A first step toward a pervasive and smart ZigBee sensor system for assistance and rehabilitation

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Abstract— **This paper shows the general concept and the primary implementation of a pervasive intelligent system for rehabilitation and assistance. The scope of this work is to highlight the possibility to join two important research fields, i.e. rehabilitation and ambient assisted living, to enhance the capabilities and independence of disable and aged people. The described system was composed of a ZigBee network, with coordinator, sensor and actuator nodes, able to identify and control patient's activities and send warning to caregiver if requests in warning functionality, and of a software interface to manage the whole network and to monitor patient in outdoor environment.**

I. Introduction

IN worldwide population, the number of elderly persons is quickly increasing: in 2000 approximately 10% of the world's people were 60 years older and recent studies expect that in 2050 this percentage will rise to over 20% [1]. This trend is also correlated to a rapid growth in the number of persons with physical disabilities [2]. Therefore the problem of care and assistance to these persons are becoming more and more important both from social and economical points of view. Because of natural consequences of ageing and diseases (e.g. cardiovascular illness, stroke, Alzheimer's syndrome, etc.) elderly subjects continuously need of supports for their health and for carrying out activities of daily living (ADLs). These cares require both the work of clinicians, nurses, health experts and the use of hospital structures and medical devices and represent a heavy load on the public welfare spending. Moreover, elderly persons are often monitored and assisted by a caregiver, that is a member of their family or a person engaged by their family to help them in ADLs. This home assistance entails lower costs but often has negative consequences on quality of life and state of health of the caregivers.

For this reason the idea of using modern technological solutions to support the work of caregivers and health workers is developed and leads to the development of robotics for personal care.

Thanks to robot characteristics, related to acquisition of sensor parameters, repeatability, precision, programmability and elaboration of information, many scientists and researchers are studying robotic solutions that should support activities of clinicians and caregivers, i.e. rehabilitation and domiciliary assistance [3]-[7].

Both for economic and logistic reasons (i.e. time, difficulties in moving), the necessity to provide medical treatments and assistance directly at home of elderly persons is strongly becoming a necessity, because with this care approach it is possible to assist the persons and at the same time guarantee and preserve their autonomy and independence, factors which deeply influence on elderly persons self-perception of quality of life. In this context Tele-rehabilitation plays an important role.

Tele-rehabilitation lies on the idea to support disabled persons or aged people during daily life activities in home and/or working environment, achieving independence from nursing stuff or caregivers. Basically patients are able to carry out rehabilitation exercises and can be monitored by clinicians remotely: patient and therapist are in different places but health worker can control in real time the rehabilitation therapy thanks to a video and information acquired by sensor and rehabilitation devices present at patient's place. These systems for remote rehabilitation allow patients to carry out rehabilitation tasks more frequently than traditional rehabilitation and on the other side guarantee that clinicians and therapists can monitor all stage of therapy [8]-[11].

However rehabilitation systems are not completely independent and still suffer for the need of a supervisor or an expert assistance and control. In this sense some works have been carried out [12]-[13], but the general trend of scientist is to provide new technical solutions, such as smart devices, ambient intelligence and intelligent home, and the interaction between robotic platforms and patients [14]-[17]. (Tele-)Rehabilitation robotics and Ambient Assisted Living (AAL) are two worlds that can be integrated and joined each other to establish complex and complete systems which addresses as a whole the themes of assistive

