If most objects have a high value, then the clustering configuration is appropriate [19].

3 Experimental Phase Description and Results Discussion

The sounds of mechanical heart valves change depending upon the degree of opening and the type of material used, even if the mechanical heart valves possess the same structure. Therefore, to obtain more trustworthy and reliable results, studies must be conducted for each type of valve model, even for valves that are structurally identical [20]. In this study, heart sounds of patients who received mitral valve replacement operations with Open Pivot AP mechanical heart valves are investigated.

To perform the trial, the cardiac tones of 20 patients (14 men, 6 women) were recorded, 5 of whom with an implanted mechanical mitral valve prosthesis. The records were made at the department of cardiology of the University of Bari at the Policlinico of Bari and at the cardio-surgery department of the Mater Dei Hospital of Bari. The auscultations and the recordings were made by cardiologists or doctors, on the mitral site, and using the eKuore-PRO® device. Recordings were digitized using the specific application software (eKuore app) that allows the registration of the recordings on smartphones and automatically shares them to a Personal Health E-Record (PHER) [21, 22]. PHER is a new type of Patient Health Record specifically designed to improve communication between patients and their care providers, increases the availability of personal medical information and boosts new technologies, such as the Internet of Medical Things [23–29], similar to the one presented in this paper. Some information on patients whose records were used is shown in Table 1.

To get the features from the audio files, we first isolated the S1 tones by means of the EEMD method to breakdown the signal in a set on IMFs, where the components of the cardiac tones are distributed on the various IMFs. The first IMF contains the highest frequencies among the IMFs, and subsequent IMFs contain lower frequencies, and the last IMF contains the lowest frequencies of all IMFs. Only the IMFs containing sufficient concentration of energy inherent in S1 to make them significant were taken into consideration and, this selection was done based on an energy-dependent criterion test. The test works in the following way: the energy of the first IMF is calculated and is divided by the energy of the original signal, and if the number obtained is less than the threshold, in this case, 0.99, the energy of the second IMF is added to the first one and the calculation is repeated (see Fig. 3). This process iterates until the ratio between the energy of the IMFs and the energy of the original signal gets above the threshold. The IMFs whose energy has not been added are discarded.

To identify the beginning and end of each heart tone, the kurtosis estimators were considered in order to detect changes on a signal and were calculated on the selected IMFs (see Fig. 4). The variations on this signal correspond to the beginning or end of a heart sound, and the kurtosis in correspondence to these variations presents a sudden change in the values and this reveals the temporal location of the heart tones on the signal.

The extraction of the S1 tones from the original signal was accomplished using the temporal location of the tones, and an audio file containing all the S1 sections of each patient's heart sounds was created.

Table 1 Patients' data

ID	Age	Valvular pathologies	Mitral valve	Aortic valve
1	36	Minor mitral distress	Native	Native
2	30	Minor mitral distress, minor pulmonary distress	Native	Native
3	37		Native	Native
4	34		Native	Native
5	36		Native	Native
6	33		Native	Native
7	28	Minor mitral distress	Native	Native
8	71		Native	Native
9	44		Native	Native
10	17		Native	Native
11	21		Native	Native
12	23		Native	Native
13	54		Native	Native
14	82	Severe aortic stenosis, atrial fibrillation	Native	Native
15	67	Hypertensive, hyperlipidemic	Native	Native
16	69		Mechanical	Native
17	66		Mechanical	Native
18	44		Mechanical	Native
19	72		Mechanical	Native
20	58		Mechanical	Native

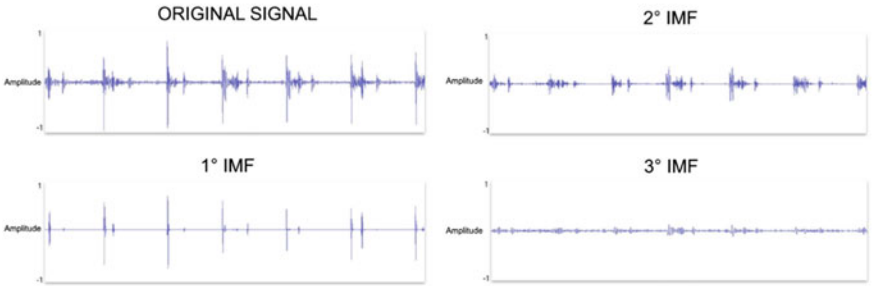

Fig. 3 Graphical representation of the first 3 IMFs calculated using the EEMD on a signal of a patient with a mitral prosthesis. Time is on the x-axis

The algorithm described was able to extract correctly, on average, 84.6% of the S1 contained in the audio files. The fact that not all S1 tones were extracted is not a hindrance, as a small group of S1 tones from each patient is sufficient to obtain the sound characteristics. Particular care was given to avoid the incorrect inclusion of S2 tones and other noise in the S1 tones audio files.

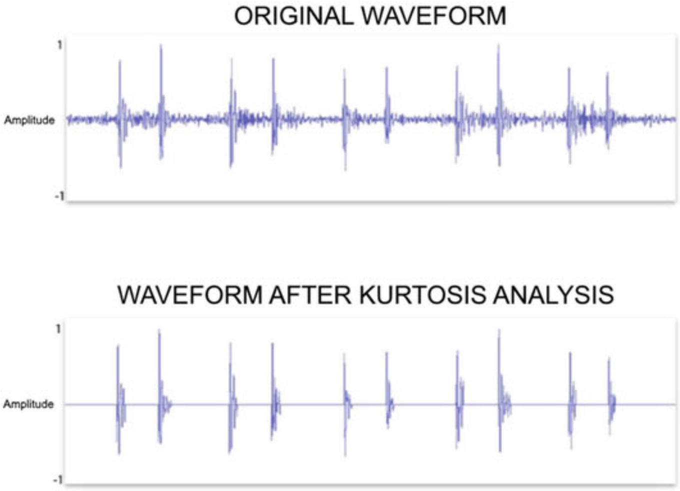

Fig. 4 Graphical representation of the signal before and after the isolation of the cardiac tones using the kurtosis analysis. Time is on the x-axis

The audio files containing S1 tones were elaborated using the Welch method explained earlier. We first obtained the PSD of the signal, and subsequently, the following 5 features were extracted:

- HF—The frequency with the highest power in the peak (Hz)
- BW—The bandwidth at 0.75 of the peak (Hz)
- TA—The total area of the spectrum
- AB1—The area in the 10–149 Hz band
- AB2—The area in the 150–400 Hz band.

The threshold values for features AB1 and AB2 were empirically determined as the best representatives of the area of the peak and the area of the tail of the PSD, respectively (see Fig. 5). Similar values have been previously observed [30].

Once the characteristics searched for were extracted, as described above, a k-Means algorithm ($k = 2$) was used to classify the mechanical and native mitral valves based on the normalized features of their sounds.

The cardiac tones used in this study are collected from 20 patients listed in Table 1. Table 2 shows the mean and standard deviation of the features used. The heart sounds of 20 patients were then classified with an accuracy of 95% and a silhouette value of 0.525. In detail, true positives are valves correctly classified as mechanical, whereas true negatives are valves correctly classified as native. False positives are native valves identified as mechanical, and false negatives are mechanical valves incorrectly classified as native (Table 3). The most interesting performance in this first study was to obtain all mechanical valves correctly identified; accuracy = (TP + TN)/(TP + TN + FP + FN) was 95% and specificity = TN/(FP + TN) was 93.3%, while the sensitivity = TP/(TP + FN) was 100%.

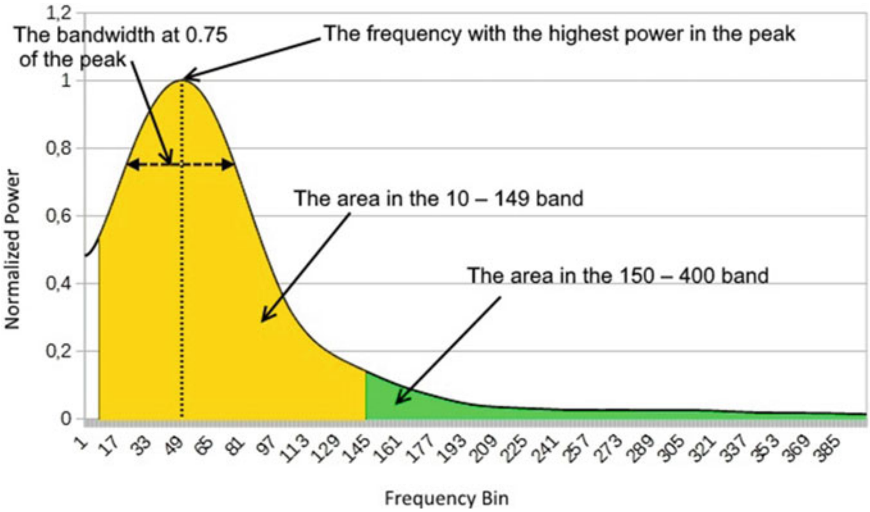

Fig. 5 Graphical representation of the feature extraction

Table 2 Mean and standard deviation of the features

Mean ± s.d.	HF	BW	TA	AB1	AB2
Native value	52.9 ± 8.7	61 ± 6.6	106.8 ± 8.4	86.8 ± 6.1	6.8 ± 2.1
Mechanical value	69.6 ± 6.9	75.6 ± 4.7	135.7 ± 7.5	104.8 ± 3.2	16.7 ± 3.6

Table 3 Confusion matrix of heart tones

Real/predicted	Mechanical	Native
Mechanical	5	0
Native	1	14

Overall, this is a satisfactory result. Although our study suffered from having a limited dataset, more important at this stage are the results graphically shown in Fig. 6. The chart in Fig. 6 was obtained through the Principal Component Analysis which allows the projection of an n-dimensional plane in an m-dimensional one, where m is less than n, and while maintaining the highest possible variance in the data. In our study n was 5 and m was 2 [31]. The results obtained confirm the validity of the features extracted. In fact, despite one instance being erroneously classified, the two clusters are well separated.

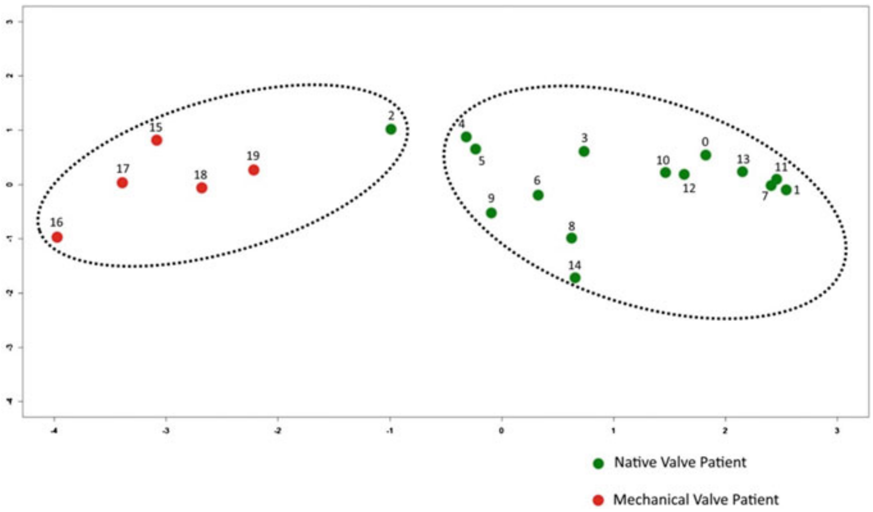

Fig. 6 Classification of patients' valves; this graph was obtained using the principal component analysis (PCA)

4 Conclusions

This study is part of a project that aims to provide an electronic stethoscope with the ability to signal the onset of alterations of a mechanical prosthetic valve. This way, by using or self-using an affordable device, it allows the patient, and not a specialist to frequently test the valve sound and be alerted early in case of dysfunction.

Given the results achieved, it can be stated that the digital signal segmentation based on the ensemble empirical mode decomposition (EEMD) and the kurtosis value, the extraction of the power spectral density (PSD), the Welch method, and the K-Means classification algorithm show very good performance in the discrimination of the cardiac tones acquired with eKuore-PRO.

The evolution of this study will be the extension of the analysis to the aortic mechanical valves in vivo and then to the analysis of different levels of malfunction in mechanical valves. The collection of valve sounds whose operation is compromised in vivo is extremely difficult: we are planning to acquire the cardiac sounds directly on the patients who have undergone the replacement of a native valve with a mechanical prosthesis, and which show malfunctions at different stages of gravity, basing on eKuorePRO. This approach could allow an early diagnosis of cases of valve malfunction, mainly related to the presence of thrombotic formations, supporting the doctor to intervene effectively with targeted drug therapy, before the appearance of severe symptoms of prosthetic malfunction. Further studies will focus on heart murmurs since they are a further sign that characterizes the malfunctioning of mechanical valves.

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References

1. Fritzsche D, Eitz T, Grimmig O, Brensing A, Minami K, Körfer R (2004) Home monitoring of patients after prosthetic valve surgery: experimental background and first clinical attempts. Thorac Cardiovasc Surg 52(4):211–217
2. Altunkaya S, Kara S, Görmüş N, Herdem S (2013) Comparison of first and second heart sounds after mechanical heart valve replacement. Comput Methods Biomech Biomed Eng 16(4):368–380. https://doi.org/10.1080/10255842.2011.623672
3. Foale RA, Joo TH, McClellan JH, Metzinger RW, Grant GL, Myers GS, Lees RS (1983) Detection of aortic porcine valve dysfunction by maximum entropy spectral analysis. Circulation 68:42–49
4. Durand LG, Guise JD, Cloutier G, Guardo R, Braism M (1986) Evaluation of FFT based and modern parametric methods for the spectral analysis of bioprosthetic valve sounds. Trans Biomed Eng 33(6):572–578
5. Sava HP, McDonnell JTE (1996) Spectral composition of heart sounds before and after mechanical heart valve implantation using a modified forward-backward prony's method. IEEE Trans Biomed Eng 43(7):734–742
6. Baykal A, Ider YZ, Köymen H (1995) Distribution of aortic mechanical prosthetic valve closure sound model parameters on the surface of the chest. IEEE Trans Biomed Eng 42(4):358–370
7. Meintjes A, Lowe A, Legget M (2018) Fundamental heart sound classification using the continuous wavelet transform and convolutional neural networks. Conf Proc IEEE Eng Med Biol Soc 2018:409–412. https://doi.org/10.1109/EMBC.2018.8512284
8. Langley P, Murray A (2017) Heart sound classification from unsegmented phonocardiograms. Physiol Meas 38(8):1658–1670. https://doi.org/10.1088/1361-6579/aa724c
9. Chen T et al (2017) S1 and S2 heart sound recognition using deep neural networks. IEEE Trans Biomed Eng 64(2):372–380. https://doi.org/10.1109/TBME.2016.2559800
10. Redlarski G, Gradolewski D, Palkowski A (2014) A system for heart sounds classification. PLoS ONE 9(11):e112673. https://doi.org/10.1371/journal.pone.0112673
11. https://www.ekuore.com/en/wireless-stethoscope/, last view on 20/04/20
12. Huang N, Shen Z, Long S, Wu M, Shih H, Zheng Q, Yen N, Tung C, Liu H (1971) The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis. Proc Roy Soc Lond A Math Phys Eng Sci 454:1998
13. Papadaniil CD, Hadjileontiadis LJ (2014) Efficient heart sound segmentation and extraction using ensemble empirical mode decomposition and kurtosis features. IEEE J Biomed Health Inform 18(4):1138–1152
14. Wu Z, Huang N (2009) Ensemble empirical mode decomposition: a noise assisted data analysis method. Adv Adapt Data Anal 1(1)
15. Kallner A (2018) Laboratory statistics. Elsevier. ISBN: 978-0-12-814348-3
16. Paschotta R (2008) Power spectral density. In: Encyclopaedia of laser physics and technology, 1st edn.
17. Smith JO (2011) Spectral audio signal processing. W3K Publishing. ISBN: 978-0-9745607-3-1
18. Hamerly G, Elkan C (2004) Learning the k in k-means. Adv Neural Inf Process Syst 16:281
19. Weise T, Wang X, Qi Q, Li B, Tang K (2018) Automatically discovering clusters of algorithm and problem instance behaviours as well as their causes from experimental data, algorithm setups, and instance features. Appl Soft Comput 73

20. Bagno A et al (2008) In vitro characterization of bileaflet mechanical heart valves closing sound. In: 2008 computers in cardiology, Bologna, 2008, pp 945–947. https://doi.org/10.1109/CIC.2008.4749199
21. Dimauro G, Caivano D, Girardi F, Ciccone MM (2014) The patient centered electronic multimedia health fascicle—EMHF. In: 2014 IEEE workshop on biometric measurements and systems for security and medical applications (BIOMS) proceedings, Rome, 2014, pp 61–66. https://doi.org/10.1109/BIOMS.2014.6951537
22. Caivano D, Colizzi L, Dimauro G, Girardi F, Personal health e-record: toward an enabling ambient assisted living technology for communication and information sharing between patients and care providers. Lecture notes in electrical engineering, vol 544. ISSN: 1876-1100. https://doi.org/10.1007/978-3-030-05921-7
23. Dimauro G, Baldari L, Caivano D, Colucci G, Girardi F (2018) Automatic segmentation of relevant sections of the conjunctiva for non-invasive anemia detection. In: In Proceedings of the 2018 3rd International Conference on Smart and Sustainable Technologies (SpliTech), Split, Croatia, 26–29 June 2018; pp. 1–5.
24. Dimauro G, Caivano D, Girardi F (2018) A new method and a non-invasive device to estimate anemia based on digital images of the conjunctiva. IEEE Access 6:46968–46975. https://doi.org/10.1109/ACCESS.2018.2867110
25. Bevilacqua V et al (2017) A novel approach for hepatocellular carcinoma detection and classification based on triphasic CT protocol. In: 2017 IEEE congress on evolutionary computation (CEC), pp 1856–1863. https://doi.org/10.1109/CEC.2017.7969527
26. Dimauro G, Ciprandi G, Deperte F, Girardi F, Ladisa E, Latrofa S, Gelardi M (2019) Nasal cytology with deep learning techniques. Int J Med Inform 122:13–19. ISSN: 1386-5056. https://doi.org/10.1016/j.ijmedinf.2018.11.010
27. Dimauro G, Di Nicola V, Bevilacqua V, Caivano D, Girardi F (2017) Assessment of speech intelligibility in Parkinson's disease using a speech-to-text system. IEEE Access 5:22199–22208. https://doi.org/10.1109/ACCESS.2017.2762475
28. Dimauro G, Caivano D, Bevilacqua V, Girardi F, Napoletano V (2016) VoxTester, software for digital evaluation of speech changes in Parkinson disease. In: 2016 IEEE international symposium on medical measurements and applications (MeMeA), Benevento, pp 1–6. https://doi.org/10.1109/MeMeA.2016.7533761
29. Dimauro G, Girardi F, Gelardi M, Bevilacqua V, Caivano D (2018) Rhino-Cyt: a system for supporting the rhinologist in the analysis of nasal cytology. In: Intelligent computing theories and application, pp 619–630. https://doi.org/10.1007/978-3-319-95933-7_71
30. Stein PD, Sabbah HN, Lakier JB, Magilligan DJ, Goldstein S (1981) Frequency of the first heart sound in the assessment of stiffening of mitral bioprosthetic valves. Aha J
31. Jolliffe IT (2002) Principal component analysis. Springer-Verlag, New York

TestGraphia, Document Analysis-Based Diagnosis of Dysgraphia

Giovanni Dimauro, Davide Di Pierro, and Lucio Colizzi

Abstract Dysgraphia is a disease related to handwriting and affects the size and distance of the characters and orthography. Patients with dysgraphia may have difficulties in motor skills and can hardly write down what they think. Dysgraphia symptoms are not rare but often are temporary. There are no specific causes known that can lead to dysgraphia, and then it is impossible to prevent it. For these reasons, it is crucial to find out dysgraphia; traditional methods are based on specific paper forms and rules to diagnose a suspect of dysgraphia. In this paper, we present a document analysis-based diagnosis process to support doctors to formulate a diagnosis. The medical examination can be completed in a short time. This system allows also large screening activities reducing any effort and permits a remote doctor-patient relationship: while it is being developed as a web-application, and due to its ease of use, it could be used at home, eventually revealing early symptoms.

1 Introduction

Handwriting is an important way to communicate, which enables the expression, recording, and transmission of ideas of students throughout their educational careers. Primary school children typically spend up to 50% of the school day engaged in writing tasks, some of which are performed under time constraints. A child's ability to write legibly, as well as quickly and efficiently, enables him to achieve both functional written communication and academic advancement.

Handwriting difficulty or dysgraphia was defined by Hamstra-Bletz and Blote as a disturbance or difficulty in the production of written language that is related to the

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mechanics of writing. It has also been referred to as a specific learning disability. The problem is manifested in the inadequate performance of handwriting among children who are of at least average intelligence and who have not been identified as affected by any obvious neurological problems. Moreover, if handwriting is very slow, children may forget the ideas and plans held in memory before they succeed in transferring them to paper [1, 2]. The term dysgraphia has customarily been used to specify a disorder of written expression of language in childhood, as opposed to a disorder of written language acquired in adulthood that is often called agraphia. Strictly speaking, dysgraphia means incorrect writing, whereas agraphia means lack of writing [3]. This disease can also cause other learning problems such as dyslexia, attention deficit, and dyspraxia. Developmental dysphasia, dyslexia, and dysgraphia are more commonly associated in affected children than not. Different members of the same family may show rather different manifestations of these disorders: for example, a dysphasic child may have a family history of specific developmental dyslexia, and dysgraphia, but no dysphasia [4, 5]. Children with dysgraphia often have also social problems since they feel less capable than the others [6].

The treatment can vary and includes motor exercises in order to coordinate the hand with the eye. The use of computers to facilitate intensive repetitive practice proved to be successful, both in terms of improvements on assessments and with evidence of functional benefits. The use of both a dictionary to support the strategy and an adaptive word processor to promote functional carryover is described. The role of the computer is discussed as a tool to facilitate the repetitive practice of therapy and encourage the independent use of the strategy embodied in therapy [7]. Sounds can be used to inform about the correctness of an ongoing movement, without directly interfering with the visual and proprioceptive feedback [8]. Evidence from recent studies suggests that writing and speaking may be an aspect of cognition capable of identifying impairments specific to patients with Parkinson and Alzheimer's disease [9, 10], or spatial dysgraphia in patients with a right hemisphere lesion [11].

In this paper, we present TestGraphia, a software system that aims to support doctors to formulate a diagnosis. The medical examination can be completed in a short time.

2 Evaluation Method

The Beknopte Beoordelingsmethode voor Kinderhandschriften (BHK), was first presented in the Netherlands in 1987, at the Department of Developmental Psychology of the University of Leiden [12]. It is currently the most widely used writing quality assessment tool in research and clinical practice. It is a scale composed of thirteen parameters to identify the characteristics of the graphic act, which allows the identification of "dysgraphia". The evaluation methodology that allows the identification and quantification of the salient characteristics of bad writing is based on a standard text to be copied, in order to ease the task of decoding the handwriting. To carry out the test are necessary: standard text to be copied, white paper without lines, A4 format, writing support, dark -colored pen, and a chronometer. The child's position must be correct in relation to the writing surface.

The Italian standard text is a readjustment of the Dutch text; the first five lines are: "leo e lo zio", "sono al porto", "mangiano un gelato", "con loro ci sono", mia e rina". The child will have to write this text in italics on the line blank sheet for five minutes and at least the first five lines: if he cannot finish the first five lines in five minutes, he will be given extra time.

The score that sets the subject to one Standard Deviation (SD) and a half below the average (−1.5 SD) indicates handwriting that is difficult to read and therefore "dysgraphic". In the presence of performances slightly inferior to these scores we are faced with bad quality of writing even if not properly "dysgraphic" [12]. Image recognition algorithms found successful usage in several diagnostic practices, mostly in diagnostic imaging [13–15] and they are particularly useful in the development of the algorithms used here.

3 Writing Parameters

The most important task is to calculate the value of the following thirteen writing parameters that allow diagnosis: writing size, non-aligned left margin, skewed writing, insufficient space between words, sharp angles, broken links between letters, a collision between letters, irregular size of letters, inconsistent height between letters with and without extension, atypical letters, ambiguous letters, traced letters, unstable track. Each parameter has a range value between 0 and 5, differently from parameter 9, which can be up to 4. It should be noted that some of these parameters are strictly geometrical while others require doctor interpretation and therefore not all parameters, at this stage, can benefit of fully automated analysis.

3.1 Writing Size

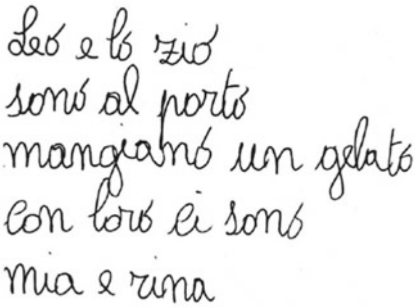
The writing size is determined by the height of the body of the letters. We can distinguish different categories depending on the average height and the value of this parameter will also depend on the class of the child; we use Table 1 as in [12]. In Fig. 1 it is shown an example of writing where the size of the characters is above the norm.

3.2 Non-Aligned Left Margin

The left margin may not be vertically aligned, it may be inclined to the right. The evaluation depends on all the copied text. In cases where the margin is irregular

Table 1 Writing size reference

Primary school class	≤ 3 mm	4 mm	5 mm	6 mm	7 mm	8 mm	9 mm
First (5–6 years old)	0	0	1	2	3	4	5
Second	0	1	2	3	4	5	5
Third	0	1	2	3	4	5	5
Fourth	0	1	2	3	4	5	5
Fifth	0	1	2	3	4	5	5



Leo e lo zio
sono al porto
mangiano un gelato
con loro ci sono
mia e rina

Fig. 1 The size of the characters is above the norm

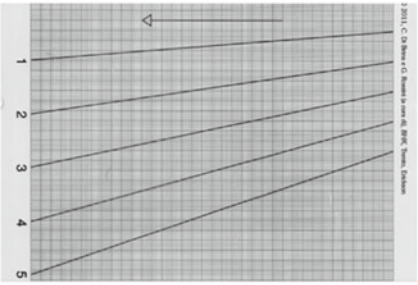


Fig. 2 Transparent matrix to detect non-aligned margin

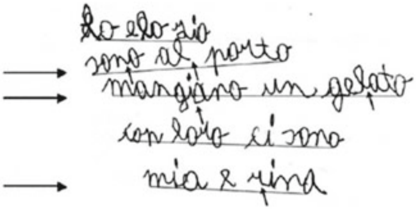
the value of the parameter will always be 0, in case it is inclined to the right the standard assessment protocol is based on the following transparent matrix (Fig. 2) to determine the correct value, as in [12]. Non-aligned writing is shown in Fig. 3.

