Design of a prototype device for remote patient care with mild cognitive impairment

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Abstract

This paper describes the design of a prototype telecare system, which allows to provide home care to patients with mild cognitive impairment and thus ensures their permanence in their usual environment. Telecare is oriented towards people who require constant attention due to conditions of advanced age, illness, physical risk or limited capabilities. Telecare offers these people a greater degree of independence.

QFD methodology is used to develop electronic devices intended to monitor the environment and physiological state of the user continuously, providing communication between the telecare system and a monitoring center in order to take the most appropriate actions in any abnormal event.
1. Introduction

The term "Assistive technology", was defined in 2004 by WHO (World Health Organization) as "An umbrella term for any device or system that allows individuals to perform tasks they would otherwise be unable to do or increases the ease and safety with which tasks can be performed" [1]. Therefore, it is important to differentiate the categories of technology used for assistance. Telemedicine is defined as “The delivery of health care services, where distance is a critical factor, by all healthcare professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the continuing education of health care providers, all in the interests of advancing the health of individuals and their communities” [2]. Telecare which is defined as "a continuous source of home care that allows users to stay in their usual environment, thereby uprooting is avoided while protection is provided in crisis situations personal, social and health " [3], therefore telecare supports independent life and the welfare of the elderly or persons with limited capabilities. The most significant concerns of older adults cognitively and physically restrained by caregivers are medical treatments in the event of an accident, which is why technology interventions have the potential to reduce adverse consequences, avoiding the transfer of patients to health centers of high complexity and allowing to prolong the period of life at home. Considering the needs of each individual whom are specific and therefore the appropriate technological interventions must be made, by redesigning the environmental conditions of life at home and providing the independence necessary for these individuals. Based on work by Barlow [4], the content of telecare monitoring includes staff, technology assistance and electronic interaction between information and communication, this creates a challenge at the time of designing a system that meets the characteristics of flexibility and modularity that can adapt to the routines and habits of adults.

According to the World Health Organization "it is expected that in developing countries the number of older adults who have lost their autonomy will have quadrupled by 2050. There are many elderly people who cannot live alone because they have difficulty moving or have poor physical or mental health" [5]. Globally about 25% of people over the age 60 are diagnosed with some form of dementia [6]. In Colombia, Pradilla, G., Vega, B., Phidias, E. (2003), Neuro Epidemiological study that included the cities of Bogota, Cali, Medellin, Barranquilla and Bucaramanga, found the following prevalence per 1,000 population: dementias 13.1% and 4.7% of Parkinson disease. Among these dementias is a mild cognitive impairment, defined as greater cognitive loss (attention, memory, language and executive functions), expected for its age and educational level, which does not significantly interfere with daily life activities [8]. It is an entity with a high prevalence in the population, which requires attention and care, involving patients, families and many groups of professionals, where diagnosis and treatment can be complex especially in the early stages. Therefore, the integration of new technologies in the area of health, where homes should be equipped with technology to monitor the environment and the individual's condition in real time and improve the safety of home and the quality of life of the user.

The objective of this paper is to present the design of a telecare device to monitor people over 60 years with mild cognitive impairment, using the QFD (Quality Function Development) methodology. The system consists of sensors and transducers located in strategic places of the individual's home, which allow continuous monitoring of the environment and the user, providing adequate assistance should an unusual situation occur, and allows a study of habits at the same time. These alerts, the moment when issued will be sent to a central module and a module hospital, where information is stored and appropriate measures be taken to provide assistance, in addition to sending an alert to the person in charge of patient care.
The Telecare system should be treated as an integration of electronic devices and network architecture of internal and external communication, which allows the management of information in a comprehensive way avoiding data loss and providing continuous monitoring. In Figure 1 you can see the interconnection between devices, the user and the central patient device.

The central patient device manages information generated by peripheral devices and sensors that are in the environment, which are:

- **Gas sensor**: Detects dangerous levels of gases, should the person be distracted or with memory loss a person can leave an open gas tap causing an accident.
- **Door Sensor**: It is designed to monitor the safety of people with cognitive problems that often leave home at inappropriate times. The device is programmed to expect a sequence of events before generating an alarm.
- **Shower temperature sensor**: Detects water temperature, generating a visible alarm to the person in case the shower temperature is excessively high. Usually people with cognitive losses, as a consequence, develop a type of sensory deprivation syndrome [9], where they lose the perception of heat or cold to the skin.
- **Smoke / Fire Detector**: Detects potentially harmful smoke particles.
- **Flood Detector**: Detects water levels caused by leaving the water open, broken pipes or electrical appliances.
- **Presence detector bed / chair**: Detects when a person stands or sits on the bed or chair, knowing their habits, generating an alarms in case the person does not get up or lie down for an unscheduled hour.
- **Motion detector**: Used to monitor the activity and inactivity of the user in the home, combined with other sensors such as the fall detector and presence detector in bed / chair can minimize unwanted effect of an event such as a fall, thus reducing the time of arrival of aid and treatment.

