ABSTRACT
Pervasive healthcare is an emerging area with its research intensification in recent years. There are a good number of new projects and many technological advances reported in literature, but the current scenario is still far away from an everyday life fulfilled with pervasive healthcare systems. The main goal of this paper is to present the main design issues of a pervasive healthcare assistive environment, specially designed for the elderly. The system integrates wheelchairs and walkers, as smart objects, and situated displays. The smart objects have embedded sensors to measure physiological parameters. RFID is used to assure user identification within the environment. Additionally, the paper presents preliminary results on the implementation and point out crucial issues for future discussion.

Author Keywords
Unobtrusive sensors, long-term monitoring, elderly, smart spaces, telemedicine, assistive systems, personalization.

INTRODUCTION
In recent years, a lot of research has been done in pervasive (or ubiquitous) healthcare, which can be defined according to two perspectives [1]: i) trying to follow the characteristics of pervasive computing applied to healthcare; and ii) making healthcare available everywhere, anytime and to anyone. It can be seen as an important solution to the current problems in the healthcare field, basically considering the widescale deployment of wireless networks (better communication among healthcare agents and delivery of information anytime anywhere) and the advances in wireless technologies, such as smart mobile devices and wearable networks [2].

AWARE of the rising costs and burden of chronic diseases with a world’s increasingly aging population, many countries are taking a comprehensive approach to reduce health costs. For example, at 65 years of age, the costs (assessed regularly or monitored continuously) rose more rapidly than did life expectancy [3]. However, implementing Electronic Health Records (EHR) and Telemedicine can reduce substantially health costs [4, 5]. Moreover, efficient pervasive healthcare approaches can alleviate the problem with supporting/caring for people with a long-term condition. Pervasive healthcare as part of telemedicine systems can permit to stabilize the tendency of rising costs caused by demographic changes [4].

This paper presents a proposal for a pervasive healthcare assistive environment initially directed for the elderly. In the following Section, we describe the pretended environment, the principles and general design issues around it, and the system’s architectures (hardware and software). The system integrates situated displays and wheelchairs and walkers as smart objects, as they have embedded sensors to measure physiological parameters and mechanical quantities such as acceleration. RFID technology is used to identify users that use the smart objects or appear in front of the situated displays. This work takes into account different types of users to address the personalization issue. We also present some preliminary results gathered with the prototyping of the smart objects (in Section 3). Related work is presented in Section 4. Finally, we present conclusions and address crucial topics for discussion as future work.

THE PERVASIVE HEALTHCARE PROPOSAL
The proposed system has the main goal of providing biofeedback in the format of automatic user-friendly information taking into account acquired and analyzed vital signals values. Simple and direct persuasive information on risks associated with measured values is presented,
embedded on the ambient of application (e.g., a home for elderly), to prevent the appearance of critical situations. Therefore, it will enable the elderly to gain increased quality of life, living more independently. A second major goal is to make the information accessible remotely through the Internet to a health caregiver in a clinic/hospital. The system takes into account the following types of users (Figure 1): i) the elderly (or even other disabled people) in various contexts: lying in bed, using a wheelchair or using a walking aid for small distances; ii) an "observer" that is an accompanying person (e.g., nurse, familiar) in the ambient (watches the elderly in a long-term health assessment); and iii) the health caregiver (e.g., doctor) that can also be an “observer” and can take decisions according to the values provided by the system. Usually, s/he lies outside of the environment, remotely accessing and monitoring the patients’ information through a web-enabled application.

Wheelchairs and walkers, among others, are considered as smart objects since they are enhanced, augmented, with health status acquisition and motion sensing, RF identification technology and wireless communication [6, 7]. Moreover, RFID will be used to estimate the position of a wheelchair, which will integrate a reader to detect passive RFID tags integrated in a carpet for some (critical) zones/areas. It is also used to assure the users' identification.

The system is based on the detection of people involved in their everyday life activities, having passive interactions (natural, “incidental”) with the smart objects (e.g., wheelchair, bed). Only the detection of the user's co-presence near or using an object will start the presentation of information or the acquisition of vital signals.

The Healthcare Smart Objects Prototypes
The unobtrusive sensing system of the wheelchair includes different sensing units (Figure 2, left): mechanical contact ballistocardiography sensors (BCG-S) based on electromechanical film sensor (EMFIT L-3030); and a contactless ballistocardiography sensor (rBCG-S), used also as motion sensor expressed by a FMCW Doppler radar (InnoSent IVS-162). The motor activity is monitored using an inertial sensing unit (IN-S) expressed by a 3D accelerometer embedded on the wheelchair’s backrest. The usage of two ballistocardiography sensing units is useful to extract correlations between the BCG signals from different parts of the user body. The conditioning circuits associated with BCG-S are expressed by a charge amplifier and a Butterworth low-pass filter (fc=15Hz) that were implemented using the TLC2274 operational amplifier. The outputs of the conditioned circuits are connected to the inputs of the multichannel acquisition module (W-DAQ), also characterized by Wi-Fi compatibility.

On the other hand, the walker in use (Figure 2, right) includes sensors mainly related to assess the user’s motor activity. Thus, a set of 2 force sensors (Tekscan Flexiforce A201) are mounted on the walker’s hand supports to measure the applied forces during the walker usage. It can be easily correlated with the necessity of the user to use the walker during the daily activities. Additionally, a microwave radar (IVS-162) is mounted on the walker level permitting to obtain the motion signals that can be used to calculate some statistical parameters (e.g., variance), used to measure the gait characteristics of the walker’s user. After analog processing of the signals, and using a conditioning circuit, the signals corresponding to the force variations and the signal from the radar channel are applied to the multichannel acquisition module.
Architecture Definition

Figure 3 illustrates the proposed architecture with two layers: 1) the smart object/environment layer; and 2) the users layer, which can be seen as a simple Tag (e.g., RFID) with a passive initial interaction with the system. On the other hand, the first layer is based on three main components, serving the smart objects and the situated displays, which are the following:

Tracking - A mechanism for detection and identification of the Tag (or User) in a predefined area or that is using a smart object. It can include an interface for short-range communication with the user’s mobile device.

