Smart Environments and Systems for Maintaining Health and Independent Living: The FARSEEING and CuPiD Projects

S. Mellone, A. Ferrari, C. Tacconi, E. Valtolina, R. Greenlaw, A. Nawaz, A. Bourke, P. Ferriol, E. Farella, L. Rocchi, H. Hawley-Hague and L. Chiari

Abstract Home Control and Automation systems are often modular and offer the flexibility and dependability to make life easier. Wearable sensor systems for health monitoring are an emerging trend and are expected to enable proactive

S. Mellone (✉) · A. Ferrari · E. Farella · L. Rocchi · L. Chiari
Department of Electrical, Electronic and Information Engineering, Guglielmo Marconi, University of Bologna, Bologna, Italy
e-mail: sabato.mellone@unibo.it

L. Chiari
e-mail: lorenzo.chiari@unibo.it

C. Tacconi · L. Chiari
Health Sciences and Technologies—Interdepartmental Center for Industrial Research, University of Bologna, Ozzano dell'Emilia, BO, Italy

L. Chiari
e-mail: lorenzo.chiari@unibo.it

E. Valtolina
Legrand Spa, Bticino Spa, Erba, CO, Italy

R. Greenlaw
Oxford Computer Consultants Ltd, Oxford, UK

A. Nawaz
Department of Neuroscience, Norwegian University of Science and Technology, Trondheim, Norway

A. Bourke
Laboratory of Movement Analysis and Measurement, EPFL, Lausanne, Switzerland

P. Ferriol
Health Department, Fundació iBit, Palma, Spain

H. Hawley-Hague
School of Nursing, Midwifery and Social Work, University of Manchester, Manchester, UK

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personal health management. Using home-based technology and personal devices the aim is to motivate and support healthier lifestyle; this is a challenge which has been addressed in the framework of FARSEEING and CuPiD EU projects. Contrary to visions that consider home automation and personal health systems as a mean to replace or to simplify the subject control and actions, in the FARSEEING and CuPiD approach smartphones, wearable devices, and home based technology are used to stimulate the user by making life mentally and physically more challenging but without losing comfort.

1 Introduction

Home Control and Automation (HCA) systems are often modular and offer the flexibility and dependability to make life easier. Every aspect of the home environment can be monitored and controlled both indoor and remotely through remote controls, touch screen panels, personal computers, tablets, or even smartphones (SPs). HCA systems can integrate a variety of environmental sensors that allow early detection and warning of equipment failures or conditions that exceed user-defined limits.

Wearable sensor systems for health monitoring are an emerging trend and are expected to enable proactive personal health management and better treatment of various medical conditions. These systems, comprising various types of small physiological sensors, transmission modules and processing capabilities, promise to change the future of personal care, by providing low-cost wearable unobtrusive solutions for continuous all-day and any-place health, mental and activity status monitoring.

Using home-based technology and personal devices the aim is to motivate and support healthier lifestyle decisions related to exercise, nutrition, TV/internet use, maintaining social relationship—in order to delay or even prevent the onset of a variety of medical problems and improve the quality of life. The great challenge is to exploit the computational capabilities of the HCA system, body-worn, and mobile devices to detect the best time to provide feedback and provide it in a way that is tailored both to the user and the situation.

FARSEEING, as well as CuPiD, aims to introduce and exploit unique features offered by ubiquitous and user-friendly ICT solutions. While FARSEEING has a focus on elderly persons, CuPiD targets specifically needs and symptoms of persons with Parkinson's Disease (PD). PD strongly affects a person's ability to move and particularly to walk, with severe consequences on participation in everyday activities and quality of life.

Contrary to visions that consider HCA and personal health systems as a mean to replace or to simplify the subject control and actions, in the FARSEEING and CuPiD approach SPs, wearable devices, and home based technology are used to stimulate the user by making life mentally and physically more challenging but without losing comfort. The aim of the present paper is to present and discuss

the FARSEEING and CuPiD approach for designing and implementing smart environments and systems to extend the time people can live in their preferred environment.

