An Environmental and Wearable System Supporting Monitoring Services at Home for Elderly People

SMARTA project experience in technology reliability and acceptance

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Abstract—**This paper presents the system validation of an integrated Personal Health System for supporting elderly remote monitoring and services. Objective of the trial as a whole is the assessment of reliability, effectiveness and usability of the SMARTA system. Outcomes from the validation tests were more than good for the system's reliability and all subjects assessed that they consider the system easy to use and that they will positively consider its introduction in their houses.**

Keywords-Personal Health systems; Reliability; Usability .

I. INTRODUCTION

The SMARTA project (acronym for the Italian title "Sistema di Monitoraggio Ambientale con Rete di sensori e Telemonitoraggio indossabile a supporto di servizi di salute, prevenzione e sicurezza per l'Active Aging", i.e., Environmental Monitoring System through a sensors network and wearable tele-monitoring to support health, prevention and security services for Active Aging)explored the validation and exploitation of innovative technologies about future healthcare services dedicated to elderly for Ambient Assisted Living and for a more accurate, personalized and widespread management of geriatric pathologies. In fact, two billion people will be aged 60 and older by 2050 [1]. This represents both challenges and opportunities. Older people make important contributions to society as family members, volunteers and as active participants in the workforce. The wisdom they have gained through life experience makes them a vital social resource. However, along with these benefits come special health challenges for the 21st century. It is important to prepare health providers and societies to meet the specific needs of older populations [2]. This includes: (1) training for health professionals on old-age care, (2) preventing and managing age-associated chronic diseases, (3) designing sustainable policies on long-term and palliative care, and (4) developing age-friendly services and settings.

In this perspective, the SMARTA project aims at developing and testing a system integrating personal and environmental sensors for the realization of healthcare services for monitoring vital signs, sudden adverse events like falls, promoting exercise and active lifestyle, communicating with caregivers, offering safety services at home (e.g., intrusion detection).

The SMARTA system can be classified into the category of Personal Health Systems (PHS): introduced in late 1990s, they are a recent concept as devices and integrated solutions offering distributed health services by exploiting the innovation in science and technology such as the biomedical, micro- and nano-technologies, and the innovation in the Information and Communication Technologies (ICT). In this specific application, PHS empower elderly in their health management together with supporting their safe home living thanks to continuous monitoring of health related signals and parameters, integrated home automation controls and a web-based assistance. In fact, PHS are empowering systems because they have been designed to place the individual citizen/patient in the center of the healthcare delivery process. They allow citizens/patients to have more awareness and responsibility in managing their own health, and they support the interaction with care providers whenever is necessary.

Among PHS, Wearable Biomedical Systems (WBS) are a specific category and they can be defined as integrated systems on a wearable platform (in the sense of clothing or devices attachable to the human body) and can offer solutions for continuous monitoring by measuring non-invasive biomedical, biochemical and physical parameters. Continuous monitoring with early detection of anomalies has likely the potential to provide patients with an increased level of confidence, which in turn may improve the quality of life. If WBS are an ideal platform for multi-parametric non-intrusive monitoring of health status, their user acceptance and reliability have been investigated in research but rarely in a real scenario. In the frame of the SMARTA project, a deployment of the system into real life has been tested: this activity was approved by Fondazione Don Gnocchi ethical committee and subjects provided and signed the corresponding informed consent.

This paper presents the results of the reliability and user compliance. In section II, the SMARTA system is generally described and the setup of the validation test is presented. Section III introduces the results obtained during the experimental phase, according to overall reliability, wearable ECG reliability and usability, and fall detection system reliability and acceptance. In Section IV, the conclusions of this experimentation are drawn.