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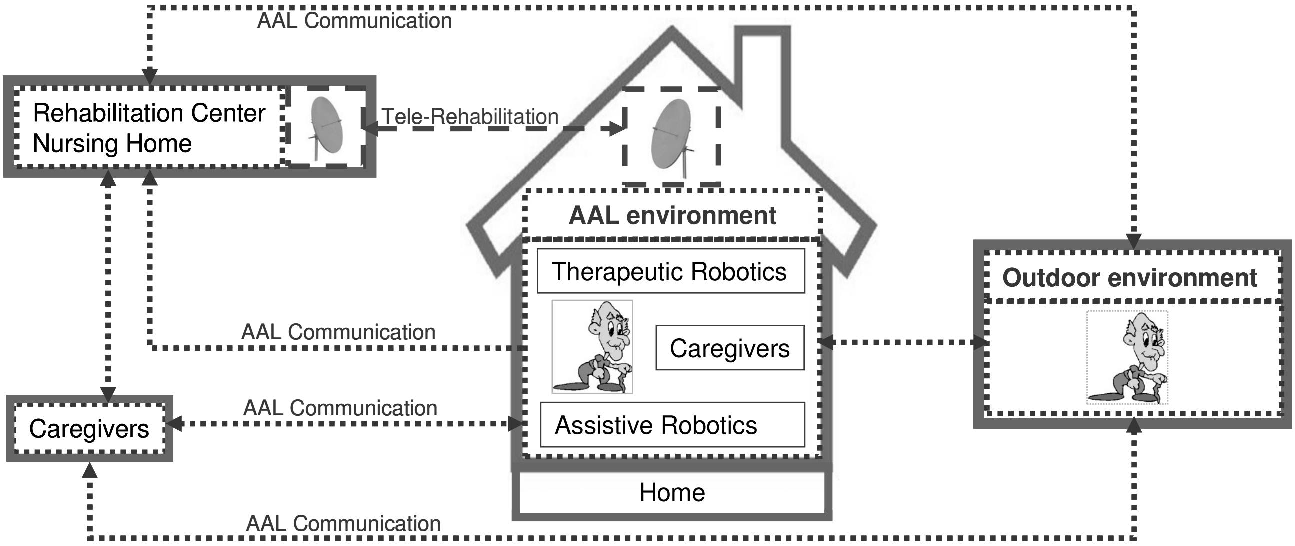

Fig. 1. Concept diagram with the all actors (Patient, Rehabilitation Center, Nursing home, Caregivers) and environments (Indoor and Outdoor). Dash line is related to tele-rehabilitation, dot line to AAL.

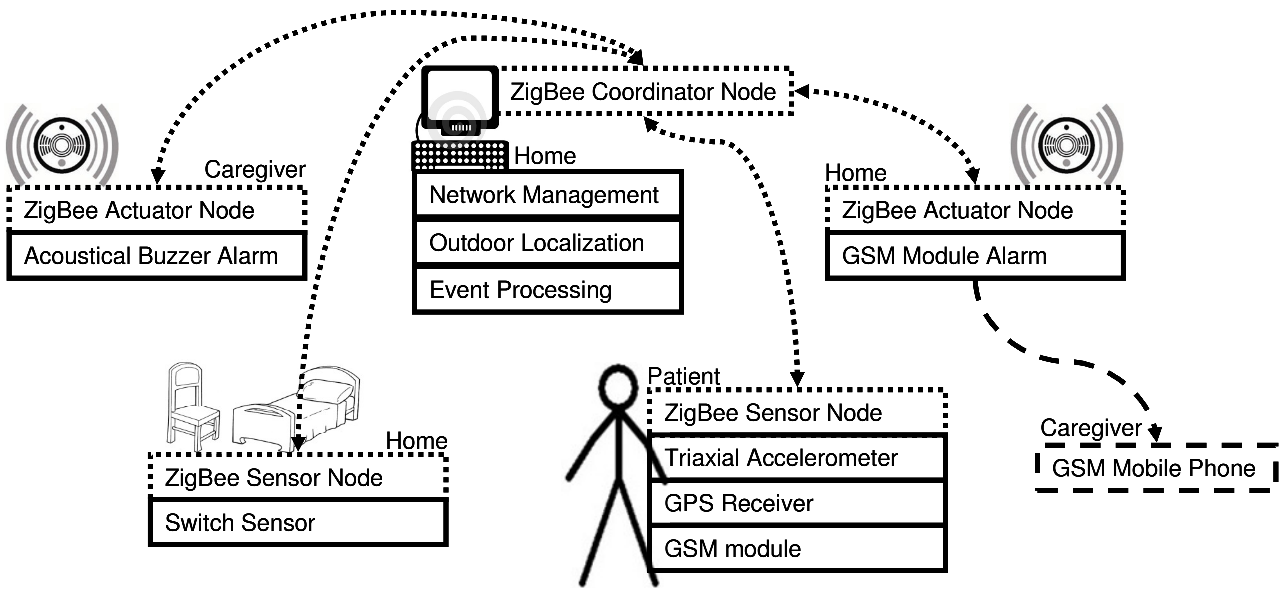

Fig. 2. Overview of the system in the AAL context. Dot line indicates the connection of ZigBee network and dash line indicates communication with outdoor environment through GSM network.

and therapeutic robotics, i.e. respectively, systems aiming to compensate for motor disabilities and systems aiming to restore motor deficiencies.

