Rehabilitative TeleHealthCare for post-Stroke Outcome Assessment

Gabriela Postolache
Instituto de Telecomunicações, Lisbon, Portugal
Universidade Atlântica, Oeiras, Portugal
gabrielap@uatlantica.pt

Claudia Maia Moura
Universidade Atlântica, Oeiras, Portugal
claudiamaiaemoura@gmail.com

Pedro Silva Girão
Instituto de Telecomunicações/DEEC, IST, Lisbon, Portugal,
p.girao@lx.it.pt.

Octavian Postolache
Instituto de Telecomunicações, Lisbon, Portugal
opostolache@lx.it.pt

Abstract — **The article summarizes ongoing research on intelligent Tele-rehabilitation Assistants for in home rehabilitation of post stroke patients. The designed system is expressed by a set of smart sensors including a microwave FMCW Doppler radar that are connected to an embedded computing platform based on digital signal processor (DSP). This platform assures advanced data processing and wireless data transmission to a human machine interface (HMI) Android OS compatible device expressed by a tablet or by a smart phone as part of a health care intelligent ambient. The information from the health status and motor activity smart sensors is added to the patient localization given by a radar RFID device. Additionally, well-established neuron-rehabilitation instruments are used to evaluate the results obtained by the proposed architecture implemented in a ubiquitous and pervasive manner.**

Keywords - RFID technology, FMCV Doppler radar, vital signs, activity of daily living, pervasive computing, stroke rehabilitation

I. INTRODUCTION

Stroke is an important cause of mortality in EU Countries, accounting for about 10% of all deaths in 2008 [1]. Stroke is increasingly recognized as a significant and expensive medical and society problem [2]. In the European Union, Iceland, Norway, and Switzerland an estimated 1,1 million new stroke events occur each year and currently 6 million subjects live in these countries having survived a stroke [3]. The rates are higher in central and eastern European countries including Bulgaria, Romania, Latvia, Lithuania, the Slovak Republic and Hungary [1]. Moreover, the total annual cost of stroke in Europe is €21,895,000,000 [3]. Direct and indirect costs of stroke are estimated to be in USA €62,700,000,000 annually, with 15% to 30% of stroke survivors being permanently disabled and 20% requiring institutional care even after 3 months from the stroke event [4-5]. In addition to being an important cause of mortality, the disability burden from stroke is substantial [6]. Approximately, 35% of survivors with initial paralysis of the leg do not regain useful function, and 20 to 25% of all survivors are unable to walk without full physical assistance [4]. The likelihood of improvement after stroke varies with the nature and severity of the initial deficit. Patients who have two or more functional disabilities of daily living, but are able to learn how to sit in a chair, and participate in therapy are likely to benefit from home or outpatient rehabilitation [5]. Stroke rehabilitation involves a combined and coordinated use of medical, social, educational, and vocational measures for re-training individuals to reach their maximal physical, psychological, social, vocational, and avocational potential. Specifically, stroke rehabilitation programs are provided to optimize neurological recovery, teach compensatory strategies for residual deficits, teach activities of daily living (ADLs) and skills required for community living, and provide psychosocial and medical interventions to manage depression [4]. Rehabilitation may occur in different environments, including inpatient rehabilitation facilities, sub-acute rehabilitation units, skilled nursing facilities, outpatient facilities, and the patient's home through visiting nurse services [4].

Recent evidences on interventions for motor recovery after stroke showed that improvements in functions, quality of life and increase speed of motor activity recovery can be achieved with the use of robotic-assisted therapy [9], biofeedback [10-12] and medical instrumentation [11][13]. In an individual with mild-moderate hemi-paretic gait after stroke, a step watch activity monitoring (SAM from Cyma) system based on embedded system provides an accurate measure of ambulatory stroke across the sub-acute rehabilitation [13]. Large-scale telemedicine reports have shown good functional outcome and mortality comparable to other case series and trials of conventionally treated patients [14-15]. As technology matures, systems that today require dedicated high-bandwidth telecommunications networks (e.g., speeds in excess of 300 kilobits per second of synchronous duplex communication) and dedicated external video processor chips will soon be able to perform high-quality videoconferencing (HQ-VTC) with inexpensive, commercially available portable computers with standard integrated software and hardware options [4].