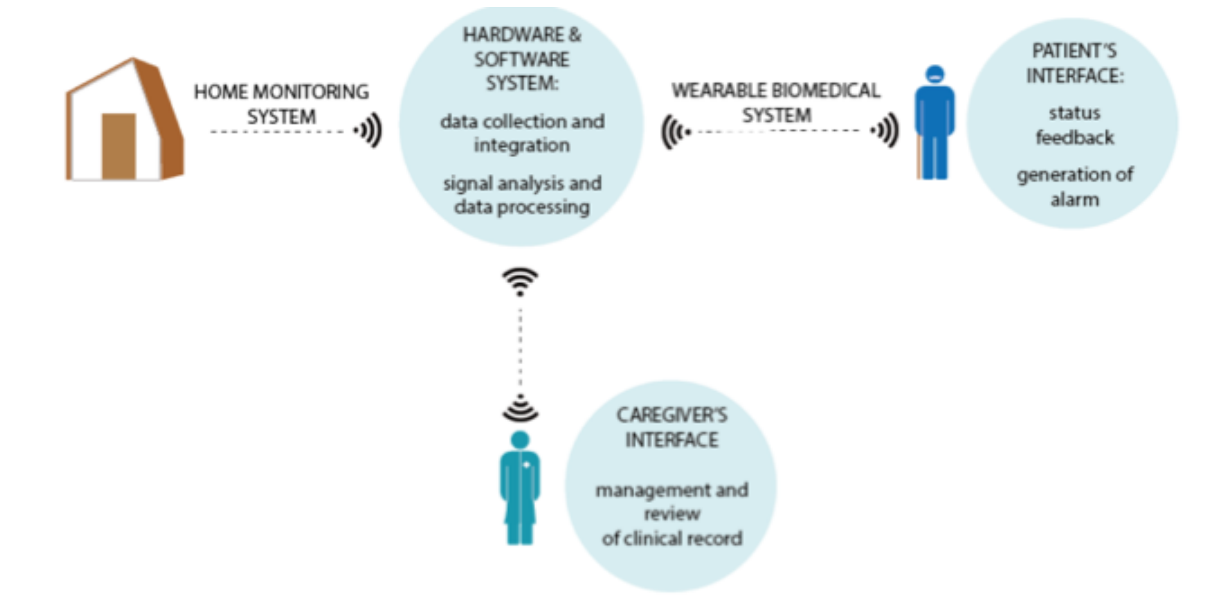

Figure 1. The diagram of the SMARTA system architecture.

II. Materials and Methods

The SMARTA system is the result of the integration of different components developed by the partners of the project. These parts correspond to specific functions of the overall system and are placed on different levels:

- monitoring of vital signs and lifestyle (e.g., no. of steps inside the house/environment);
- supporting the adoption of active lifestyles (e.g., performance monitoring of motor and physiological fitness exercises/prevention) and/or rehabilitation (exercises driven through video and the system is able to record the performance and movements);
- safety system environment (detection of falls, intrusion detection through detection of footsteps on the floor);
- communication with caregivers for continuous assessment and follow up.

These systems send data to a body/home gateway that redirects them to a center which concentrates the data and implements the above services (figure 1). The biomedical monitoring system is composed by wearable and non-wearable sensors. The considered sensors are: pulse-oximeter, glucometer, sphygmomanometer, thermometer, weighting scale, garment provided with sensors for ECG, fall detectors. The system was settled-up at the Smart Home of the "IRCCS S.Maria Nascente" Center, Fondazione Don Gnocchi.

The objectives of the test of the SMARTA system were the following ones. The main goal was the evaluation of the technical reliability of the prototype system in terms of:

- correct recognition and processing of the signals collected through the various system components;
- proper display/data management in the medical record;
- suitable provision or communication to the subject of information related to measures/alarms through the dedicated interface.

This first testing phase was carried out on 10 healthy subjects.

Whenever the technical reliability was good, the second set of evaluations was related to the procedure compliance, system usability and acceptance by the different endusers; in particular, the following elements were considered:

- simulation of the real applicability of the SMARTA system, through usability tests carried out in a controlled home environment;
- assessment of the perception of the SMARTA system in terms of patient's utility, usability, acceptability and attractiveness;
- evaluation of the perception of the SMARTA system in terms of caregiver's usefulness, usability, acceptability and attractiveness.

Thirteen elderly subjects (mean age 66.5 years) affected by cardiologic pathologies were recruited in this second testing phase.

For each trial, a dedicated testing protocol and the related methodology for measuring the proper outcomes and related indexes were defined. This paper is focused on the outcome for (1) the overall system, (2) the wearable monitoring system, and (3) the ground monitoring system.

III. Results and Discussion

A. *Overall SMARTA system reliability*

The first phase of testing revealed that the SMARTA system has some improvement fields in term of technological stability. In fact, some failed measurements are still present in the system (Table I).