In this paper, the general concept and the primary implementation of a Pervasive Intelligent System for Rehabilitation and Assistance (PISRA) is presented. This system would be a first step toward a modular and intelligent home environment solutions, to enhance the independence of patients and facilitate their communication with outdoor environments.

II. CONCEPT

Considering previous reasoning, it was developed the idea to use the technologies and the robotics as bridge between elderly persons and caregivers and medical services. The AAL and the rehabilitation are two branches that, combined together, can carry out the novel approach of assistance more efficaciously, that is monitoring and assisting continuously elderly persons both in rehabilitation exercises and in ADLs, both in indoor and outdoor environment (Fig. 1).

The integration of AAL and Tele-rehabilitation in one technological solution allows elderly subjects to get at home appropriate rehabilitative treatments and to be continuously monitored and assisted in case of necessity and at the same time to help caregivers and health workers in their functions of care and support to the persons in question.

It is important underlining that to make effective this novel care approach and to be accepted by elderly persons, it is fundamental make sure that the technological systems are easily integrable in domestic environment (elderly persons should not perceive them too much invading and extraneous) and are easy to use both by elderly and by caregiver and health experts.

III. SYSTEM ARCHITECTURE

The domestic environment was arranged with two different typologies of device. It included a pervasive wireless network with sensors and remote warning actuators and two interactive software for managing the whole PISRA (Fig. 2).

A. *Interactive Software*

The first interface (Fig. 3) was developed on C#-platform to allow users (caregivers) to manage the network system, such as seeing the state of all nodes and enabling/disabling the warning functionalities.

Fig. 3. Management interface to real-time monitor all nodes, enabled/disable functionalities and control status of the network (up); localization interface to monitor patient in outdoor environment using Google Map website.

Data coming from sensor nodes, through the coordinator node, were processed by means of an appropriate algorithm, which was able to identify activities of patient (if he is on the bed or sitting in front of TV, is fallen or leaves the house) and send warning to caregiver if requests in warning functionality.

Up to now three functionalities have been implemented: if the patient rises form the bed (Bed Monitoring - BD), a warning signal could be send to the caregivers by means of an acoustical or mechanical buzzer; further, if the patient falls (Fall Detection - FD) or goes out from the house (Indoor Outdoor Position - IOP), a SMS could be send to caregivers by means of the GSM network.

The second interface (Fig. 3) was developed on C#-platform to allow users (caregivers) to localized patient's location in outdoor environments just clicking one button. Using the GSM network, it requests the geographical coordinate to the GPS-GSM module worn by the patient and, with an internet connection, it is able to display on the Google Map panel the exact position of patient. This function is useful both for evaluate the daily activities of a patient and his/her position if he/she gets lost.

B. *Pervasive Network*

The pervasive network was developed based on the ZigBee protocol and was developed with three kind of nodes, named coordinator, sensor and actuator (Fig. 4).

The use of ZigBee technology is ideal because it is a standards-based technology with worldwide approval and provides the reliability and scalability, necessary to easily adapt the technology of wired home system into a wireless solution. Thank to this technology, different ZigBee-based and sensorized devices can be easily added to PISRA, communicate each other, and change from sleep to active mode in less than 15msec. These features give to the entire system, respectively, the capabilities to be very modular in terms of functionalities and applications, very efficient in terms of robustness of the network for sending data without failures or latencies, and very inexpensive for reduction of power consumption.

1) *Coordinator node*

The coordinator node was used to create and hold the network. It was USB connected to a personal computer and was able to receive all data coming from other nodes and send signals to actuator nodes for activating warning message. Data coming from sensor nodes are stored and processed on the personal computer.

2) *Sensor nodes*

The sensor nodes were used to monitor beds, chairs, posture and location of patient in his environment. The sensor for beds and chairs were produced using two metallic layer, inserted in a cushiony casing, and placed on the chairs or under the mattress of beds. The two layers worked as a

Fig. 4. System's components: coordinator node (up-left), ZigBee node connected to sensor and actuator nodes (down-left), bed sensor (up-right) and wearable sensor device for patient (down-right)

switch, such that when the patient goes bed or sits down they touch each other and generate the closure of the switch.