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Furthermore, recently review of the randomized clinical stroke rehabilitation trials have shown that most of the studies on effectiveness of interventions for motor recovery after stroke, enrolled small numbers of patient which precluded their clinical applicability (limited external validity) [16]. Also, preliminary results of European Project - Collaborative evaluation of rehabilitation in stroke across Europe - have shown large discrepancies in recovery pattern and organization of the rehabilitation centers [17]. These data suggest the necessity of large studies for assessment of patients recovering from stroke based on Information technologies (IT), technology assessment deployment and medical liability. Adding telecommunication tools to the practice of rehabilitation, especially if integrated with home rehabilitation, may provide researcher with timely access to adaptive rehabilitative processes and to design large studies with better ecological validity, lowering key constraints to timely assessment and therapeutic intervention during the continuum of care [18].

The two factors that may be the biggest barriers to provider adoption and utilization are associated with inadequate provider training (especially when the equipment installed includes features that are more complex and sophisticated than necessary) and the role of the provider as the gatekeeper of telemedicine access [19]. Moreover, vulnerable populations are at greater risk for impaired recovery due to limited geographic or financial access to appropriate rehabilitation services [20].

One of the aims of the work group is to establish a contextual aware system that continuously assess physical and motor activity and stimulate post stroke patient users to take actions that contribute to improve their health.

As far as we know, only one project currently addresses development of ambient intelligence for stroke rehabilitation. Oovit PT is an ongoing project at MIT Media Lab having as main goal the development of an end-to-end virtual rehabilitation system for supporting patient adherence to home exercise. Using the proposed system, the physical therapist and patient would make shared decisions about appropriate exercises and goals and patients would use a sensor-enabled gaming interface at home to perform exercises. Quantitative data is then fed back to the therapist, who can properly adjust the regimen and give reinforcing feedback and support.

Our team is currently exploring the viability of a system for Rehabilitative TeleHealthCare combining a low cost smart sensors installed in a wheelchair, walker, bed or chairs and a wearable device attached to the wrist of the patient. They are parts of a pervasive computation architecture that delivers diagnostics and decisions in autonomic form based on performance measures (process and outcomes measures) performed with well-established instruments (questionnaire) used in rehabilitation and also integrated with new methods and technologies. This system will allow electronic healthcare data storage, update and retrieval of information in a distributed, ubiquitous and pervasive manner. Continuing the previous work in the area of the health status monitoring in ubiquitous context [21-25], this article reports a set of architectures that combine microwave FMCW (Frequency Modulated Continuous Wave) Doppler radar, RFID technology, photoplethismography, force sensors, ferro electret film sensors, appropriate software developed with Android OS SDK and Java under Eclipse as part of pervasive health care environments.

II. Pervasive Health Care Scenario

The continuous assessment of physical and motor activity can provide an early indication of decline in health and functional ability. Better identifying and assessing problems, while they are still small can provide a window of opportunity for intervention, which will improve therapeutic intervention. Several studies have demonstrated that the limited access to patient-related information during decision-making and the ineffective communication among patient and care team members is often cause of medical errors in healthcare [13]. Thus, the pervasive and ubiquitous access to health and activities of daily living (ADLs) or instrumental activities of daily living (IADLs) data is considered essential for the proper diagnosis and therapeutic procedures.

The proposed system has the main goal of providing IT-based diagnostic of patient and rehabilitation outcome monitoring.

Important part of our implemented system is expressed by a pervasive computing architecture that includes a smart sensor network (IEEE1451 compatible) as part of smart environment where the intervenient can obtain information related with the monitored health and motor activity characteristics in a passive or active interaction way, using a tablet computer and RFID technology.

A. *General Architecture and "Players"*

A graphical representation of the implemented architecture that presents two layers, the scenario/ambient layer; and the user's layer, is represented in Figure 1.

The user layer can be seen as a simple Tag (e.g., radio frequency identification - RFID), placed on the wrist of a patient or in the wearing clothes, which has a passive interaction, having a natural presence in the scenario.

The ambient layer is based on three main components: the smart sensor network, the situated displays and the fundamental principle of pro-activity of these in relation to the users. The "players" on the pervasive health care scenario, described in Figure 2 are:

a) the stroke patient during the rehabilitation period;

b) the "observer" that is an accompanying person (e.g., nurse, physiotherapist, occupational therapist, physician, familiar) in the ambient – practicing the rehabilitation or watching the evolution of patient health status;

c) the health caregiver (e.g., nurse, physiotherapist, occupational therapist, physician, familiar), that can also be an "observer" and can take decisions according to the values provided by the implemented system.