3.3 *Skewed Writing*

The writing line may not be straight but wavy, as in Fig. 4. As a special case, a word going up or down should also be noted. The value is calculated by examining, for each line, whether there are letters too much below or above the baseline. The baseline is virtually drawn by joining the lowest points of the first and last letter of

Fig. 3 This is an example of non-aligned writing

Fig. 4 An example of skewed writing

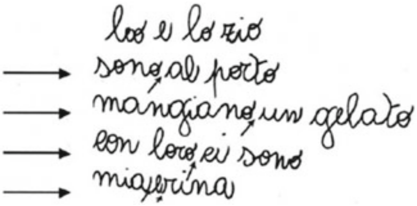


the line. If an anomaly is found within a line, the value 1 will be assigned, otherwise 0. The value of the parameter will be given by the sum of the values of the lines.

3.4 Insufficient Space Between Words

The space between two words is considered insufficient (Fig. 5) if it is less than the width of a referring letter, usually the "o". For each line, the value 1 is given if there is not enough space between at least two words, otherwise 0. The value of the parameter will be given by the sum of the values of the lines.

Fig. 5 This is an example of text with insufficient spaces between words



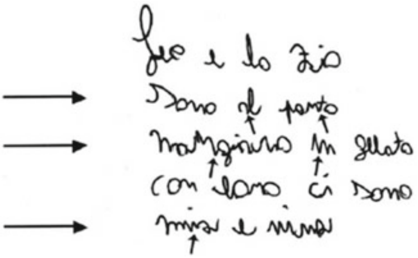


Fig. 6 An example of text with sharp angles

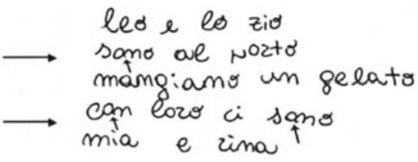


Fig. 7 Text with broken links between words

3.5 Sharp Angles

Sharp angles are elongated horizontal links or acute angles which are present instead of curved ones (Fig. 6). For each line, we determine whether there are acute angles and we assign 1 if there are ones, 0 otherwise. The value of the parameter will be the sum of the values of the lines.

3.6 Broken Links Between Letters

Broken links are created when the pen movement is interrupted or the pen is moved off the paper. This can be indicated by sudden changes in the direction of writing or by a lack of connection between letters of the same word. For each line, it will be assigned a value of 1 if there are broken links, otherwise 0. The value of the parameter will be the sum of the values of the lines (Fig. 7).

3.7 Collisions Between Letters

Two letters collide if they are too close together so that an overlapping area is created (Fig. 8). For each line, it will be assigned the value 1 if there are collisions between at least two letters, otherwise 0. The value of the parameter will be given by the sum of the values of the lines.

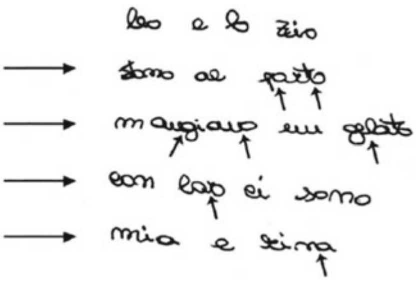


Fig. 8 This is an example of text with collisions between letters

Table 2 Letters' size reference. Depending on the lowest letter's height, the highest one cannot exceed the value on the right column

Body height of the smallest letter (mm)	Body height of the highest letter (mm)
6	8
6.5	8.5
7	9.5
7.5	10
8	11
9	12

3.8 Irregular Size of Letters

It happens when the body of the letters does not have a regular height. It can occur either within two letters of the same word or within the same line. For each line, we consider the height of the highest letter and the height of the lowest one, without elongations. Depending on the size of the lowest letter, the highest letter has a maximum value to respect. For each line, if the height of the highest letter exceeds its maximum value, the value 1 is assigned, otherwise 0. The value of the parameter will be given by the sum of the values of the lines. In Table 2 is reported the correct letters' size reference (Fig. 9).

3.9 Inconsistent Height Between Letters with and Without Extension

This condition occurs when there is a little difference in height between letters with and without extension. For each line, it will be assigned the value 1 if the difference is not very significant, otherwise 0. The value of the parameter will be given by the sum of the values of the lines (Figs. 10 and 11).

Fig. 9 This is an example with text with irregular size of letters

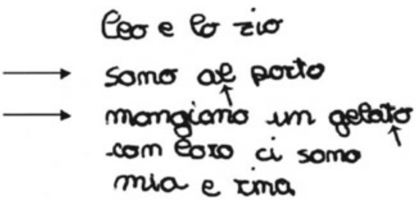


Fig. 10 Inconsistent height between letters with and without extension

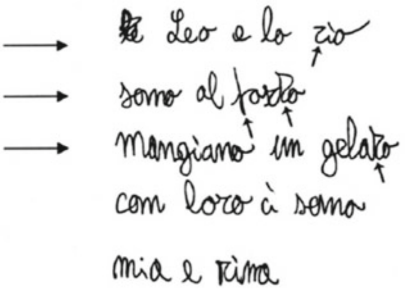


Fig. 11 Text containing atypical letters

3.10 Atypical Letters

A letter is considered “atypical” if it presents diversities that make it different from the standardized form. For each line, the value 1 will be assigned if there are atypical letters, otherwise 0. The value of the parameter will be given by the sum of the values of the lines.

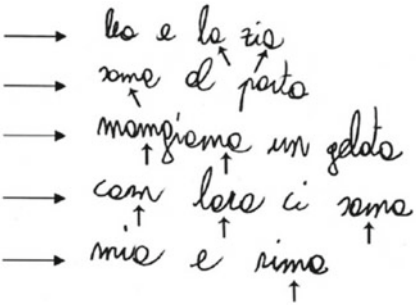


Fig. 12 Some ambiguous letters are indicated

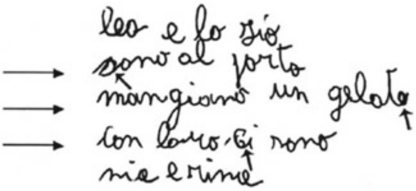


Fig. 13 Text with traced letters

3.11 *Ambiguous Letters*

"Ambiguous letters" are those which are part of the referring alphabet but can cause difficulties in interpreting the letter. For each line, the value 1 will be assigned if there are ambiguous letters, otherwise 0. The value of the parameter will be given by the sum of the values of the lines (Fig. 12).

3.12 *Traced Letters*

A letter is called "traced" if it has been rewritten, in its entirety or in part, to adjust its shape. For each line, the value 1 will be assigned if there are traced letters, otherwise 0. The value of the parameter will be given by the sum of the values of the lines (Figs. 13 and 14).

3.13 *Unstable Track*

An unstable track is defined when the writing is uncertain, hesitant, or shaky. For each line, the value 1 is assigned if an unstable track along the line is detected, otherwise 0. The value of the parameter will be given by the sum of the values of the lines.

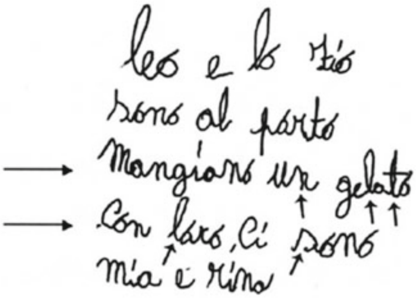


Fig. 14 This is a text with some unstable tracks

4 System Description

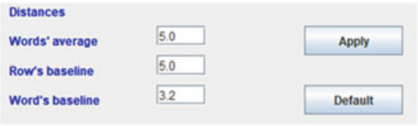
The aim of TestGraphia is to automatically estimate some parameters and to support the easy setting of the remaining ones, in order to facilitate the diagnosis; the doctor will set only parameters that require interpretation. At the end of the evaluation process, a report is generated, describing what the system has detected such as anomalies, the values of the parameters, the final score, and some space for annotations.

A one-line header has been added to the standard text with the following text: "a a o o o m m". The aim of this choice is twofold: to calculate the first parameter it is necessary to perform an average of the height of the letters without elongations and this header is made ad-hoc for this purpose; the second reason is that for parameter 4 it is necessary to know the average width of the letter "o" of the child and this is possible by mediating the widths of the two "o" present in the header. Furthermore, the header allows the child a minimum of warm-up for the writing of the actual text.

TestGraphia shows a very simple home panel, as you can see in Fig. 15, where you can enter the child's data and choose the image file to import (standard png or jpeg format) and the final report name.

Clicking on 'Index' the default parameters settings will be shown and edited if allowed. Not all parameters relevant for diagnosis can be modified. Parameter 3, as reported in Fig. 16, is based on three values that can be modified.

Parameter 8 is the only one that is calculated semi-automatically: it is necessary to indicate, for each line, the extremes of the highest and lowest letter. So, having to draw two points per letter and two letters per line, we ask the doctor just to draw twenty points on the screen to proceed with the analysis execution (Fig. 17). The points drawn are highlighted while the number of missing points is reported.

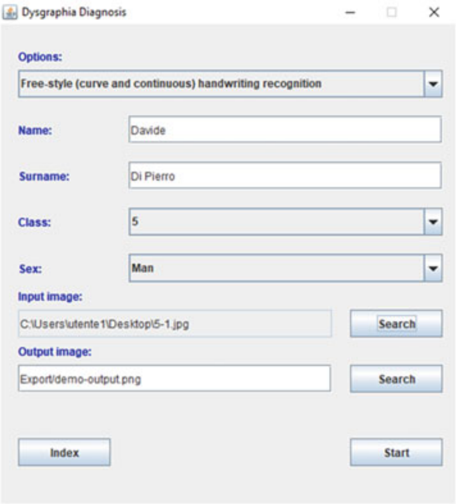

Distances

Words' average 5.0

Row's baseline 5.0

Word's baseline 3.2

Fig. 15 Some settings for parameters, as distance: words average, rows baseline, and word baseline



Options: Free-style (curve and continuous) handwriting recognition

Name: Davide

Surname: Di Pierro

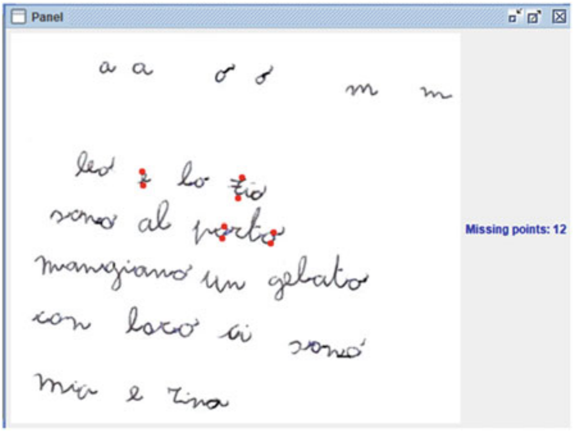
Class: 5

Sex: Man

Input image: C:\Users\utente1\Desktop\5-1.jpg

Output image: Export/demo-output.png

Fig. 16 Main panel, where to input main data



Missing points: 12

Fig. 17 ImagePanel in which twenty points must be set. In the example, eight of them are already defined and twelve are missing

At the end of this interaction, parameters 1, 2, 3, 4, 8, and 9 will be calculated directly by the system using the following algorithms and the other must be set using the panel shown in Fig. 19. TestGraphia has been implemented in Java.

Well known document analysis algorithm has been used (i.e. to segments lines and words) but some of them were modified and adapted to this specific goal, such as the skewed writing algorithm and the non-aligned left margin algorithm. The algorithms used have been summarized in Appendix I.

5 Results

During image processing a window as that reported in Fig. 18 is shown, in order to check the correct text segmentation. When the process is concluded, red entries (Fig. 19) requires a supervised check, then the final report can be generated.

The final report in Fig. 20, has been designed and organized to contain all the information that the doctor needs. Reports can be automatically transferred to the patient's personal health record and stored to assess the progression of the disease over time as well as in many diagnostic applications [16–17]. A first section keeps track of settings and anomalies found for each parameter; the second section show the parameter values and the final score compared to the standard thresholds (higher, lower or normal).

Thanks to some examples of children who suffer from this disturb, it was possible to experience the effectiveness of the system. The results obtained are interesting. The system here presented is reliable in cases of clearly separated writing (that is mandatory during writing) while presents minor problems in the separation of words

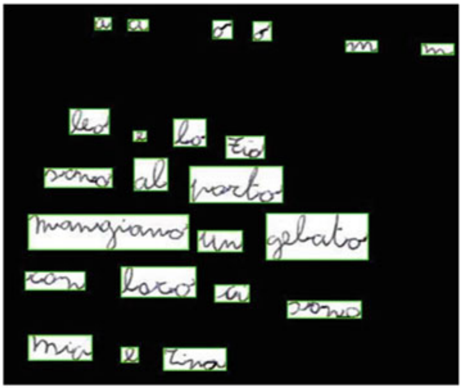
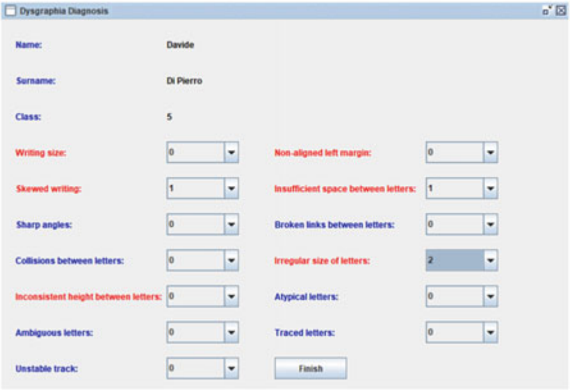


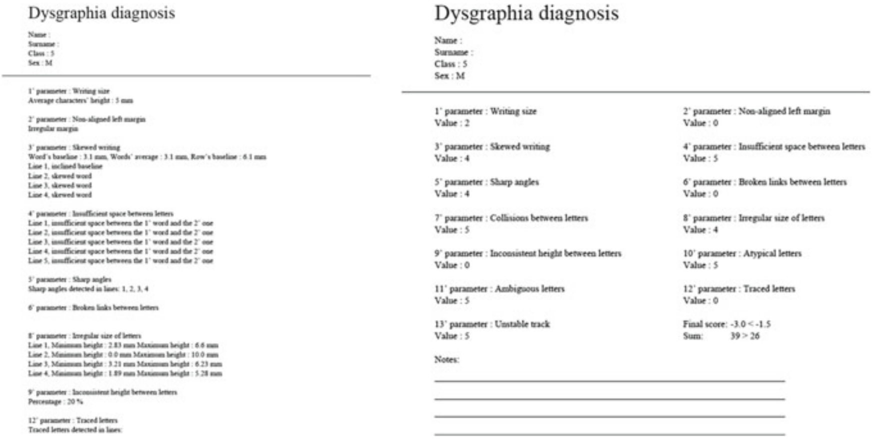
Fig. 18 Input image after processing: the white background has been overlaid with black and words are enclosed in green rectangles



☐ Dysgraphia Diagnosis

Name:	Davide		
Surname:	Di Pierro		
Class:	5		
Writing size:	0	Non-aligned left margin:	0
Skewed writing:	1	Insufficient space between letters:	1
Sharp angles:	0	Broken links between letters:	0
Collisions between letters:	0	Irregular size of letters:	2
Inconsistent height between letters:	0	Atypical letters:	0
Ambiguous letters:	0	Traced letters:	0
Unstable track:	0	Finish	

Fig. 19 This check panel contains all the preliminary score results. Red ones are calculated while blue ones must be set by the doctor



Dysgraphia diagnosis

Name :
Surname :
Class : 5
Sex : M

1° parameter : Writing size
Average characters' height : 5 mm

2° parameter : Non-aligned left margin
Irregular margin

3° parameter : Skewed writing
Word's baseline : 3.1 mm, Words' average : 3.1 mm, Row's baseline : 6.1 mm
Line 1, inclined baseline
Line 2, skewed word
Line 3, skewed word
Line 4, skewed word

4° parameter : Insufficient space between letters
Line 1, insufficient space between the 1° word and the 2° one
Line 2, insufficient space between the 1° word and the 2° one
Line 3, insufficient space between the 1° word and the 2° one
Line 4, insufficient space between the 1° word and the 2° one
Line 5, insufficient space between the 1° word and the 2° one

5° parameter : Sharp angles
Sharp angles detected in lines: 1, 2, 3, 4

6° parameter : Broken links between letters

8° parameter : Irregular size of letters
Line 1, Minimum height : 2.83 mm Maximum height : 6.6 mm
Line 2, Minimum height : 0.0 mm Maximum height : 10.0 mm
Line 3, Minimum height : 3.21 mm Maximum height : 6.23 mm
Line 4, Minimum height : 1.89 mm Maximum height : 5.28 mm

9° parameter : Inconsistent height between letters
Percentage : 20 %

12° parameter : Traced letters
Traced letters detected in lines:

Dysgraphia diagnosis

Name :
Surname :
Class : 5
Sex : M

1° parameter : Writing size
Value : 2

2° parameter : Non-aligned left margin
Value : 0

3° parameter : Skewed writing
Value : 4

4° parameter : Insufficient space between letters
Value : 5

5° parameter : Sharp angles
Value : 4

6° parameter : Broken links between letters
Value : 0

7° parameter : Collisions between letters
Value : 5

8° parameter : Irregular size of letters
Value : 4

9° parameter : Inconsistent height between letters
Value : 0

10° parameter : Atypical letters
Value : 5

11° parameter : Ambiguous letters
Value : 5

12° parameter : Traced letters
Value : 0

13° parameter : Unstable track
Value : 5

Final score: -3.0 < -1.5
Sum: 39 > 26

Notes:

Fig. 20 First half of the report: child's data with information obtained by the system for each parameter (left); Second half of the report: child's data with summary of the values, the final score and notes (right)

in the case, although rare because not allowed in the standard protocol, of letters of different words that coincide.

6 Validation

To verify the validity of our software system, manuscripts of children from the second to the fifth year of primary school have been collected. The number of males and the number of females were taken in a homogeneous way. For some individuals, we also have information about sex that allows us to make a complete diagnosis. A total of 21 samples were collected. For the collection, primary school teachers offered their help to submit this test to their students. Provided with all the necessary information mentioned in paragraph 2, they then collected and delivered the manuscripts indicating class and, if the teacher allowed it, also sex. After the collection, it was found that 5 manuscripts were not valid for the purpose of the test and were discarded for the following reasons: lack of header, writing in capital letters or non-compliance with the standard text provided. The 16 samples collected are summarized in Table 3.

After the collection, for each child, the parameters that the system has the task to identify (1, 2, 3, 4, 8, and 9) were calculated manually by doctors. The results obtained were collected in Table 4.

Then, all the manuscripts were taken as input from the system that generated the results shown in Table 5.

Finally, it is necessary to overlap the results to check if there is a good match between the parameters identified manually and those calculated by the system. To

Table 3 The entire sample with information about sex and the number of children affected by DSA

Sample	Males	Females	Not specified	Total
Affected by DSA	2	0	1	3
Not affected by DSA	3	3	7	13
Total	5	3	8	16

Table 4 Parameters 1, 2, 3, 4, 8, and 9 were manually identified for each child. The first number in the first column indicates the class while the star indicates that the child is affected by DSA

Manually	Param.1	Param.2	Param.3	Param.4	Param.8	Param.9
2,1	0	0	1	1	3	1
2,2	1	0	0	5	4	1
2,3	0	0	0	5	3	0
2,4	1	0	3	5	2	0
2,5	2	0	0	0	5	2
2,7	2	0	0	4	5	3
2,8*	4	0	2	3	4	2
3,1*	2	0	2	5	5	1
3,3	2	0	2	4	4	1
3,4	3	0	1	2	5	1
3,5*	3	1	1	5	5	2
3,6	2	0	1	4	5	0
3,7	3	0	2	3	4	0
3,8	2	0	0	5	4	1
4,1	2	0	0	2	5	3
5,3	2	0	1	0	5	0

achieve this, we have created a subtraction table, field by field, from Tables 4 to 5. If we consider the tables as matrixes of integers, we have that S = A − B. Table 6 shows the results of the matrix S.

To identify the correlation, we consider two indices: the first indicates the percentage of corresponding parameters (N_{COR}) and the second the average gap between the value calculated by the system and the actual value (P_{ACT}). If N is the number of samples, P the number of parameters to be calculated, $m_{i,j}$ the value of row i and column j of the matrix in the subtraction table, and knowing that N = 16, P = 9, the first index can be calculated in this way:

$$\forall i \in \{1, \ldots, N\} \forall j \in \{1, \ldots, P\}$$

$$s_{ij} = \begin{cases} 1\, se m_{i,j} \neq 0 \\ m_{i,j} else \end{cases}$$

Table 5 Parameters 1, 2, 3, 4, 8, and 9 were identified by TestGraphia for each child. The first number in the first column indicates the class while the star indicates that the child is affected by DSA

TestGraphia	Param.1	Param.2	Param.3	Param.4	Param.8	Param.9
2,1	0	0	1	1	3	1
2,2	1	0	0	5	4	0
2,3	0	0	1	5	3	0
2,4	0	0	4	5	2	0
2,5	1	0	0	0	5	2
2,7	2	0	0	3	5	2
2,8*	5	0	2	3	4	2
3,1*	3	0	2	4	5	1
3,3	2	0	2	4	4	1
3,4	3	0	1	2	5	1
3,5*	3	1	2	5	5	2
3,6	3	0	1	5	5	0
3,7	4	0	2	5	4	0
3,8	2	0	0	5	4	1
4,1	1	0	0	1	5	2
5,3	3	0	1	0	5	0

Table 6 Subtraction between values in Table 4 and those in Table 5

Subtraction	Param.1	Param.2	Param.3	Param.4	Param.8	Param.9
2,1	0	0	0	0	0	0
2,2	0	0	0	0	0	−1
2,3	0	0	1	0	0	0
2,4	−1	0	1	0	0	0
2,5	−1	0	0	0	0	0
2,7	0	0	0	−1	0	−1
2,8*	1	0	0	0	0	0
3,1*	1	0	0	−1	0	0
3,3	0	0	0	0	0	0
3,4	0	0	0	0	0	0
3,5*	0	0	2	0	0	0
3,6	1	0	0	1	0	0
3,7	1	0	0	2	0	0
3,8	0	0	0	0	0	0
4,1	−1	0	0	−1	0	−1
5,3	1	0	0	0	0	0

$$\left(\mathrm{NCOR} = 1 - \frac{1}{NP}\sum_{i=1}^{N}\sum_{j=1}^{P} s_{ij} * 100\right)$$

The second index, $\mathrm{P_{ACT}}$, does not count how many values calculated by the system are different from the original, but the average gap.

$$\mathrm{PACT} = \frac{\sum_{i=1}^{N}\sum_{j=1}^{P} \underline{|m_{ij}|}}{\sum_{i=1}^{N}\sum_{j=1}^{\dot{P}} s_{ij}}$$

$$\text{if and only if} \sum_{i=1}^{N}\sum_{j=1}^{\dot{P}} s_{ij} \neq 0$$

In our case, $\mathrm{N_{COR}} = 80\%$ and $\mathrm{P_{ACT}} = 1.05$.

7 Conclusion

The key point of this study and software is to facilitate the task of the doctors by reducing workload allow its diffuse execution, eventually revealing early symptoms. The aim is to be able to examine more children in less time with the obvious consequence of being able to diagnose any problems earlier. This system also allows a remote doctor-patient relationship, while it is being developed as a web-application. The support provided by this system is relevant and, moreover, relieves the doctor also from the use of the graph paper shown in Fig. 2, which requires a remarkable effort and precision.

Well known document analysis algorithm has been used but some of them were modified and adapted to this specific goal, such as the skewed writing algorithm and the non-aligned left margin algorithm. This system clearly foresees future developments such as the calculation of missing parameters, which in any case must be controlled by a doctor as they are subject to interpretation and the improvement of the interaction with the user, which is however not very complex.

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Appendix I—Algorithms

Writing Size Algorithm

The average of the heights of the letters can be easily calculated using the first line of the text, added to the original standard text. Knowing the coordinates of the extreme points of each letter, the height will be given by the difference of the ordinates of the extremes. Once the average has been obtained, it is rounded to an integer and the table shown above is used to obtain the value of parameter 1.

Non-Aligned Left Margin Algorithm

The left margin can be easily calculated by considering the first column of words, the closest to the left border excluding the first line. If, when scrolling between the lines, the distance in the x-axis from the left margin increases, the left margin is not aligned. To calculate the value, we make the difference between the x-coordinate of the beginning of the word in the second line and the one at the beginning of the first word in the last line.