The sensor for posture and localization were included in the same device worn by the patient. The sensor for posture is developed with a triaxial accelerometer and its vertical component on the sagittal plane was used to asses the inclination of sensor with respect to the horizontal plane. The accelerometer signals were acquired at 20Hz sampling frequency and low-pass filtered at frequency of 5 Hz with a four order Butterworth filter and inclination was calculated comparing the static acceleration of the sensor with the gravity acceleration. Three position were recognized with a threshold based algorithm: standing up, completely lying down, and just inclined.

The sensor for localization was used to detect the presence of patient into the apartment. While the patient is in the apartment, the worn sensor node is included in the ZigBee network. As soon as the patient goes out, the sensor node disconnects from the network, and the leaving house is recognized.

3) Actuator nodes

The actuator nodes were used to activate and send alarms both as acoustical signal with a buzzer for indoor warning and as SMS message with a GSM module for outdoor warning.

IV. Preliminary Evaluation

The PISRA system and its assistive functionalities (included some functionalities which will be soon added to it) were firstly validated together with a multidisciplinary work-team of a nursing home for elderly people [19], consisting of clinicians, psychologists, therapists and engineers.

In order to assess and evaluate its usability, efficiency and acceptability, PISRA was showed to fifteen sociomedical expert workers, which daily follow thirty one old domiciliary cases of Dementia and Alzheimer's syndrome.

The PISRA was described as normal domestic system with a wireless sensors network that allows to monitor and to assist elderly people in carrying out some of daily activities:

- Sleeping: Bed Monitoring (BM) and the agitation states (AG);
- Localization: recognizing when subject is at home (Indoor) or Outdoor and localizing his/her outdoor Position (IOP);
- Posture: Fall Detection (FD);
- Tele-rehabilitation: applied both to motor (TRM) and cognitive level (TRC);
- Social Communication: with relatives and friends (SC);
- Taking drugs: reminding and Delivering Drugs (DD);
- Activity: remembering events and appointments (MEM).

The work-team had the possibility to see the preliminary version of the PISRA, which implemented the BM, IOP and FD functions, and test it in an opportunely furnished apartment for elderly people. All work-team's operators expressed their opinion about the applicability and validity of the PISRA and its functionalities for the end-users they really followed during their work. They compiled a 5-points scale questionnaire ('1' for the most negative judgment and '5' for the most positive one), which included appropriate questions on utility, obstruction, easiness to use the control interface, acceptance by end-users, assisted and monitored in the specific task, and the consciousness of patients about their general necessity to be supported and monitored. The mean values and standard deviations of the obtained results are showed in Table I.

A similar questionnaire was provided to the same operators for what concern the other functionalities which were not yet ready to be tested in real condition, but whose judgement was considered by ourselves important to have a preliminary overview, in terms of acceptability, utility and usability, of the whole system we are going to develop.

Results related to the utility were enough positive, obtained score higher than the mid value of the scale. Also we have to observe that standard deviation of scores was quite high with respect to mean value, and this was generally true for all results. In our opinion this phenomenon was due to different propension of operators to use technological and innovative assistive aids. Some operators accept innovative technology with enthusiasm and with consciousness to better operate by means of new devices. Instead, some others perceive technology with scepticism, thinking that it could substitute at all the operators' work.

Opinion about easy integration in the domestic environment and low perception of obstruction of these systems was positive for all the functions except ones, in which users should wear a sensor (IOP and FD). Indeed persons with dementia have some difficult in autonomously

TABLE I
RESULTS OF THE PRELIMINARY EVALUATION FOR PISRA

	Utility	Not Invasive	Control Interfaces	Acceptance
BM	2.8 ± 1.4	4.0 ± 1.1	3.5 ± 1.1	2.4 ± 1.0
IOP	3.1 ± 1.4	2.3 ± 1.3	3.2 ± 1.1	2.6 ± 1.0
FD	3.6 ± 1.0	2.2 ± 1.1	3.5 ± 1.1	2.5 ± 1.1

The table shows the mean value and the standard deviation of judgments about the BM, IOP and FD functionalities of PISRA.