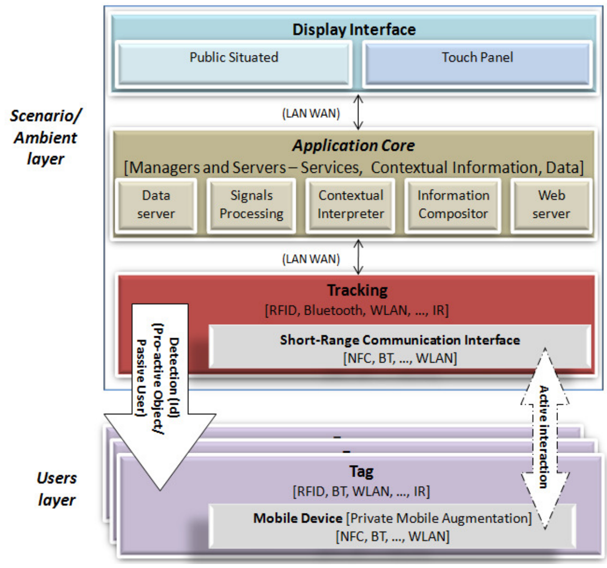

Figure 1. Pervasive healthcare architecture block diagram

Practical and ethical issues were evaluated in order to identify what type of sensors were going to be used and what type of information would be captured and transmitted throughout network.

The proposed distributed system associated with a pervasive computing architecture includes a set of smart objects such as 'smart' wheelchair, 'smart' walker, 'smart' chair and 'smart' bed as part of an intelligent ambient, where the intervenient can obtain information about the patient under rehabilitation: physical and physiological patterns from collected motor activity, and health data in passive or active interaction way, through the usage of HMI touch screen, situated displays and RFID technology for identification purpose. The used sensors are smart in the sense of context awareness or decision support properties.

B. Hardware Implementation

The main components of the hardware implementation are the sensing modules (SSm) for physiological and motor activity assessment, the RF identification modules (RFID reader and tags), the acquisition, primary data processing and data communication modules (APCm), and the human computing interfacing modules (HCI) expressed by touch panels (mounted on the wheelchair and walkers) and situated displays. The sensors considered in the present implementation, distributed on home furniture or embedded in assistive instruments for the rehabilitation are: 1). flexible force sensors (Flexiforce A401 from TekScan) - mounted in the walker's hand supports giving information about the force values applied by the patient during the therapeutic program; 2). FMCW Doppler Radars (24GHz) mounted on the walker and oriented through the stroke patient legs, used for evaluation of kinematic parameters and measurement of gait performance; 3). pressure mapping sensors (TekScan Conformat - installed under the bed linens, wheelchair or chair), sense person position in bed, wheelchair or chair and enable identification of in bed restlessness, and help to prevent and minimize sleep related dysfunctions, skin breakdown, spasticity, contracture, and pain; 4). photoplethysmography devices embedded in the wheelchair and walker hand support, give values of heart rate, oxygen saturation (SpO2) and respiration rate, 5). ferro-electret film sensors (EMFi sensors) placed in bed, chair and wheelchair, give information on heart rhythm and rate, heart rate variability (HRV) and respiration sensing the ballistocardiography signal 6). 3D accelerometers (ADXL335) in users' pocket, wrist or different parts of the patient's body, can give information on posture and patient movement on wheelchair, walker or chair. Values of heart rate, oxygen saturation (SpO2) and respiration rate, posture, gait, motor activity, activities of daily living (ADL), and instrumental activity of daily living (IADLs) are obtained after digital processing of the acquired signals including artifact and noise removal based on implemented wavelet and independent component algorithms (ICA).

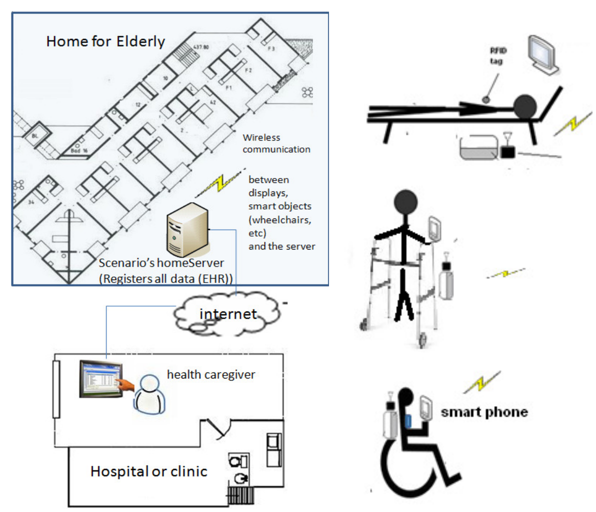

Figure 2. Client-server architecture view (e.g., a home for elderly scenario).