Skewed Writing Algorithm

The skewed writing algorithm has two different levels: skewed word and skewed line. If a line is skewed or contains a skewed word, the value 1 will be assigned. The value of the parameter corresponds to the number of lines in which a skewed element is present. To carry out this task, a vector of minimums is created starting from the matrix of points of the word. To check if the word's direction is consistent, the distance between the word's initial minimum and the word's average minimum is calculated. A word with a coherent direction has a difference below a threshold. In formal words, this is the condition to respect for each word:

$$\forall i \in \{1, \ldots, n\}$$

$$\left| m_0 - \frac{1}{n} \sum_{i=1}^{n} m_i \right| < S_0$$

With n the number of horizontal pixels in a word, m_i the minimum in position i and S_0 the threshold. At the line level, an extended minimum vector is created that considers all the words in the line. From this extended vector, we calculate the averages of the minimums of all the words. Finally, we measure the difference between the various averages to see if the baseline is consistent. A line with a coherent direction presents a difference between the averages below a certain threshold, which can be modified as shown above. For our purposes, it has been verified that the value 5 mm represents a very reliable threshold for the recognition of the anomaly. In formal words, this is the condition to respect for each line:

$$\forall i \in \{1, \ldots, n\} \vee j \in \{1, \ldots, n\} \wedge i \neq j$$

$$\left| \frac{1}{l_i} \sum_{i=1}^{l_i} m_i - \frac{1}{l_j} \sum_{i=1}^{l_j} m_j \right| < S_1$$

with n the number of horizontal pixels in a line, li the number of pixels of the word in position i and S1 the threshold. Finally, at line level, it is also necessary to verify that the beginning and the end are not too distant. The difference between the lowest point of the first word and the lowest point of the last word is calculated from the extended minimum vector in absolute value. A line with a coherent trend has a difference between the two minimums below a threshold, which can be modified as shown above. In formal words this is the condition to respect for each line (n the number of horizontal pixels in a line and S_2 the threshold):

$$|m_0 - m_n| < S_2$$

Insufficient Space Between Letters Algorithm

The measurement of the width of the letter “o” is easily determined by calculating the average of the width (the difference between the final and initial x-coordinate) of the two “o” present in the first line. For each line, therefore, we check if there are two words that are distant less than the average width of the “o”. The distance between two words w and (w + 1) is simply given by the difference between the initial x-coordinate of the word (w + 1) and the final x-coordinate of the word w.

The value of the parameter will simply be the number of lines in which two words are far less than the average width of the “o”.

Irregular Size of Letters Algorithms

As we said, for this parameter it is necessary to have an interaction with the user that will indicate, for each line, the extremes of the highest and lowest elongation-free letter. The system will examine the pairs of points per line and will execute the difference between the ordinates. Recognizing, for each line, which of the two letters is higher, it will use the table shown above to assign the value 1 or 0. The value of the parameter will be the number of lines in which the height between the highest and lowest letter is inconsistent.

Inconsistent Height Between Letters With and Without Extension Algorithm

In order to calculate this parameter, it is necessary to know, for each word, whether it has elongations. A word is considered "with elongations" if it contains one of the following letters: b, d, f, g, h, j, k, l, p, q, t, y.

For each line, we measure the height of the words with elongations and the height of the words without elongations. If there is at least one ratio between words with and without elongations that does not respect a proportion, the value 1 will be assigned. For our purposes, it has been noted that the percentage of 20% provides certain reliability of results. This implies that a word with elongations must be at least 20% higher than a word without elongations. The value of the parameter represents the number of lines in which the proportion is not respected; the value can reach up to 4 because in the last line there are no words with elongations.

References

1. Rosenblum S, Weiss PL, Parush S (2004) Handwriting evaluation for developmental dysgraphia, vol 1993, pp 1996–1997
2. Pratelli M (1995) Dysgraphia. Erickson. ISBN: 9788879461597
3. Deuel RK. Development Dysgraphia and Motor Skills Disorders
4. Ingram TTS. Paediatric Aspects of Specific Developmental Dysphasia, Dyslexia and Dysgraphia
5. Dmitrova ED, Dubrovinskaya NV, Lukashevich IP et al (2005) Hum Physiol 31:125. https://doi.org/https://doi.org/10.1007/s10747-005-0020-5
6. Adi-Japha E. ADHD and Dysgraphia: Underlying Mechanisms
7. Mortley J, Enderby P, Petheram B. Using a computer to improve functional writing in a patient with severe dysgraphia
8. Danna J et al. Handwriting Movement Sonification for the Rehabilitation of Dysgraphia
9. Caivano D, Girardi F, Dimauro G, Bevilacqua V, Di Nicola V (2017) Assessment of speech intelligibility in Parkinson's disease using a speech-to-text system. IEEE Access, vol 5. DOI: https://doi.org/10.1109/ACCESS.2017.2762475
10. Dimauro G, Caivano D, Bevilacqua V, Girardi F, Napoletano V (2016) VoxTester, software for digital evaluation of speech changes in Parkinson disease. In: 2016 IEEE International Symposium on Medical Measurements and Applications (MeMeA), Benevento, pp 1–6. doi: https://doi.org/10.1109/MeMeA.2016.7533761
11. Silveri C, Misciagna S, Leggio G, Molinari M. Spatial dysgraphia and cerebellar lesion
12. Di Brina C, Rossini G (2011) TestBHK—Scala Sintetica per la Valutazione Della Scrittura in Età Evolutiva. Portland, OR, USA: Erickson

13. Dimauro G, Baldari L, Caivano G, Colucci G, Girardi F (2018) Automatic segmentation of relevant sections of the conjunctiva for non-invasive Anemia detection. In: Proceedings of 3rd International Conference on Smart and Sustainable Technologies (SpliTech), ISBN 978–953290083–5
14. Rubaiat SY, Rahman MM, Hasan MK (2018) Important feature selection accuracy comparisons of different machine learning models for early diabetes detection. In: 2018 International Conference on Innovation in Engineering and Technology (ICIET), pp 1–6. doi: https://doi.org/10.1109/CIET.2018.8660831
15. Dimaur G, Guarini A. Caivano D. Girardi F. Pasciolla C. Iacobazzi A (2019) Detecting clinical signs of anaemia from digital images of the palpebral Conjunctiva. IEEE Access 7:113488–113498https://doi.org/10.1109/access.2019.2932274
16. Dimauro G, Caivano D, Girardi F, Ciccone MM (2014) The patient centered electronic multimedia health fascicle—EMHF. In: 2014 IEEE Workshop on Biometric Measurements and Systems for Security and Medical Applications (BIOMS) Proceedings, Rome, pp 61–66. doi: https://doi.org/10.1109/BIOMS.2014.6951537
17. Brunetti A, Carnimeo L, Trotta GF, Bevilacqua V. Computer-assisted frameworks for classification of liver, breast and blood neoplasias via neural networks: A survey based on medical images. Neurocomputing 335, 274–298. https://doi.org/ https://doi.org/10.1016/j.neucom.2018.06.080
18. Bevilacqua V et al. (2017) A novel approach for Hepatocellular Carcinoma detection and classification based on triphasic CT Protocol. In: 2017 IEEE Congress on Evolutionary Computation (CEC), pp 1856–1863. doi: https://doi.org/10.1109/CEC.2017.7969527
19. Shiraishi J, Li Q, Appelbaum D, Doi K (2011) Computer-aided diagnosis and artificial intelligence in clinical imaging. Semin Nucl Med 41(6):449–462. https://doi.org/10.1053/j.semnuclmed.2011.06.004
20. Dimauro G, Caivano D, Girardi F (2018) A new method and a non-invasive device to estimate anemia based on digital images of the conjunctiva. IEEE Access 6:46968–46975. https://doi.org/10.1109/ACCESS.2018.2867110
21. Halalli B, Makandar A (2018) Computer aided diagnosis—medical image analysis techniques. In: Kuzmiak CM (ed) Breast Imaging, InTech
22. Song Y et al (2014) A deep learning based framework for accurate segmentation of cervical cytoplasm and nuclei. Conf Proc IEEE Eng Med Biol Soc 2014:2903–2906. https://doi.org/10.1109/EMBC.2014.6944230
23. Dimauro G, Girardi F, Gelardi M, Bevilacqua V, Caivano D (2018) Rhino-Cyt: a system for supporting the rhinologist in the analysis of nasal cytology. Int Comput Theor Applic, 619–630. doi: https://doi.org/10.1007/978-3-319-95933-7_71
24. Dimauro G et al. Nasal cytology with deep learning techniques. Int J Med Inform 122:13–19, Feb. https://doi.org/10.1016/j.ijmedinf.2018.11.010

Assistive Technologies: Case Studies

Integrated ICT System for the Implementation of Rehabilitation Therapy for Alzheimer's Patients and for the Improvement of Quality and Efficiency in Managing Their Health: The Rehab-Dem Project

Massimo Pistoia and Paolo Casacci

Abstract Dementia, Alzheimer's and neurodegenerative diseases in general are closely interconnected with advancing age. Neurodegenerative diseases cost approximately 130 billion € a year to European social-health and welfare systems. Currently existing treatments for neurodegenerative diseases are very limited, aimed mainly at treating symptoms rather than coping with causes and are quite expensive. Furthermore, no new Alzheimer's drugs have been discovered or approved by the scientific community in the last five years. It is necessary to explore new paradigms of care and support for the increasing number of patients suffering from these diseases and their caregivers in the years to come. The Rehab-Dem Project has the main purpose of improving the health and psycho-physical well-being of people affected by neurodegenerative diseases by tackling the most important issues such people face.

1 Introduction

Individuals with dementia confront a syndrome that increasingly compromises their cognitive, thinking, memory, their behavior, as well as the ability and capacity to perform even the simplest daily activities, especially in the most serious stages of the pathology.

The average duration of this process leading to dementia, goes from two to ten years and ranges from the average cognitive declines to the most serious and compromising stages of the pathology. The neurodegenerative pathologies represent a burden not only for the people who are affected, but also for all those involved in the care

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processes, especially caregivers and family members, both in psycho-physical and economic terms. Numerous studies show that the majority of patients suffering from dementia and in general neurodegenerative pathologies reside in their own domestic environment (about 70%) and many of them live alone (about 30%). Only 40% of them are formally diagnosed with the disease. Also, a percentage is recovered in nursing homes, typically because of the absence of a family member/caregiver. On average, informal caregivers are over their sixty and 70% of them are women [16].

The five main challenges experienced by users affected by neurodegenerative diseases and in particular by dementia or Alzheimer's are the following: loss of confidence/self-esteem (about 70%), fear of getting lost and easily disoriented (60%), mobility problems (60%) and physical health in general (59%). Many of them have to give up, in a more or less conscious way and in line with the level of cognitive degradation, to numerous daily activities: from domestic services to those outdoor: go out; go shopping; take public transport; carry out simple physical exercises and also enjoy the simplest recreational activities [13].

The caregivers and family members instead, find themselves facing hard challenges, typically:

- Managing sudden changes in mood and/or behavior;
- Psychophysical overload in the daily management of the individual;
- Resistance by the patient himself against possible moving to a nursing home;
- Incompetence to handle a particular situation and the fear of not being able;
- Ignoring how and from whom to receive help;
- Poor communication with specialized medical personnel.

In light of such situations, it is estimated that smart and ICT technologies can offer enormous potential in supporting not only dementia patients or Alzheimer patients to lead a life in better health and wellness conditions, but also their families, formal and informal caregivers and specialized medical personnel involved in the care processes. Furthermore, they can facilitate the community's commitment to creating stimulating and "friendly" environments both for users suffering from neurodegenerative diseases and for those who take care of them [7]. ICT can also play an important role in prevention, intervention and self-management activities [8], in particular:

- For users in the early stages of the disease, ICT technologies can provide support to cope with the first signs of dementia, stimulating their engagement in recreational and leisure activities that can compensate for the loss of ability, supporting the mnemonic-cognitive faculties and reducing episodes of isolation and depression. In this regard, the project employs two electronically advanced devices: MYO's easily wearable bracelet, containing sensors capable of detecting the movement of the muscles of the upper limbs and a camera that captures RGB and depth frames, for detecting movement and position the user and the recording of the executed movement. These technologies allow the user suffering from early symptoms of cognitive degradation to perform targeted therapy through simple physical rehabilitation exercises that exploit recreational aspects able to maintain cognitive faculties, balance, memory and promptness in movement, at the same time conveying clinical-therapeutic objectives. To enrich this experience, the use of advanced graphics and avatar technologies is applied to the case, with speech recognition features able to guide the client, as a virtual trainer, in the performance of the indicated exercises and receive assistance even remotely, when necessary;

- For users in an intermediate stage of dementia or Alzheimer, ICT and smart technologies are believed to be helpful in improving their safety both indoor and outdoor, helping them to find their way even outside their own home environment, providing additional support in the event of more severe memory leaks and monitoring the sleep/wake rhythm. The work employs a smart sensor, easily wearable and minimally invasive, able to carry out a detection and constant monitoring of vital parameters of the user (such as ECG, heart rate [1, 2] and respiratory rate, blood pressure, sleep/wake rate and user position) that can be collected and evaluated even remotely. This improves the sense of safety perceived by the user even within his own domestic environment. In the event of critical situations, a caregiver will be able to promptly intervene. Furthermore, thanks to vital data collection, the competent doctor can also check the effect of the drugs and calibrate doses. Together with a handheld device it is also possible to follow and geo-locate the user along a path outside his own home to monitor his activity in the event of memory loss and act if necessary;
- For users who are in a more severe and compromising stage of dementia, ICT technologies can help them stimulate communication with others and feel more involved in society. In this regard, particular dedicated serious games are implemented. These can be performed, with an appropriate guide by caregivers, in collaboration or competition with other users, with the aim of stimulating the cognitive faculties, socialization and communication, despite the strong limits imposed by the pathology and which would prevent the user to perform other type of physical rehabilitation therapy;
- For caregivers, on the other hand, ICT technologies can help reduce the burden of psycho-physical stress, improving the flow of communication with specialized medical personnel, operators and therapists, who can promptly provide advice and suggestions on how to manage particular critical situations, even remotely arranging the data collected and monitored with respect to each user. This makes it possible to improve the effectiveness and efficiency of therapy management by caregivers/family members, who can also come into contact with one another to exchange advice, experiences and skills about care and assistance services to patients;
- For specialized medical personnel ICT technologies are of fundamental importance in improving the effectiveness and efficiency of the prescribed therapy and in enriching the quality of communication with the rest of the stakeholders involved in the care processes. Moreover, thanks to these technologies, each doctor or therapist is able to manage, even remotely, more patients at the same time, thus improving the quality of the services delivered, the well-being of the patient himself, reducing the waiting times of clients and family members and therefore

episodes of psycho-physical stress both for the user and for the medical staff himself.

2 Project Rationale

The Rehab-Dem project aims to improve the health and psycho-physical well-being of users and caregivers by the implementation of an integrated and technologically advanced ICT system.

The project takes into account the different levels of decline that can characterize the pathology and with the ultimate goal of improving the level of health, well-being, quality and efficacy of social and health care services. At the same time, it means to optimize the management of care and physical rehabilitation therapy in a highly personalized, innovative and stimulating manner. To this end, the project aims to implement personalized therapeutic paths, calibrating the specific doses of the drug administered to the patient on the basis of his state of health, detected by constant monitoring of his vital parameters. The proposed system also aims to improve the psycho-physical health and mobility level of the user. This is done through a domestic rehabilitation system consisting of smart sensors and electronic devices that are easily wearable and poorly invasive, aimed at gesture recognition to assess the correctness of the performed exercise while monitoring vital parameters. This will contribute to the formation of a virtual model of the person, containing the specific data and information of each user with the purpose of giving them a greater sense of security, assistance and well-being even within their domestic environment [14].

Additionally, the project proposal aims to alleviate the work of caregivers/family members involved in the daily care of the client, reducing their overload and allowing them to improve the flow of direct communication with specialized medical personnel, receiving support even remotely in dealing with critical situations. To the doctors, the project provides ability to manage multiple patients at the same time, thanks to constantly updated data of the patient's state of health.

Together with the decline of the user's cognitive and mnemonic faculties, numerous studies show that it is of fundamental importance to face another challenge, namely the episodes of isolation and depression which these types of users often encounter, due to a drastic reduction in the level of socialization. Dementia-affected people, in fact, renounce activities outside their home environment and, by experiencing loss of memory, orientation and self-confidence, often tends to isolate themselves and reduce opportunities for socialization and commitment in a more or less conscious way. It is therefore of fundamental importance to intervene also in this respect and to restore as much as possible the opportunities for socialization for the users, so that they can continue to feel part of the community in which they find themselves and thus improve their level of well-being. Thanks to the navigation and geo-localization features in outdoor contexts, this type of user can also undertake specific paths aimed at allowing him to cope with his daily activities and services, with the aim of contrasting at the same time the fear of becoming disoriented, lost or confused and receiving assistance from remote caregiver or family member when necessary. In turn, this function also aims to improve not only the cognitive faculties, but also the motor abilities of the user, thus reducing episodes of isolation, depression and improving the quality of life despite the pathology.

The project also gives the possibility to access a dedicated web portal to undertake further exercises or serious games to be performed in partnership with other users through collaboration or competition strategies, if helped by their caregivers when necessary. This, precisely for conveying clinical rehabilitation purposes through playful and recreational aspects, improving at the same time their cognitive and mnemonic faculties, at the same time increasing the level and opportunities for socialization with other users, satisfaction and social commitment, thus again countering possible episodes of isolation and depression.

3 Tools and Technology

The Rehab-Dem project has as its final goal the realization of an innovative combination of products and services at different levels specifically designed and implemented. All with the aim of conveying the clinical-therapeutic targets through playful aspects, in the context of a personalized domestic rehabilitation therapy, finally giving life to a community able to collect the interests of the main stakeholders involved in the care and assistance processes of the user. The project will pursuit the realization of a product/service that will consist of the following elements:

- A kit for the domestic execution of physical rehabilitation exercises, including: an electronic bracelet for gesture control, such as the one developed by MYO (Fig. 1), i.e. a light and easily wearable elastic bracelet which consists of a certain number of metal contacts capable of detecting the movement of the muscles of the upper limbs and transmitting them remotely; a device equipped with an RGB-D sensor, that means it captures RGB and depth frames capable of detecting the position and movement of the user and with some video cameras incorporated for recording the movement performed.

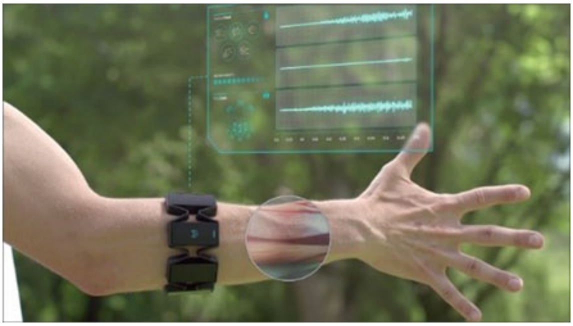


Fig. 1 MYO bracelet (*source* TechWeb Today)

- In addition, the exercises performed will make use of Avatar technologies, i.e. graphic representations of the user or his alter ego that can be either in 3D or in 2D. The avatars will act as a bridge between the man and the machine, and will be able to recognize speech and voice commands, as well as start operations even without physical contact, thus guiding the user in virtual mode through the proposed exercises.
- A kit for monitoring vital signs that includes a smart sensor for detecting the ECG, heart rate [3, 4], respiratory rate, blood pressure of the sleep/wake rhythm and that by a handheld device also allows geo-navigation functions; a patch sensor for detecting the level of electrolytes and a handheld device for displaying them and for accessing the web portal. In this regard, we will use the i-STAT System, created by Abbott and able to release results on the analysis of small blood samples in a few minutes, using special cartridges that require 2 or 3 drops of blood and contain chemically sensitive biosensors on a silicon chip configured for specific analyzes, such as those of plasma electrolytes. They, if altered, are in fact responsible for confusion syndromes and loss of orientation. In this way, it is possible to periodically verify that the electrolytic level assumes the clinically most suitable value for each patient (Fig. 2).

  A research was carried out on the devices for the detection of the ECG available on the market and three possible devices suitable for use within the project were identified. Specifically, the devices are the following:

  - D-Heart electrocardiograph
  - XYZlife Patch Bc1
  - Zephir Bioharness 3 with chest strap

  The devices were tested and evaluated together in collaboration with the University “La Sapienza". The D-Heart device is an electrocardiograph capable of performing

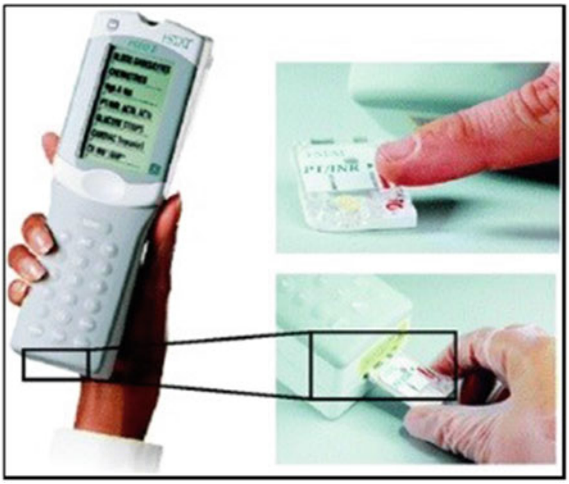


Fig. 2 i-STAT system (*source* Abbott Point of Care)

an 8-lead ECG. It provides an excellent ECG reading but is cumbersome and requires the application of adhesive electrodes. The XYZlife Patch Bc1 device is not bulky but only allows to start and stop the ECG reading manually. It also requires the application of adhesive electrodes. Only ECG measures, the battery lasts 12 h. The Zephir Bioharness 3 device allows the measurement of several parameters:

  - ECG
  - Respiratory rate
  - Posture
  - Temperature.

  It is not bulky, it can be applied through a chest strap or electrodes, it has a battery with a duration of more than 24 h. The acquisition can be controlled by software.

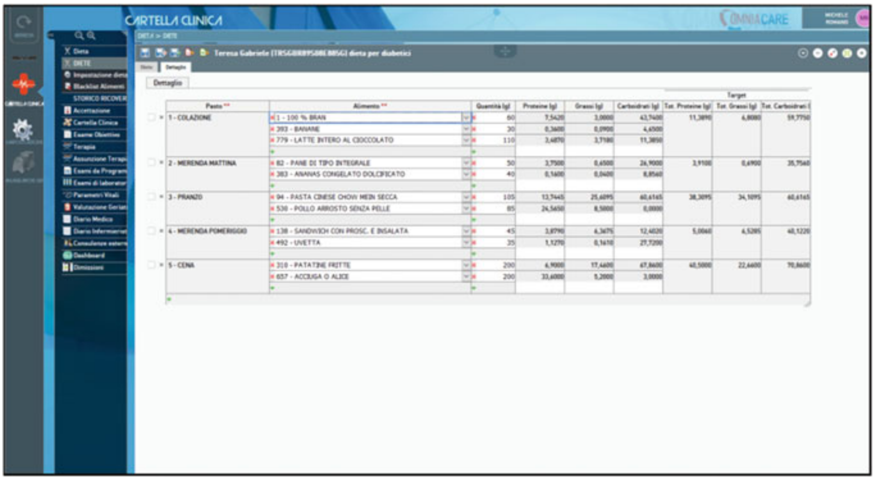
- A dedicated web portal through which users, based on their level of cognitive decline and consequent therapeutic-rehabilitative needs, and their caregivers/family members and specialized medical staff, will access. The former will benefit from recreational activities, socialization and serious games aimed at increasing the level of integration and well-being of the individual by counteracting episodes of depression and isolation. The second will act in an environment where it is possible to receive information and suggestions to increase the quality of their social and health care services to the individual, even in difficult cases in which the caregiver himself would not know how to behave, thus exchanging ideas inherent to his activity and interacting also directly with specialized medical personnel. Finally the latter, will be able to benefit from a system that will allow to evaluate and intervene remotely, making changes to the ongoing physical and pharmacological therapy and making it more personalized, verifying progress over time.

  The OMNIACARE platform, which will also be appropriately extended to integrate the dedicated web portal, will realize the above mentioned features and functionalities (Fig. 3).

4 Study and Research

Among the main scientific and R&D challenges that the Rehab-Dem project intends to respond, it is possible to include the following:

- To obtain a picture as clear and objective as possible about the implementation of a pharmacological therapy that ought to be tailored, with respect to the state of health of the patient and therefore to foresee the exact doses of drug to be administered. To do this it is necessary first to identify the parameters of actual clinical interest for the pathology and subsequently the correlation existing between the values measured and the way in which they are influenced by the drugs;
- The integration of various sensors and intelligent devices and their dynamic configuration, without user intervention, is one of the most important aspects in



Teresa Gabriele ([illegible]) dieta per diabetici

Dettaglio

Pasto **	Alimento **	Quantità (g)	Proteine (g)	Grassi (g)	Carboidrati (g)	Target Tot. Proteine (g)	Tot. Grassi (g)	Tot. Carboidrati (
1 - COLAZIONE	1 - 100 % BRAN	60	7,5420	3,0000	43,7400	11,3890	6,8080	59,7750
	393 - BANANE	30	0,3600	0,0900	4,6500			
	779 - LATTE INTERO AL CIOCCOLATO	110	3,4870	3,7180	11,3850			
2 - MERENDA MATTINA	82 - PANE DI TIPO INTEGRALE	50	3,7500	0,6500	26,9000	3,9100	0,6900	35,7540
	383 - ANANAS CONGELATO DOLCIFICATO	40	0,1600	0,0400	8,8540			
3 - PRANZO	94 - PASTA CINESE CHOW MEIN SECCA	105	13,7445	25,6095	60,6165	38,3095	34,1095	60,6165
	530 - POLLO ARROSTO SENZA PELLE	85	24,5650	8,5000	0,0000			
4 - MERENDA POMERIGGIO	138 - SANDWICH CON PROSC. E INSALATA	45	3,8790	4,3675	12,4020	5,0060	4,5285	40,1220
	492 - UVETTA	35	1,1270	0,1610	27,7200			
5 - CENA	310 - PATATINE FRITTE	200	6,9000	17,4600	67,8600	40,5000	22,4600	70,8600
	657 - ACCIUGA O ALICE	200	33,6000	5,2000	3,0000			

Fig. 3 OMNIACARE portal example screen

the design of intelligent environments. At the application level it is necessary to abstract from the heterogeneity and distribution of resources and allow the execution of commands independent of the specific network infrastructure or hardware used. Mechanisms for discovering resources and services must be adopted and supported by a software layer that hides the heterogeneity of resources, and facilitates communications between system nodes. Communication and integration middleware plays a fundamental role in sharing context information; in fact, not all services can acquire complete context information due to the limited computational resources of the devices they operate on. A communication middleware must create virtual channels on which to let the context information flow, carry out the discovery and access the services and send control information for the ordinary management of the system and alarm situations. Moreover, in line with the virtualization operated with Cloud Computing, the level of abstraction introduced by the communication middleware must make it possible to reallocate the computational resources in a transparent way and allow a remote management of the processing nodes in order to reduce deployment costs;

- The system through active vision technologies will need to measure movements (gesture) accurately, calculating the deviation from predetermined sequences, evaluating the correctness of the exercise in terms of temporal sequence and execution metrics and providing a performance value (score). The choice of exercises and the performance evaluation during the execution must be linked to the virtual model of the user to take into account its specificity and preferences. Within this profile, the sequences of planned exercises will be defined, chosen within a set present in the server platform. This set can be constantly enriched with new elements, each of which must be correlated to age, the required clinical condition, and compatibility with any problems or pathologies. The performance trends detected must be constantly correlated to the user's condition, in order to allow an improvement on the physical level without causing excessive fatigue.