TABLE I. SMARTA RELIABILITY ANALYSIS – ALL SUBJECTS

Reliability	GUI	Measured parameters						
		T	W	AP	SpO2	Gl	ECG	TS
% passed	100%	65%	65%	70%	70%	70%	70%	65%
Parameter legend: T = temperature, W = Weight, AP = Arterial Pressure, SpO2 = , Saturation of Peripheral Oxygen Gl = glycaemia, ECG = ElectroCardioGram, TS = Tinetti Score.								

In particular, the user interface (GUI) is the most stable component (100% of positive results) while during the measurement of the physiological parameters a 30-35% of failed test are shown. These problems were due to some intercommunication bugs distributed in the different hierarchical levels of the system. This test highlighted the need for a further step of tuning to increase the stability and the reliability of the system, even if the performance is generally encouraging.

The system underwent the judgement of thirteen patients in terms of utility (Figure 2), usability (Figure 3), and acceptance (Figure 4). A set of subjective assessment was administered through a dedicated questionnaire to the recruited subjects (Table II). The Likert scale with 7 values (from -3 = fully disagree, to 0 = neutral, up to +3 = fully agree) was chosen for ranking the subjective evaluations.

TABLE II. SMARTA RELIABILITY ANALYSIS - ELDERLY

Parameter/ question no.	Question
Utility	
Q1	Better health status monitoring
Q2	Increased safety at home
Q3	Reduced stress from continuous medical visits
Acceptance	
Q1	Patient privacy compliance
Q2	Comfort of wearable sensors
Q3	Easy to use system
Usability	
Q1	Clarity and immediate understanding of the SMARTA GUI
Q2	Pleasantness of the SMARTA GUI
Q3	Interest in SMARTA system adoption

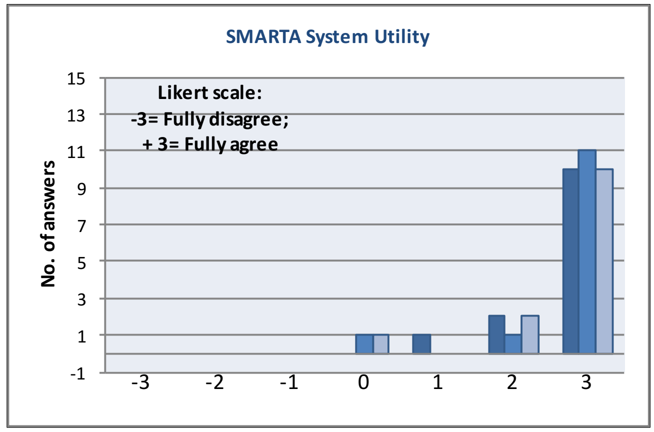

Figure 2. Results of the subjective assessment for the SMARTA system utility.

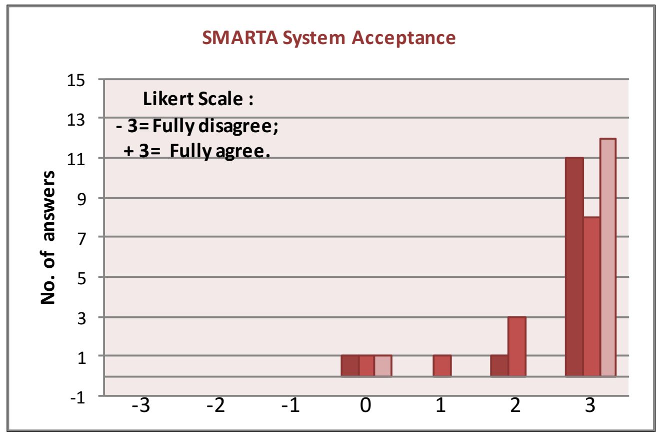

Figure 3. Results of the subjective assessment for the SMARTA system acceptance.

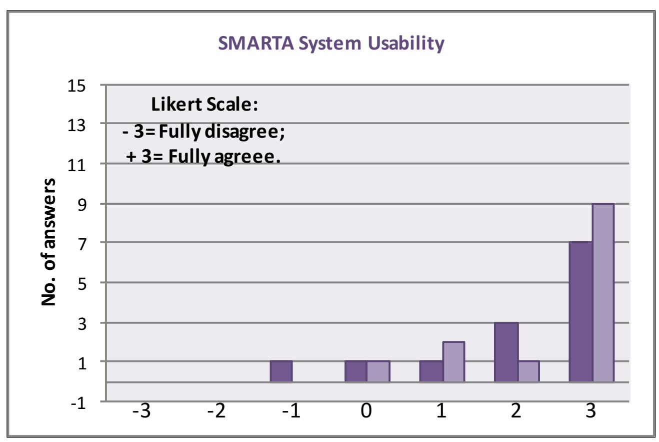

Figure 4. Results of the subjective assessment for the SMARTAsystem usability.

