Sensors for Ambient Assisted Living (AAL) and Smart Homes

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Abstract. Smart homes have developed from science fiction in the middle of the XX century into a reality of the XXI century. Initial developments were centred in the automation of comfort, energy saving and safety. More recent developments are far more ambitious, aiming to facilitate independence of elderly through the support of daily living activities and to connect the human at home with the health and social services available. This chapter refers to a variety of technologies available for the development of such infrastructures and, without aiming to be an exhaustive survey, it provides a glance at the state of the art in the area. We provide a description of systems which have been developed to assess biometrical indicators of health such as blood pressure, sleeping patterns and stress, all of which have the potential to shape up the healthcare systems of the future.

Keywords: smart homes, Ambient Assisted Living, biometrics.

1. Introduction

Home healthcare is a fast growing discipline as the amount of dependent people (elderly or disabled) progressively increases and the costs of hospitalization increase. In fact, chronic disease management has become a priority issue in the insurance health systems of Europe. Every country has consistent statistics showing that a small percentage of the population absorbs a substantial part of resources in each national health system. The current passive model implies the doctor waits for the chronic patient, as opposed to an active model including family members and a caring environment which helps monitoring the patient where s/he is. It is estimated that this way of monitoring would reduce the number of hospital admissions between 40 and 50 percent.

Based on the perceived advantages of achieving a more flexible and decentralized healthcare system, companies and research centres have started to develop solutions based on innovative technologies which can obtain information from a person at anytime and anyplace and use that to relate the patient to the healthcare system. A prototypical telecare kit from a company is Tunstall's ADLife (See Figure 1) which consists of a control box which gathers events captured by a range of sensors and other devices (e.g., blood pressure monitor) and periodically send the data through an internet connection to a dedicated secure server.

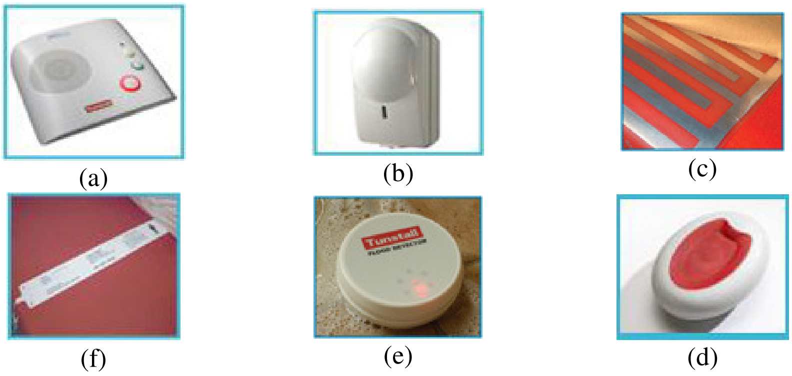

Fig. 1. Some few of the wide range of components available with the ADLife collection. Clockwise: (a) control box, (b) PIR (Passive Infra Red) sensor, (c) enuresis sensor, (d) alarm button, (e) flood sensor, and (f) pressure pad sensor.

Most of the ADLife components can be connected to the control box wirelessly. This offers advantages in term of installation but requires batteries to power the units and a careful monitoring plan to avoid sensors running out of power. Acces in real-time is also a problem as data is transmitted periodically (typically once a day) so that it can be analysed and used for the decision-making related to a client, but this does not facilitate real-time detection of problems and actuation. Also the system is closed to the Tunstall development team so for applications which seek a more flexible framework to develop new solutions, i.e. different combinations of equipment and software can be tried, other platforms are available in the market.

X10 technology has been the undisputed pioneer to support domotic projects around the world. It is easy to use and relatively easy to install and it is cheap. This is where the advantages stop. The main barrier which created the need for alternative technologies to appear in the market is that it uses the domestic power line to send and receive commands, this makes it susceptible to disruptions when the power line of the house is not good or when domestic appliances are functioning. As X10 does not have handshake it is not possible to guarantee that a device received an order.

Universal Powerline Bus (UPB) is an evolved version of X10 as it works over the power line of the house but it improves on X10 by adding handshake on the message packets containing transactions from-to the sensors and devices attached to the network, so whilst the infrastructure of the house still may have problems, e.g., with domestic appliances interfering, the system has a way to check whether a device received an order which increases the confidence on the actuation of the system. It also improves over X10 in the sense that the control boxes usually can cope with a bigger and faster volume of transactions coming from or going to the nodes in the network.

Zwave is based very much on the same type of concepts and sensing equipment mentioned above, the main difference is that communication is done wirelessly and it uses handshake to verify communication between the controller box and the actuating devices. This comes at a cost if increased price and battery maintenance. As any system currently available there is no guarantee the sensors will work all the time or the box will be able to process all events correctly so software systems built on top of this infrastructure has to be conceived in such a way that it can cope with some degree of uncertainty and still be able to deliver a service which is valuable (i.e. better than not having it).

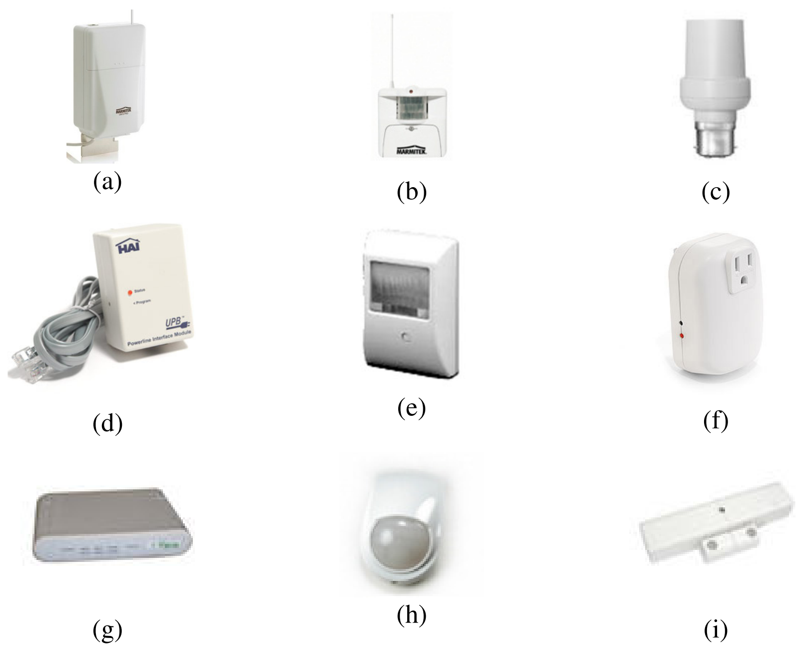

Fig. 2. Some few samples of the technologies available. Top row: X10 (a) control box, (b) PIR sensor, (c) light controlling bayonet. Medium row: UPB (d) interface module, (e) PIR sensor, and (f) light dimmer switch. Lower row: Zwave (g) control box (h) PIR sensor (i) door switch.

Table 1 summarizes the main characteristics of the three types of technology mentioned above.

Table 1. Comparison of basic features of sensing platforms for AAL projects.

Technology	House transmission	Pros	Cons	Compared cost
X10	Powerline	Easy to use, open to development	Unreliable	Lower
UPB	Powerline	Reliable (handshake), open to development	Availability	Medium
ADLife	Wireless	Reliable, easy to set up	No real time broadcasting	Medium
ZWave	Wireless	Reliable (handshake), open to development	Battery maintenance	Higher

The technologies cited above provide a quick way to deploy sensing equipment in a house to measure important parameters of safety and lifestyle which can be used to support independence and wellbeing, see [1] for an example. There are other technologies which provide alternatives, e.g., Insteon allows a combination of power line and wireless communication amongst nodes in a system, increasing flexibility.