- Realization of socialization features. These functionalities will have to consider the well-being of the individual from the relational and social point of view. They will have to be closely related to the virtual model to adapt to people of different age groups, dissimilar needs and different levels of confidence with technology. They will also provide suggestions related to the person's preferences, and contacts with people with similar interests.
- Implementation of the system for forecasting critical events. The system presents a high number of variables deriving from the multiple data sources and from the different types: unstructured data, images, relational data, temporal space data, multi-variable data deriving from "integrated smart systems". Each individual event may originate from each of these variables and could be correlated to each of them, even though they are the same in terms of format and type. Therefore, it assumes a decisive role for the detection of critical issues and the mitigation of errors the realization of a predictable event management system, through the evaluation of behavioral patterns and not just through security analysis methodologies.

One of the main technological problems is attributable to the lack of interoperability with the external devices used and the solutions implemented by third parties. However, in order to address this issue, the technical team will use existing standards to ensure interoperability as much as possible. Furthermore, due to the data exchange between MYO and the camera, the ISO IEEE 11073 standard is due to be used together with Bluetooth specifications. In fact, communication with MYO is based on a standard Bluetooth connection. The Bluetooth communication profile used is SPP, which is compatible with almost all hosts available on the market including the standard PC, Smartphone or simple BT modules for embedded applications. The wearable sensor will be in line with the IEC 60601, IEC 60529, EC38, EC57, UL 60601-1, CAN/CSA C22.2 standards, while the OMNIACARE platform server is based on widely accepted Internet standards such as HTTPS and XML. Communication with the platform server and data exchange will make use of XML Web Services. While, the health data within the OMNIAPLACE database is be saved using HL7/ICD10 format. The communication of health data with external systems is based on the HL7/CCD standard (Continuity of Care Document). Authentication between OMNIACARE and external data sources is based on identity and authentication APIs that use OAuth 2.0 as a basis. Therefore, the adoption of the standards just mentioned ensures a high interoperability between the different components of the product/service that will be carried out and by facing one of the main technological problems that are likely to arise.

Finally, another technical-scientific problem is closely related to the difficulty of anticipating user behavior and trends, therefore, the risk of a low level of acceptability and usability of the product/service by the final user. However, the UCD—User Centered Design approach—that will be adopted and which envisages a direct involvement of the user at the center of the entire solution development process will be able to deal with this. In fact, the needs of the end user, the limits and expectations will be strongly taken into account. The prototype will be re-calibrated, following the pilot tests, based on the feedback obtained, until reaching a solution that is as close as possible to the results, expectations and what is requested by the user and caregivers during the design and development phase of the solution.

5 Scientific and Technical Preliminary Results

The project scientific partners provided support in the definition of the digital systems to be tested, in particular in the evaluation of serious games aimed at cognitive stimulation, improvement of memory, reflexes, visual-spatial and movement abilities. In collaboration with the University of Tor Vergata, Bioresult and Liferesult chose to carry out computer simulation of several games to be performed with recognition systems of the player's movement. Cooperativa La Casa, during numerous meetings held at the University of Tor Vergata with the medical team, designed the operational procedures for validating and testing the tests related to such serious games. The joint project team also analyzed the profiles of potential patients and caregivers, based on the results of the experiments already carried out in this field and of the realized analyses and came out with the following.

Parametric template design and definition of a set of rehabilitation exercises. Design of a battery of diagnostic tests of different cognitive dimensions based on parametric templates

With the collaboration of Tor Vergata University, a series of rehabilitation exercises based on parametric templates was defined and the template design activity was carried out in order to proceed with the implementation on the OMNIACARE platform. Also, a series of neuro-psychological tests for the assessment of cognitive abilities based on such parametric templates was planned. The tests are administered to the patient in digital form via a tablet [9] and the data relating to the execution of the test are transmitted to the OMNIACARE platform. The test battery will be validated by submitting it to a large sample of subjects over 65 who do not have dementia problems in order to guarantee their scientific reliability.

The scope of the software is to execute rehabilitation and evaluation tests for dementia, based on general templates. The design of parametric templates was oriented to the possibility of creating exercises with personalized content for each user and to be able to constantly insert new contents in relation to each template. This will also allow in the future to enrich the system with new exercises and to insert specific contents for each individual user.

The software generates several kinds of tests and it is highly parametric in order to be able to create test with different structure based on the information downloaded from a backend server. The software consists of a frontend application for three different environments: Android Tablet, Windows Application and Web Application. The frontend communicates with the OMNIACARE backend server which contains the user profile and the associated test batteries. The client application is executed on tablet, PC, and web browser. The application downloads the tests batteries from the backend server, personalized for each user, generates and executes each test and saves the results on the server itself. Test evaluation takes place on the backend server and the application sends the data entered by the user to the server. The tests are based on specific parametric templates, so the application downloads the test configuration data from the server and generates each test based on the related template. Communication between the Application and the Backend server takes place through specific Web Services. The templates can send messages to a user, the messages could be displayed by an external application (Avatar), providing the message with a specific structure. Communication with the avatar takes place by Web Services and specific broadcast messages.

It is possible from the application, by a button, to suspend the test execution and resume it later from the point of interruption. The user is asked to choose whether to continue with the test or not. Each template saves the time and the number of pauses. For each template the server sends a "mandate" (assignment) consisting of a text and an image that shows what the user has to do. The mandate can be displayed still on the screen or it can be displayed for n seconds. Another parameter indicates if the possible answers are displayed only after the "mandate" has been obscured.

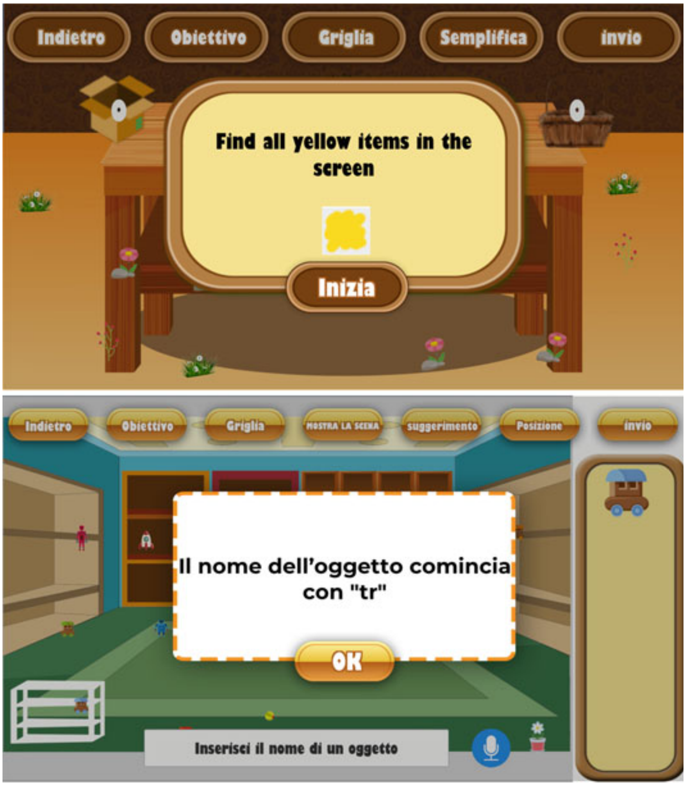
To check the correctness of an answer, a metric called "distance" is used for the evaluation. It checks letter by letter whether the "distance" of the definition matches with the correct answer (like a corrector). It verifies as well if there is an inversion of letters, lack of letters, and replacement of letters. If all three elements are present, the distance is 3, above 3 the answer is considered to be wrong. If the word inserted does not exist in the dictionary, this evaluation is not made. If the word exists and does not correspond, it is marked as wrong. The "distance" is used to evaluate all the answers.

Each template can be interruptible or not. If the template can not be interrupted, it is necessary to postpone any possible avatar appearances not related to the template at the end of the exercise. The template itself must take responsibility for suspending the avatar and reactivating it. Communication with the avatar can take place by web services (all platforms) or broadcast messages (specific option for Android). Speech recognition is also configured in such a way to be required if what has been pronounced is the same (or approaching) to a given text. For example, it is useful to recognize words in reverse way.

Each template is aimed to create tests that have common points. The test structure can vary a lot but all the tests in the template will contain one or more questions and will requests one or more answers. The content, details and features of each test can vary a lot (Fig. 4).

Design of an Avatar application with TextToSpeech and Speech Recognition features

We proceeded to design the features of an avatar to be integrated with diagnostic tests, able to provide the user with a tool for interaction and management of activities and appointments that present a user-friendly interface. The Avatar APP primarily has



Find all yellow items in the screen

Il nome dell'oggetto comincia con "tr"

Fig. 4 Examples of Template rehabilitation exercises (Apps AttivaMente and OrientaMente)

a push notification function. It is shown in the foreground and depending on how it is configured, it shows a text or it synthesizes the voice by producing the text or reproduce a sound. The avatar is started based on the occurring of an event and has different moods, to be chosen among the following:

- Normal
- Angry
- Happy
- Strict
- Amused

Each one of these status shows a different icon of the same kind of avatar and eventually, if it is possible, a different tuning of the voice. The icon of the avatar is an animated GIF so that it may be also possible to "imitate" a speaking character. The avatar waits for a vocal answer to the question and if it is correct it gives a positive feedback while it saves the answer. Then the notice ends. Otherwise, it says it is not correct and it asks to try again. After the second mistake, it suggests the right answer. Each attempt is saved and sent to the server. The user might also have

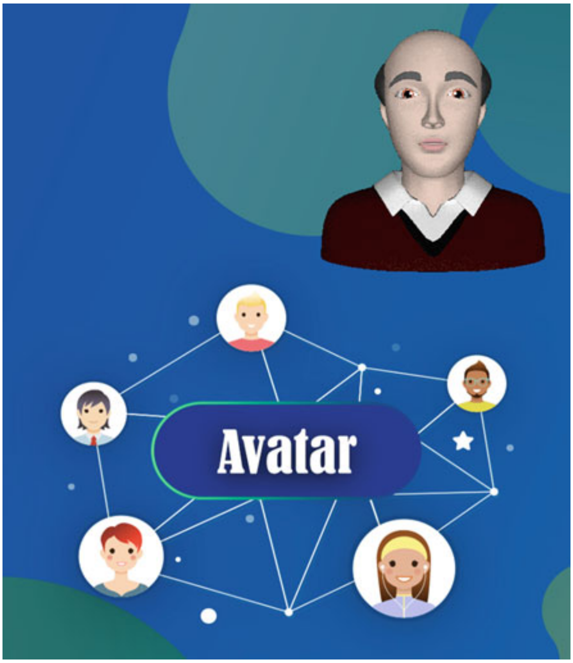


Fig. 5 Avatar example screen

different devices (tablet, handheld device, PC), every time he connects to a device, if the Avatar App is installed it connects to the server to update itself with the new updates, therefore depending on which device the user is using he could have the same "supporting" avatar. In the configuration process, the avatar can also be shut down if one does not want to display it anymore (Fig. 5).

Realization of the serious game "Bocce" based on movement detection

We proceeded to design and implement a serious game that reproduces a real and playful activity, which is particularly useful for training the mind by stimulating the different memory abilities, quick reflexes, visual-spatial and movement abilities. It also provides a stimulation of socialization. The Serious Game implements the game of Bowls, and is based on the recognition of the player's movement, which through the movement of the arm is able to launch the bowl by varying the angle and power. The game can be played in multiplayer mode both through collaboration and competition strategies and allows you to compete with real players or against computer-controlled players. In order to detect the improvement of the player's abilities, for each game the positions of the individual bowls, and the distances from the ball are recorded, in order to have an objective and measurable confirmation of the subject's abilities and therapeutic efficacy.

The game requires players from a team to launch their ball in turn, alternating with the players of the opposing team. The aim of the game is to get as close as possible with the highest number of balls to a "small ball" which has to be always visible to the

Fig. 6 "Bocce" game initial screen

players. There are countless variations to the rules of this sport, especially regarding the number of players. This game could be played individually in competition (one vs. one), in pairs and then in collaboration (two vs. two), three versus three up to a maximum of four versus four. In the case of a solo player, he could play against a virtual player generated by the system.

Regarding the score, there are countless variations as well. Usually, it is evaluated which is the nearest bowl to the "small ball" and the first score is assigned to the team that has played that "bowl". Then, it is considered the second nearer bowl to the "small ball"; if it belongs to the same team, another point is then added, otherwise the counting is interrupted. In order to assess the movement, a tool was used such as the ORBEEC Budles Astra Sensors with Gestural interaction, which is able to recognize the strength with which the bowl is launched, the speed, the power and the trajectory curve. The software is also able to show visual and sound messages to the player. Messages are editable in text, and if desired an upload-able sound file shall be associated to reinforce the visual message with a human voice (Fig. 6).

The game connects to the OMNIACARE server side to log in the user and to share results and values. Each playing session is logged. Logs are transmitted in real time to the external server via web services. An appropriate amount of local buffering of playing logs is provided, in case the external server is temporarily unavailable. During the playing session, the software performs event-based logging:

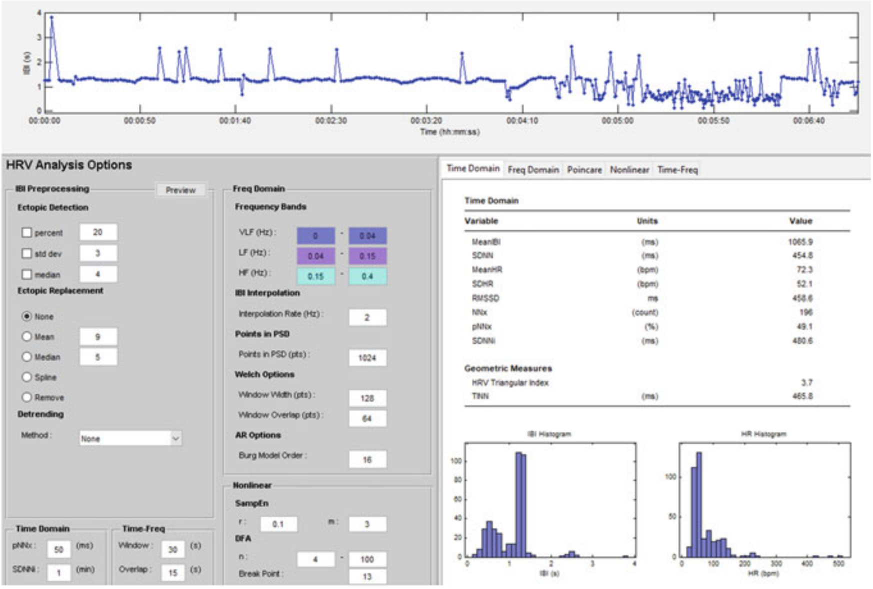
- Current date and time
- The distance from the target for each ball
- The power of each the launch
- Hitting balls
- Scores

Design of HRV analysis functionalities

We finally proceeded with design of functionalities related to HRV (Heart rate Variability) analysis and methods of integration and implementation of Matlab libraries to be used for analysis [5, 10], with particular reference to:

- Planning of the acquisition of an ECG [6, 11]
- Real-time identification of an R-R track [15]
- Data filtering
- Analysis in the time domain
- Analysis in the frequency domain [12]
- Charts of Poincarè
- Non-linear analysis.

We defined the methods for transferring the data, detected in real time, to the central OMNIACARE software platform. We decided to use the MQTT protocol, due to its low latency, low impact and low bandwidth usage qualities. For the signals related to the other vital parameters, such as respiratory frequency, posture, temperature, it was decided to use Web services in REST mode. We then proceeded to design the architecture linked to the acquisition and analysis of ECG signals, identified in the present analysis phase and to the design of the cardiological clinical file (Fig. 7).



HRV Analysis Options

IBI Preprocessing

Ectopic Detection

☐ percent 20
☐ std dev 3
☐ median 4

Ectopic Replacement

● None
○ Mean 9
○ Median 5
○ Spline
○ Remove

Detrending

Method: None

Time Domain

pNNx: 50 (ms)
SDNNi: 1 (min)

Time-Freq

Window: 30 (s)
Overlap: 15 (s)

Freq Domain

Frequency Bands

VLF (Hz): 0 - 0.04
LF (Hz): 0.04 - 0.15
HF (Hz): 0.15 - 0.4

IBI Interpolation

Interpolation Rate (Hz): 2

Points in PSD

Points in PSD (pts): 1024

Welch Options

Window Width (pts): 128
Window Overlap (pts): 64

AR Options

Burg Model Order: 16

Nonlinear

SampEn

r: 0.1 m: 3

DFA

n: 4 - 100
Break Point: 13

Time Domain

Variable	Units	Value
MeanIBI	(ms)	1065.9
SDNN	(ms)	454.8
MeanHR	(bpm)	72.3
SDHR	(bpm)	52.1
RMSSD	ms	458.6
NNx	(count)	196
pNNx	(%)	49.1
SDNNi	(ms)	480.6
Geometric Measures		
HRV Triangular Index		3.7
TINN	(ms)	465.8

Fig. 7 HRV analysis in OMNIACARE

6 Conclusions

The Rehab-Dem project addresses people affected in general by neurodegenerative disorders and in this case dementia and Alzheimer, acting on those which are considered to be the main challenges that are faced by these types of users. It also has complementary purposes, among which is to meet the needs of caregivers/family members and medical staff and therapists involved in the care of the assisted. We believe in the possibility to contribute in improving the health and psycho-physical well-being of people affected by neurodegenerative diseases, thanks to the implementation of a properly-designed integrated ICT system. By conveying skills of excellence in different and specific areas, the strategy pursued by the partners involved in this project stems from the will of create a highly innovative system to deal with needs arising from patients with dementia and with the socio-economic burden resulting from their disease. The work to be carried out in next months will provide experiences and clues to reach this ambitious objective.

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References

1. Akselrod S, Gordon D, Ubel FA, Shannon DC, Berger AC, Cohen RJ (1981) Power spectrum analysis of heart rate fluctuation: a quantitative probe of beat-to-beat cardiovascular control. Science 213(4504):220–222
2. Allan LM, Kerr SR, Ballard CG, Allen J, Murray A, McLaren AT, Kenny RA (2005) Autonomic function assessed by heart rate variability is normal in Alzheimer's disease and vascular dementia. Dement Geriatr Cogn Disord 19(2–3):140–144
3. Balocchi R, Cantini F, Varanini M, Raimondi G, Legramante JM, Macerata A (2006) Revisiting the potential of time-domain indexes in short-term HRV analysis. Biomed Tech 51:190–193
4. Brennan M, Palaniswami M, Kamen P (2001) Do existing measures of Poincare plot geometry reflect nonlinear features of heart rate variability? IEEE Trans Biomed Eng 48:1342–1347
5. Casacci P, Pistoia M (2016) Remote circadian rhythm monitoring in Alzheimer-affected people: a telehealth experience. In: Proceedings of ISOCS-MINAB-ICT
6. Coppola L, Mastrolorenzo L, Coppola A, De Biase M, Adamo G, Forte R, Fiorente F, Orlando R, Caturano M, Cioffi A, Riccardi A (2013) QT dispersion in mild cognitive impairment: a possible tool for predicting the risk of progression to dementia? Int J Geriatr Psychiatry 28(6):632–639
7. Davis FD (1989) Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Q 13(3):319–340
8. Ferrazzoli D, Sancesario G (2013) Development and significance of the frailty concept in the elderly: a possible modern view. CNS Neurol Disord Drug Targets 12(4):529–531
9. Graziola I, Pianesi F, Zancanaro M, Goren-Bar D (2015) Dimensions of adaptivity in mobile systems: personality and people's attitudes. In: Proceedings of the 10th international conference on intelligent user interfaces (IUI '05)
10. Kasanuki K, Iseki E, Fujishiro H, Ando S, Sugiyama H, Kitazawa M, Chiba Y, Sato K, Arai H (2015) Impaired heart rate variability in patients with dementia with Lewy bodies: efficacy of

electrocardiogram as a supporting diagnostic marker. Parkinsonism Relat Disord 21(7):749–754

11. Leitch A, McGinness P, Wallbridge D (2007) Calculate the QT interval in patients taking drugs for dementia. BMJ 335(7619):557
12. Malliani A, Pagani M, Lombardi F, Cerreti S (1991) Cardiovascular neural regulation explored in the frequency domain. Circalation 84:1482–1492
13. Mellingsæter MR, Wyller TB, Ranhoff AH, Bogdanovic N, Wyller VB (2015) Reduced sympathetic response to head-up tilt in subjects with mild cognitive impairment or mild Alzheimer's dementia. Dement Geriatr Cogn Disord Extra 5(1):107–115
14. Pistoia M, Parata C, Giugni P, Urlini G, Loi S, Borrelli G (2017) Virtual modeling of the elderly to improve health and wellbeing status: experiences in the active ageing at home project. In: Proceedings of ForITAAL 2017
15. Raimondi G, Legramante JM, Scordamaglia B, Masci I, Montanari G, Pampena R, Skroza N, Potenza MC (2014) Linear and non-linear R-R interval variability analysis in the neurovegetative cardiovascular assessment in Psoriasis and Obesity. Appl Inf Syst Eng Biosci 61–69
16. Raimondi G, Casacci P, Sancesario G, Scordamaglia B, Melchiorri G, Pistoia M (2016) Telemedicine for dementia-affected patients: the AAL-ACCESS Project experience. In: Ambient assisted living proceedings of 7° ForITAAL

Preliminary Analysis of the OPENCARE System Architecture in Residential Facilities

**Vera Stara, Paolo Olivetti, Ennio Gambi, Adelmo De Santis,
and Rossana Galassi**

Abstract The constant increase in the age of the population requires the construction of a model of care able to satisfy ever-increasing requirements of hospitality for the elderly in care facilities. At the same time, however, a demand for great transparency comes from families regarding the type and quality of care provided to patients. The OPENCARE project, now in its third year of activity, has the objective of creating an automatic tool to promote communication between residential structures and families, so as to increase the exchange of information without further weighing on the workload of the operators. This paper describes the technological platform that has been developed, based on the acquisition of data by sensors and on a WEB application through which operators memorize the performed activities. All the information acquired is the basis for processing communications to be sent to families, via messages or apps on smartphones.

1 Introduction

The unprecedented growth of older adults worldwide is pushing the quality of care and services offering by nursing homes. Information technology seems to drive quality improvement, support accounting, human resource, and regulatory compliance in the long term care sector [1]. An italian experience in the field is represented

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by the OPENCARE project, that aims to improve efficiency and efficacy of care processes in the residential facilities, through the use of a modular platform integrated with a distributed smart environment [2, 3]. The project envisages a modular user-centered platform for residential facilities based on a distributed intelligent environment that integrates technological solutions for guest beds and work trolleys with a domotic sensorial infrastructure. The project therefore aims to create a management model based on the use of the new data collected for monitoring and evaluating the processes and predicting the associated risks up to reaching an industrial plan shared between the participating companies. The integrated platform is able to acquire and process the data generated, integrate this information with the user data so as to allow the display of the complete picture relative to the user's situation. Through this platform it is therefore possible to have an immediate picture of the state o it is therefore possible to have an evidence of the state of health of the user, of the drug therapy, of his diet and of the treatments to which he/she is subjected during his hospitalization. The platform therefore represents the essential basis on which is developed the interaction model with the user's family members, who can participate clearly and immediately in the life of their relative.

Based on the system architecture described in [3], the platform currently implemented at the residential facilities for the elderly participating in the OPENCARE project consists of:

- A WEB application executed on a touchscreen tablet, appropriately designed to provide operators of residential facilities with a simple and effective tool for storing the user's health condition, the therapies, the activities performed and particular situations of interest that can be presented. This application shows the operator a "button" graphic interface that reduces the need for writing as much as possible.
- An intelligent bed system in which an accelerometer sensor has been installed under the mattress. The purpose of this sensor is to acquire the BallistoCardioGraph BCG signal to extract useful information regarding the time spent in bed by the user, the state of agitation, the heart rate, the breathing rate. The bed is also equipped with a video-communication system whose interface has been designed to be extremely simplified, therefore suitable also for elderly users or those with reduced cognitive abilities;
- An environmental data sensor, which detects air quality data in the rooms where users are hosted. In particular, the temperature and humidity of the air are constantly monitored, as well as the presence of ammonia NH3 particles and VOC Volatile Organic Components. The combination of these data provides an indication of the healthiness of the rooms, and of the degree of attention paid to the care of the guests and the cleanliness of the rooms.

All generated data are stored in multiple databases in order to be processed to generate appropriate information to share with family members. The need to have multiple databases is due to the different communication protocols implemented, their acquisition period and nature of sored data. In fact, the bed sensor uses the HTTP protocol with an acquisition time of 1 min, the air quality sensor uses MQTT [4] with an acquisition time of 10 min, while the operator information is asynchronously entered via a WEB application and stored directly on a database. Interoperability [5] between these different data is therefore implemented at the processing application level, which deals with extracting the data from the databases, organizing them on the basis on their timing in order to obtain the required outputs. The information to send to the families is mainly related to the primary needs of guests, as health information is immediately processed by medical or nursing staff to activate the necessary therapies. The family members of the guests are therefore provided daily with information relating to their relatives and concerning:

- Feeding—it is communicated if the user has fed, which food has preferred and in what quantity; it is communicated if the user is subjected to a particular diet;
- Hydration—it is communicated if the user has taken liquids, in what quantity and at what time of the day;
- Movement—how many times, at what time of day and where did he/she go;
- Mobilization—how many times during the day;
- Sleep—quality and duration of sleep;
- Bathroom—it is communicated when the user is washed;
- Animation / physiotherapy activities—it is communicated when the user performs physical activity, group animation or personalized physiotherapy.