As parts of the scenario layer are mentioned the tracking component and the application core. The tracking component is materialized using the RFID technology and is responsible for "sensing" the co-presence of the independently user (e.g. post-stroke patient) in a predefined area. The architecture can be seen as applying the typical client-server model. Both the Tag component and the object's Display Interface component are considered as clients. The application core is responsible for data management.

III. Results

A pressure mapping sensor (TekScan Conformat), electromechanical film (EMFi) sensor and a low frequency (LF) RFID tag were placed in a 'smart' bed. The LF RFID based sensor activation mechanism was implemented in order to diminish the power consumption and increase the system autonomy. When the patient with the passive tag is in the bed region, the sensor data acquisition and data processing is started.

The pressure mapping sensor, installed under the bed linen, senses person position in bed. As mentioned before, it enables identification of in bed restlessness, preventing and minimizing sleep related dysfunctions, skin breakdown, spasticity, contracture, and pain by biofeedback approach, using visualization of the time the patient spends in the same position in bed. EMFi sensors, placed under the pressure mapping sensor, give information on heart rhythm and rate, heart rate variability and respiration. HRV analysis using frequency or time frequency algorithms, together with information on heart rate and in bed restlessness, give personalized profile of user's acute illness, level of psycho-physiological stress and the therapeutic effect on post-stroke patient physical activity.

During the therapeutic program the captured motion is on-line analyzed at the APCm level and the obtained data are compared with historical values received through client-server data synchronization in order to highlight the therapy progress. Interventions may include training antispastic positioning and proper positioning to avoid pain and skin breakdown, keeping the patient active during the day, teaching relaxation techniques, and changing medications.

Stroke survivors are at increased risk of falls. Risk factors include problems with perceptual deficits, visual impairments, impaired communication, confusion, drug side effects, environmental hazards, mobility, balance, and coordination. The risk is increased by rehabilitation treatments aimed at increasing mobility [26]. Addressing this problem and necessity of supervised motor activity, gait and balance control, a 'smart' wheelchair and 'smart' walker are implemented.

Regarding the "smart" wheelchair prototype for therapeutic program it includes a 3D accelerometer (ADXL335) embedded in the wheelchair backrest, an EMFI L-type sensor for ballistocardiography and a pressure mapping sensor (TekScan Conformat) used to extract the information about the pattern of movement and patient position on the wheelchair (Figure 3 and Figure 4). The physiological information associated with the patient is obtained using a set of ballistocardiography sensors (EMFIT L series) embedded in the wheelchair seat and backrest to extract the heart rate and respiration rate after appropriate digital signal processing embedded in the touch panel (Figure 5). Additional information regarding the cardio-respiratory status is obtained from the reflective photoplethysmography device (PPG) implemented with bifurcated fiber bundle [25] and embedded in the wheelchair' hands support. The control of the PPG device is performed by the acquisition and communication module included at the wheelchair level that communicates with a touch panel using the Wi-Fi protocol. The APCm module includes a RS232 port that is connected to the LF RFID reader whose antenna is embedded in the wheelchair to extract the user ID through tag reading action. The display interface, as part of the scenario ambient layer, includes specific modules to smoothly present the trends of physiological (heart rate, hemoglobin oxygenation, respiration) and motor activity data for the identified stroke patients in situated displays (mainly, to the observers).

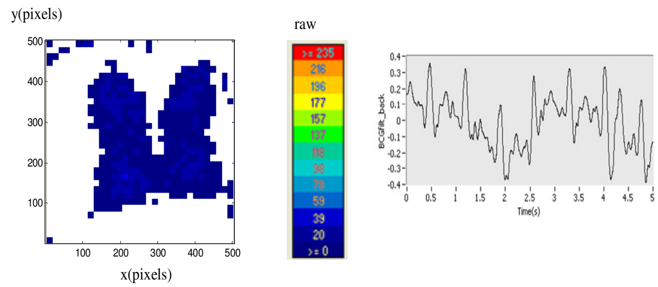

Figure 3. The pressure distribution for a subject seated on the wheelchair and the ballistocardiography signal obtained from the EMFi sensor mounted on the wheelchair seat