Still there are several elements which relate to the reliability of the system, the quality of service and the quality of interaction with the client which are not covered. The next section describes a more holistic approach where those important issues are considered.

2. Sensor integration for home healthcare

The Prague Declaration [2], adopted during the eHealth European Ministerial Conference celebrated in Prague in February 2009, shows the relevance that eHealth has nowadays and in the future. This declaration presents the different stakeholders involved in the development of eHealth, and it highlights as well that "…lack of interoperability has been identified as one of the main areas to address".

The main target group which can benefit with the solution proposed here are people chronically ill, elderly or handicapped. Telecare is a domain inside Ambient Assisted Living (AAL) that utilizes information and communication technologies to transfer medical information for diagnosis and therapy of patients in their place of domicile while telemedicine is related to the delivery of clinical care at distance [3], for example a teletransmission of ECG (electrocardiograph). Telecare services can significantly increase the quality of life for this group of people. However, there is still a lack in standardization that would allow to connect and to maintain the equipment provided from different vendors in a compatible and reliable way. Beyond the pure technical aspect, the incorporation of persons forming part of daily life is a crucial point.

Previous telecare proposals were often organized in a way not taking into account the communication with the relatives and friends of a patient. However, this seems to be a strong demand from the patient's point of view. According to several studies [4], elderly or dependent people are reluctant to use telecare services because they do not personally know the operator or like to contact a person in the telecare service center. Usability can be increased when incorporating relatives and friends into the flow. In a possible scenario, a doctor initiates a video call with the patient to remotely check some data about the health status, like the blood-pressure, heart rate or the weight. The platform keeps an address list of relatives and friends; so, the patient can be virtually accompanied while talking to the doctor. Moreover, relatives and friends can check medical remainders to help the patient during the treatment. In summary, typical scenarios covered by the telecare service are:

- An elderly man has a medical appointment with the doctor to review his heart health.
- An elderly woman that lives alone receives a video call from an assistant or a relative to take care about her.
- The system reminds the patient when he has to be prepared for a planned video-conference or when it is time to take a medicine or a measurement.
- The system sends an alert when some measurement in the monitoring is not in the valid range.

The integration of key healthcare actors is required to offer an efficient service based on a sensor and device-based home system. However, these systems often lack of adequate interoperability, which slows down their acceptance and usage. Additionally, healthcare applications and technologies are usually proprietary and unreasonably complex for embedded systems.

Interoperability can be achieved by defining a system architecture that reduces complexity combining a central management device with a service platform to integrate different telecare services. The main service of this architecture is a Universal Plug and Play (UPnP) [5] wrapper that provides transparent connectivity and discovery of telemedicine devices.

The main element of the architecture is the Residential Gateway (RGW) [6] that provides connectivity between Internet and the local network and provides a place for installing an 'Open Services Gateway initiative' (OSGi) service platform [7], which provides an execution environment as well as a remote control architecture for services.

Figure 2 shows the elements present in these scenarios, including the patient surrounded by multimedia devices for videoconference, the healthcare equipment for monitorization and the residential gateway as a central control point with the OSGi platform. This service platform includes services for health data transmission, videoconference and other. The eHealth equipment is connected to the residential gateway by some wired or wireless protocol, commonly via Bluetooth. Any medical information is forwarded to the eHealth Service Provider using HL7 messages [8], [9]. HL7 provides a standard communication system or other prospective external health systems. During an on-line medical citation between for example a nurse and the patient, a video call can be established. This functionality is based on the UPnP AV standard (Universal Plug & Play for Audio-Video) because it provides a modular framework for multimedia communications. Nowadays, many end-user devices are supporting this standard.

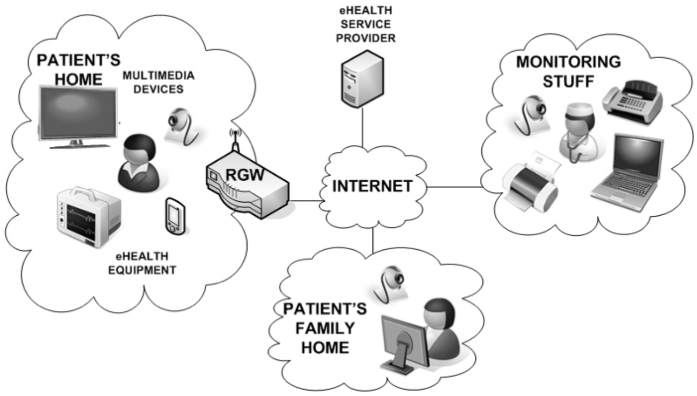

Fig. 2. Environment description

2.1 Healthcare related work and technology

This section presents the work and research lines related to the integration of healthcare in AAL and other relevant developments, followed by a brief introduction to the technologies and standards used in the system.

Home telecare is foreseen as an important factor for future medical assistance [10], [11]. Some telemedicine and telecare approaches are based already on OSGi [12], [13], [14], [15] but they do not offer a complete integration of all needed services. For example, the Seguitel system [16] is a social and telecare service platform based on OSGi. It is oriented to provide services designed under a methodology that ensures a SLA (Service Level Agreement) but this approach introduces several middleware layers and it is not covering healthcare standard interoperability. Other projects that work in similar environments like HEALTHMATE [17] (Personal intelligent health mobile systems for Telecare and Teleconsultation), TELECARE [18] (A multi-agent tele-supervision system for elderly care) or PIPS [19] (Personalized Information Platform for Life and Health Services) have similar lacks as Seguitel.

Home telecare requires that patient data must be transmitted following a messaging standard. Currently, HL7 ([8], [9]) is a widely applied protocol to exchange clinical data. Moreover, there are open source tools available to process and transmit HL7 messages [20], [21]. Furthermore, there is a standard under development, the ISO/IEEE 11073 (also known as x73) standard [22], to transmit medical information among devices, but there are hardly any medical devices in the open market supporting this standard. Many available devices follow proprietary protocols or don't offer open interfaces, so it is not possible to interact with other devices or platforms.

The OSGi framework is a Java-based open architecture for network delivery of managed services. Services are added through software components (bundles). The platform carries out a complete management of bundles' life cycle: install, remove, start, stop and update. The bundles are Java applications running on the same JVM (Java Virtual Machine), which can share code.

The videoconference system allows the communication between the patient and any other member of his group. For example, an assistant or medical personal as well as his relatives can be members of the group. The videoconference functionality needs a multimedia device infrastructure managed by the RGW. The UPnP AV is a standardized UPnP architecture for multimedia systems in home networks. It allows an automatic discovery of multimedia services with a low CPU usage for a streaming negotiation and management. Additionally, there are open source libraries of the standard available. Other approaches are based on the Session Initiation Protocol (SIP) and the IP Multimedia Subsystem (IMS) [23] but UPnP devices are more widely spread in the market.

The Bluetooth wireless protocol [24] is a short-range communications technology intended to replace wires connecting fixed or mobile devices. The Bluetooth specification supports secure and low power communication for a wide range of devices to connect and transmit information with each other. There are low-cost Bluetooth adapters available in the market as well as medical measurement devices like the UA-767PBT Blood Pressure Monitor from A&D Medical. Thanks to Bluecove [25], an open-source library that provides a JSR-82 Java interface for Bluetooth Profiles, it is possible to implement OSGi bundles that communicate with Bluetooth devices available for many operating systems.