The introduction of this platform not only increases the quality of the working conditions of the operators and the life of the guests, but also that of their family members who can take advantage of a special smartphone application in which to view all the assistance processes in real time and the care provided to the guest guaranteeing absolute transparency of the residential structure.

The paper is organized as follows: Sect. 2 describes the Participatory Design Approach; Sect. 3 discusses the data obtained from the Air Data Sensors while Sect. 4 concludes the paper.

2 The Participatory Design Approach

The OPENCARE project follows a participatory design approach since the beginning. The definition of the design concept was developed providing insights from the involvement of 5 companies, 3 care service providers, two universities and one research centers. The active involvement of all stakeholders from the outset represents a strategic path to match the needs of future beneficiaries with the proposed technology. As reported in Stara et all [2], the preliminary participatory design phases of the OPENCARE development were the definition of the users' need framework and the elicitation of system's goals and secondly, the match between these users' needs and the system functionalities. A step forward from these phases has been the definition of the user interface (UI).

2.1 The User Interface

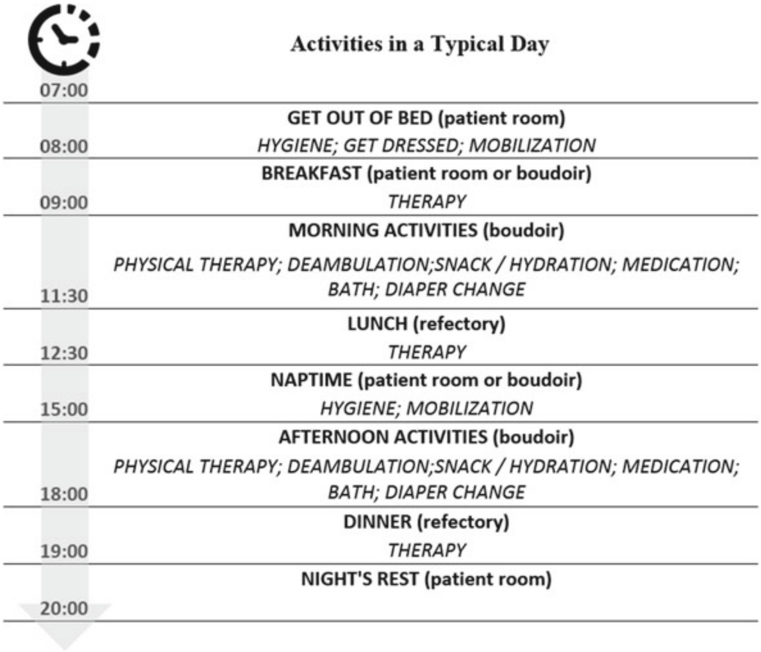
In order to correctly focuses on anticipating what users might need to do and ensuring that the interface has elements that are easy to access, understand, and facilitate their daily activities, each care service providers involved in the project were further investigated.

Firstly, through direct observations and collection of work plans in the three facilities an analysis of what a typical day looks like was performed. The main objective was to recognize types and methods used by professionals to record and track information. The information collected were elaborated to understand how to support nurses and operators in the care process among the day.

Figure 1 shows a view of a typical day of the guests. Activities and locations are described as a function of the time.

Secondly, information collected were categorized and analyzed to draft a highly intuitive user interface tables to support all the 3 care providers in the daily data entry activity.

The first problem arose in the design of the UI was the log-in as a required action to work with the OPENCARE track system and consequently match information with the specific guest. At the beginning of the project, to ensure an adequate efficacy of the solution, the authentication of each guest was supposed to be done automatically



Activities in a Typical Day

07:00

GET OUT OF BED (patient room)
HYGIENE; GET DRESSED; MOBILIZATION
08:00

BREAKFAST (patient room or boudoir)
THERAPY
09:00

MORNING ACTIVITIES (boudoir)
PHYSICAL THERAPY; DEAMBULATION;SNACK / HYDRATION; MEDICATION; BATH; DIAPER CHANGE
11:30

LUNCH (refectory)
THERAPY
12:30

NAPTIME (patient room or boudoir)
HYGIENE; MOBILIZATION
15:00

AFTERNOON ACTIVITIES (boudoir)
PHYSICAL THERAPY; DEAMBULATION;SNACK / HYDRATION; MEDICATION; BATH; DIAPER CHANGE
18:00

DINNER (refectory)
THERAPY
19:00

NIGHT'S REST (patient room)
20:00

Fig. 1 View of a typical day of the guests through nfd/rfid technology fixed in the smart cart that are very close to the guest and in particular, in most of cases, to the bed of the guest.

After a check in all the care providers' sites, it was quite clear that this approach was difficult to realize due to concerns about hygiene rules and maneuvering spaces of the cart. For this reason, a portable barcode reader was implemented to facilitate the selection/authentication of the guest.

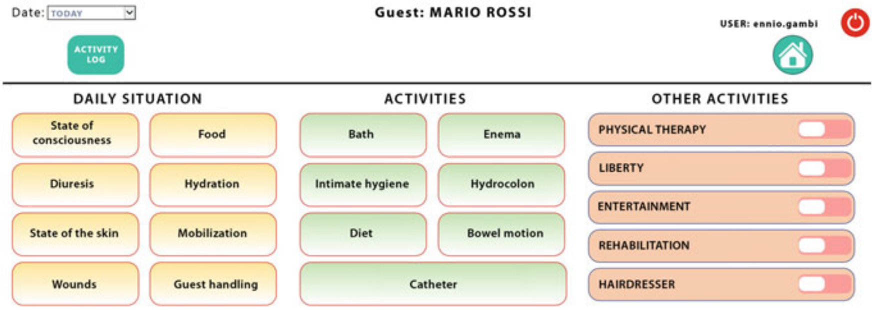
Figure 2 shows a view of the page where is possible to select guest through the barcode or manually by opening the list. Figure 3 shows the mockup of the dashboard of a specific guest.

After the log-in, the UI is composed by three different modules that displays all the different actions mapped in the typical day. This structure enables professionals to easily record data by pressing the related button. This flexible and modular approach allows the adaptability of such interface to the different pilot sites. The effective impact of this flexibility will be investigated during the field test.

Actions were categorized in three different categories: daily situation; activities; other activities. Daily situation includes all the information related to (or directly attributable to) a specific observation done by the caregiver on the health status of the guests. Activities and other activities include actions performed by professionals: from personal care to residents and nursing care to other activities that highlights to the professionals not common activities performed during the day (this section contains all the activity that are not related to the clinical assistance).

USER: ennio.gambi

Fig. 2 Guest selection

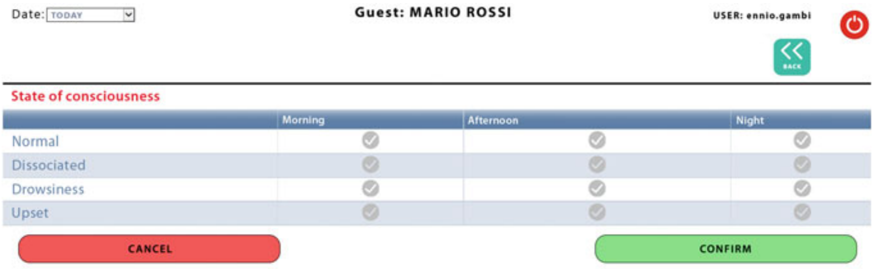


Date: TODAY

Guest: MARIO ROSSI

USER: ennio.gambi

Fig. 3 Mockup of the dashboard of a specific guest



Date: TODAY

Guest: MARIO ROSSI

USER: ennio.gambi

State of consciousness

	Morning	Afternoon	Night
Normal	✓	✓	✓
Dissociated	✓	✓	✓
Drowsiness	✓	✓	✓
Upset	✓	✓	✓

Fig. 4 Mockup of the status of conscious subpage

Date: TODAY

Guest: MARIO ROSSI

USER: ennio.gambi

Date	Registered on	Anatomical part
20190219	2019-02-19 14:14:37	Hand LH
20190219	2019-02-19 13:30:24	Foot RH
20190131	2019-01-31 10:55:51	Ear RH
20190131	2019-01-31 10:53:49	Sacrum
20190131	2019-01-31 10:52:56	Ear RH

Fig. 5 Mockup of the wounds subpage

Some exceptions in the categorization were made (i.e. handling) by prioritizing the timeline of observation/activities that normally professionals perform rather than the respect of the category.

Finally, for each information (excluding "other activities") a subpage was drafted to simply confirm the observation/action or to specify the required attributes. Below an example of two different subpages. Figure 4 shows the mockup of the status of conscious subpage. In this case professionals are asked to select the state of conscious and confirm the selection.

Figure 5 shows the mockup of the wounds subpage. In this case professionals are asked to select the state and the location of the wounds recognized.

2.1.1 The First Analysis of the Interface

In order to test the usability and learnability of the interface, a sample of 9 care workers (three representatives of each validation site), filled The System Usability Scale [6] that is a questionnaire which provides a quantitative measure of how usable a system is based on a ten statement Likert Scale (the range is from 1 to 5, with 1

Table 1 The system usability scale (Mean value and standard deviation)

Item	Mean	sd
1.-I think that I would like to use this system frequently	3,9	1,2
2.-I found the system unnecessarily complex	1,1	0,3
3.-I thought the system was easy to use	3,7	1,7
4.-I think that I would need the support of a technical person to be able to use this system	1,2	0,4
5.-I found the various functions in this system were well integrated	3,8	0,8
6.-I thought there was too much inconsistency in this system	1,7	0,9
7.-I would imagine that most people would learn to use this system very quickly	4,1	0,9
8.-I found the system very cumbersome to use	1,6	0,9
9.-I felt very confident using the system	3,6	1,2
10.-I needed to learn a lot of things before I could get going with this system	1,6	1
SUS score*(0–100)*	**79,7**	

= not satisfied and 5 = satisfied.), scored from 0–100 with 100 indicating perfect usability.

The overall score of the SUS analysis reports a 79,7 score that is a very good result (Table 1).

In terms of comparing this score to what is considered a reasonable score in literature, we can compare them to a study carried out by Jeff Sauro [7], where he calculated from a review of nearly 500 products that a score of 68 means that your product is more usable, according to the SUS, than 50% of the other products tested. With a score of 79,9 the OPENCARE interface has scored a higher Sauro's mean (with a sample of 9) making it very competitive in terms of usability. After the analysis of these results, minor improvements were implemented in the interface.

3 The OPENCARE Air Data Sensors

In recent years, attention to the air quality in healthy and long term care residences has received considerable attention [8]. Day and night monitoring of air composition, even if not performed both in qualitative and quantitative modes, can provide direct and indirect data about various aspects. In general, the information that can be obtained is related to well-being, conceived as the perception of good ventilation, the absence of undesirable odors, of appropriate humidity level but also as the monitoring of a regular functionality of human body organs [9]. In fact, it is known that in the case of diseases such as kidney failure, diabetes mellitus or infections of the gastro-enteric apparatus, unusual volatile compounds, considered markers of some diseases, are delivered through breathing or with the urine secretion [10]. In the present monitoring system, the air analysis has a multiple value: both to analyze the conditions of residence in general and the quality of the air breathed as well as to have an immediate, visual detail, even if generic and to be validated, on the occurrence of a specific disease status or to monitor if it is already known. Furthermore, an accidental event, such as the copious spillage of a detergent, disinfectant or any other sudden event that changes the composition of the gaseous mixture of the air in the room, is immediately detected and recorded, adding a further data to the multivariate information that the system implemented in this study is able to process. Noteworthy, the record of data over the day long scans systematic activities of the operators, making possible the survey of any sudden change.

For this purpose, an electrochemical multiple sensor has been chosen as detector for ammonia, a volatile compound which is related to urine components, for carbon monoxide, a pollutant due to the exposition at combustions, and for other Volatile Organic Compounds, such as ethanol, named VOCs. According to this multiple signaling sensor, concomitant or successive events resulting to a change of air's composition are recorded over the time. A cross relation of the data with the timetable recorded by nurses or assistants allows the recognition of the single event. The choice of this kind of sensor was based on its low cost and on the wide range detection of volatiles, skilled to give feedbacks of events of different nature.

4 Measurements of the Air Quality

The quality of the air has been monitored by using an electrochemical gas sensor. Technical data refers about a long life, highly sensitive and stable sensor able to furnish responses for the presence of humidity, temperature, ammonia and some VOCs. The electrochemical sensors have been installed in three residences rooms, one for each of the three long care residences participating in the project. In two of the rooms considered, two users are hosted, while in the third, there are four guests. The data was collected continuously from February 2018 with a 10 min acquisition time and was stored on a database hosted at the Polytechnic University of Marche. Following are reported typical plots of sensor responses in a cycle of 24 h.

The profile of ammonia and VOCs detection over the time highlights a trend of concentration which is witness of the daily life in a long care residence (Fig. 6). In order to correlate the data collected with the normal daily activities carried out inside the rooms, an interview was conducted with the staff of the three residential structures to find out the type and timing of the activities, and the care staff were asked to fill in a daily diary of the carried out activities. The days start at 8 am with the beginning of the personnel work inside the rooms, consisting of cleaning the room, sanitation of the patients and their mobilization. The sensor reveals clear peaks due to an increase of volatile compounds (cleaners and/or other) at 8:15, at 10:30 am and 3 pm while a broad intense profile is observed from 5 pm till 10 pm more or less. It is reasonable to assume that during the cleaning the windows were opened to allow an air fluxing. This fact leads to a steady decrease of the baseline's height, and therefore of the volatiles, in the range 9–12 am. In the afternoon the air quality

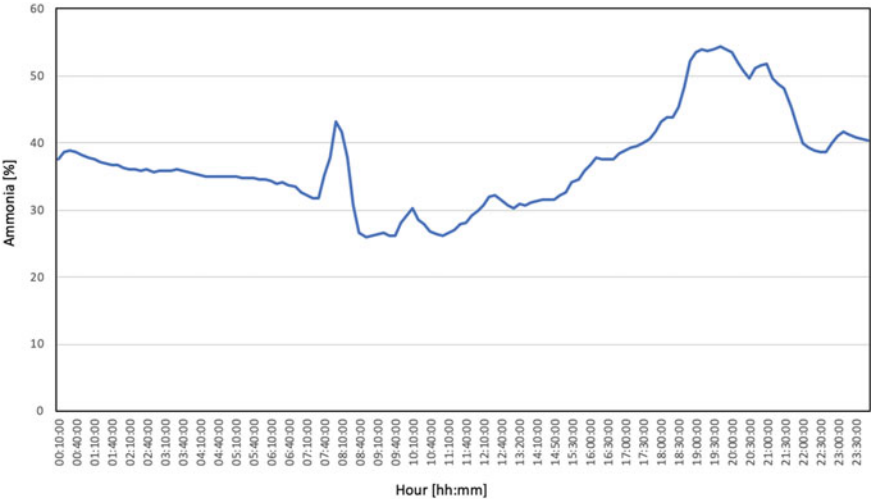


Fig. 6 Detection of the ammonia by the gas sensor over 24 h in a room of a long care residence

is likely damaged from the nap's breathing, eventual visits, dinner delivery (volatiles from meals) and other indoor activities occurring with partially or completely closed windows. The discussion of the daily activities and the interpretation of the ammonia evolution in Fig. 6 are encouraged also by the trend of humidity recorded during the 24 h cycle and reported in Fig. 7. The peaks of humidity in the morning is likely due

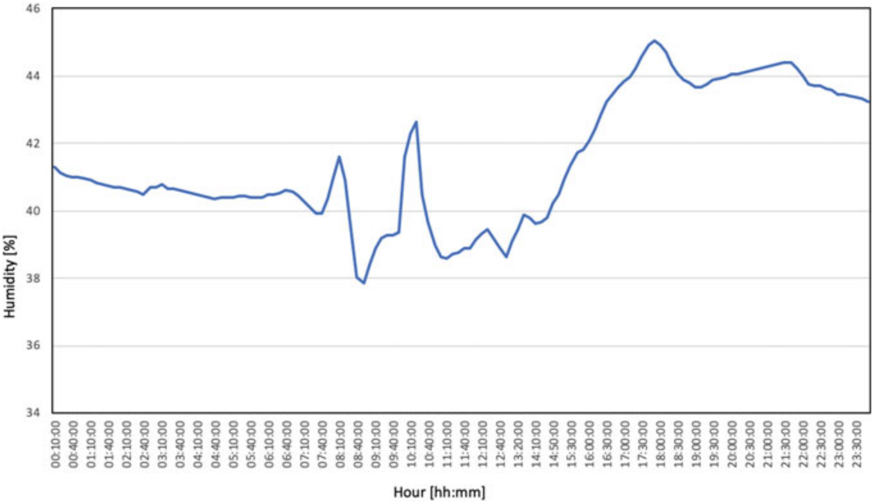


Fig. 7 Trend of the total humidity in the room in a 24 h last

to the room's floor cleaning. In the afternoon, the smooth increase of the humidity level hides the detection of most VOCs restricting the response of the analysis.

For a better comprehension, a sequence of values acquired in three successive days was chosen in one of the rooms under observation; this sequence is representative, from a qualitative point of view, of the same values acquired in the three rooms for about a year. The correlation of three days long data for ammonia, VOCs, temperature and humidity were reported in a single graph (Fig. 8), with the addition of some information obtained with the report sheets obtained from the assistant staff.

At a first glance, it is evident that this electrochemical sensor generalizes the detections, hampering any disquisition on the specific compound responsible of the outputs. In particular, we can observe that the temperature remains somehow constant during the time, unless a decrease of few degrees in the morning corresponding to the opening of the window. The constant temperature rules out the possibility to explain the smooth increase of humidity and VOCs in the late afternoon and night, both by considering a temporarily volatilization of the chemicals in the room as a consequence of an increase of the local heating, and by any influence on the sensor activity, also because the sensor technical output is independent from variation of temperature. Occasionally, the humidity levels (in example, red line, at 8:20, first day, at 11:00 s day, and at 8:00 third day) abruptly increase and the peaks coincide with those of ammonia and VOCs, even though these latter with greater intensity; these data are markers of cleaning events and care of personal hygiene and it occurs according to habitual times. In few cases, discrepancies from the two set of detection are observed, as in example at midnight of the second day a peak was detected as VOCs but not as humidity as well as in 19:00–20:40 of the third day. These discrepancies might be diagnostic of specific events which fall out the classic routine; hereby, they become the sensible parameters to be monitored and correlated to the data of the personnel sheets to be engineered. At this point of the study, from the data recorded with this set up, we can argue that the electrochemical response is sensitive of water related polar compounds (such as humidity, ammonia, alcohols) in different

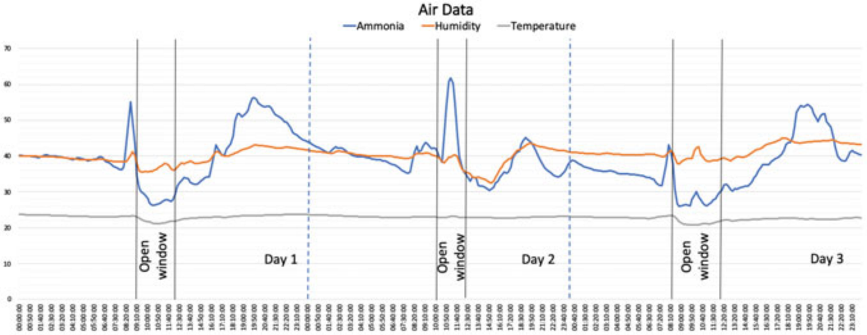


Fig. 8 Cumulative graph with the humidity (red line, top), ammonia and VOCs (blue line, in between), and temperature (grey line, bottom) detections. Vertical lines delimit time gaps of open windows of three consecutive days

extents from the quantitative point of view, but it is not able to discern the quality of the compounds; however the analysis of the data allow elaborations useful for the purposes of this project such as the remote monitoring of the general air quality, the presence of eventual pollutant, the routine of the assistance care, causal or accidental events changing the composition of the air.

5 Future Steps and Conclusion

The paper describes the activities of the OPENCARE project at the end of the second year of work. The technological substrate of the project is completed, so allowing the collection of the data related to the status of the patients, of the air quality inside the rooms and about the patient's daily activities. From this collection of the data the information to be sent to the patient's families is generated. On the basis of the preliminary data collected about the air quality, we can assess that this very cheap sensor performs the functions that have been budgeted for this real system, even if at this stage of study, only the feasibility and the potential applications have been highlighted. Future perspectives might be to provide the system with additional more specific sensors to correlates the total VOCs to the response of specific chemicals and to plan an automatic response by an intelligence elaboration of all the complex set of data obtained from the gas sensors.

References

1. Degenholtz HB, Resnick A, Lin M, Handler S (2016) Development of an applied framework for understanding health information technology in nursing homes. J Am Med Direc Assoc 17(5):434–440
2. Stara V, Spinsante S, Olivetti P, Rossi L, Montanini L, Gambi E, Ciattaglia G (2017, June) OPENCARE: emergent technologies for the care of older adults in residential facilities. In: Italian forum of ambient assisted living. Springer, Cham, pp 241–248
3. Gambi E, Ricciuti M, Ciattaglia G, Rossi L, Olivetti P, Stara V, Galassi R (2018, July) A technological approach to support the care process of older in residential facilities. In: Italian forum of ambient assisted living. Springer, Cham, pp 71–79
4. Del Campo A, Gambi E, Montanini L, Perla D, Raffaeli L, Spinsante S (2016) MQTT in AAL systems for home monitoring of people with dementia. In: Proc of IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC
5. Rossi L, Belli A, De Santis A, Diamantini C, Frontoni E, Gambi E, Palma L, Pernini L, Pierleoni P, Potena D, Raffaeli L, Spinsante S, Zingaretti P, Cacciagrano D, Corradini F, Culmone R, De Angelis F, Merelli E, Re B (2014) Interoperability issues among smart home technological frameworks. Proc of MESA 2014—10th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications
6. Brooke J (1996) SUS-A quick and dirty usability scale. Usabil Eval Ind 189(194):4–7
7. Sauro J (2011) Measuring usability with the system usability scale (SUS)
8. Dales R, Liu L, Wheeler AJ, Gilbert NL (2008) Quality of indoor residential air and health. CMAJ 179(2):147–152. doi:https://doi.org/10.1503/cmaj.070359

9. Yanyan L, Jiajie X, Xiurong S (2017) Analysis of urine composition in type II Diabetic mice after intervention therapy using holothurian polypeptides. Front Chem 5. https://doi.org/10.3389/fchem.2017.00054
10. Smith S, White P, Redding J, Ratcliffe NM, Probert CSJ (2010, Jan) Application of similarity coefficients to predict disease using volatile organic compounds.IEEE Sensors J 10(1):92–96. doi: https://doi.org/10.1109/JSEN.2009.2035771

Analysis of Human Behavior in Five Healthcare Centers for the Development of New Technologies, in Support of the Improvement of Life Quality

Margherita Rampioni, Paola Nicolini, and Luigi Mandolini

Abstract With a U-turn on the traditional view that people need to adapt to technological innovations and their surrounding environment by merely reacting to the machines' inputs, a new approach places the human being at the center of the picture, with technology serving humans by providing the right services for users and their environments. The exploration of the different aspects of human behavior in daily life contexts can contribute to the development of smart devices, in order to improve people's quality of life, notably non-self-sufficient senior people. Of the four sections of the research, in this paper we will concentrate on the 75 observations who took place in 5 facilities, in order to gather information about behaviors of the elderly that live in. The checklists' analysis shows that both men and women seem to act, physically react and voice their discomfort more in relation to cold. A huge gap seem to exist between the perceptions of senior people and those of the healthcare workers that take care of them. The aim of this study is understanding human beings through the detection of their actions and physical reactions, taking their everyday-life environments into account, in order to develop smart devices that can truly ensure users' comfort.

1 Introduction

The present research project focuses on technology enhancing users' wellbeing and comfort, especially in more vulnerable subjects, notably non-self-sufficient senior people. Over time, people have always had to adapt to technological developments,

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innovations and their surrounding environment by simply reacting to inputs provided by the machines. The analysis of human behaviors in real everyday-life situations starts from the assumption that people who act on indoor devices (related to temperature, lighting, sound, etc.), at home and in offices alike, all too often are not entirely conscious of the functioning of these systems and cannot actually achieve well-being as intended. Actively interacting with a device in order to adapt technology to the specific needs any given time can lead to non-negligible physical and cognitive efforts in weaker subjects. Precisely for this reason, such systems should "interpret" users' behaviors based on the latter's perceptions of thermal, luminous, acoustic, etc. comfort and/or discomfort in everyday-life indoor environments. According to the Domotics philosophy, the houses, if skillfully designed, can help to save mental energy and money, to pollute less and not to waste time, dedicating it for social activities and improving the quality of human lives. The elderly and the people with disabilities also benefit from a domestic environment equipped with smart devices that make life easier.

We referred to Lifespan Psychology [1, 2] that introduces an idea of humans as ever-changing beings and a new vision of elderly people and ageing: ageing is, in fact, regarded as a heterogeneous process implying decay of fluid intelligence (i.e. speed of perception, memory capacity, problem-solving) in which, conversely, crystallized intelligence-based skills (including cultural intelligence, language and social skills based on experience and expertise) can be enhanced all along one's lifespan.

Recent studies have dealt with this topic. "An intelligent domotics system to automate user actions" [3] develops a similar idea, but only from a technological point of view. "Gender differences in office occupant perception of indoor environmental quality (IEQ)" [4] points out a significant association between female gender and dissatisfaction with thermal environment. What differentiates our research from the previous ones is that our starting point of inspiration for the innovation is the human being and the human behavior.

The analysis of human behavior is achieved by using naturalistic observation in daily contexts, where human actions normally occur and the researcher exerts a minimum level of control on his/her object of study. The aim of this study is understanding human beings through the detection and the assessment of their actions and physical reactions, taking their real-life and every-day life environments into account, in order to develop devices that can truly ensure users comfort.

2 The Project

The project was developed within a Eureka Research Program funded the Marche region, the University of Macerata and the company MAC srl.

MAC designs, develops and produces cutting edge electronic systems, putting the user experience at the center of every project. The central idea of this research was conceived by MAC, that then asked the University of Macerata to collaborate with a humanistic contribution. Both the University of Macerata and MAC agree that studying human being and his/her behavior is the starting point of inspiration for the innovation. According to both these visions, the end user becomes the sensor that guides the research and the design of smart devices.