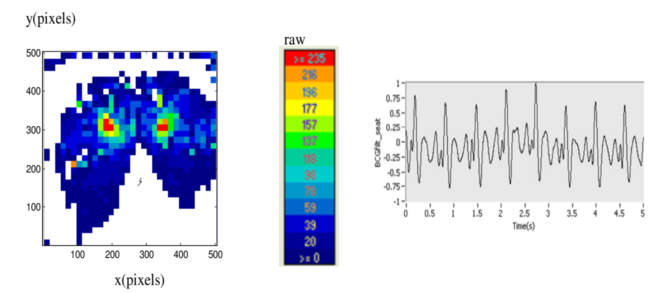

Figure 4. The pressure distribution for a subject seated on the wheelchair and the ballistocardiography signal obtained from the EMFi sensor mounted on the wheelchair back

Figure 5. The developed cardiac, respiratory and motor activity graphical interface implemented on the Android OS tablet computer

For biofeedback reasons "cartoon" type images and sounds are associated with the physiological and motor activity values and presented using a touch panel (e.g.

Android OS pad) at the wheelchair level (mainly, to the stroke patients).

Sensors were also installed in another assistive instrument for the rehabilitation, a walker. Flexible force sensors (Flexiforce), FMCW Doppler Radar (24GHz) sensors, and two photoplethysmography devices embedded at the level of the hand support were mounted in the walker in order to obtain information on muscular force on hand, gait performance and balance. The gait pattern is detected using a FMCW Doppler Radar (24GHz) mounted on the walker and oriented through the stroke patient. To monitor the cardiac and respiratory function two photoplethysmography devices were embedded in the walker' hand support. Values of heart rate, oxygen saturation (SpO2) and respiration rate can be obtained after digital processing of the acquired signals including artifact and noise removal based on implemented wavelet and ICA algorithms. The implemented system supports simple one-sensor alerts as well as alerts that involve more complex interactions among multiple sensors.

The application core is responsible for implementing the data management. It analyzes and processes the information given by the tracking component, crossing it with contextual information related to the object, the user profile and the acquired values associated with vital signs and motor activity monitoring. As parts of the application core are mentioned: the database server, the advanced digital signal processing module (e.g. noise and artifacts removal ICA processing module), a Contextual Interpreter (CI) module, an Information Compositor module, and a Web server (e.g. Apache). Decision-support modules that assist patient and caregiver with outcome assessment and with optimizing the rehabilitation intervention strategy are provided using well established instruments (questionnaire) in post stroke rehabilitation: Stroke Impact Scale (SIS) Domain Score, Stroke Recovery Rating, Stroke Rehabilitation Assessment of Movement (STREAM), Mini Mental State Examination (MMSE), Functional Tone Management (FTM) arm training program, Fugl-Meyer Assessment (FMA), Upper Extremity Range of Motion (ROM), Modified Ashworth Scale, Wolf Motor Function Test (WMFT), Motor Activity Log (MAL), Center for Epidemiologic Studies – Depression (CES-D). The CI includes another data server and manages the data coming from the identification tags through RFID reader to make all the needed associations between the user, his profile, the acquired health data and the smart object used for that.

In addition to the display interface as "cartoon" type images and sounds associated with the physiological and motor activity, work is also underway to make the information accessible remotely through the Internet to a health caregiver in a clinic or hospital. This agent will be able to monitor the health status of the patient and control values and functions through a Web client application (Figure 2). It is planned the customization of the system management in order to specify who has access to the data and what kind of data will be transmitted through the Web based management system.

IV. CONCLUSION

This paper describes a prototype implementation of a mobile healthcare information management system based on pervasive computing and Android OS. The system enables the management of patients in post stroke rehabilitation by providing more accurate and up-to-date information using pervasive computing of electronic health records, motor activity and activities of daily living. It is a promising patient-centered management approach that can provide accurate and reliable data, empowers the patients, influences their behavior, and potentially improves their medical condition. It also has potential to save time and cost by reducing the visits and travel of physiotherapists or occupational therapists, and reducing hospital admission in health hazardous situations. We are especially interested in further investigating the relations between data from sensors used in our prototype and health, ADL or IADLs monitoring. The next step of this process requires product evaluation by potential consumers. A variety of situations will be simulated in order to determine the effectiveness of the implemented system.

Future research will be carried out in order to establish which rehabilitation services can be best delivered via telemedicine at a level comparable to traditional methods or at a lower cost and higher effectiveness.

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