2.2 Ubiquitous healthcare platform

The healthcare platform is distributed and widely connected. This platform includes videoconferencing between the different parties, but also offering medical appointments and remainders with automatic integration of the medical devices at home. The middleware for developing telemedicine and telecare services in this platform is implemented based on OSGi. The telemedicine service provider server, hereafter the eHealth server, also runs an OSGi platform.

The next subsections show the general architecture implemented in a RGW. After that, the detailed descriptions of the different subsystems are presented (the eHealth system, the Measure system and the Multimedia system). Finally, the communication protocol between the RGW and the eHealth server is included and completed with some sequence diagrams.

2.2.1 System overview

Telecare supports the integration of patient-oriented services, like medical data transmission, audio/video calls or healthcare appointment management. The implementation is based on the OSGi Framework because it provides a scalable solution. This middleware supports an environment for the modularization of applications into smaller bundles. Each bundle is a Java software module consisting of dynamically loadable collection of classes, jars, and configuration files that explicitly declare their external dependencies. The OSGi bundles can export and import services to provide a service layer that connect bundles in a dynamic way. In our design, the bundles for the telecare functionality are grouped in four basic systems: eHealth, Measure, Data and Multimedia.

These elements are managed by a RGW running with Linux and the mentioned above OSGi framework hosting the different services which can be managed remotely by the telecare or access provider. An architecture schema of the four subsystems is shown in Figure 3.

The eHealth system manages the patient's appointments and remainders that includes the medical treatments and implements a graphical user interface (GUI). Moreover, it carries out the transmission in HL7 messages by the HL7 bundle. The Measure system can include a wide variety of devices and protocols. In this approach we have integrated Bluetooth devices to take some measures from the patient and it will be made by the implementation of two bundles: the *Measure Notifier* and the *Medical Bluetooth Driver*. The Data system includes a Database to save the whole information about patient health data, home sensors data, etc. Finally, the Multimedia system establishes the communication between doctors, patients and relatives by means of monitors and webcams.

The system architectures in the customized doctor/nurse and relatives platforms are a simplification of this general architecture. For example, relatives only need the multimedia systems and the doctor does not need the measure system as he receives the patient's data from the HL7 Driver. The GUIs are similar to Patient GUI but customized for their needs health professionals. Details of the eHealth, measure and multimedia systems are described in the following.

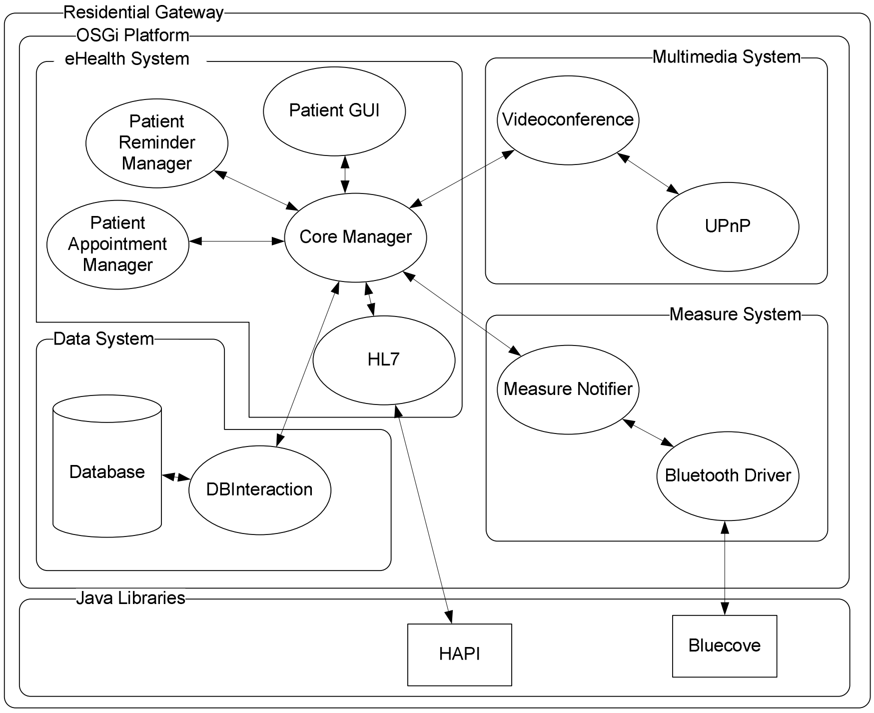

Fig. 3. Architecture of the home healthcare platform

2.2.2 eHealth system

The eHealth system in the patient's RGW (see Figure 3) is composed of a set of bundles that include a graphical user interface, remainder and appointments managers and an HL7 Driver that provides the medical communications. The Patient GUI is a Swing-based application adapted to the patient. Using the patient's GUI, it is possible to access to a simple patient's Electronic Health Record (EHR), to look up treatments, medical appointments and remainders to access to the Medical Health Record.

In telecare systems, two types of medical appointments are used: online and offline. The *offline* medical appointment is presented for periodic medical check-ups. This assumes that the patient performs a daily or weekly monitoring session in which he/she interacts with the medical equipment at home, like a blood pressure monitor, a pulse oximeter or a personal scale. The check-up is usually scheduled by the doctor through an application connected to the eHealth Server and the schedule is sent to the RGW using the HL7 protocol, as is detailed below. The patient performs the medical test (see Figure 4, left) following the instructions.

Fig. 4. Patient GUI (left) and online appointment (right)

The systolic blood pressure, the diastolic blood pressure and the heart rate are measured in a single operation. The Mean Arterial Pressure (MAP) is calculated and the data group is sent to the RGW as described in the Medical Subsystem section. These health data are relevant to perform a monitoring of the elderly people health. An example of the Patient GUI window with patient measurement results is displayed in Figure 4 (right).

After data acquisition, the HL7 Driver composes the HL7 message and sends the data for a further check to the health staff. Also the RGW saves the data in an internal database for the patient reference and as backup system if the eHealth Server is not reachable. In this last case, the RGW will forward the data when the eHealth Server is available.

Additionally, the telemedicine service relies on an *online* appointment. In this case, the patient talks to the health staff by an audio/video conference. During the session, the patient takes his vital measures and the RGW sends them to the eHealth Server and the doctor or nurse can analyze the patient's health data (online).

2.2.3 Measure system

The Measure system (see Figure 3) is in charge of fetching the health data through the medical wireless devices, processing the information and delivering the formatted data to the Healthcare subsystem in the RGW platform. It consists of a Measure Notifier and the Medical Bluetooth Driver. The Measure Notifier is implemented to receive data from device bundles by using the ServiceListener functionality from the OSGi framework. Thus the Measure Notifier avoids an active wait and provides an interface to fetch data from several types of medical devices. The Measure Notifier offers a service to communicate to the Healthcare Subsystem on the arrival of new data.

There are several devices available to perform this monitoring, however, only few of the can be integrated in a general AAL platform. Two examples are the A&D UA-767PBT blood pressure monitor that measures the blood pressure and the heart rate, and the A&D UC-321PBT personal weight scale. These patient medical equipments include a Bluetooth transceiver to send the data to RGW. The Java-based Bluecove library, an open source implementation of the JSR-82 standard, is loaded in the Medical Bluetooth Driver to receive the data wirelessly in the RGW.