Starting from the concept of thermal comfort, we worked on this project for over three years and we would consider further possibilities of application of the methodology we are testing.

3 Objectives

We began with a research question: "Is it possible to create the ideal comfort (thermal, luminous, acoustic, etc.) in an indoor environment, while minimizing the end user's activity when he/she is searching for it?".

To answer this question, we set the following objectives:

1. To profoundly study the different aspects of human behavior in everyday life;
2. To make available to the company useful data for the possible development of smart and multifunctional indoor systems, able to "interpret" end users' behaviors (for example, through sensors), above all on the basis of age and gender, in order to provide them—in particular, non-self-sufficient ones—with the ideal comfort level, in private and institutional environments.

4 Methods

4.1 Observations in Different Indoor Environments

From April 21st, 2016 to July 12th, 2018 we made observations in various indoor environments, public and private—houses, offices, universities, etc.—both in Italy and abroad, in order to detect the different behaviors and physical reactions an end user has when feeling uncomfortable with the environment around him/her, specifically indoor ones, in terms of temperature.

We also recorded dates and places of observation, age and gender of the observed people, as well as indoor and outdoor temperature of the examined environment.

4.2 Observations in Healthcare Centers

We contacted 5 healthcare centers (nursing homes and rehabilitation centers) in the center of Italy, that were selected on the basis of the regional offering and their willingness to participate in this project.

From October 26th, 2016 to July 4th, 2017 we conducted field observations to collect data about behaviors and live reactions regarding temperature, lighting, security, etc. of the elderly that live in these facilities.

Within the centers, we noted everything under or above the threshold of normal conditions, considering it irregular and, for this reason, symptomatic of some discomfort or disease.

4.3 Interviews with Health Professionals

From November 21st, 2016 to May 30th, 2018 we conducted interviews with 6 different categories of Health Professionals (*Doctors, Psychologists, Nurses, Nursing Assistants, Physiotherapists, Social Educators*) to gather information and opinions based on their direct experience with the context and the people who inhabit it.

4.4 Questionnaires to Different Age Groups

From April 5th to July 17th, 2018 we administered a frequency scale questionnaire to five different age groups [15–29 years (*young*), 30–44 years (*young adult*), 45–59 years (*middle adult*), 60–74 years (*young seniors*), 75–89 years (*middle seniors and oldest seniors*)], gender balanced, in order to evaluate the validity of the observation sheets, collected through the checklist, in various indoor environments and to gain more information about observed people's perceptions.

5 Research Instruments

5.1 The Naturalistic Observation

Checklist on Temperature: is made up of two lists of potential behaviors, the first one on the sensation of heat and the second one on the sensation of cold.

Checklist on Lighting: the first part pertained to insufficient illumination, the second one to excessive illumination.

5.2 The Structured Interview

We asked Health Professionals to analyze a list of possible behaviors that an elderly person could implement in an indoor environment and to specify which ones could be perceived as symptoms and, eventually, symptoms of what type of discomfort or disease.

5.3 The Questionnaire

We asked 5 different age groups to express how they behave when feeling (too) hot or (too) cold in an indoor environment and, for each behavior on the list, to select only a recurrence among “never”, “rarely”, “often” and “always”.

6 Data Collection

We collected 800 observation sheets in different indoor environments (universities, restaurants, offices, houses, etc.), 75 observation sheets in 5 healthcare centers, 60 interviews with Health Professionals and 100 questionnaires to five different age groups.

Of the four sections of the research, in this paper we will concentrate on the observations who took place in the facilities.

6.1 The Healthcare Facilities Participating in the Project

Five healthcare centers—more specifically, nursing homes and rehabilitation centers—located in the Italian region Marche took part in this project. Selection took place based on geographical proximity and availability to join the project.

Table 1 lists the healthcare centers that participated in the present research, together with their respective location, healthcare categories and number of residents.

The healthcare centers are: I.R.C.E.R. Foundation—Assunta in Recanati (Province of Macerata), Villa Letizia in Civitanova Marche (Province of Macerata), the “Santo Stefano” rehabilitation institute in Porto Potenza Picena (Province of Macerata), Casa Hermes in Loreto (Province of Ancona) and the care home Casa di Ospitalità in Castelraimondo (Province of Macerata).

Inside these healthcare centers, a total of *75 field observations* (15 for each healthcare center) have been carried out in relation to mainly temperature and lighting. Observations took place from October 2016 to July 2017, spanning all four seasons. Two checklists have been devised to conduct field observations. Both checklists aim at detecting behaviors (directed towards both oneself and one’s environment), physical reactions and occurrences of verbal communication which can be read as a display of discomfort, both at thermal (hot/cold) and luminous (lighting) level, as felt by senior residents inside these facilities. Dates and places of observations,

Table 1 Healthcare facilities joining the project

Name	Town	Healthcare category	N. of residents
I.R.C.E.R. Foundation	Recanati	Care home Nursing home	65
Villa Letizia	Civitanova Marche	Care home Temporary relief facility	57
Santo Stefano	Porto Potenza Picena	Long-term care facility	40
		A3 ward	33
Casa Hermes	Loreto	Care home Nursing home	72
Casa di Ospitalità	Castelraimondo	Care home Nursing home Day care center	40

time of the day, age and gender of monitored subjects as well as indoor and outdoor temperatures in every location have all been recorded.

7 Data Analysis

We carried out a descriptive analysis of the 75 observation sheets collected in five healthcare centers.

Table 2 is an overview of all behaviors related to heat, cold, lighting and various factors. Their respective frequencies are sorted by gender.

8 Discussion

The detected behaviors amount to a total of 83. Generally speaking, female residents are much more than their male counterparts inside these healthcare facilities. Consequently, this may have an impact on the fact that most detected behaviors are female ones (74). Actions directed towards oneself are more frequent than physical reactions and occurrences of verbal communication. *No action directed towards one's environment has been detected*. The single heat-related behavior with the highest frequency is taking off one's clothes (9), with coughing ranking highest among cold-related behaviors (12). In relation to lighting, putting on one's spectacles ranks highest (2), whereas the category "various" is dominated by yawning (3). *Coughing* (12) is the single reaction with the highest frequency. Most occurrences of verbal communication are related to the sensation of cold (10); among these, there is also one male occurrence. *Third-person statements* display the highest frequency compared to other categories, in relation to both heat (3) and cold (6). As shown in Table 2, *both men and women seem to act and react to, and voice their perceptions more in relation*

Table 2 Overview of all detected behaviors: frequencies are sorted by gender

Behaviors	M	F	Total
Heat			
Taking off one's clothes	0	9	9
Verbal communication occurring	0	6	6
Pulling up one's sleeves	0	4	4
Fanning oneself with one's hand/piece of paper	0	2	2
Wiping off one's sweat with hand/handkerchief	0	1	1
Unbuttoning/unzipping one's coat	1	0	1
Taking off lap blanket	0	1	1
Unbuttoning one's shirt/sweater	1	0	1
Pulling one's collar	0	1	1
Pulling up one's trouser legs	0	1	1
Touching one's face	1	0	1
Subtotal	3	25	28
Cold			
Coughing	1	11	12
Verbal communication occurring	1	9	10
Rubbing/cleaning one's nose with handkerchief/tissue	0	9	9
Putting on ones' clothes (also on shoulders only)	1	5	6
Pulling down one's jumper sleeves	0	2	2
Getting closer to the heater (also on wheelchair)	1	1	2
Sneezing	0	2	2
Sipping from a hot drink	1	0	1
Getting away from the door/window	0	1	1
Subtotal	5	40	45
Lighting			
Putting on one's spectacles	0	2	2
Verbal communication occurring	0	1	1
Subtotal	0	3	3
Various			
Yawning	0	3	3
Wiping off/rubbing one's eyes with handkerchief/hands	1	1	2
Snoring	0	1	1
Rubbing/scratching one's upper body	0	1	1
Subtotal	1	6	7
Total	9	74	83

to cold than heat (45). Inside these healthcare facilities, cold-related behaviors are more than heat-related ones, the ratio being 4 to 1. The one and only facility where most detected behaviors are related to heat is I.R.C.E.R. Foundation, despite the fact that observations there took place during the colder part of the year (autumn/winter). It is safe to say that the indoor heating system there is probably set at a very high temperature, as reflected in the perceptions of senior residents. At I.R.C.E.R. Foundation, moreover, the lower variety of behaviors has been recorded, with the larger variety being at "Santo Stefano". At "Santo Stefano", the largest number of behaviors has been detected compared to all other healthcare facilities (20), presumably because two different wards have been monitored. The highest average age among residents has been recorded at Casa di Ospitalità (89.4 years), while the lowest has been recorded at "Santo Stefano" (81.3 years), probably due to the fact that generally people from all age groups enter rehabilitation centers like this one, from young adult to older seniors.

9 Conclusions

The present paper outlined data resulting from field observations on the subject of ageing which took place in five healthcare facilities (nursing homes and rehabilitation centers) in the Marche region (Italy), in order to detect behaviors (directed towards oneself and one's environment), physical reactions and occurrences of verbal communication that can be interpreted as display of any discomfort at thermal (hot/cold) and luminous level as perceived by senior residents inside these facilities. The following step was a descriptive analysis of all behaviors detected in the five healthcare facilities in relation to both temperature and lighting, with attention given also to gender differences. Additionally, the sentences uttered by the subjects in relation to their perception of heat/cold/lighting were recorded during observations and later analyzed. These have been divided into impersonal statements, first-person statements and action-related sentences. Impersonal statements display the highest frequency compared to all other categories, both in relation to heat (3) and cold (6). Lastly, a global analysis of all behaviors detected in all five facilities in relation to temperature, lighting and other categories followed, with attention given to gender too.

Observations indicate that, generally speaking, in these facilities the number of female residents is much larger than that of men, which is probably the reason why more female behaviors have been recorded (74). *Actions directed towards oneself are more frequent than physical reactions and occurrences of verbal communication, and no action directed towards one's environment has been recorded.* The single heat-related behavior with the highest frequency is taking off one's clothes (9), while the single cold-related behavior with the highest frequency is coughing (12). The single most frequently detected behavior in relation to lighting is putting on one's spectacles (2), whereas the category "various" is dominated by yawning (3). Coughing (12) is the single reaction with the highest frequency. Most occurrences of verbal communication are linked to the sensation of cold (10); they include a male occurrence. Moreover, *both men and women seem to act, physically react and voice their discomfort more in relation to cold (45).* Women additionally tend to act much more than men, and they are normally sensitive to temperature and choose more carefully the right clothes based on indoor and outdoor temperatures.

Scholarly sources [5] suggest that elderly people display a reduced thermoregulatory capability, which is linked—together with additional changes of one's body composition—to a decrease of the total of water in the human body. Body temperature is therefore lower in senior people, *their perception of cold being one symptom of ageing, especially in bedridden and non-self-sufficient subjects* [6]. Also in relation to temperature, men and women dress differently. Women have a lower metabolic rate than men during sedentary activities, and their regulatory hormones affect their reactions with regard to their thermal comfort, thermoregulation and thermogenic thresholds, as women have different hormone levels as compared to men [4]. Additionally, as the outcomes of other studies [7, 8, 3, 4, 9, 10], [11] carried out in various indoor environments indicate, *women are less satisfied with room temperatures and generally prefer higher temperatures than men, with discomfort in relation to both heat and cold being reported much more frequently in women than men.*

Based on observations, the behaviors displayed by senior people residing in healthcare facilities seem to indicate their discomfort in relation to both temperature and lighting. *A huge gap seem to exist between the perceptions of senior people and those of the healthcare workers that take care of them.* Two occurrences of verbal communication, namely by the woman who suffered from a stroke and the 100-year-old woman, respectively, indicate that the need to communicate one's need transcends physical and mental conditions and age alike. This shows that also those seniors whose health is most heavily affected try—insofar as possible—to continue voicing their discomfort. Subsequent data analysis provided for an insight into frequent displays of thermal and luminous discomfort experienced by senior people in their everyday-life environments, that they are not always able to communicate to the healthcare staff who takes care of them. These data can be used to plan devices that can effectively ensure comfort and improve the quality of life of individuals, including more vulnerable categories such as non-self-sufficient senior people. In this regard, while planning these devices, it will be crucial to consider what a number of scholarly sources [12–21, 9, 22, 23] cite as the most important characteristics of smart devices for senior people: these are reliability, user-friendliness, emergency detection, reduced user's input, low maintenance costs, low invasiveness (privacy) and voice interface technology (audio input). Acceptance by senior users is reportedly a key factor in integrating new technologies into already existing houses. The success of new technological devices lies not only in the tools per se, but also in the assistance and training that is provided. This feeds into the notion of Ageing in Place, by which senior people can exert control over their own environment and daily activities to improve their perceived autonomy, health, wellbeing and dignity.

References

1. Baltes PB (ed) (1978) Life-span development and behavior, vol 1. Academic Press, New York, NY
2. Baltes PB (1987) Theoretical propositions of life-span developmental psychology: on the dynamics between growth and decline. Dev Psychol 23:611–626
3. Kcomt Ché N, Pardons N, Vanrompay Y, Preuveneers D, Berbers Y (2010) An intelligent domotics system to automate user actions. In Augusto JC, Corchado JM, Novais P, Analide C (eds) Ambient intelligence and future trends—international symposium on ambient intelligence (ISAmI 2010). Advances in intelligent and soft computing, vol 72. Springer, Berlin, Heidelberg, pp 201–2014, 16–18 June 2010
4. Kim J, de Dear RJ, Candido C, Zhang H, Arens E (2013) Gender differences in office occupant perception of indoor environmental quality (IEQ). Build Environ 70:245–256
5. Franceschi C, Pauletto P, Incalzi RA, Fabbri LM (2011) Invecchiamento, infiammazione sistemica e malattie croniche complesse. Ital J Med 5S:S3–S13
6. Bragagni G, Alberti A, Castelli G, Lari F (2012) Ipotermia accidentale nell'anziano. Ital J Med 6(1):47–51
7. Choi JH, Aziz A, Loftness V (2010) Investigation on the impacts of different genders and ages on satisfaction with thermal environments in office buildings. Build Environ 45:1529–1535
8. Karjalainen S (2007) Gender differences in thermal comfort and use of thermostats in everyday thermal environments. Build Environ 42:1594–1603
9. Parsons KC (2002) The effects of gender, acclimation state, the opportunity to adjust clothing and physical disability on requirements for thermal comfort. Energy Build 34(6):593–599
10. Zalejska-Jonsson A, Wilhelmsson M (2013) Impact of perceived indoor environment quality on overall satisfaction in Swedish dwellings. Build Environ 63:134–144
11. Karjalainen S (2012) Thermal comfort and gender: a literature review. Indoor Air 22: 96–109
12. Baldewijns G, Debard G, Mertens M, Devriendt E, Milisen K, Tournoy J et al (2013) Semi-automated video-based in-home fall risk assessment. In: Encarnação P, Azevedo L, Gelderblom GJ, Newell A, Mathiassen N (eds) Assistive technology: from research to practice (AAATE 2013 conference proceedings), vol 33. IOS Press, Amsterdam, pp 59–64
13. Coughlin J, D'Ambrosio LA, Reimer B, Pratt MR (2007) Older adult perceptions of smart home technologies: implications for research, policy & market innovations in healthcare. In: IEEE proceedings of the engineering in medicine & biology annual conference, pp 1810–1815
14. Demiris G, Rantz MJ, Aud MA, Hussam AA (2004) Older adults' attitudes towards and perceptions of 'smart home' technologies: a pilot study. Med Inform Internet Med 29(2):87–94
15. Dohr A, Modre-Opsrian R, Drobics M, Hayn D, Schreier G (2010) The internet of things for ambient assisted living. In: ITNG'10—proceedings of the 2010 seventh international conference on information technology: new generations, pp 804–809
16. Hamal Mishra B (2015) Attitude of senior citizens towards smart home technologies: a literature review. Bachelor's dissertation, Arcada University of Applied Sciences, Helsinki, Finland. https://www.theseus.fi/handle/10024/103748
17. Kleinberger T, Becker M, Ras E, Holzinger A, Müller P (2007) Ambient intelligence in assisted living: enable elderly people to handle future interfaces. In: UAHCI'07—proceedings of the fourth international conference on universal access in human-computer interaction: ambient interaction, pp 103–112
18. Krafft M, Coskun K (2009) Design aspects for elderly using a health smart home. Bachelor of Software Engineering & Management thesis
19. Losardo A (2014) Strumenti per l'analisi comportamentale in contesti di Ambient Assisted Living. PhD thesis, Università degli Studi di Parma, Parma, Italy. https://dspace-unipr.cineca.it/handle/1889/2534
20. Mohammadi M (2010) Empowering seniors through domotic homes: integrating intelligent technology in senior citizens' homes by merging the perspectives of demand and supply. PhD thesis, Eindhoven University of Technology, Eindhoven, The Netherlands. https://repository.tue.nl/674707

21. Motta T (2015) Ambient Assisted Living: Indicatori quantitativi per monitorare la routine di una persona. Bachelor's dissertation, Politecnico di Milano, Milano, Italy. https://www.politesi.polimi.it/handle/10589/119301
22. Portet F, Vacher M, Golanski C, Roux C, Meillon B (2013) Design and evaluation of a smart home voice interface for the elderly—acceptability and objection aspects. Pers Ubiquitous Comput 17(1):127–144
23. Sun H, De Florio V, Gui N, Blondia C (2009) Promises and challenges of ambient assisted living systems. In: ITNG'09—proceedings of the 2009 sixth international conference on information technology: new generations, pp 1201–1207

MAESTRO, an Integrated Quality Assurance Framework for Seniors

Marie-Laure Watrinet and Francesca Fracasso

Focus on the repository and profile functionalities of the MAESTRO platform.

Abstract The current chapter introduces the Integrated Quality assurance framework implemented in MAESTRO's project. This framework aims at improving seniors' quality of life and well-being by the way of an ICT platform enabling to view a selection of health-related products recommended to seniors based on their needs by the use of profiling and of assessment methodologies. A focus is done on several functionalities offered by the MAESTRO platform: the repository of products organised by using a taxonomy built during the project; profiling functions for the products and the end-user enabling to recommend products to the end-user, and the assessment function provided by qualified users that evaluate the usage of the products by end-users. On this chapter, we focus on the repository of products and profiling functions proposed by the project.

1 Introduction

1.1 Introduction to MAESTRO's Project

MAESTRO (Sustainable Reference Framework evaluating quantified-self equipment and services for seniors) is an AAL (Active Assisted Living) programme project that started in October 2015 until December 2018. The partnership is composed of members from Luxembourg (lead partner), Italy, Switzerland and Ireland.

MAESTRO consists in an Integrated Quality assurance framework [1] having objective to help increasing the quality of health-related monitoring systems and

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services (called "products") in order to improve the seniors' quality of life. For this, MAESTRO proposes a Reference Framework [2] (methodological framework, taxonomies, profiling and assessment methodology) and a web-based ICT platform applying the principles defined within the Reference Framework.

This article focusses on the functionalities of platform developed during the project; the usage of the platform is explained following the example of a product: Memoride.

1.2 Introduction to MAESTRO's Platform

The platform enables to access to a database of products dedicated to seniors that can be from a bracelet monitoring the heart beat to some equipment enabling a senior to stay at home as a fall detector, bed sensors and alarm buttons.

Different kind of roles can access the platform:

- Manufacturers that are producing products and would like to sell them or solution providers that are distributing the products. Manufacturers and solution providers have the possibility to use the platform to increase the visibility of their products and to propose them to end-users.
- End-users: seniors or organisations of users can use the platform to identify the products that best fit their needs.
- Assessors: qualified users using the platform to assess the usage of products visible on the platform.

2 Repository and Taxonomy of Products

2.1 Repository

MAESTRO aims at proposing a repository of health-related products to improve senior's well-being and health. Part of this repository (also called database) are AAL solutions. Those products are structured according to a taxonomy that has been defined during the project.

It is composed of different system types (e.g. fall detection, sleep monitoring, alerting) and system characteristics supporting different health needs (e.g. blood pressure device). Social relations and communication are also taken into account (e.g. facilitating contacts).

2.2 Taxonomy

The used taxonomy is based upon a merge of the identified user needs that have been identified at the beginning of the project through interviews with potential end-users and the categories of the WHO's (World Health Organization) International Classification of Functioning, Disability and Health (ICF) [3, 4].

The categories considered through the ICF-related taxonomy covers the following aspects and sub-aspects:

- Home environment: Environmental control & Safety
- Mental wellbeing: Mental wellbeing / Emotional wellbeing / Communication / Social life
- Sensory wellbeing: Vision / Hearing / Other senses
- Life style and fitness: Sleep / Physical activity / Health monitoring / Diet & nutrition / Hydration / Self-care / Domestic life

The taxonomy serves for identifying both the user's needs and the solutions accordingly to the needs that they can deal with. For this purpose, a dedicated questionnaire has been developed upon these categories during the project life to be filled in by both seniors and solution providers. Through this process, the senior should be matched with the solutions that better match with his needs.

2.3 Management of Products

The manufacturers, or services providers create and manage their products by specifying their name and description, adding pictures and indicating several information such as: price, autonomy, certifications and efficiency. Manufacturers can translate the product description in different languages (English, French, Italian and German). Categories can be associated to the products (this is the taxonomy presented above), as well as tags.

Those products managed by the manufacturers and by solution providers is the repository of MAESTRO that is classified according to the defined MAESTRO's taxonomy.

2.4 Memoride Example: Product Added on the Platform

We will use from here an example of product experimented by the Switzerland pilot team during the project: Memoride [5]. Memoride is a stationary bike connected to Google Street-view enabling seniors to ride the bike exploring past familiar places.

The manufacturer of Memoride would like to see his product on the MAESTRO portal. For this, he first creates an account, if he doesn't already have one. He connects

A system developed by the Belgium firm Activ84Health, called Memoride, and consisting in a cycling utility making use of a software allowing for cyclists to visualise their riding progress in visiting European city streets. Memoride aims not at pushing seniors for performance, but producing an emotionally motivating context to exercise almost without noticing it.

Fig. 1 Example of the product “Memoride” added on the MAESTRO platform

on the portal and clicks on “Add Product”. He can then create the page description of Memoride. The result of the creation can be seen in Fig. 1.

3 Product and User Profiles

The product and user profiles are used to recommend products that best fit the users’ needs.

3.1 Product Profile

Once the manufacturers have added their products in the MAESTRO repository, they can complete it with the product profile information. The product profile consists in replying to several questions organized by groups (home environment, mental well-being, sensory well-being and lifestyle & fitness) that help identifying the user needs covered by the product. There are around 60 questions in total. The product profiling technique is also used in other domains as described by Moussaoui and Varela [6].

For instance in the “Control & Safety” group, the manufacturer has to reply to the question “How much do you think that your product can help with managing the indoor air quality” by selecting a number between 0 and 4: 0 if the product doesn’t help with managing the indoor air quality, and 4 if it fully helps with it. Indeed, the

Table 1 Answering options for product profile

Answering option	Description
0	Not at all (0–4%)
1	Slightly (5–24%)
2	Somewhat (25–49%)
3	Moderately (50–95%)
4	Extremely (96–100%)

Table 2 Answering options for end-user profile

Answering option	Description
0	None (0–4%)
1	Soft (5–24%)
2	Medium (25–49%)
3	Serious (50–95%)
4	Full (96–100%)

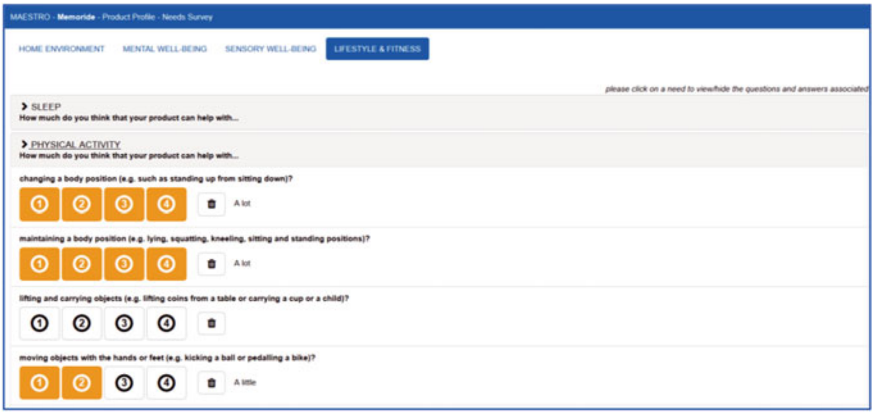
scale for the responses of the manufacturer to the profiling questions is shown in Table 1.

3.2 End-User Profile

The same profiling functionality exists on the end-user side. Indeed, when a senior or a senior organisation connects on the platform to look for the product that best fits his needs, he will also have to indicate its profile by answering the same kinds of questions that the manufacturer, but formalised on an end-user point of view. Similar approaches of senior profiling are used in other domains as in tourism, as presented by Alén, Losada and de Carlos [7]. For instance in the "Control & Safety" group, the senior has to reply to the question "How much difficulty do you have in managing the indoor air quality" by selecting a number between 0 and 4: 0 if the senior doesn't have difficulties in managing the indoor air quality, and 4 if he really has issues with managing it. The scale for the responses of the senior to the profile questions are displayed in Table 2.

3.3 Memoride Example: Product and End-User Profiles

To create the product profile of Memoride, the manufacturer fills the profile for each of the defined categories (Home environment, Mental well-being, Sensory well-being, Lifestyle & fitness), as can be seen in Fig. 2 for "Lifestyle & fitness" and the sub category "Physical activity".



please click on a need to view/hide the questions and answers associated

› SLEEP
How much do you think that your product can help with...

› PHYSICAL ACTIVITY
How much do you think that your product can help with...

changing a body position (e.g. such as standing up from sitting down)?
A lot

maintaining a body position (e.g. lying, squatting, kneeling, sitting and standing positions)?
A lot

lifting and carrying objects (e.g. lifting coins from a table or carrying a cup or a child)?