2 Methods

FARSEEING aims to develop a predictive model of mobility and risk of falls in elderly individuals by introducing and exploiting some unique features offered by pervasive but unobtrusive ICT solutions. The design of the FARSEEING architecture is based on a mixed-strategy involving both community dwelling and high-risk subjects. More than 300 real falls have been collected so far through wearable sensors and SPs, which represent the world's largest fall repository ever established. The database enables, for the first time, researchers to study the aetiology of a fall based on enough objectively measured data, also in association with most relevant biomarkers. The FARSEEING technological 'cocktail' allows the measurement and analysis of movement patterns during daily life activities, motor performance, and environmental/contextual information to identify fall risk factors. SPs, further than a communication tool, become a transparent companion (Fig. 1a, b) ultimately able to: (i) early detect changes in the fall risk profile of its users and, in consequence, (ii) adapt the degree of living assistance; (iii) timely involve carers and family, as and when needed. Another important ingredient of the FARSEEING recipe is the HCA system, based on the BTicino MyHome system (http://www.bticino.com), which is able to support elderly users in their daily activities. An RFID-based locator system is integrated with the HCA system; the user wears a small RFID tag that can be hidden in clothes, embedded in the SP, or in the wearable sensing unit; the latter is a system specifically designed for long-term monitoring at home (Fig. 1c). The integration of the HCA and control system with the RFID technology, a gateway, and a processing unit, makes it possible to provide contextual information to the user generating a series of warnings or simply providing useful reminders and suggestions.

The CuPiD project has a focus on people with PD. Until recently, treatment goals for PD focused almost exclusively on symptom relief, but motor learning and rehabilitation principles can be effective even in the presence of PD. It is critical to make rehab-like therapies accepted by patients since long-term treatments in clinical settings are not feasible, cost effective, or likely something that patients can comply with year after year. CuPiD is designed to meet this challenge. ICT-enabled systems have been developed to provide, in the home settings, personalized treatment integrated into PD person's everyday routine; and tailored solution to target balance, walking performances, safety of movements, cognitive function, and debilitating symptom (e.g. freezing of gait). Motor rehabilitation programs include: (i) "exergaming" by means of virtual reality, to train balance, onset of movements and upper limb motor function, (ii) "training of walking" by means of an intelligent tutoring system able to guide and promptly correct patient gait pattern and (iii) "training for preventing Freezing of Gait episodes".

Fig. 1 **a** Elderly person wearing the smartphone as a monitoring unit by means of a custom elastic waist belt. **b** Waist belt used for wearing the smartphone for both activity monitoring and functional assessment. **c** FARSEEING wearable monitoring unit specifically designed for long-term monitoring of people at high risk of falling

Table 1 reports the topics which have been investigated and developed in the framework of FARSEEING and CuPiD projects; details about the specific implementation are reported in the following subsections.

2.1 Stimuli Provision

The FARSEEING Smarthome user interface is developed by customizing the BTicino touchscreen interface used to control the standard HCA (Fig. 2a). Due to the fact that the screen size of the SP is much smaller than that of wall mounted touchscreens, the user interface cannot be the same of the smarthome. The interaction with the user is minimized and the SP mostly act as a reminder (Fig. 2b): (i) to inform the user that a specific message is available on the wall mounted touchscreen; (ii) to remind the user that an activity is scheduled at a certain hour of the day.

Table 1 Topics investigated and developed in the framework of FARSEEING and CuPiD projects

Topics	FARSEEING	CuPiD
Stimuli provision	Yes	Yes
Long-term monitoring	Yes	No
Training/Rehabilitation at home	No	Yes
Exergames	Yes	Yes
Functional assessment	Yes	Yes
Telemedical service	Yes	Yes

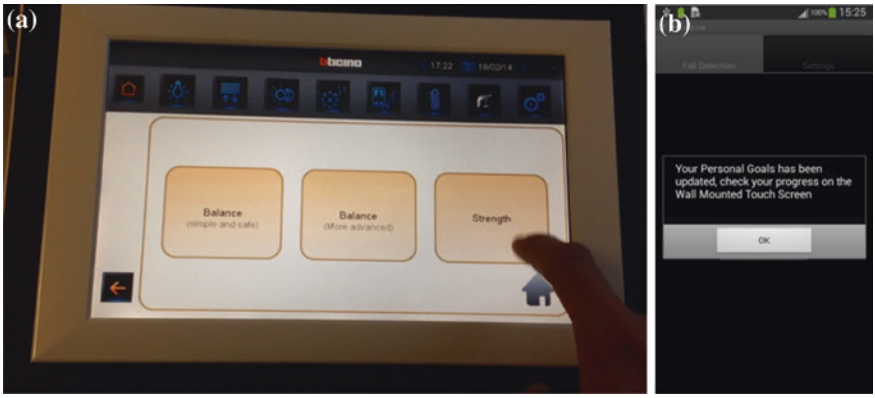

Fig. 2 **a** Wall-mounted touchscreen used for providing tips, feedbacks, and exercise guidance to the user. **b** The Smartphone provides remainders and inform the user about the content available on the wall-mounted touchscreen

In CuPiD, the Virtual Reality (VR) system implementing the exergame platform, is adaptive to enable individualization and graded levels of difficulty to fit patients' performance. To enhance motor learning and provide motivation and engagement, the VR simulation will provide immediate feedback about performance in the form of auditory and visual cues, as well as knowledge of results in the form of a score pertaining to the success rate and error rate in achieving the target goals. The gait rehabilitation system developed in CuPiD (Sect. 2.3) is able to provide real-time customized feedback to patients on how to maintain an effective and safe walking pattern. Target values for each specific gait feature (e.g. step length) are decided by the patient's usual therapist during a training session performed at the clinic. The system used at home acts as a virtual therapist: a SP application continuously process the data in real time and generates vocal messages like those that their usual therapist would say for correcting patients' errors.