Some efforts to provide open source stack implementations for the ISO/IEEE 11073 standard for the Bluetooth Health Device Profile (HDP) have been recently developed [26], but the compliant devices are taking a long time to be released to the market. However, the ISO/IEEE 11073 is well suited for interoperability because it provides a standard for coding the observed results.

The values and units of the observations are coded following the ISO/IEEE 11073 Nomenclature standard [27]. Table 2 shows an example of a coding format. This format is used to make the OBX segments for the observations.

Table 2. Coding format for the observations reporting

Measure	ISO/IEEE 1073 Nomenclature	Measure unity	Measure unity in 1073 Nom.
Map	MDC_PRESS_BLD_ART_MEAN	Millimeters of mercury (mmHg)	MDC_DIM_MMHG
Systolic	MDC_PRESS_CUFF_SYS	Millimeters of mercury (mmHg)	MDC_DIM_MMHG
Diastolic	MDC_PRESS_CUFF_DIA	Millimeters of mercury (mmHg)	MDC_DIM_MMHG
Pulse rate	MDC_PULS_RATE_NON_INV	Pulse per minute (ppm)	MDC_DIM_PULS_PER_MIN
Weight	MDC_MASS_BODY_ACTUAL	Kilogram (kg)	MDC_DIM_X_G

2.2.4 Multimedia system

In a home telecare scenario, a multimedia infrastructure is required to allow a seamless communication between healthcare actors, as it was shown in Figure 3. Figure 5 gives a detailed view of the internal design of a possible Multimedia system. The AudioVisual (AV) subsystem handles the AV communication according to the UPnP AV specification using a UPnP Control Point. The UPnP standard allows automatically detecting and configuring new devices (audiovisual devices like cameras, TVs and smartphones or other devices like monitoring healthcare devices) and the functionality of these devices can be offered as an OSGi service to the general system.

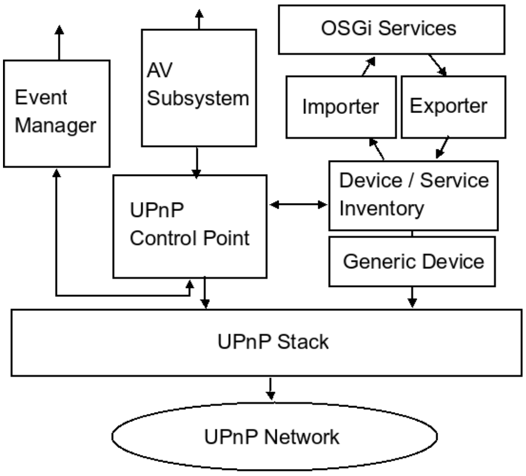

Fig. 5. Multimedia system

2.2.5 Healthcare communications

The interoperability is one of the goals of home healthcare systems. There are many health informatics standards but the most widespread standard for electronic health information exchange is the HL7 v.2 standard. One example of an the interoperability experience for mobiles described in the MOTOHEALTH solution [28].

An example of a sequence diagram of an online appointment is shown in Figure 6. Previous to the data exchange, a new user should be added in the eHealth Server if it does not exist yet. For security reasons, only the eHealth Server administrator is allowed to perform this step. The EHR data is filled in by the Doctor GUI and saved in the database of the eHealth Server.

The first step is an ADT-A05 (pre-admit a patient) HL7 message with patient data sent to the RGW. This message avoids the manual introduction of the patient data in the RGW. Then, an SRM-SO1 (Schedule Request Message with an Appointment Request) is sent to the RGW. If it accommodates in the patient schedule, a SRR-S01 (Schedule Request Response for an Appointment Request) message is sent to the eHealth Server.

When the patient finishes the measurements, his/her vital signals or health data like weight, blood pressure, etc., are sent to the RGW over Bluetooth. The results are processed by the HL7 Driver and sent to the remote eHealth Server in the corresponding OBX (observation result) segments inside an ORU-RO1 (Unsolicited Transmission of an Observation) HL7 Message.

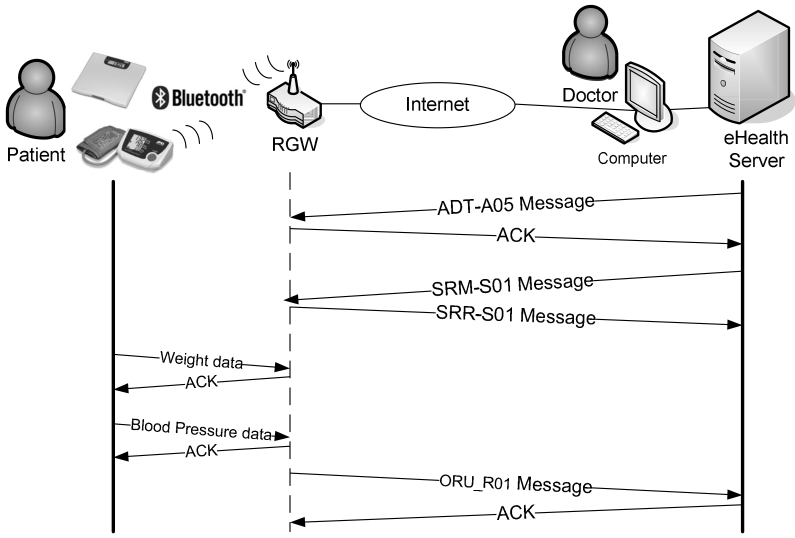

Fig. 6. Example of a sequence diagram of an online appointment

3. Sensor support for stress monitoring

It has been advocated elsewhere on the importance for an Ambient Intelligent system to know as much as possible the state of mind of a user (see for example [29] and [30]). The more the system knows about the feelings and current emotional state of a user the better informed the decision-making on how to interact with and server the user. For example, a system which perceives the user as stressed can decide not to interrupt the user about the next shopping or it may decide to play specific calming music selected by the user in such circumstances. But how a system can get to know if a home owner is stressed?

There have been studies which focused on the actions of the users and the tone of voice or the words they use. They can be useful, still inconclusive. This chapter adds to that body of literature by investigating a number of sensors available in the market which are relevant to the specific area of stress measurement.

The development of this technology has evolved through several decades; we will start our introduction on the topic only from the last decade. Focusing on the neurophysiological stress response of the autonomic nervous system, Cacioppo [31] found that some physiologic variables change with stress (heart rate, blood pressure, respiratory rate, perspiration, inhibition of digestive system and sexual functions). Following this line of research, other studies ([32], [33], [34]) showed that there is a relation between heart rate variability derived from the electrocardiogram (ECG/EKG), blood pressure, and stress. Work reported in [35] describes the relationship between the changes in heart rate, blood pressure, skin temperature, and muscle tension in stressful moments. Skin conductance [36], the breathing rate [37], the brain waves [38] and the pupil diameter [39] are related to stress too. Based on these studies we can conclude that there are some main variables that change in stress situations: heart rate, blood pressure, breathing rate, brain waves, muscle tension, pupil diameter, skin conductance and temperature.

Finally some research addresses the measurement stress through biometric variables (sometimes referred to as biosignals). For example Kobayash et al [40], attempt to detect stress by using biosignals under visual search tasks. Sul et al [41] evaluate stress reactivity and recovery with biosignals and fuzzy theory. The method of stress measurement through biosignlas has indeed been applied to some aspects in natural situations such as for quantifying driver stress (Healy et al [42]).