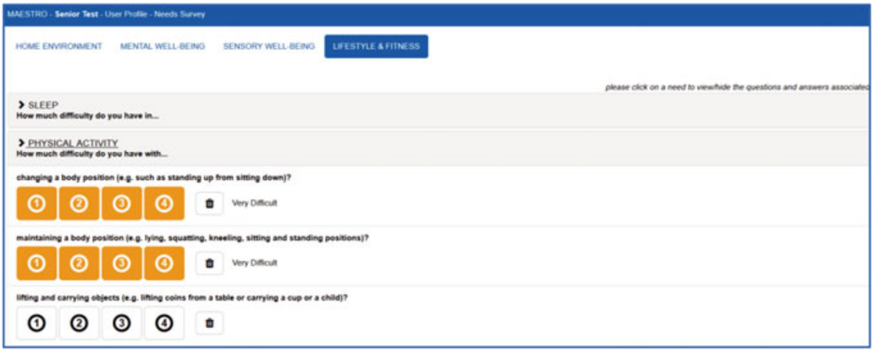
moving objects with the hands or feet (e.g. kicking a ball or pedalling a bike)?
A little

Fig. 2 Memoride's product profile on "Lifestyle and Fitness"

A senior can create an account on the portal if he wants to find products responding to his needs based on his profile.

To create an account, he registers himself, and connects on the platform. He accesses to the "User Needs", and fills in the questionnaire (user profile) that is similar to the product profile, as can be seen in Fig. 3.

Having now the product and the senior profiles, the platform can use a dedicated matchmaking functionality to recommend products that best fits the senior's needs. This and the assessment proposed by the platform are not presented in the current chapter that focusses on its first functionalities.



please click on a need to view/hide the questions and answers associated

› SLEEP
How much difficulty do you have in...

› PHYSICAL ACTIVITY
How much difficulty do you have with...

changing a body position (e.g. such as standing up from sitting down)?
Very Difficult

maintaining a body position (e.g. lying, squatting, kneeling, sitting and standing positions)?
Very Difficult

lifting and carrying objects (e.g. lifting coins from a table or carrying a cup or a child)?

Fig. 3 End-user profile on "Lifestyle and Fitness"

4 Conclusion

This short article presented the ICT platform developed during MAESTRO project and focused on some of its functionalities: repository of products organised according to a dedicated taxonomy, manufacturer and user profiles. Those functionalities aim at improving the life of seniors by proposing them the products that best fit their needs. It also presented the functionalities on a real life example: Memoride.

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References

1. Coan K, Aggoune-Mtalaa W, Bond R, Khadraoui D (2017) MAESTRO: towards a collaborative AAL market quality assurance platform for monitoring devices, systems and services. In: Proceeding of the 30th International Business Information Management Association conference, Madrid, Spain
2. Ouedrago M, Aggoune-Mtalaa W, Khadraoui D (2017) MAESTRO: constructing a reference framework for self-monitoring devices dedicated to seniors. In: Proceeding of the IEEE International workshop on Intelligent Multimedia Applications and Design for Quality Living, Taichung, Taiwan
3. https://www.who.int/classifications/icf/en/
4. Dahl TH (2002) International classification of functioning, disability and health: an introduction and discussion of its potential impact on rehabilitation services and research. J Rehabil Med 34(5):201–204
5. https://www.memoride.eu/en/
6. Moussaoui KA, Varela P (2010) Exploring consumer product profiling techniques and their linkage to a quantitative descriptive analysis. Food Qual Prefer 21(8):1088–1099
7. Alén E, Losada N, de Carlos P (2017) Profiling the segments of senior tourists throughout motivation and travel characteristics. Curr Iss Touri 20(14):1454–1469

ICF-Based Classification to Bridge the Gap Between End-Users and AAL Solutions

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Abstract MAESTRO (Sustainable Reference Framework evaluating equipment and services for seniors) is a web-based ICT multi modal platform providing a broad range of services and benefits in the domain of monitoring and self-monitoring systems for well-being and health-related information acquisition. Specifically, MAESTRO aims at realizing an innovative framework to facilitate the interaction and communication between producers and consumers at different levels, taking into account needs of end-users and features of products. This paper provides an overview of the key concepts and capabilities of MAESTRO focusing on the use of the International Classification of Functioning, Disability and Health (ICF) to build profiles of end-users and discover and rank products that meet their health-related needs. Additionally, the paper shows the results of a study aimed at evaluating the classification capabilities of MAESTRO and the integrated ICF-based taxonomy with respect to products and services developed within AAL (Active Assisted Living)

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Projects. The evaluation points out more recurrent health-related needs of end-users of AAL projects focus and underscore some limits and possible enhancements of the integrated ICF-based taxonomy.

1 Introduction

There has been a growing trend towards self-surveillance in the last 30 years. Only recently, however, technologies, both as stand-alone systems, with the sensor-level components, and the related "connected object" value chain, with its cabled and/or wireless communication means, along with big data acquisition and management capabilities, have really been delivering the kind of performance and service corresponding to expectations. What can be observed is a proliferation of announcements, in particular in an expanding market comprising wristbands, smart watches, smartphone applications and to a lesser extent smart glasses, shoes and clothes, with connections and data acquisition at home, in cars or other venues. Many sectors or markets are supporting this trend, in particular sports, wellness and defense/security activities. However, while such tools tend not to be designed for or to target older adults as end users, this group can benefit enormously from such self-monitoring technologies. In this fast-proliferating context, the clues and control references for adequate orientation of the consumer are lacking and the result is a media-supported image of a fantastic potential for follow-up of one's activities and even some vital parameters, but with often no verified nor legitimised/verified less certified criteria regarding such key dimensions as performance, reliability, user-friendliness, acceptability, potential for delivering medically ascertained data, privacy issues, etc. This confusing and probably in many cases misleading landscape, is even more problematic for the elderly, often non fully digitally literate and in any case not always in the capacity to know, understand and distinguish the key elements of the underlying promises associated with these technologies.

There is therefore at the same time a claim to give access to truly helpful systems for well-being and health-related monitoring capabilities, but most of the time as an emerging market not accompanied by the kind of references and metrics which could establish the basis for an effective user centered affordance of these new means. In this scenario, MAESTRO (Sustainable Reference Framework evaluating equipment and services for seniors) is a web-based ICT multi modal platform providing a broad range of services and benefits in the domain of monitoring and self-monitoring systems for well-being and health-related information acquisition. It tackles specific user groups with clearly identified service scenarios, the overall objective is to build upon of this results a reference framework, so as to bring to a variety of users enhanced orientation and evaluation capabilities based on user profile, selected solution or service, as well as decision-making readiness for developments and investment. In literature, there exist some databases that tries to categorise the technological aids available for supporting the autonomy and self monitoring, certified according to the ISO 9999 standard and its subclasses and allow for their search on a web platform.

The EASTIN portal [1] and all the national portals [2, 3] connected to it are updated to the latest version, published in 2016 (ISO 9999: 2016). Usually these platforms allow the user to navigate between the devices and search for them based on the name of the product, the manufacturer, or through keywords related to the ISO code. None of these platforms, as far as we understand, allows the user to perform a profiling of user's needs and to automatically obtain a list of solutions capable of satisfying the specified needs. In this respect MAESTRO offers the added value that lies in the matchmaking between needs and solutions without the user having to search for the most appropriate device on her own. Furthermore MAESTRO, in suggesting solutions to the user, also combines several devices that can together provide overall support to the expressed needs. Finally the idea of MAESTRO is to offer an additional service related to the evaluation of solutions by independent third parties, thus presenting, if available, the results of the "MAESTRO qualified" evaluation and also the feedback of the users who have used the device over time. It aims at building-up, testing and disseminating in the broad European context, through an open platform, a dynamic Reference Framework (RF) concerning monitoring and self-monitoring systems, connected or not. The Reference Framework MAESTRO intends to construct does not mean to define ideal tools and forms of usage but on the contrary needs to be built upon existing efforts and experiences, in particular best practises and corresponding functionalities and services (see further), to specify the options and criteria supporting these exemplary configurations. After providing an overall description of the main concepts of MAESTRO, this paper focuses on the classification and recommendation capabilities of the platform.

2 The MAESTRO Project

MAESTRO aims at realizing a set of services that allow seniors and/or caregivers to keep in contact with product manufacturers. Dedicated services allow seniors/caregivers to search and buy products suited for their specific needs, and manufacturer to sell their own products.

The challenging objective of MAESTRO is to realize a framework capable of facilitating the interaction and communication between producers and consumers at different levels, taking into account needs of end-users and features of products. On the one hand, MAESTRO proposes a clear taxonomy to characterize end-users according to their health-related needs, and products according to health-related needs they can address/satisfy. On the other, MAESTRO proposes a "standard" to assess products according to a number of well-defined metrics and qualities. Assessments rely on direct user experience characterizing several aspects of products and provide manufacturers with useful feedback to improve their solutions.

MAESTRO realizes a twofold *value chain*: (i) a *Business-to-Business* (B2B) value chain aims at supporting manufacturers in improving the quality of their products; (ii) a *Business-to-Consumers* (B2C) value chain aims at facilitating manufacturers in reaching their potential consumers as well as consumers in findings products suited

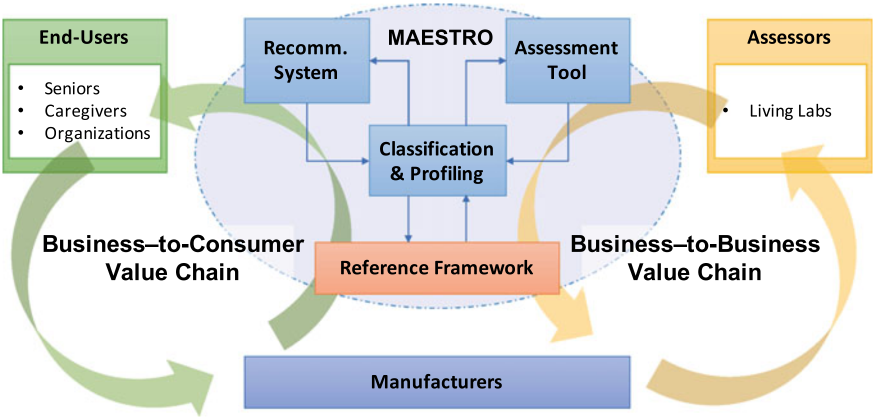

Fig. 1 Overview of the MAESTRO framework

to their specific needs. Figure 1 shows the core components of MAESTRO and their relationships with respect to these two value-chains.

As can be seen, three types of stakeholders are involved within MAESTRO. *End-users* represent seniors, caregiver or caregiving organizations that want to find products that are suited to their specific needs. They are interested in using MAESTRO because it supports them in finding high quality products that are suited for their needs.

Manufacturers are companies that produce one or more types of products and that want to reach a large number of highly interested consumers. They are interested in using MAESTRO because it represents a well-structured channel with potential clients but also because it defines a clear "evaluation standard" which provides them with structured feedback from the market.

Assessors are actually part of the B2B value chain of MAESTRO as they assess products by checking their compliance to the MAESTRO quality attributes. Namely, they apply MAESTRO evaluation criteria in order to "certify" products with respect to the "MAESTRO standard". These stakeholders play a crucial role in the platform. They are in charge of making assessments and feedback that characterize products with respect to different quality dimensions.

The core element of MAESTRO is the *Reference Framework* (RF). it consists of concepts, properties and taxonomies that define the proposed "MAESTRO standard". RF is the basic element used to classify manufacturers' products according to different dimensions and profile end-users according to their specific health-related needs. Two main services rely on these classification and profiling capabilities and the related RF.

The *Recommendation System* service (RM) is in charge of analyzing health-related profiles of end-users and products to dynamically match supply and demand. There are a huge number of products available through the MAESTRO platform. Each product has its own features and qualities. The recommendation system service supports end-users by *ranking* available products according to their specific profiles. This service is crucial to realize the B2C value chain of MAESTRO. The classification and profiling capabilities allow MAESTRO to support end-users showing products whose profiles that "fit" their specific needs.

The *Assessment Tool* service instead is in charge of dynamically selecting the evaluation criteria assessors must take into account to assess products. Specifically, it analyzes the metrics and qualities that, according to RF and to the specific profile of a product, are relevant for evaluation. This allows assessors to make evaluations that comply with the "MAESTRO standard" and that enable (fair) comparisons among similar products (e.g., products supporting similar health-related needs). Assessment capabilities allow MAESTRO to guide assessors in the evaluation process and provide manufacturers with valuable and "high-quality" feedback.

This paper focuses on the recommendation services of MAESTRO and therefore next section provides additional details on the structure of the RF. Specifically it characterizes the set of information used to both classify products and profile end-users according to their specific needs.

3 The ICF-Based Recommendation System

The key objective of RM is to characterize health-related needs of end-users and find out the products that best fit these needs. MAESTRO should internally represent information about needs of end-users and "link" this information to products.

To support such mechanisms it is necessary to endow MAESTRO with *knowledge representation and reasoning* techniques in order to generally characterize health-related information about users (i.e., user profiles), contextualize assistive capabilities/features of known products (i.e., product profiles) and generate recommendations accordingly. Such techniques usually rely on some general descriptions defining properties and relationships among general concepts that characterize a particular domain. In the most general case, such descriptions follow a logic formalism and are called *ontologies*. Ontologies can be seen as formal descriptions of objects, properties and relationships among objects collected in a particular data structure called the Knowledge Base (KB).

In computer science, ontologies have been defined in different ways by different scientists. Studer et al. [12] combined the definitions by Gruber [7] and Borst [14] stating that an ontology is "an explicit, formal specification of a shared conceptualization. The different characterizations of ontology are complementary and can be combined together. Hence, according to [10], it can be said that "an ontology is an artificial representation, that represents types or universals of a certain domain and the relations that hold according to a certain theory in a formal structure.

Depending on application needs, different types of ontology can be defined. Guarino proposes a classification based on levels of generality [8] and defines four classes: (i) *Top-level or Upper ontologies* describe very general concepts like e.g., space, time, event or action, that are independent from a particular problem or domain; (ii)

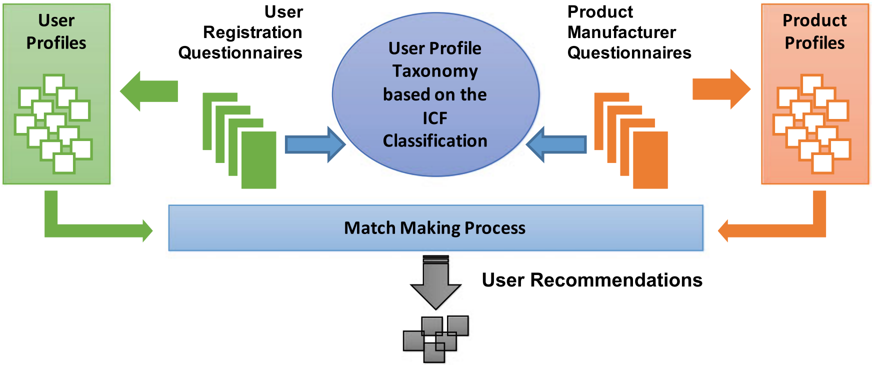

Fig. 2 A conceptual overview of the MAESTRO recommendation system

Domain ontologies describe general concepts related to a specific domain; (iii) *Task ontologies* describe generic tasks or activities. (iv) *Application ontologies* characterize a specific application and describe concepts whose relevance is limited to a specific domain and task.

MAESTRO defines a *taxonomy* of health-related information about users and products. A taxonomy can be seen as a simplified ontology formalizing only hierarchical relationships among concepts [5, 9, 15]. Specifically, the MAESTRO Reference Framework integrates a taxonomic representation of the *International Classification of Functioning, Disability and Health* (ICF), proposed by the World Health Organization (WHO) [13]. The ICF defines the core concepts needed to build profiles of end-users and products. These profiles are then used by a recommendation system to support end-users. This classification has been used also in other previous works like e.g., [4] which proposed an Assistive Technology Device Classification (ATDC) based on ICF. In our work we made an operational version of the classification and linked it to additional functionalities like RM.

Figure 2 shows a conceptual representation of RM. It shows how recommendations are generated starting from end-users and product profiles. Both of them built on top of the integrated ICF taxonomy.

End-user profiles are built by means of questionnaires that are filled at registration time. Similarly, product profiles are built by means of other dedicated questionnaires that are filled when manufacturers register them into MAESTRO. These questionnaires consist of a number of questions that allow the system to characterize end-users and products with respect to the internal representation of the ICF taxonomy. Namely, each question characterizes a user or a product with respect to a specific perspective and dimension of the ICF. When completed, the resulting profiles completely characterize health related needs of end-users and health-related needs satisfied by products.

These profiles are then analyzed by a match making process which is in charge of actually generating product recommendation for a particular end-user. The match making process takes as input the profile of an end-user interacting with MAESTRO. According to this profile, it analyzes the registered profiles of products and search for those that are relevant with respect to the profile of the interacting end-user. These products represent the outcome of the recommendation system service and are shown to the end-user.

3.1 Why the ICF Taxonomy

The ICF classification aims at organizing and documenting information on functioning and disability. The framework proposes the interpretation of functioning as a dynamic interaction among the health condition of a person, environmental factors and personal factors. ICF proposes a standard language and semantics for defining, measuring and classifying *disability*. It is worth observing that functioning and disability denote respectively the positive and negative aspects of functioning from a biological, individual and social perspective. It pursues a multi-perspective, bio-psycho-social approach whose outcome is a multi-dimensional model. This multi-dimensional view is well-suited for the objectives of MAESTRO.

ICF defines a scientific, operational basis to describe, understand and study health and health-related states. Broadly speaking, the classification is organized into two parts. A part deals with *functioning and disabilities* while the other part deals with *contextual factors*. These two parts are then further organized into two sub-components. The components *body functions* and *body structure* belong to the part concerning functioning and disabilities. The components *environmental factors* and *personal factors* belong to the part concerning contextual factors.

Figure 3 shows a graphical representation of ICF components and their interactions. The key idea underneath ICF is that the functioning of an individual in a

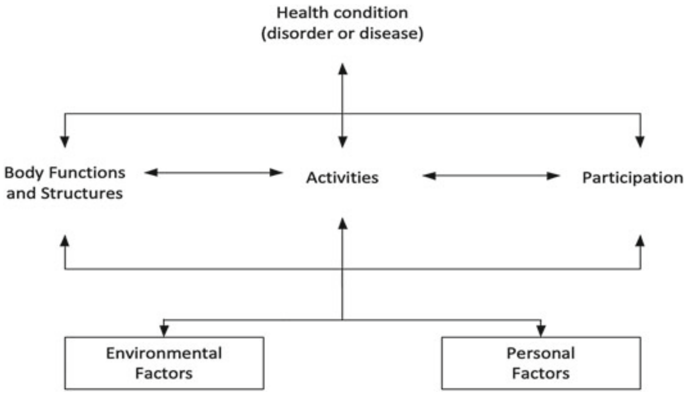

Fig. 3 An overview of the ICF classification

specific domain reflects an interaction between the health condition and the contextual in terms of environmental and personal factors. Each ICF component consists of multiple domains, and each domain consists of categories that are the entities of the classification. The conceptual framework thus defines a common language and the high-level structures of the classification that enable specific description and quantification.

MAESTRO integrates and adapts this framework to define a semantics for representing and reasoning about health-related needs of end-users and products. The integration of ICF particularly focuses on the part concerning functioning and disabilities and specifically the components *body functions and structure*, and *activities and participation*. Therefore an ICF-based taxonomy has been defined by leveraging OWL [11] which represents a standard semantic language. The defined taxonomy relies on a foundation ontology called DOLCE [6] which provides a clear and well-defined semantics for basic concepts like e.g., properties, qualities and capabilities/functions. Specifically, MAESTRO leverages a simplified subset of DOLCE called DUL (*DOLCE Ultra Light*)[1] whose expressiveness is sufficient for the specific objectives of the project.

Each class of the integrated ICF taxonomy characterizes a specific aspect of the physical and cognitive capabilities of a person. The level of each capability is measured leveraging the class `DUL:Quality` of DUL ontology. Specifically, each capability composing the profile of a person can be associated with a `low`, `regular` and `high` values, where `low`, `regular` and `high` are constant individuals of the class `DUL:Quality`. A `low` level of a physical or cognitive capability means that a person has a “low functioning” of that capability which represents a “disability” in the ICF sense. Conversely, a `high` level of a physical or cognitive capability means that a person has a “high functioning” of that capability which represents a “functionality” a person can perfectly use.

3.2 Body Functions and Structures

The ICF component *body functions and structures* concerns aspects of physiology and anatomy. The body is an integral part of human functioning and the biopsychosocial model considers it in interaction with other components. More specifically, body functions are the physiological aspects of body systems, while structures are the anatomical support. For example, sight is a function while the eye is a structure. Figure 4 shows an excerpt of the integrated ICF classification. MAESTRO focuses on the *body function* component of ICF which provides a representation for many aspects that are relevant to characterize the assistive services a person needs within his/her daily-home living.

For example the class `MentalFunctioning` allows MAESTRO to model capabilities concerning the use of mental faculties ranging from the capability of

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[1] http://www.loa.istc.cnr.it/ontologies/DUL.owl.

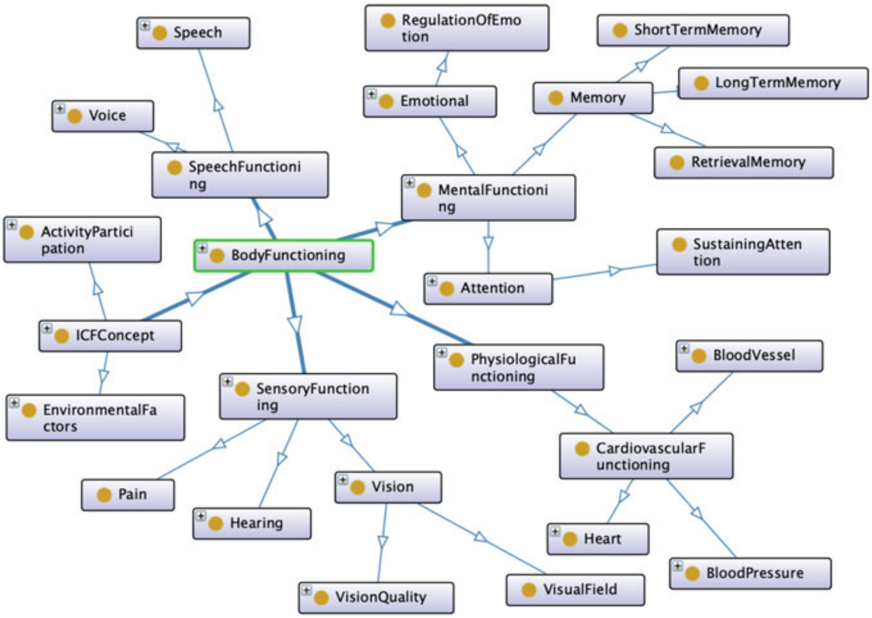

Fig. 4 An excerpt of the integrated body functions and structures ICF category

maintaining the attention on some subject (the class `SustainingAttention`) to the capabilities of maintaining long term or short term memory (respectively the class `LongTermMemory` and the class `ShortTermMemory`). The class `PhysiologicalFunctioning` allows MAESTRO to model capabilities concerning the *status* of physiological parameters of a person like e.g., blood pressure (the class `BloodPressure`) or the heart (the class `Heart` and related subclasses not shown in Fig. 4 for the sake of simplicity). Other interesting elements of the ICF that allow MAESTRO to characterize the interaction capabilities of a person are the class `SensoryFunctioning` and the class `SpeechFunctioning`. In particular the class `SensoryFunctioning` and related subclasses like e.g., `Hearing` or `Vision` allow MAESTRO to model the capability of *sensing* the environment and receiving signals and information.

3.3 Activity and Participation

The ICF component *activity and participation* concerns actions and tasks executed by individuals (i.e., activities) and the involvement in social life situations (i.e., participation). This category covers all aspects of life, from basic actions such as *walking* and *moving* to complex and socially collaborative situations such as *interacting with others* or participating in school or in community life. Figure 5 shows an excerpt of

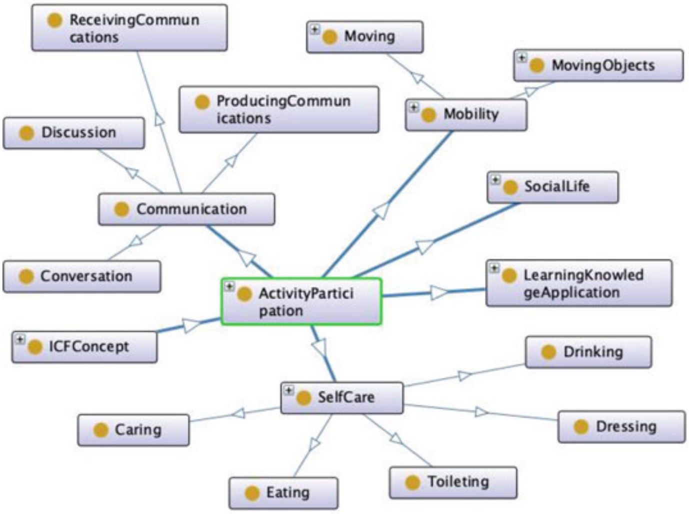

Fig. 5 An excerpt of the integrated activity and participation ICF category

the integrated ICF classification. In this case MAESTRO focuses mainly on the categories that characterize the autonomy of a person in performing his/her daily-routine activities.

For example the class `Communication` allows MAESTRO to model capability of performing complex communication activities that range from the capability of sustaining discussions (the class `Discussion`) to the capability of receiving complex communications or producing complex communications (respectively the class `ReceivingCommunications` and the class `ProducingCommunications`). The class `SelfCare` allows MAESTRO to model the capability of a person of autonomously perform self-care related tasks like e.g., the capability of eating autonomously (the class `Eating`), the capability of dressing autonomously (the class `Dressing`) or the capability of drinking autonomously (the class `Drinking`). Another interesting element of the ICF which allows MAESTRO to characterize the capability of a person of autonomously and safely interacting with the environment is the class `Mobility`. In particular, the class `Moving` and related subclasses like e.g., `Walking`, `Jumping` or `Running` (not shown in Fig. 5 for the sake of simplicity) allow MAESTRO to model the capability of moving within an environment with different modalities.