**Figure 1. Devices in patient’s home**

The central patient device manages information generated by peripheral devices and sensors that are in the environment, which are:
Similarly, in the system are monitoring devices for patients, among them are:

- **Falls Detector**: Older adults who have cognitive impairment have an increased risk of falls associated with motor impairment, visual impairment, low bone mineral density, fragility among others, so it is important to monitor users and when the system detects a fall, sends an alert to the monitoring center and the caregiver.
- **Panic Button**: Generates a warning message when the user requires or is in an emergency situation
- **Monitor Vital Signs**: It has special sensors to monitor physiological variables, such as body temperature, heart rate, oxygen saturation and blood pressure. This monitoring is done depending on the requirements of each patient and sends an alert when any of these parameters change.

Some of the mentioned devices are being designed and implemented in full as will be described later, while others are being adapted to the system considering that with commercial devices, the manufacturing cost decreases significantly.

For the connection between the devices that make up the remote assistance system, the different communication protocols should be taken into account. The first is between peripheral devices and the Central patient device which will be made by radio frequency, based on the modulation technique Gaussian Frequency Shift (GFSK) [10], which is a modulation method for digital communication coding data as a series of changes in a carrier signal frequency. To code a signal by means of this technique, the Enhanced ShockBurst, a baseband protocol is implemented, which allows automatic packet data bidirectionally to transfer between transceivers, the main configured as a receiver (PRX) and others are configured as transmitters (PTX). The communication starts when the PTX sends a data packet and ends when it receives an acknowledgment packet (ACK) from the PRX. If PTX does not receive the acknowledgment packet the original data packet is retransmitted after a set time interval and the PTX is put in receive mode waiting for ACK, preventing data loss when an event alarm is detected.

The second communication protocol, is the SMPP (Short Message Peer to Peer), which is a standard protocol designed to provide a flexible interface for data communication between a central message and a central messaging server [11]. This protocol supports GSM technology (Global System for Mobile).

2. **QFD methodology**

The QFD methodology (deployment of the quality function) was used to design the prototype patient telecare system module and consists of the systematization of product requirements and defines the technical and operational characteristics to satisfy these needs. The following describes each of the stages.

**Stage I: Clarify and define the task**

**Device specs:**

- Maintain two-way communication between peripheral devices and the Central patient device, and between the latter and the registered external modules, central module and module hospital.
- Send a text message when an alarm event occurs.
- User-friendly interface for the user.
- Continuous feeding (24 hours a day / 7 days a week).

**Common questions about device performance were:**

- How often the device will be used?
- Daily (24 hours a day / 7 days a week)
- Would it be mobile device?
- Environmental peripheral devices and the Central patient device would be fixed in certain places of abode and peripherals; patient would be mobile.
- What kind of power supply does it have?
- The Central patient device will be supplied with 110V power supply with battery backup and peripheral devices will be battery-powered.
- How will the information obtained from peripheral devices be shipped?
- Radiofrequency.
- How will the information of an alarm event be sent?
- GSM network, via text messages.

The device must be versatile, easy to use for users, reliable and easy to configure for the different needs of each individual, in addition to real communication at present time and an alarm event. As a device often used, it must have a system that allows the user to know the state of the batteries of peripheral devices to prevent data loss.

The characteristics of "WHAT'S" featured devices are described as.

Those “WHAT’S”:
- Establish two types of two-way communication in real time.
- The user peripheral devices must be small and light.
- Protect the user, and orient it for management.

Stage II: Determine the functions and structures
At this stage the possible solutions or mechanisms to help meet requirements are discussed:
- Allow easy connection between peripheral devices and the Central patient device.
- Optimally manufactured components to reduce size and weight.
- Transmission of data in real time between Central patient device and the core modules and hospital.
- Pleasing design.
- Marks on the connection points to guide the proper use of the device.