Based on the studies discussed above illustrate that the biometrical variables which have a direct impact on stress levels are as follows:

1. GSR (Galvanic Skin Response): this measures the electrical conductance of the skin. The signal can be decomposed into Skin Conductance Responses (SCR), related to short events, and the Skin Conductance Level (SCL), related to the underlying basal arousal activity. The GSR is often the primary psychophysiological measure used when gauging emotional and stress activation as it responds very quickly (1-3 seconds after onset of stimulus);
2. BVP (Blood Volume Pulse): is an indicator of blood flow using a photoplesthysmyography. In stress, the amplitude of the blood volume pulses tends to decrease following sympathetic arousal;
3. HR (Heart Rate): is computed from the raw BVP waveform by finding consecutive local maxima. An increase in sympathetic activity will increase the heart rate. Besides the Heart Rate Variability (HRV) and the Electrocardiogram (ECG/EKG) in stress is inconsistent (cortical inhibition);
4. EMG (Electromyogram): this is the electrical activity of the skeletal muscles (characterizes neuromuscular system). The greater the stress, the more likely the muscles will produce a synchronous twitching effect;
5. EEG (Electroencephalogram): measurement of electrical spontaneous brain activity and other brain potentials. Stress could throw the frequency to the higher beta range brain waves;
6. Temp (body/skin Temperature): this is the actual temperature of the body and the skin. In stress situations the temperature of the body and skin changes;
7. BR (Breathing Rate): this is the number of movements which are indicative of inspiration and expiration per unit time. Under stress, this number is altered; and
8. EOG (Electrooculography): measurement of retinal function by recording changes in steady, resting electric potentials of the eye. Under stress, important changes in these measurements take place.

In summary, higher stress is detected with lower BVP values, higher BR, EMG, GSR, SCR, HR values and changes in TEMP, EOG, and HRV. If it is possible to measure these variables in real time, it is possible to gain a significantly accurate understanding of the person's stress levels. The next section provides a survey of products which can capture those important parameters.

3.1 Stress sensing technology

This section reviews and discusses the sensors that are available on the commercial market which are suited to obtain the necessary biosignals to measure the user's stress levels. Besides, some current research projects on this type of sensor technology are presented.

These sensor devices are also called biofeedback or biometric devices, understanding that biofeedback is the process of becoming aware of various physiological functions using instruments that provide information on the activity of those same systems, with a goal of being able to manipulate them at will [43].

According to literature and the commercial products available on the commercial market we propose to divide the products for measuring stress into five categories:

1. Individual sensors to obtain individual biological parameters where we show individual sensors to obtain individual biosignals related to stress;
2. generic sensors for gathering the data where specific devices are shown which are capable of obtaining and processing as many biosignals as necessary;
3. wearable sensors, intelligent clothing with some examples of the application of this sensor technology in clothes;
4. stress-specific sensors which provide a direct stress measure; and
5. other types of sensors including some interesting systems that could not be directly related to one of the previous categories.

Different tables are presented in the review to illustrate the sensors (one per category). The tables contain the following columns: sensor: name of the sensor; figure: a small illustration of the sensor; developer/reference: manufacturer of the sensor and a reference for further information; measured signals: the stress-related signal or signals that can be measured by the device will be indicated (it should be noted that some sensors can measure other biosignals which are not related to stress measurements and these kinds of signals are not included in the tables); and communication capabilities: the way in which the device transmits the data.

In order to compare the different biometric sensing technologies, the principles outlined in Table 3 will be considered along the following sections. These principles are based on the seven pillars of biometric wisdom [44]: universality, distinctiveness, permanence, collectability, performance, acceptability and resistance to circumvention. However, we change the focus from identification to the characterization of the state of the user (stress) and this movement changes slightly the principles.

Table 3. Biometric sensor principles to detect stress in smart home context.

Principles	Explanation
Universality	Stress has impact in all human beings in the same physiologic variables: blood volume pulse, breath rate, electromyogram, galvanic skin response, heart rate, temperature, electrooculography and electroencephalogram.
Permanence	Meanwhile stress persists the anomalous values of the physiologic variables persist.
Performance	A person's physiologic measure need to be collected in a reasonably easy fashion for quick measurement of stress levels avoiding delays.
Accuracy	The degree of accuracy of user's stress levels must be enough to provide truthful information.
Acceptability	Applications will not be successful if the user offers strong and continuous resistance to intrusive biometrics.
Adaptability	The measures must be adaptable. From real time measures to a time window required measures.

It is possible to appreciate that the two first principles, universality and permanence, are closely related to the physiological variables that change in our body under stress influence. If we want to monitor people in any environment, the first consideration to take into account according to the universality principle is to select a sensor capable of measuring one or several of these specific variables. According to the permanence principle the measures should be continuous, this allows monitoring the person and to determine at what point the user enters into a stress period. We consider that the two first principles are essential and they must be fulfilled before considering the rest of the principles.

According to the performance principle it is desirable to avoid delays obtaining the stress measurement. These delays could come from diverse circumstances. For example, the communications capabilities of the sensor limit the performance of the sensor to collect the measures taken. That means, if the sensor only offers infrared protocol to transmit the data, the speed of this protocol limits the information that the sensor can send in a time period. Another circumstance is for example the need to apply algorithms to the measurements collected to get a stress level measurement (it is necessary to translate the sensed biometric measures to a stress level). The more signals are processed in this algorithm; the more time is needed to obtain a stress level measurement.

Currently, there are no studies about what kind of biometric variable measure is more precise with respect to measure stress. However, the more different biometric samples we gather to get the stress measurement, the closer we approach to the real perception of the stress levels. This is the reason why we have related the accuracy principle with the number of sensors that are sensing the user. If the stress level measurement is based on one biometric variable, this measurement is less truthful than if it is based on five biometric variables avoiding in a better way false positives. For example, if a user turns on the heater, his/her temperature will increase and will be detected by the sensor. If the stress level measurement is based on only in the temperature, changes might provoke a stress level indication. If the algorithm is based on temperature, heart rate and breath rate, it does not produce this false positive. Furthermore, in cases where a psychological variable is deliberately altered (for example a user with a pacemaker) we can avoid this variable in a system where more variables are contemplated.

Consistent with the acceptability principle, some sensors may be more suitable than others for the smart home context. Ideally, a user should be monitored by a device in a non-invasive manner. We consider that this would be achieved if the user retains sufficient physical mobility to carry out his life in the house and the sensor should not feel uncomfortable to the user. Furthermore, the "invisibility" of the sensor will be ideal for increasing the acceptability, for example there are people that consider less invasive the use of lens instead glasses.

Finally the adaptability principle deals with the capacity of the sensor, being more precise with the software that manages the sensor to adapt the measures taken to the user profile. For example, a user could have more interest to be informed of his/her stress levels continuously in real time (as watching a football match) rather be more interested to be informed in a variable time period of his/her predominant stress levels as a default scenario.

3.1.1 Sensors for an isolated parameter

The first category consists of sensors which are specialized on obtaining an individual biological parameters, e.g., to gather the biometric data necessary related to stress: heart rate, blood pressure, breathing rate, brain waves, muscle tension, skin resistance, temperature and retina changes.

Nowadays, it is possible to purchase several devices to measure each biosignal, and Table 4 selects one representative example for each device that is available on the market. The acronym "N.A." is used to indicate that the information is not available for a particular product. In addition, each category has been added some particular information common to the category sensors referred into the specific table. This specific information will be explained in each category. For ease of reference, in the comparison which follows, a lower case letter is added before the name of the sensor to reference it in the comparison table.