2.2 Long-Term Monitoring

The FARSEEING smarthome continuously monitor all the peripherals installed in the home environment like switches, buttons, touchscreens, PIRs, RFID system, etc. Any interaction between the user and the smarthome is recorded by means of a listener-like or a polling approach depending on the specific device. Behaviour is seen as the product of the person, the context of the environment, and the task being performed; the latter is identified and assessed by means of the long-term activity monitoring of the user. Depending on the mounting option, the SP or the dedicated wearable unit are used for estimating:

- Mounting option 1—the device is used/placed without any constraints. Available features: Sedentary/active periods; walking bouts; lying times; energy expenditure; number of steps.
- Mounting option 2—the device is worn on the lower back. Available features, in addition to the mounting option 1: Temporal gait parameters like cadence, regularity, symmetry, coordination, and smoothness; analysis of the turns including turning angle, duration, mean velocity, peak velocity, and smoothness.

2.3 Training/Rehabilitation at Home

Gait in PD is impaired particularly in its semi-automatic nature, precluding patients to walk while thinking or planning other activities. People with PD, in order to perform an effective and safe walk dedicate each attentional resource to accomplish what normally, instead, is a fully automatic activity. They drive feet and lower limbs trying to maintain an augmented speed, large steps, good clearance from the ground, increased gait rhythm, upright trunk posture, etc. This continuous focus on motor movements prevents the possibility of executing contextually any other task and hence to carry out with ease the everyday activities that make up our personal, domestic and social lives.

With the progress of the disease, many of the balance deficits as well as gait impairments become resistant to most pharmacological and surgical treatments. However, it has been demonstrated that also motor learning and rehabilitation principles can be effective to limit these motor deficits. Considering that PD is a chronic neurodegenerative disease, to make rehabilitation exercises maximally effective persons are in need of a continuous training integrated into everyday routine. CuPiD has therefore developed systems for being used at home. CuPiD solution consists of a wearable and stand-alone system able to perform an accurate gait analysis and at the same time to act as an intelligent tutoring system for gait rehabilitation. The system consists of a wireless body area network (Fig. 3a) of 3 inertial sensors, 2 worn on top of the shoes (Fig. 3b) and one on the waist, and a SP acting as central processing unit (Fig. 3c).

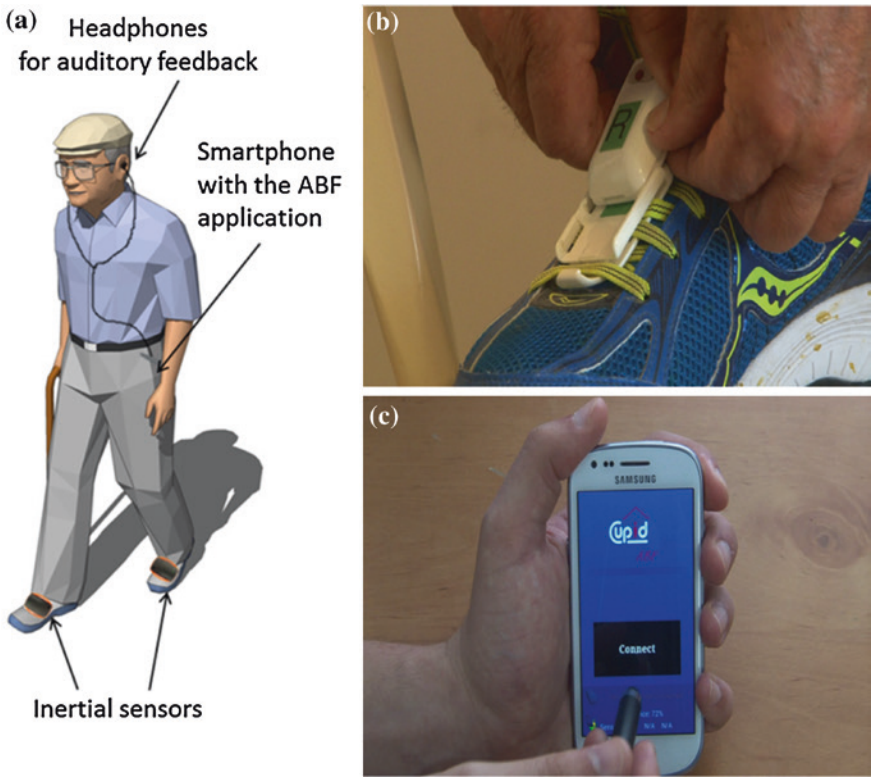

Fig. 3 **a** CuPiD system for gait rehabilitation at home composite of three inertial sensing units, a smartphone, and headphones. **b** Inertial sensors placed on the shoes by means of a dedicated clip. **c** CuPiD Android application which is able to collect and process the data in real-time and to provide vocal messages to the user