Taking the above information to obtain the "HOW’S" or characteristics this device should have in the end:
- Peripheral Devices lightweight and portable patient.
- Communication between peripheral devices and the Central patient device is made by the RF transceiver module.
- Communication between Central patient device and the central module and hospital will be made through a GSM Shield, which allows the sending and receiving text messages.
- constant measurement of the variables is done by specific sensors for every need.
Stage III: Looking for the principles of solution and its variants
At this stage the solution to the telecare system characteristics are shown.

Table 1. Solution module features

| No. | Characteristics                  | How to do it                                                   |
|-----|----------------------------------|---------------------------------------------------------------|
| 1   | Light                            | Reduction of components and protective polymer surface         |
| 2   | RF Communication                 | Module NRF24L01                                               |
| 3   | Sending alarm messages           | Shield GSM / GPRS M95                                         |
| 4   | Constant medical measuring of    | Arduino Mini, specific sensor or                               |
|     | physical variables and the detection of changes in physical phenomenon | detector for each event                                       |

Stage IV: Split into realizable modules
Depending on the area the appropriate solution from the point of view of the user considering the following specified:
- Operation (A)
- Robustness (B)
- Cost (C)
- Manufacturing (D)
- Maintenance (E)
- Assembly (F)

This will take into account the product life cycle. The following table shows only the importance of each product feature, with each of the above parameters, and thus it determines what should be focused on when developing the device. The importance is given a rating on a scale of 1 to 10, with 1 being the least and 10 being the most important.

Table 2. Relevance of features

| No. | Feature             | A  | B  | C  | D  | E  | F  |
|-----|---------------------|----|----|----|----|----|----|
| 1   | Light               | 10 | 8  | 9  | 8  | 5  | 10 |
| 2   | RF Communication    | 10 | 10 | 8  | 4  | 3  | 6  |
| 3   | Sending messages    | 10 | 5  | 8  | 4  | 3  | 6  |
| 4   | Detection and       | 10 | 10 | 8  | 7  | 9  | 10 |
|     | measurement variables |    |    |    |    |    |    |
|     |                     | 10,00 | 8.25 | 8.25 | 5.75 | 5.00 | 8.00 |

As shown in Table 2, the most important features are operating, robustness, cost and assembly. Here these are the most influential for the development of the device.
3. Results and discussion.
In Figure 2, the block diagram of the overall system Telecare, where the RF link between peripheral devices and the Central patient device, which in turn sends a text message by GSM communication to the central module and hospital when an alarm event is generated.

The central patient device has both hardware and software components, which must meet the above design features.

Hardware:
- **Central patient device**: its main function is to receive the information from the sensors by nRF24L01 transceiver configured as PRX, so that it can check the communication between peripheral devices and avoid collisions or loss of data. Upon the arrival of a Patient Alert module it sends a text message via the Shield GSM / GPRS to external modules M95.
- **Communication external modules (Central node / Hospital node)**: receiving alarm messages generated by the Central patient device is made by using the Shield GSM / GPRS M95, where it is stored in a database to keep track of events.
- **Peripheral Devices**: as mentioned, some of these peripheral devices are completely designed and the architecture design is very similar for all of them, ie each device must have a radio frequency module for communication, microcontroller and specific sensor or detector for each device. Among these are:
  - **Falls Detector**: for the design and implementation of one IMU (Inertial Measurement Unit) of nine degrees of freedom, where an algorithm is implemented to detect falls and differentiate each of the activities of daily life in which are used: standing, sitting, lying down, picking up an object and walking. This device will be placed on the patient’s waist and have a button that will serve as a panic button.
• **Presence detector bed / chair:** This detector requires, the RF module and the microcontroller, and a device capable of detecting user presence in bed or chair, using a piezoresistive materials, which has the characteristic of changing its resistance when applying a force.

• **Shower temperature sensor:** 10k NTC thermistor is used to monitor the temperature provided by the shower, where temperature ranges are established for which notice is given to the user visually, should the increase in water temperature rise. In figure 3, one can observe the temperature ranges set.