Depending on the user's preferences, some sensors may be more suitable than others for the smart home context. Ideally, the user should be monitored by the device in a non-invasive manner. We consider that this would be achieved if the following conditions are met:

1. The user retains sufficient physical mobility to carry out his normal life in the house;
2. The sensor should not feel uncomfortable to the user and he/she should not be distracted from his normal tasks as a result of any discomfort generated by the sensor.

It is possible to find biosignals that can be non-invasively monitored with existing technology in real time. However, the following problems arise with these options:

1. It is necessary to translate the sensed biometric measures to a stress level in real time;
2. The accuracy will depend on how many different kinds of sensors are used (electrocardiogram, blood pressure, skin resistance, etc...) so with one sensor usually the accuracy principle is compromised; and
3. Each kind of sensor will process the stress level in a different way, so it will be necessary the design a different software according to the sensor's measure;

Generally the communications capabilities of these sensors are limited which has a high impact in performance principle. Some sensors transmit the data via USB port (devices "a", "c", "d"), only one, "f", uses wireless and the others have not available communications module.

Table 4. Individual sensors

Sensor	Figure	Developer/ Reference	Communications	Measured Signals
a) Polar RS800		Polar / [44]	Polar IrDA USB	HR, HRV
b) GSR 2		Thought Technology / [46]	N.A	GSR
c) HEM 790IT		Omron / [47]	Omron USB cable	BP, HR
d) PS2133		Pasco/ [48]	PASPORT™ USB	BR
e) SC911		Bio-Medical Instruments / [49]	N.A	TEMP
f) Neurobics A3		Neurobics / [50]	Wireless	EEG
g) Clinical EMG		Metron / [51]	N.A	EMG
h) S225		Qubit Systemsb / [52]	USB	EOG

3.1.2 Multichannel sensors

This category includes the multichannel devices which are capable of gathering various biosignals at the same time - fulfilling the accuracy principle. Usually companies which offer these kind of devices also offer different models of the same product.

The main difference between the models relates to the number of biosignals that the device can gather at the same time (number of channels). It should be taken into account that depending on the device, more than one channel is needed for one biosignal (usually electroencephalogram), Table 5 shows some devices of this kind. We have attempted to select the appropriate model of each device to measure all biosignals related to the stress level. A column entitled “channels” has been added to Table 5.

Table 5. Multichannel sensors for gathering data

Sensor	Figure	Developer/ Reference	Communications	Signals/ Channels
i) Biopac MP150		Biopac Systems /[53]	Ethernet	All/16
j) Nexus 10		Mind Media B.V /[54]	Bluetooth	All/10
k) I-330C2+		J+J Engineering / [55]	USB /RS232	All/12
l) Flexcomp Infiniti		Thought Technology/ [56]	USB/Bluetooth	All/10

The advantage of using multichannel devices is that they can gather several biosignals at the same time to detect stress levels with the highest degree of accuracy. Furthermore, they usually include software to manage all data in real time.

However, the following problems arise:

- The stress level is not directly measured with this kind of product, so we need to apply algorithms in real time to compute the data collected;
- Apart from using the computer to process the information, the user has to carry a unit (to connect the sensors) which is not very comfortable and thus breaking the acceptability principle;
- The device requires a more complicated configuration setup in order to place the sensors on the user; and
- In the case of “j”, “k”, “l”, the power supply is through batteries, this feature has associated the risk of information loss when the batteries do not

work and also the uncomforting obligation of checking battery levels and of changing batteries periodically.

The problem with this type of unit (the device and all the sensors) carried by a user, is that the physical movements of the user are limited due to the equipment. The best sensors available in the market to fulfil the acceptability principle are the wearable sensors.

3.1.3 Wearable sensors

“Intelligent clothing is becoming an emerging area within ambient intelligence regarding that ambient intelligence is focused on building digital environments that proactively, but sensibly, support people in their daily lives” [57]. According to [58], “smart textile and garment applications will be available in the market between five and ten years’ time, most likely in sports and extreme wear, in occupational and professional clothing and in technical textiles.”

There are some examples of wearable sensors that could be used by users achieving in a successfully way the acceptability principle according to the comfort of the user. Table 6 illustrates some examples.

Table 6. Wearable sensors

Sensor	Figure	Developer/ Reference	Communications	Measured Signals	Autonomy
m) Lifeshirt		Rae Systems / [61]	Wireless	HR,BR, TEMP	220 hours
n) Vital Jacket		Mind Media B.V /[62]	Bluetooth	HR, ECG	72 hours
o) Smart Underpants		Joseph Wang / [63]	N.A	HR, BP	N.A
p) Exmocare BT2		Exmovere Holdings /[64]	Bluetooth	HR,BVP, TEMP	18 hours
q) Emband 24		Emsense / [65]	Wireless	HR,EEG, TEMP	N.A

Recently, Pantelopoulos and Bourbakis published a complete survey [59] about this kind of sensor for health monitoring and prognosis. We agree with the views expressed by the authors that the great advantage for the devices based on smart textiles (“*m*”, “*n*”, “*o*”) is the high wearability and comfort for the user. Besides, they are highly reliable as they guarantee good contact between the skin and the biosensors even when the subjects are in motion.

Even the other wearable sensors presented in Table 6 (*"p", "q"*) are not invasive. This is illustrated by the research conducted by Leon et al. [60] whereby a prototype T-shirt is used to measure the transmission of biosignals through bluetooth in order to determine an affect-aware behaviour model within an intelligent environment.

However, the problem remains that there are no available sensors that provide the stress level measurement. Furthermore, as in the previous category (*"j", "k", "l"*), as wireless technology is used in most cases (*"m", "n", "p", "q"*), the sensor requires small batteries in order to be wearable. This means that the user needs to check that the device has enough battery, which breaks an acceptability principle. Table 6 indicates the autonomy of the battery of each of the devices.

3.1.4 Stress-specific sensors

In this category, sensors developed to provide stress level measurements to the users have been included. There are not many examples of this type of sensors on the current commercial market. Table 7 provides a good representation of the designs that are currently available.

There is no concrete unit to measure the stress level, but it is possible to detect two main tendencies between the manufactures of this kind of devices:

- usage of colour: the stress measurement is indicated with colours. For example, in the cases of "s" and "v", a high coherence level (no stress presence) is shown in green, normal coherence (stress levels not in a risky zone) is shown in blue and poor coherence (high stress levels) is shown in red. Furthermore, in the case of "t", the higher the stress level, the more intensely the colour appears. The colour shifts from a soft yellow, to orange and to a deep red;
- usage of waves: in this case, the stress measurement is shown with a wave shape. In "r" a wave related to heart rate variability is presented after a recorded session (not in real time) and following the detection of stress levels by a process carried out by proprietary software. The example of "u" illustrates the usage of wave presentation for stress levels in real time. A wave is shown on the device representing the pattern of the pulse rate. Depending on the wave, a series of triangles appear on the screen which work as cues to modify the breathing and to reduce the stress.

A "Real Time Stress Measure" column has been added in Table 7 to show if the device offers a real time stress measure. Similarly, an "Indication" column has been inserted to show the method of communication of the stress level (wave or colours).