A similar assessment was carried out on the clinical operators that used the system. A set of subjective assessment was administered through another dedicated questionnaire to the four recruited subjects. The three investigated aspects were *utility*, *acceptance*, and *usability* according to the following questions/factors (Table III); the results (Likert scale) are summarized in Table IV.

TABLE III. SMARTA RELIABILITY ANALYSIS - CAREGIVERS

Parameter/ question no.	Question
Utility	
Q1	Reduction of visit number
Q2	Continuous monitoring
Q3	Efficacy of recorded clinical parameters in the personal healthcare folder
Acceptance	
Q1	Patient privacy compliance
Q2	Easy training to use the system
Q3	Technical appropriateness and reliability of the SMARTA system
Usability	
Q1	Clarity of personal healthcare folder consultation
Q2	Clarity of personal healthcare folder setup and management
Q3	Interest in SMARTA system adoption

TABLE IV. SMARTA: RELIABILITY ANALYSIS - CAREGIVERS

Caregivers	Utility			Acceptance			Usability		
	Q1	Q2	Q3	Q1	Q2	Q3	Q1	Q2	Q3
Mean value	2.8	2.8	2.5	3.0	1.8	2.8	1,0	1,8	3.0

The results show that the prototype of the SMARTA system has been highly appreciated by its potential users (both patients and clinicians) due to its potential in terms of improving home care and simultaneous decrease of the workload of caregivers.

Patients consider the interface clear and effective, but further developments should include the implementation of the feedback alarm relating to home automation. Also the management of measurements can be optimized in terms of questions and confirmations to the end-users.

Instead, the dedicated interface to clinical services (medical records), should be partially revised to match more effectively the needs of the operators. Further developments should include a general revision of the GUI and, in particular, an improved version of the management of the patient profile (profile creation and management of custom settings) and of the visualization of the results of the ECG (the track is neither readable nor understandable by patient and their relatives as end-users).

B. *Wearable ECG system reliabiliy and usability*

The wearable system was a system for non-intrusive monitoring of one ECG lead and trunk actigraphy. The ECG signal is acquired at a sample frequency f_s = 256 Hz with 24 bit resolution. The raw signal and the processed data are stored in an internal flash memory then downloaded through Bluetooth connection. The same device has also a three axes accelerometer used for wearable fall detection. Wearable solutions include two sensing components to be used with the same hardware device for ECG recording and transmission: an adhesive patch embedding the standard silver/silver chloride electrodes, and a garment provided with sensors (a t-shirt for the male patients and a belt for the female subjects as shown in Figure 5). These second elements embed conductive yarns to implement textile electrodes. Being not adhesive but simply adopting the t-shirt/belt elasticity to keep the sensors adhering to the skin and to minimize the skin motion artefacts. Specific attention has been paid to their design and the choice of materials.