2.4 Exergames

Exercise games or exergames are games aiming to improve and increase the users' physical activity through exercise [1–3]. Exergames are designed specifically to track body motion and provide the player with entertainment during exercise.

The CuPiD exergaming platform includes three dedicated serious games for Parkinson's patients developed to increase physical activity and specifically address problems in balance control, sit-stand transition, and onset of walking. The three games that were developed for this purpose combine a motor as well as a cognitive component. The rationale is that activities of everyday living are goal-oriented movements that in essence are a series of combined tasks involving both motor and cognitive aspects such as information processing, planning, strategic choices and execution of movement.

Unlike CuPiD, FARSEEING has chosen a commercially available system, Silverfit (http://www.silverfit.nl), for exergame-based interventions at home. Commercially available exergames were examined to assess the user preferences and movement qualities when performing the games, operationalized as weight shift, step size, movement speed, vision attention, and movement direction.

2.5 Functional Assessment

The same system used in CuPiD for gait rehabilitation at home also allows clinicians to remotely assess motor skills of the patient on a daily basis. Gait features like step length, foot clearance, spatio-temporal step/stride variability, single/double support, etc. can be accurately assessed and monitored over time.

For investigating motor-related fall risk factors in older adults, instrumented versions of some of the most popular clinical functional tests have been developed. Instead of using a body area network like in CuPiD, a minimal set-up has been chosen in FARSEEING; the set-up consists of a single inertial sensing unit placed on the lower back by means of a waist belt or directly applied to the skin (Fig. 1). Automatic algorithms are used for activity recognition and features extraction. Completely standalone applications are also used to allow the user to self-administer the test at home.

2.6 Telemedical Service

CuPiD provides a telerehabilitation service, which addresses the concerns of recent telemedicine reviews: interoperability, accessibility and reliability. Each individual component of the telemedical service is developed as a web application with a clear clinical-base/home-base split.

One of the FARSEEING objectives is to develop feasible telemedicine service models for detection of accidental falls, fall risk assessment and exercise counselling. Service models are independent of the system infrastructure. Telemedical services make use of the FARSEEING infrastructure for exchanging information between the user and the caregivers; the aim is to provide individualised guidance based on data on activity patterns collected through the SP or the wearable sensor and the HCA system.

3 Discussion and Conclusions

An issue we have well in mind is that technologies themselves present a series of challenges for older people and for chronic-disease patients like PD and for those implementing technological solutions for everyday living problems. Technologies

may be viewed as intrusive. Non-acceptance and non-usage can be regarded partly as a consequence of the failure of designs and operational procedures to respond to the wishes and feelings of a very heterogeneous group as the older people.

Evidence from the FARSEEING and CuPiD studies shows that there is great diversity in the acceptance of, and willingness to use, different technologies. Some older adults are very confident using various technologies such as personal computers, SPs, and games consoles. Others describe being afraid of using devices and systems. They are afraid of something going wrong; that they might break the equipment; that the technology will fail; or that their privacy is being compromised. Our research [4, 5] indicated that it is more important to find out what motivates individuals to use technologies. It was reported that the key factor in overcoming the 'entry barrier' to adopting technologies is finding a motivation.

With the use of wearable technology, able to monitor and support an intervention strategy, the user can play an active role in her/his prognosis with an increased emphasis on health education, patient empowerment, secondary prevention and self-management of individual conditions, including co-morbidities and frailty. CuPiD and FARSEEING solutions can have a beneficial impact on empowering the user/patient for improving health-related quality of life in the comforts of their own home.

The importance of maintaining independence with regard to the acceptance of technologies has been reported in several studies [6–10]. Maintaining independent physical function was cited by many participants as a primary reason for older adults accepting technologies in their homes. Being able to live in their own homes, by themselves, for as long as possible and thus avoiding a change in their lifestyle habits was a strong motivation for acceptance. Therefore in the FARSEEING and CuPiD approach, stimuli and messages provided to the user have a focus on the possibility of regaining or maintaining independence. We envision that the health-care burden would be dramatically lowered just by adopting consumer electronic devices like SPs as front-ends for the delivery of services like self-assessment tools, feedbacks about own mobility, and guidance for training and rehabilitation at home.

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