Table 7. Stress-specific sensors

Sensor	Figure	Developer/ Reference	Comms	Measured Signals	Real Time Stress Measure	Indication
r) Stress Monitoring		Firstbeat / [66]	N.A	HR, ECG	No	Wave
s) Emwave desk-top		Heart Math / [67]	USB	HR, HRV	Yes	Colours
t) Rationalizer		Philips / [68]	Wireless	GSR	Yes	Colours
u) Exmocare BT2		Helicor Inc. / [69]	N.A	HR, HRV	Yes	Wave
v) Emwave Personal Stress Reliever		HeartMath / [70]	N.A	HR, HRV	Yes	Colours

The primary advantage of these sensors is that it is possible to obtain a stress level measurement. In most of the cases ("s", "t", "u", "v"), this measurement is obtained in real time. However, in some cases ("r", "u", "v") the difficulties already discussed about usage of batteries remain compromising the acceptability principle. Furthermore, the stress measurement is based on only a few biosignals. In most cases, only heart rate or heart rate variability ("r", "s", "u", "v") are measured, or in the case of "t", only galvanic skin response is measured compromising the accuracy principle.

3.1.5 Other sensors

In this last category, we look at some interesting systems (Table 8) that could not be directly classified as belonging to any of the previous categories. In the case of "w", the device is highly useful because it gathers a lot of information in a non invasive way. However, the user is required to be in constant physical contact with the mouse in order to obtain continuous feedback failing in the adaptive principle. On the other hand, this problem is the great advantage of "x" (the electrooculography goggles) where it would always be possible to obtain feedback in real time (although only one biosignal measure is obtained, the electrooculography, failing in the accuracy principle). None of the device is a commercial product but in prototype state. In Table 8, a commercial device, the

VitalSense XHR, “y” is included which measures two biosignals, electrocardiogram and breath rate through a chest-worn wireless sensor. However, the battery problems arise again in “y”.

Table 8. Other sensors

Sensor	FIGURE	Developer/ Reference	Comms	Measured Signals
w) emotional mouse		Quian Ji /[71]	USB	HR,GSR, EMG, TEMP
x) EOG Goggles		A. Bulling ETH Zurich / [72]	Bluetooth	EOG
y) VitalSense XHR		Philips /[73]	Wireless	ECG, BR

3.1.6 Research projects

In this section, some projects are selected where the sensor biofeedback field plays an important role. Although the target of these projects is not related directly to the stress measurements, they provide an idea of the focus in current research with regard to biofeedback measurements.

The following projects illustrate what we can expect from the results with respect to stress measurement.

The DARPA-ASSIST (Advanced Soldier Sensor Information System and Technology) program [74] enhances battlefield awareness via exploitation of soldier-collected information through a light-weight, wearable multi-sensor collection device. It is possible to find some study related to this project [75] with a wearable sensor system. The system consists of a multi-sensor board with a 3-axis accelerometer, microphones for recording speech and ambient sound, phototransistors for measuring light conditions and temperature and barometric pressure sensors. Another system related with this project (Vanderbilt University’s System [76]) is developing a shooter localization technology with ten acoustic sensors that detects gunfire, determines bullet trajectory, localizes the shooter, etc...

The SESAME [77] consortium is a multidisciplinary group that investigates the use of wireless sensor-based systems with offline and real time processing and feedback in enhancing the performance of elite athletes and young athletes who have been identified as having world class potential. The current work in progress includes pressure sensors in shoes (1000 samples/sec) to analyze foot contact intervals from shoe pressure and inertial sensors on limbs to measure the speed of motion from inertial and foot contact.

The Healthcare@Home project [78] aims to integrate invasive and non-invasive patient monitoring systems with analysis of this information via grid infrastructure. The infrastructure promotes continuous and discontinuous (push/pull) monitoring of patients at home, employing a new class of dedicated home healthcare server relaying data from and to prototype Bluetooth sensor/comms devices. The project uses diabetes as the exemplar disease context and glucose monitoring sensors to provide real-time continuous measurements [79].

The WearIT@work Project ([80], [81]) aims to empower the mobile worker by wearable computing intelligent clothing. The project maintains that wearable technology can change the organization's way of working in three ways: improving worker productivity and flexibility; increasing the number of tasks performed simultaneously and reducing the length of time for the performance of each task. Various low-embeddable physiological sensor modules, for measuring ECG (electrocardiogram), SpO2 (pulse oximeter), HR (heart rate), aortic pressure wave, and breath-to-breath CO2 / O2 concentrations, are used in the project scenarios. These sensors, for example, are particularly relevant to the BSPP (Brigade des Sapeurs Pompiers Paris) / Rescue scenario where physiological monitoring of firemen is required.

HeartCycle project [82] works to improve the quality of life for coronary heart disease and heart failure patients by monitoring their condition and involving them in the daily management of their disease. Monitoring each patient's condition is achieved by using a combination of unobtrusive bio-sensors that are built into the patient's clothing or bed sheets and home appliances. Some sensors used are cuff-less blood pressure, wearable SpO2 (pulse oximeter), inductive impedance, electronic acupuncture system and new sensor development like contact-less ECG, arrays of electrets foils, motion-compensation in ECG, cardiac performance monitor (bio-imped.). The consortium also develops mechanisms to automatically report relevant monitoring data back to clinicians so that they can prescribe personalized therapies and lifestyle recommendations.

In these research projects we can see the application of the sensors in different disciplines (military, sports, healthcare, and rescue scenarios). The sensor measurements are focused in the outside environment or in the human being tuned to a project's objective.

This review illustrates the sensor technology that is currently available on the commercial market (categories 1, 2, 3, 4 and 5) and where current research projects are focusing on.

3.2 Comparisons

In this section we compare the sensing technology described above. The main objective is to have a global idea of what kind of sensors we can find in the market and what factors we should bear in mind to apply these sensors to the smart home context. This table illustrates how every sensor fits to every criterion in the following way: very good relation: “++”; good relation: “+”; low relation: “-” ; very low relation: “- -”; not applicable relation: if the criterion is not applicable to the sensor, “Na” is inserted; and if no information is available for an applicable criterion, a “?” is inserted.

The criteria used in Table 9 is based on the basic principles mentioned in Table 3, applied to sensors shown in tables 4 - 8. In order to provide a more exhaustive comparison we associate these principles to nine technical criteria referred to as technological characteristics important for smart homes. This association allows us to show the impact of the current characteristics of the available technology in the basic principles. This gives us an indication which areas need improvement. Bearing in mind that the universality and permanence principles are considered to be achieved by all the sensors, we use these principles to select the examples illustrated previously. Below are described the eleven criteria relating them with the basic principles in format “Criteria. Principle: Description”. Only two criterions are no related to the basic principles, price and available sellers. However, we decided to add this information in order to complete the gathered data related to all devices.