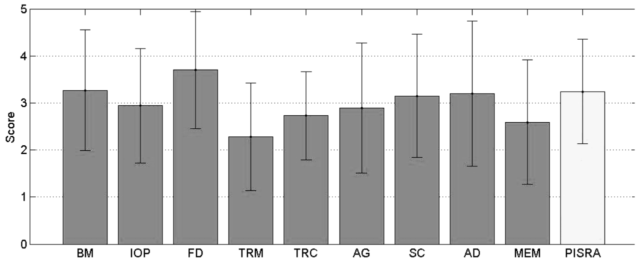

Fig. 5. The overall assessments for each functions (dark bars) and for PISRA as a whole (clear bar).

remembering to wear a device; further they are useful to draw away from any extraneous object. Sociomedical experts suggested to study more miniaturized solutions for these functions. Anyway the presence of the other systems was positively judged: old persons get used to see monitors and remote control switch in their house (as television set and computer workstation) and the other ZigBee nodes are small and without wires so their visibility in the space is really reduced.

The workers had the possibility to see and to try to use the software control interfaces showed in Fig. 3. After this test they believed that these interfaces were clear and simple to use. However they noted that if a caregiver is old and is no to so inured to use a mobile phone or a computer, the interface could appear complicated, so other solutions should be conceived.

To better understand the needs and features of persons suffering from Alzheimer's disease and dementia, sociomedical experts also expressed a judgment for each of their end-users, about the consciousness of their motor and cognitive deficits and about how much they could accept to be monitored and supported in carrying out daily tasks. The results about the consciousness were low (1.9 ± 1.0), because subjects in initial and advanced stage of dementia are not aware of their conditions and this increase the dangerous level of these subjects and confirm the necessity to be continuously helped and assisted.

Fig. 5 shows the overall assessments for each functions (dark bars) and for PISRA as a whole (clear bar). These results were positive and confirmed the importance to continue the study for developing the complete versions of PISRA with all the conceived functionalities. However a specific remark can be couched about motor and cognitive tele-rehabilitation. These kinds of functionalities are based on approaches completely innovative and different from the standard ones and sociomedical workers, having not practical experience about them, were doubtful about the validity of this kind of technological solutions. They believed that a system for carrying out rehabilitation therapy at home without the real presence of a physiotherapist, sending to the physiotherapist feedbacks about the effectiveness of the tasks and giving to him/her the possibility to correct from remote the occurrence of errors by patients, is a fantasy and unrealizable project. To overcome the skepticism of sociomedical experts and to have useful opinions and remarks on how to improve the systems, it is fundamental to show them concrete prototypes.

For sociomedical workers the functionalities conceived to be integrated in domestic environments are suited and useful for elderly persons suffering from dementia or Alzheimer's disease. Thanks to these functions users can live longer independently and safely and at the same time caregivers and relatives can monitor them and be alerted in case of dangerous contexts and, consequently can quickly intervene.

V. DISCUSSIONS

Nowadays home rehabilitation and assistance is becoming an important binomial because has strong social and economic motivations, effective solutions for aged and disabled people and could make human life more pleasant and easier. Moreover, AAL and smart home technology are demonstrating that they could be very profitable for intelligent and smart management of different environments. The conjunction between rehabilitation and AAL leads to a multidisciplinary and synergic research line, which robotics, telecommunications, intelligent algorithm and processing, sensors and human-machine interface are included in.

This approach allows us to define an Ambient Assisted Rehabilitating and Living (AARL) in which all actors, i.e. patient, robots, sensor network, indoor devices in general and caregivers, form an integrated system and are able to communicate each other and with outdoor actors. In this context, also the software solutions play a fundamental rule in terms of intelligent algorithm and framework for interaction of humans, robots and environments [18].

What it is possible to see in future is that smart home will be characterized by technological components, which will provide human-friendly interaction with users, and will meet the individual user's needs, emotional characteristics, and preferences.

VI. CONCLUSIONS AND FUTURE WORK

This study represents the first step towards a pervasive, modular and integrated network for rehabilitation and assistance. The effectiveness of preliminary experiments with aged people with dementia have provided good motivation for continuing this work. Although we need more experimental data to validate this system, the response we received from caregivers and nursing stuff was highly encouraging.

Future work include a new set of sensors to monitor more activities, i.e. movement and location of patient in indoor or physiological parameters, the development of a robust event stream processing software for real time management of events and the conceiving of a module to carry out tele-rehabilitation.

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