Application Core - This component presents a five-tier architecture, including the database server, a Signals Processing unit, a Contextual Interpreter (CI) module, an Information Compositor module and a Web server. The CI includes another data server and manages the data received from the Tracking component to make all the needed associations between the detected user profile, the acquired vital signals values and the context (including the used smart object). This module communicates directly with a Personalization sub-module of the Compositor. The personalization reasoning mechanism recommends specific data to the Compositor, which will query the database to gather all the needed data to compose a final document. It has more information as it also indicates which display (situated or on a wheelchair) will be used, which is determinant for the web server, because it will have indications for the final presentation.

Display Interface – This component includes specific modules to smoothly present the biofeedback information in situated displays (mainly, to the observers) and in touch panels of the wheelchairs (mainly, to the elderly).

Depending on the application’s environment, the Application Core can be shared by several objects, with several users behaving as clients of the system. The system has a scenario’s homeServer with the Application Core that will also register the acquired vital signals in an EHR format. The tracking and the displays components are placed near of smart objects or in predefined areas. Moreover, any smart wheelchair will integrate the tracking component and a touch panel as Display Interface.

RESULTS

In this Section, we present some preliminary results taken from the sensors mounted on the smart objects. Thus, in the wheelchair case, the signals from BCG-S and rBCG-S channels are presented in Figure 4.

![Figure 4. Contact and contactless ballistocardiography: (top) normalized contact BCG and (bottom) normalized radar.](image)

The BCG signals are processed to obtain the heart rate and heart rate variability as so as the respiration rate. As can be observed, the rBCG requires advanced signal processing, expressed by wavelet detrending and noise removal algorithms and EMD [8], as so as the digital wavelet decomposition, which can be used to extract respiration rate through the approximation coefficients calculation [9].

In the walker case, the applied forces and the legs motion were measured during walking tests. Some signals were obtained for two scenarios: walker’s user with normal gait (VF1_normW) and walker’s user with anomalous gait. In order to extract information related to the gait, different statistical parameters were calculated for one minute time record. Thus, for the particular case of the signals presented in Figure 5, the calculated values are presented in Table 1, where interquartile rank computes the difference between the 25th and 75th percentile of data and represents a measure of spread. Therefore, it is more resistive to outliers than the other measures.

Observing the results, one verifies that for normal gait the amplitude spread is smaller than in the anomalous gait (a subject motor disability). This is easy to identify through the standard deviation and the interquartile ranked spread.
parameter values. The daily walking condition that can reflect the health status of the walker user can be estimated by statistical analysis of the signal obtained through the microwave radar.

![Microwave Doppler radar output signal](image)

Figure 5. Walker Microwave Doppler radar output signal: (top) normal and (bottom) anomalous gait.

<table>
<thead>
<tr>
<th>VF1 signal</th>
<th>mean</th>
<th>std. dev</th>
<th>interquartile rank</th>
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<td>0.2253</td>
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<td>VF1 anormW</td>
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<td>0.3190</td>
<td>0.4074</td>
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Table 1. Statistical analysis of the gait signal.

RELATED WORK
A wide range of pervasive healthcare systems and smart objects have been proposed over the years, but mostly with evident different goals from ours. Regarding only pervasive systems, the Magic Medicine Cabinet [10] was one of the first interesting proposals to appear, implementing the concept of a medicine cabinet in the bathroom augmented with information technology. A milestone and an important reference is the AWARE project [11], which implements a context-aware space in a hospital. The system is essentially composed of a tracking module for clinics and patients, an infrastructure for acquisition, management and distribution of contextual information, and tools like situated displays and mobile phones. On the other hand, ANGELAH [12] is a middleware-level solution integrating both elderly monitoring, emergency and networking solutions. It provides a solid framework for creating and managing rescue teams composed of individuals. Finally, [13] presents a user-friendly model of a smart home that provides telemedicine for elderly at home. The environment monitors the elderly continuously and sends an emergency call for help in case of an occurrence of an accident or a severe health problem.

CONCLUSIONS AND DISCUSSION
The paper presents a novel approach for pervasive healthcare systems as it ‘augments’ everyday life healthcare supporting objects that acquire health vital signals to give automatic biofeedback. It is directed to the environment of patients and integrates situated and mobile (on the wheelchairs) displays to provide embedded personalized information. Future work will include elements of gait recognition used for user identification as so as a validation based on RFID technology.

Topics for Discussion
We want to use this work to get reliable results about the bio and physiological measurement technologies embedded on smart objects crossed with pervasive, continuous and reliable long-term monitoring systems. Moreover, we want to use them for personalization studies related with interactions between users and pervasive healthcare environments. We consider personalization as a very important basis for pervasive healthcare, which should focus on a human-centered paradigm.

Additional discussion and future research is important in the following topics: i) persuasive information for prevention as a key element to maintain lifelong wellness; ii) design and evaluation methods for pervasive healthcare human-centered technologies; iii) privacy issues about personalized information; and iv) appropriate integration of mechanisms to support mental health.

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REFERENCES