The criteria used in Table 9 are enumerated below:

C1: data shown in real time. Adaptability principle: This indicates whether the sensor is able to send gathered data from the human body in real time. For this criterion in the table “++” is inserted when the sensor has real time support and “- -” if it does not;

C2: stress measurement. Performance principle: It is important to know if a specific stress parameter is supplied as otherwise it will be necessary to transform the data gathered into a suitable stress parameter. For this criterion “++” is inserted when the sensor provides stress measurement and “- -” if it does not;

C3: inclusion of software. Performance principle: Depending on the sensor, it may be sometimes necessary to develop own software to access to the measurements (assuming that there is an open interface). For this criterion “++” is inserted when the software is included and “- -” if it is not;

C4: data logging. Performance principle: This is a significant parameter if the user wants to review the data and save his/her sessions to study or improve decisions of the system in the future. For this criterion “++” is inserted when the sensor has data logging and “- -” if it does not;

C5: wearability (visibility). Acceptability principle: In some cases this parameter could be crucial depending on the user preferences. In this case “++” is inserted when the sensor is not visible, “+” when it is not visible but it is still wearable, “-” when it is not wearable but the sensor could be carried, “- -” is inserted when the sensor should be fixed and it is impossible to carry;

C6: intrusive/non intrusive (comfortable). Acceptability principle: Depending on the scenario, it may not be necessary to have a wearable sensor; however in most cases a non invasive sensor is necessary so that the user is not disturbed.. The symbol “++” is assigned when user movements and comfort are not compromised, “+” is assigned when the user can move freely but comfort is compromised. The symbol “ -” is used when the sensor is linked with cables or comfort and movements are compromised and “- -” is marked when the sensor is connected to cables and comfort or movements are compromised;

C7: accuracy. Accuracy principle: The more biosignals are measured by the sensor, the greater the accuracy in calculating the user's stress level measurement. In this case, the symbol “++” is used when the device gathers all of the biosignals measurements, “+” is inserted if it gathers more than two biosignals, “-” when it measures two biosignals and “- -” when only it measures only one biosignal;

C8: available sellers. Some sensors shown in the previous tables are prototypes and it is not possible to buy them. This criterion is referred to so that it can be seen if it is possible to purchase the device. The symbol “++” is inserted when the software is available on the market and “- -” is inserted if it is not available.

C9: price. In this case, the price category has been defined in the following way: “++” for under 500€, “+” for between 500 and 1000€, “-” for between 1000 and 2000€ and “- -” for above 2000€ and Na is used when the device is not a commercial product.

C10: autonomy. Acceptability principle: For users, the need to be aware about the battery life of the sensors is not a good point. In this case, the symbol “++” is inserted to show that the device can be plugged into the power supply as well as having batteries. The symbol “+” is inserted when it only can be plugged into the power supply or the power supply source is through a USB port. The symbol “-” is inserted when the sensor only has batteries (we consider that changing the batteries is worse than an USB connection) and we put “- -” when it only as batteries and the battery life is lower than 24 hours; and

C11: communication capacities. Performance principle: The more communication capacities the sensor has, the more possibilities available to the user to adapt the sensor within daily life. In this case, the symbol “++” is inserted when the device has wired and wireless capabilities. The symbol “+” is inserted to indicate when the sensor only has wireless capabilities. The symbol “-” is inserted when the sensor only works with wired communication and “- -” shows that the device has no communication capabilities

In the following, we can see Table 9 with all the sensors (in the first column from “a” to “y” keeping the same name that was used in the previous tables) and all criteria described above (From C1 to C11). For every sensor 11 criterions have been applied, so the table can be read in two ways: Per sensor (per row) or per criterion (per column).

The table provides information about different sensors that may be applied to the relevant principles. In all cases, and aside from the criteria, it is possible to identify where improvements could be made in sensors, particularly from the point of view of the technology.

Table 9. Comparison of sensors

Sensor	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
A	++	- -	++	++	++	++	-	++	++	-	+
B	++	- -	- -	- -	-	+	- -	++	++	-	- -
C	++	- -	++	++	-	- -	-	++	++	++	-
D	++	- -	++	++	-	- -	- -	++	- -	?	-
E	++	- -	- -	- -	-	-	- -	++	++	-	- -
F	++	- -	++	++	-	-	- -	++	-	-	+
G	++	- -	- -	- -	- -	- -	- -	++	-	+	- -
H	++	- -	- -	- -	- -	- -	- -	++	-	?	-
I	++	- -	++	++	-	- -	++	++	- -	+	-
J	++	- -	++	++	-	- -	++	++	+	-	+
K	++	- -	++	++	-	- -	++	++	- -	-	-
L	++	- -	++	++	-	- -	++	++	- -	-	-
M	++	- -	++	++	++	++	+	++	-	-	+
N	++	- -	++	++	++	++	-	++	+	-	+
O	++	- -	?	?	++	++	-	--	Na	?	?
P	++	- -	++	++	++	++	+	++	-	- -	+
Q	++	- -	++	++	+	++	+	++	?	?	+
R	- -	++	++	++	++	++	-	++	?	-	- -
S	++	++	++	++	- -	-	-	++	++	+	-
T	++	++	?	?	++	++	- -	- -	Na	?	+
U	++	++	- -	- -	+	+	-	++	++	-	- -
V	++	++	- -	- -	+	+	-	++	++	-	- -
W	++	- -	++	?	++	++	+	- -	Na	+	-
X	++	- -	++	?	+	-	- -	- -	Na	+	-
Y	++	- -	++	++	++	++	-	++	-	-	+

We consider that improvements could be made in the following areas helping to fulfil successfully the basic principles:

1) performance: a standardization process is required for interoperability between various types of sensors. This is raised because the software is proprietary and even the communication in some cases is not following a standard (*"a", "c", "d", "m", "q"*). For example, if a user gets some category 1 sensors and later wants to take advantage, using them in category 2 devices, this is not possible.
2) accuracy / acceptability: security in wireless transmissions must be improved in the cases where the biosignals are communicated by the wireless method. The Bluetooth protocol is commonly used but it has some security problems

([83], [84]). It would be desirable therefore to ensure that this data is reliable (accuracy) and protected (acceptability) to avoid security risks; and

3) acceptability: the battery life of the sensor could be in some scenarios crucial. It is possible to identify an important area for improvement in all the sensors using batteries. The batteries are possibly too big to wear in many cases. This problem is accentuated in the case of wearable sensors. Longer duration of the batteries and batteries of smaller size would be desirable.

Having considered this comparison, it is possible to identify how sensor technology can assist users to be aware of their stress and take advantage of it in a smart home. Furthermore, we have suggested some points on how the technology can be improved to fulfil the basic principles of the biometric sensors.

4. Conclusions and future work

Ambient Assisted Living has evolved from previous telecare/telehealth solutions which provided healthcare at home. Currently there is substantial interest on making a concerted effort around the world to transform the model of centralized heathcare into one which is more flexible and helps humans where they are, at home, at work and on the move. This transformation requires the development of technologies which can supervise aspects of human health and wellbeing in a reliable way. Whilst these technologies are still considered to be in an exploratory stage, there have been significant advances and the forecast is optimistic.

This chapter provides a synthesis of some of the technologies available for the development of such infrastructures. We provide a description of systems which have been developed to assess specific biometrical indicators of health such as blood pressure, sleeping patterns and stress, and also systems which goes beyond measuring an isolated parameter as an indicator of help and can provide a platform for a more holistic understanding of people's health or lifestyle. These technologies can be applied at home through the concept of Smart Homes, at work through the concepts of Smart Offices or in other concepts, consistent with the ethos of Ambient Assisted Living. We hope our survey and comparative analysis is beneficial to future developers in this field.

What will be the final outcome of this new technological exploration is still unknown. Current achievements are positive and seem to indicate technology which has the potential to gather information from humans and make it available to other machines or humans will be given careful consideration and used in the non-so distant future. This will bring new opportunities for health, growth, and also ethical and social dilemmas. In this sense it will not be substantially different than other technological developments humans experienced before, but there are strong possibilities that we may be entering a stage of human history which will be remembered as a revolution in healthcare as well as on the relation between humans and technology.

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