4 MAESTRO as a Mean to Classify AAL Projects

The classification described above is then at the basis of the MAESTRO Reference Framework. As part of the RF evaluation an effort has been performed to investigate the feasibility of applying the MAESTRO profiling framework to classify AAL projects. AAL projects are supposed to develop complex systems to support the integration of health ageing products and providing services useful both for primary and secondary users. For this reason, investigating the efficacy of our taxonomy in their categorization could provide valuable insights into its capacity to cover as many AAL dimensions as possible.

A systematic procedure has been followed for retrieving all the available information for each project. The AAL portal[2] served as starting point, since it is considered as the more reliable database on the existing projects. Projects belonging to call 2017 and previous ones have been considered in the analysis (more recent projects have not been considered since not enough information exists yet on them). The AAL programme funded more than 220 projects since 2008. In this investigation, and as said above, we focused our attention on those funded till 2017, the more recent projects not providing sufficient information considering their state of progress. In fact, we considered 198 projects funded through yearly calls from 2008 to 2017.

Starting from the AAL portal, the information we were looking for has been retrieved from the official website of each project, and from any other type of dissemination materials available. Additionally, scientific production such as scientific papers, conference presentations and workshops have been also used as sources.

4.1 Overview of Classification Results

The MAESTRO taxonomy has been applied to categorize the AAL projects in the attempt to validate it through a number of AAL existing applications. Out of 198 funded projects, 73 could not be properly profiled through the proposed taxonomy because of insufficient available information. More specifically, not enough scientific data have been found, and in some cases the project's official websites were not active anymore. Although some projects could not be profiled, interesting findings emerged from this analysis.

First of all, it appeared that the major part of the projects addressed needs of older population in general, with not specific target. Some exceptions were related to the projects funded through the call 2016, which was specifically dedicated to Dementia patients ("Living well with Dementia"), and the target end-users were patients with pathological cognitive decline and/or their caregivers. Other examples can be found among other projects. For example, the VUK project specifically addressed blind people, and SmartBEAT was dedicated to heart failure patients.

While the major part of the projects foresaw some kind of "domestic support" where ICT solutions were supposed to be deployed in the indoor environment, a number of projects aimed instead to provide support in other fields of active ageing. For example, SoulMate project's goal was to support older people in travelling, both in organizational phase by managing the trip and facilitating encounters with companions, and by supporting the trip itself. Moreover, CARELINK aims at managing

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[2] http://www.aal-europe.eu/projects.

the wandering problem on patients with dementia. Other attempts have made in order to foster contact between older people and caregiving realities, and their work. For example, iCareCoops was supposed to develop a new way of promoting and supporting elderly care cooperatives as a model to organize elderly care in an efficient way, as well as SpONSOR, which aimed at developing, testing and implementing an ICT platform that facilitates the posting, browsing and exchange of key information between competence-offering seniors and search-based requests, from competence-demanding organizations from the public, private and voluntary sectors. In fact, a specific call (Call 6) was supposed to fund projects proposing "ICT-based Solutions for Supporting Occupation in Life of Older Adults".

While the major part of projects addressed at first the older persons' needs and just indirectly those of caregivers, some proposals came also focusing on supporting caregivers directly. For example, the SUCCESS project provides an innovative mobile training application to support formal and informal caregivers to appropriately interact with people with dementia. As for the POSTHCARD platform, which is an engaging simulation were caregivers can practice daily life situations with Alzheimer patient.

Beside these, there are some different projects like MAESTRO itself, which proposed not to design and/or develop new solutions, but a sort of "meta-solution" capable to support the whole range of users in orienting and exploiting the AAL offers, and to validate the efficacy of these offers. Another example of these "meta-solution" can be I-evAALution which integrates solutions that have been developed in previous AAL-projects in order to combine all functions in one solution providing support covering the needs of the involved end-users.

Figure 6 shows a summary of the classification results. Among all the dimensions considered within the MAESTRO framework, it resulted that support to mental and emotional wellbeing, social life and health monitoring are those mostly addressed by the AAL project. On the contrary, it emerged how specific needs on sensory difficulties were somehow neglected by the developed AAL solutions with the exception of few cases which focus on specific needs (VUK for blindness).

4.2 A Closer View to Following the ICF Dimensions

Figure 6 shows an aggregated view of the results taking into account abstract categories of the ICF taxonomy. Interesting results can be found going deeper into the single dimensions of the ICF taxonomy considered in Fig. 6 to see the specific aspects addressed by AAL projects.

Considering the dimension of *mental wellbeing*, the aspects mostly addressed are those regarding memory support and temporal orientation. For the dimension of *emotional wellbeing*, it clearly emerged how in AAL projects, the main concerns is towards designing and developing ICT solutions able to mitigate negative mood which can be overwhelming in the ageing population. Promoting solutions to foster

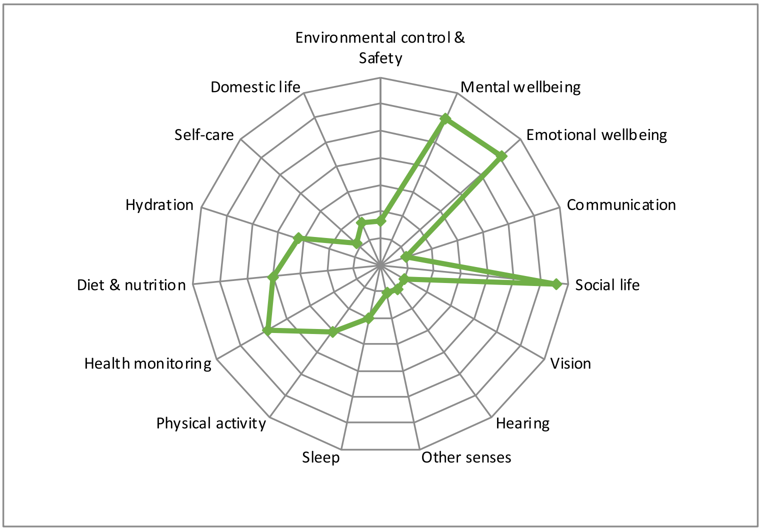

Fig. 6 Classification results of AAL proejcts with respect to the dimensions of the ICF taxonomy

good feelings of positive mood, i.e., being happy and content, and calm and relax, was the goal of these projects.

Social life support seems to be mostly oriented in maintaining existing relationships between older people and beloved ones, and between older people and caregivers, both formal and informal. Additionally, it seems that AAL solutions developed within the AAL program are intended to support the involvement of ageing people in the community social life.

Health monitoring emerged to be a crucial aspect in designing AAL technological solutions. Although a number of aspects have been neglected within the MAESTRO framework, it emerged the importance e of AAL community to make efforts in ensuring a reliable and effective monitoring of people health, especially with respect to parameters linked to chronic diseases of cardiorespiratory system and diabetes. Figure 7 shows the aggregated results divided by the specific ICF dimensions considered.

4.3 Considerations on the Classification Capabilities of MAESTRO

The MAESTRO taxonomy was proven to be a valuable categorization framework for systems functions and services provided by AAL systems. Nevertheless during the pilots, some shortcomings emerged that highlighted missing aspects to be considered. Hereafter a list of major issues follows, as result of the pilot findings analysis:

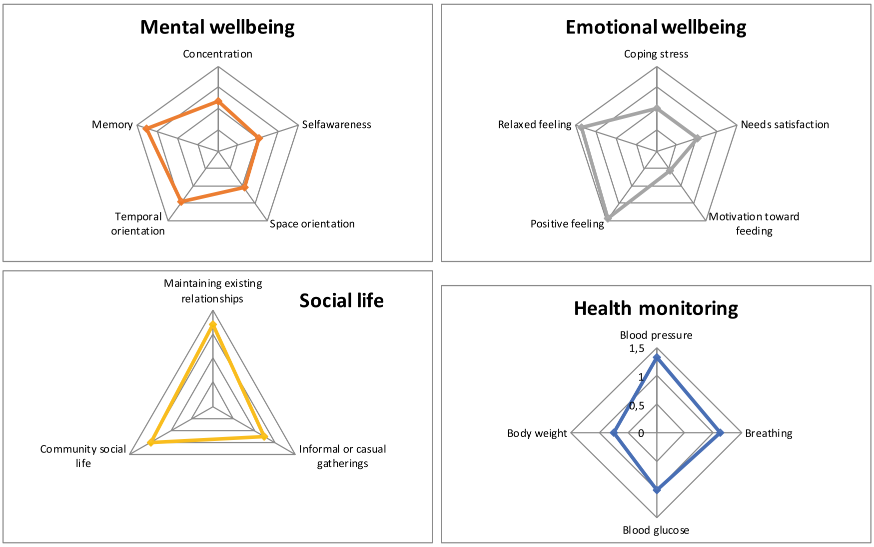

Fig. 7 Aggregated results on four different dimensions of the ICF taxonomy

- The current version of the taxonomy specifically addresses needs and functionalities of primary users. The most part of AAL projects focuses on primary users, and often indirectly also on secondary ones. Nevertheless, a there is still a part of AAL projects that specifically focuses on secondary users' needs and the pilot analysis revealed that they could not be properly profiled according to the MAESTRO taxonomy (they do not have necessarily the same problems). More specifically, aspects such as training/support for caregivers is missing in the current version of the MAESTRO taxonomy (some example of projects: POSTHCARD, SUCCESS, SOCIALCARE, iCareCoops.
- Emergency management is not enough considered in the current version of the taxonomy. Some AAL projects offer a specific service in case of emergency which alerts formal and informal caregivers. Related to this, it is worth highlighting the importance to integrate the profiling process with the description of devices included in more complex systems. For example, there is the urgency to consider in the categorization, objects like alarm buttons and fall detectors which are crucial for many systems for the management of emergency situations (i.e. IONIS, SmartBEAT). In the current MAESTRO taxonomy, they appear only as part of alerting ecosystems, we should be able to discriminate down to the components.
- Another aspect which seems not to be addressed enough in the proposed profiling framework concerns the concept of therapy adherence which is somehow linked to the issue already mentioned of daily life monitoring. Considering the frequent presence in older persons of chronic diseases which require long-term therapies, an aspect worth being monitored in the daily routine can be surely the adherence to therapy.

- The monitoring of user's habits can sometimes be exploited by AAL systems for delivering healthy advices through a sort of coaching service (i.e. PersonAAL, Ella4Life). Actually, this service has not been considered in designing the MAESTRO profiling framework. In order to overcome this limit, an improvement should be done to the framework by including among possible delivered services those of personalized advices delivering.

Beside these punctual comments, it is important to highlight that the proposed framework mainly focused on needs related to body and mental functioning, instrumental activities of daily life and domestic environmental issues. Considering the global view of AAL program on Active Ageing, there are AAL projects which intend this concept in its broadest sense, and consider the older persons as active members of society.

More specifically, the call 6 focused on "ICT-based Solutions for Supporting Occupation in Life of Older Adults". Those projects resulted difficult to profile through the MAESTRO framework considering the different environmental context intended for application.

5 Conclusions and Final Remarks

The paper presents the MAESTRO project providing a brief description of its objectives and an overview of the main components and services. MAESTRO aims at providing innovative ICT services to bridge the gap between end-users like e.g., seniors or caregivers and manufacturers of health-related products. It realizes a twofold value chain which supports end-users in finding products suited for their needs and supports manufacturers that receive feedbacks about the qualities of their products.

The paper specifically focuses on the profiling capabilities of MAESTRO and the developed recommendation system services developed to rank products according to the specific health-related needs of end-users that interact with the system. In this way, MAESTRO can facilitate end-users in finding products that best fit their capabilities and health condition.

User and product profiles are built and processes leveraging an internal taxonomy based on the International Classification of Functioning, Disability and Health (ICF) proposed by the World Health Organization (WHO). The ICF model is well suited for the objectives of the project because it provides a multi-dimensional classification schema which can be then used to characterize end-users and products according to different correlated perspectives.

Finally, the paper briefly shows an experimental evaluation of the classification capabilities of MAESTRO taking into account AAL projects. It clearly emerged from the pilot results the good capability of the MAESTRO taxonomy of capturing a considerable number of nuances representing the complex and interrelated factors affecting Active Ageing. The choice of relying on the multidimensional ICF classification has resulted excellent in order to identify and classify the end users' needs.

Nevertheless, since the ICF focused on individual dimensions, it somehow fails to capture those networking aspects which characterize the AAL world.

In fact, the secondary users point of view was not directly addressed by the Profiling Tool. Additionally, while the efficacy of describing single aspects influencing Active Ageing has been proven, more difficulty emerged in highlighting those aspects resulting from aggregated factors, like for example the daily routine. It represents an aggregation of different dimensions already investigated by the Profiling Tool, but which need additional crucial and high leve reasoning could not easily grasped through this profiling process.

Starting from the current version of the Profiling Tool, and taking into account these few considerations, the commercial version of the Profiling Tool will needs some integrations in order to fully embrace the complexity of the offers from the AAL world.

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References

1. (2020). The global assistive technology information network: The worldwide search engine on assistive technology. http://www.eastin.eu/it-it/searches/Products/Index. Accessed 15 Jan 2020
2. (2020). Portale siva sulle tecnologie per la diabilità e l'autonomia. http://portale.siva.it/it-IT/home/default. Accessed 15 Jan 2020
3. (2020). Rehadat. https://www.rehadat.de/. Accessed 15 Jan 2020
4. Bauer S, Elsaesser L-J, Arthanat S (2011) Assistive technology device classification based upon the world health organization's, international classification of functioning, disability and health (icf). Disability and rehabilitation. Assist Technol 6:243–259
5. Crié D (2003) Consumers' complaint behaviour. taxonomy, typology and determinants: Towards a unified ontology. J Database Market Custom Strategy Manage 11(1):60–79
6. Gangemi A, Guarino N, Masolo C, Oltramari A, Schneider L (2002) Sweetening ontologies with dolce. In: Gómez-Pérez A and Benjamins VR (eds), Knowledge engineering and knowledge management: ontologies and the semantic web. Springer, Berlin, Heidelberg, pp 166–181
7. Gruber TR (1995) Toward principles for the design of ontologies used for knowledge sharing? Int J Human-Comput Stud 43(5):907–928
8. Guarino N (1998) Formal opntology in information systems. IOS Press
9. Hakeem A and Shah M (2004) Ontology and taxonomy collaborated framework for meeting classification. In *Proceedings of the 17th International Conference on Pattern Recognition*, vol 4, pp 219–222
10. Jansen L and Schulz S (2011) The ten commandments of ontological engineering. In: Proceedings of the 3rd workshop of ontologies in biomedicine and life sciences. pp 1–6
11. McGuinness DL, Van Harmelen F et al (2004) Owl web ontology language overview. W3C Recommendation 10(10):2004

12. Studer R, Benjamins VR, Fensel D (1998) Knowledge engineering: principles and methods. Data Knowl Eng 25(1):161–197
13. WHO (2001). International classification of functioning, disability and health: Icf
14. Willem Nico B (1997) Construction of engineering ontologies for knowledge sharing and reuse. Ph.D. thesis, Centre for Telematics and Information Technology (CTIT)
15. Yalcinalp S, Gulbahar Y (2010) Ontology and taxonomy design and development for personalised web-based learning systems. Br J Educ Technol 41(6):883–896

Active Paintings. Design Project for a Portable Exhibition for People with Dementia or Cognitive Impairment

A. Lupacchini, A. C. Daniso, and M. Palpacelli

Abstract Portable exhibition composed by six stations, each of which represents a different painting, associated with a manual or cognitive activity designed for elderly people with dementia or cognitive impairment and their caregiver.

1 Introduction

Art was found to be an excellent therapy for various disorders, it helps to connect with one's own creativity and inner self, to express our self in a non-verbal way, but equally (or more) effectively.

For some categories of people unfortunately it is not easily accessible: this is the case of elderly people, in particular the ones with dementia or cognitive impairment.

The project's purpose is to bring art directly into retirement homes, to a group of people that usually has not the possibility to enjoy it and that, instead, would benefit a lot. This is possible also due to the development of specific activities, connected to every painting, that aim to exploit the residual abilities of the elderly with dementia and/or cognitive decay, to improve their general state of well-being.

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2 Dementia Treatment and Art Therapy

In a society like the one where we live with high life expectancy, the high rate of people with some type of dementia brought to the conduct of several studies to be able to resolve, stop or delay the deterioration of the brain in people who are affected.

Pharmacological therapy in these cases is currently still not very effective and sometimes more evident results can be achieved with psycho-social interventions, both from a physiological and psychological point of view.

These activities' most important purpose is to act on the general well-being of the person, rather than on the individual cognitive and physical functions. The possibility of being effectively active, engaged in something sensible and being able to carry out a task, perhaps producing a concrete result, helps to improve the degree of happiness and daily well-being of the person, reducing disorientation and anxiety.

Artistic activities turned out to be very effective from this point of view: the perception of artistic beauty can indeed help reduce stress and improve well-being. For this reason Art therapy has proven to be a valid tool for coping with dementia, both to counteract the deterioration of cognitive functions and to counteract the psychological disorders that may be related to it, such as anxiety and depression. This is possible thanks to the enhancement of the residual capacities, thus also strengthening the elderly self-esteem. Furthermore, creativity can be an excellent non-verbal tool to allow the elderly to communicate in new and deeply expressive forms.

In recent years, various museum experiences have been developed aimed at an audience affected by dementia, both in Italy and abroad. The MoMA (Museum of Modern Art, New York) was one of the first museums, starting in 2006, to implement programs explicitly designed to make its collection accessible to people with dementia and their caregivers (MoMA Alzheimer's Project). In the following years many related experiences took place all over the world.

3 The Project

Unlike the previous experiences, the project was developed in the form of a portable exhibition that can be installed directly inside a retirement home (or any other organization or association that deals with these issues), in order to get as close as possible to the relevant public.

Bringing the setup directly to people with dementia can solve any problems related to the transport of people with mobility difficulties, as well as possible behavioral disorders due to the execution of non-routine activities.

Fig. 1 Example of a possible setting

The exhibition is composed by six single panels that are easy and quick to assemble and disassemble, which can be customized and easily transported even by a single person. The panels are also equipped with various accessories (shelves, niches, lights, tables, tablets, etc.) useful for carrying out the activities. The curved shape allows to create different paths.

All the design choices were shared with expert professionals working in a retirement home, in particular with a psychologist expert in gerontology and neuropsychology of dementia, in order to achieve a balance between the well-being of the elderly and the needs of the project (Fig. 1).

4 The Paintings

The first aspect that has been taken into consideration is linked to the perception that people with dementia or cognitive impairment may have if they faced a work of art, especially when it is abstract.

During the selection of the paintings, more importance was given to those which, on the one hand, were appreciated by the relevant public and, on the other, created a motivation for dialogue.

To do this, a selection of paintings has been submitted to a small group of elderly people with dementia: it has emerged that the most appreciated works are the ones with family and work related themes, that are able to bring to life tales and memories of real life. Abstract paintings were appreciated too, because they leave room for multiple interpretations. A particularly appreciated element was the light blue color, which was used as a background or shade.

At the end of the analysis, six paintings by six different artists were selected: La Récolte des Foins, Éragny by Camille Pissarro, Two Sisters (On the Terrace) by Pierre-August Renoir, The siesta (after Millet) by Vincent Van Gogh, Figures in the Night Guided by the Phosphorescent Tracks of Snails by Joan Mirò, Yellow–Red-Blue by Vasillij Kandinskij, Blue Poles by Jackson Pollock.

5 The Activities

For each exhibited painting there is a manual or mental activity, designed to link to the theme or style of the work itself.

To verify the actual feasibility for an audience affected by dementia and to evaluate the obtained results, each activity was tested on a selected group of 9 elderly people, with mild to moderate cognitive impairment, under the supervision of the retirement home's psychologist and educators.

Below the six proposed activities.

5.1 Pissarro

Pissarro's painting reminds of a world that has almost disappeared, of work in the fields and peasant life. With the painting, a series of objects from everyday and home life are exhibited. Visitors are invited to pick them up, tell what they were used for, how they were used, etc., succeeding in recovering different memories thanks to the implicit memory.

5.2 Renoir

The painting is associated with an activity based on Doll Therapy. A doll and clothes like those used in the paintings are available for the visitors, who are invited to dress the doll and interact with it. Doll Therapy is a widely used therapy, which has proved to increase relaxation and reduce anxiety, wandering and agitation disorders.

5.3 Van Gogh

Van Gogh's panel reminds to the theme of Rest. Remaining in line with this principle, the guest is invited to listen, through a tablet and headphones, to sounds of nature, while some hay is exposed on the shelf, in order to recreate the environment of the painting and help the relaxation between the different activities.

5.4 Mirò

Together with the painting, some figures with hooks are provided, taken from the exposed painting and others of the same series. They can be fixed on the wire mesh to try to recreate the artist's work or giving life to a personal new version.

Both these figures and the magnets for the following activity with Kandinsky must be large enough to not be ingested involuntarily.

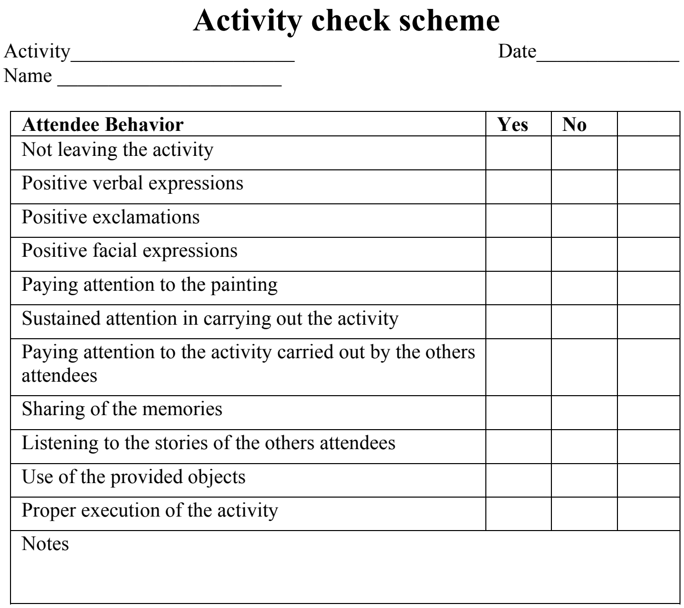
5.5 Kandinskij

Together with the painting, two series of magnets are provided: the first takes the forms of the figures present on the painting on display, the second is composed of figures extracted from another work by the same artist. The visitor can choose whether to use a single series or both, whether to recreate Yellow–Red-Blue or give life to an original composition. The magnets will be inserted inside the figures, so as to prevent them from being accidentally swallowed.

5.6 Pollock

This is the freest activity: sheets, paints and brushes are provided so that everyone can express their creativity in the most personal way possible.

All the activities were evaluated according to a scheme that detects the general state of well-being of the person thanks to his utterances, whether voluntary or not (scheme in the following page).



Activity check scheme

Activity______________________ Date______________

Name ______________________

Attendee Behavior	Yes	No	
Not leaving the activity			
Positive verbal expressions			
Positive exclamations			
Positive facial expressions			
Paying attention to the painting			
Sustained attention in carrying out the activity			
Paying attention to the activity carried out by the others attendees			
Sharing of the memories			
Listening to the stories of the others attendees			
Use of the provided objects			
Proper execution of the activity			
Notes			

6 The Paths

Thanks to the choice of using single curved panels, it is possible to create different path arrangements.

The most effective solutions are those that keep the panels isolated from each other, reducing the distracting aspects that could cause loss of attention by visitors with dementia.

The order of visit also represent the increase in complexity: the former can be faced more easily by everyone, compared to the latter.

The ideal path turns out to be a circular one because, in addition to separating the different activities, it is positive in case of wandering and leaves an isolated space, inside the circle, to perform the last activity which, being the most complex, would result favored by having a specially dedicated and isolated space. In case you do not have sufficient space available for setting up, it is also possible to divide the exhibition into different rooms, according to the needs of the host structure (Figs. 2, 3, and 4).

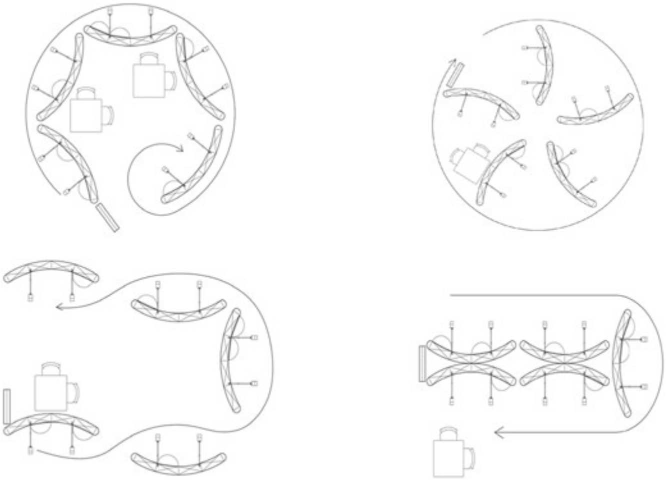


Fig. 2 Four proposed path arrangements

Fig. 3 Example of a possible setting

Fig. 4 Example of a possible setting

References

1. Boccardi M (2002) La riabilitazione cognitiva e comportamentale nella demenza: un approccio pratico per le R.S.A. Brescia, Edizioni Fatebenefratelli
2. Boccardi M (2007) La riabilitazione nella demenza grave: manuale pratico per operatori e caregiver. Trento, Edizioni Erickson
3. Acocella O (2013) Rosati, a cura di. Le Nuove Arti Terapie. Percorsi nella relazione d’aiuto, Angeli, Milano
4. Malchiodi C (2009) Arteterapia. Giunti, Firenze
5. Moschini L (2009) Arteterapia con pazienti difficili. Erikson, Trento
6. Winnicott DW (1971) Gioco e realtà. Armando, Roma

7. Sunderland M (1997) Disegnare le emozioni. Espressione grafica e conoscenza di sé, Erikson, Trento
8. Grignoli L (2008) Percorsi trasformativi in Arteterapia. Angeli, Milano
9. Warren B (1995) Arteterapia in educazione e riabilitazione. Erikson, Trento
10. Muret M (1983) Arte-Terapia. Red, Milano