![Temperature ranges](image)

A) Temperature: ≤ 17°C. 
B) 17°C < Temperature: ≤ 40°C 
C) Temperature: > 40°C

• **Vital Signs Monitor:** for this device a pulse sensor was used, where the variables of heart rate and oxygen saturation are obtained. Taking the values of the graph by mathematical calculations the value of pulse pressure P. Equation (1) is obtained. Where Pd is the diastolic pressure and Ps is the systolic pressure.

\[ P = \int Pd + \frac{1}{3}(Ps - Pd) \quad (1) \]

Figure 4. Identification of parameters in the wave of heart rate. [12]

Besides this, the vital signs monitor also has an implemented body temperature sensor integrated with LM35, this generates the emergency message when finding the value of the temperature outside established ranges. (Hypothermia: Less than 36 °C, average: 36.1 °C - 37.2 °C, hyperthermia: Higher than 37.2 °C)

**Software**

To program the various peripheral devices including tele-assistance system, it was decided to use the software and development boards Arduino Mini Arduino Nano, with ATMega328P microcontroller, which have their own programming language, because of the benefits it offers, to be able to develop a modular, simpler, clearer and with fewer lines of program code.

Central patient device architecture of the code is more complex so the used programming language is C language, using a microcontroller Freescale FRDM - KL25Z, since the features of this algorithm are
essential, because values are shown the moment that an alarm is generated, and sends an SMS alert to the hospital and central module and also allows the voice channel to activate if necessary as well as storing history records.

4. Conclusions
The implementation of a prototype module patient with peripheral devices, allowing the status of the patient and their environment, to be notified in any alarming situation to the central module located at the Universidad Autónoma de Manizales and the nearest hospital to the patient's home. The implementation of these devices are so they can perform continuous monitoring to individuals who have been diagnosed with cognitive impairment, such that they are not apart from their home, in many cases reducing travel costs for both the patient and medical staff.

This prototype module is versatile because each person is an individual case and the module must be adjusted to the needs of each individual.

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6. References
[1] A glossary of terms for community health care and services for older persons. Recuperado: Abril 30, 2015. Disponible en: http://www.who.int/kobe_centre/ageing/ahp_vol5_glossary.pdf
[2] WHO (World Health Organization). Telemedicine. Opportunities and developments in member states. Report on the second global survey on eHealth. Global Observatory for eHealth series. Volume 2. ISBN 978 92 4 156414 4 ISSN 2220-5462© World Health Organization 2010. Disponible en: http://www.who.int/goe/publications/goe_telemedicine_2010.pdf
[3] Miriam Atienza Mañas, C. C. (2014). In Paraninfo, Teleasistencia (Primera ed., p. 2). España: Paraninfo.
[4] Barlow, J., Curry, R., Wardle, D., Bayer, S., & Trejo Tinoco, M. (2004). Implementing telecare: Strategic analysis and guidelines for policy makers, commissioners and providers. In Public sector national report. London: Audit Commission.
[5] Organización Mundial de la Salud. (n.d.). Día Mundial de la Salud. Recuperado Febrero 6, 2015. Disponible en: Día Mundial de la Salud 2012 - ¿Está usted preparado?: http://www.who.int/world-healthday/2012/toolkit/background/es/index2.html
[6] Carbonell, C. (2000). La depresión en el anciano. Actas Españolas de Psiquiatría.
[7] Pradilla A. Gustavo, Vega A. Boris E., León-Sarmiento Fidias E. (2003). Estudio neuroepidemiológico nacional (EPINEURO) colombiano. Rev Panam Salud Pública
[8] Gauthier, S., Reisberg, B., Zaudig, M., Petersen, R. C., Ritchie, K., Broich, K., & Winblad, B. (2006). Mild cognitive impairment. The Lancet, 367(9518), 1262-1270.
[9] Guía práctica clínica. Recuperado Mayo 7 de 2015. Disponible en: http://www.cenetec.salud.gob.mx/descargas/gpc/CatalogoMaestro/144_GPC_DEMENCIA_AM/Imss_144_08_grr_demencia_am.pdf
[10] Implementation of Digital Signal Processing: Some Background on GFSK Modulation. Recuperado Junio 6. Disponible en: http://wwwhome.ewi.utwente.nl/~gerezsh/sendfile/sendfile.php/gfsk-intro.pdf
[11] Short Message Peer to Peer Protocol Specification v3.4, Document Version: 12 de Octubre de 1999, Issue 1.2.
[12] Imagen recuperada el 27 de Febrero de 2015. Disponible en: http://ocw.unican.es/ciencias-de-la-salud/fisiologia-humana-2011-g367/material-de-clase/bloque-tematico-1.-fisiologia-del-aparato/tema-6.-circulacion-arterial.-presion-arterial/tema-6.-circulacion-arterial.-presion-arterial