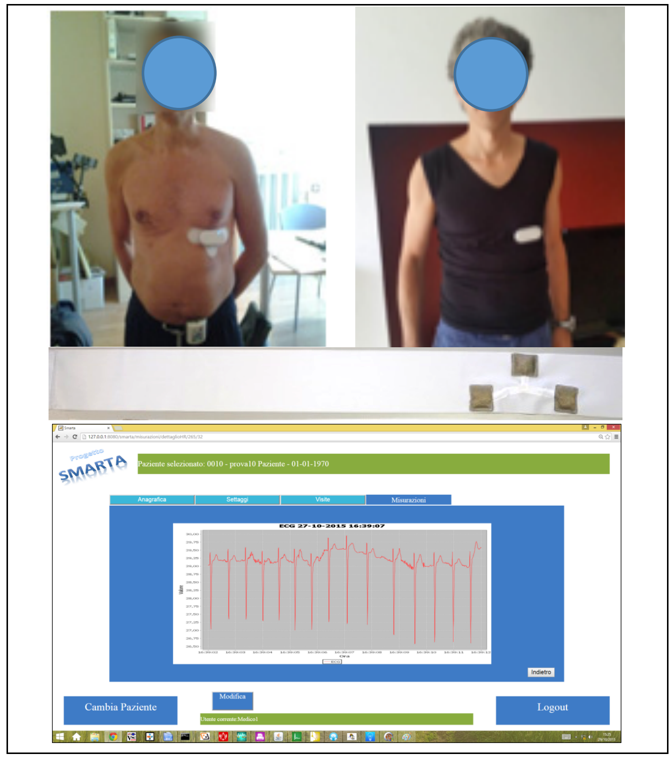

Figure 5. Wearable components of the SMARTA system (the patch, the t-shirt, the belt) and an example of acquired signal.

Preliminary design validation was related to recorded ECG tracks quality compared to the actual one. This analysis demonstrated the clinical suitability of the proposed system. Both solutions provided clinical quality ECG tracks. The validation tests showed also that the sensing patch was preferred for its simplicity in putting it on, while the belt and the t-shirt required more demanding operations. Despite this aspect, prolonged t-shirt or belt wearing was comfortable and did not provoked any skin irritation effect, while adhesive patches usually do. No such tests on the SMARTA patches were carried out during this validation phase.

C. *Ground fall detection system reliabiliy and usability*

The ground fall detection was set-up with tri-axial MEMS accelerometers [3] located on the ground. The signals were acquired by a Raspberry PI based system and it was analyzed in real time by extracting the RMS and the maximum values of the waveform. An example of the vibration time history is shown in Figure 6.

The vibration measured by the accelerometers was used to estimate if the event can be related to a fall or if it is due to the daily-life activities. The dependence between the measured acceleration and the force generated by the impact was quantified with the ground apparent mass, that was identified with preliminary experiments not described in this work.

The procedure for the fall identification is based on the data fusion at feature level as in [4]. To date, there were no falls and consequently it was not possible to validate the fall detection system. However, results showed that the system are useful to identify the human activities (between 11 and 18.30 in Figure 6) from the period where there was no activity in the room (after 18.30). The vibration spectra evidenced that there were no dominant frequency components up to 50 Hz, coherently with what was evidenced in other kinds of building at the ground floor.

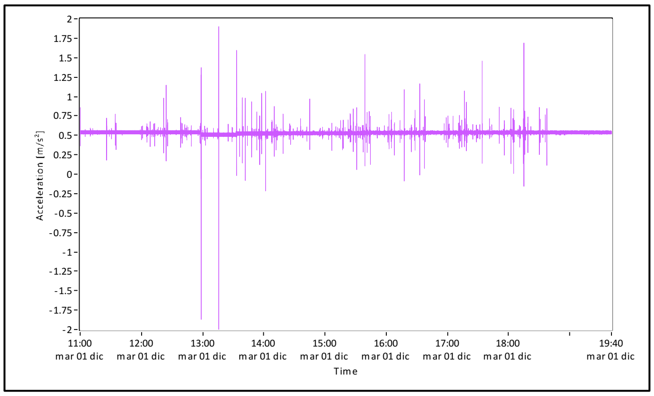

Figure 6. Vibration measured on the floor during the system usability tests.

Experiments performed in laboratory conditions evidenced that the simultaneous use of at least three accelerometers located on the ground allows identifying the position of the event that generated the vibration. The detection is based on a particular triangulation method that uses the wavelet transform to localize the source position; in our case, the triangulation was not effective given the limited bandwidth of the system. The validation of the source localization procedure is deserved to forthcoming studies.

IV. CONCLUSIONS

The SMARTA system demonstrated not only a good technical reliability but also a more than positive usability and acceptance judgement by the end-users. This is a key point for its deployment into real applications. In parallel, the residual problems of communication between the various hierarchical levels of the system, which in particular cases may introduce errors into the proper recording and data storage, were solved and now the robustness of the system ensures its applicability to the patient's home. About the sensors, further developments should be designed with respect to the design and ergonomics of the sensor-shirt and belt to facilitate their use in full autonomy. In doing so, the exploitation of the SMARTA system will aim to bring benefits to citizens and health authorities alike: first, by improving the quality of care for the individuals themselves; second, by containing the rising healthcare costs through the proper and efficient use of technological capabilities.

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