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Carla Taramasco, Cristina Espinoza, Fabián Riquelme. Telemonitoring ADL platform based on non-intrusive and privacy-friendly sensors for the care of the elderly in smart homes. Journées d'Etude sur la TéléSanté, Sorbonne Universités, May 2019, Paris, France. hal-02161094

HAL Id: hal-02161094

<https://hal.science/hal-02161094>

Submitted on 20 Jun 2019

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Telemonitoring ADL platform based on non-intrusive and privacy-friendly sensors for the care of the elderly in smart homes

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Abstract - During the last years, several sensor-based monitoring systems have been developed to detect in real time frequent problems in older people, such as falls and nocturia. Some devices can also measure different variables of the environment (e.g. temperature, pollution, etc.) to generate alarms and thus help the user's welfare. All these devices generate numerous sensitive data related to the health and behavior of user/patients. The presence of some of these sensors in homes can mean a vulnerability of the user's privacy. In this article we propose a telemonitoring ADL platform based on non-intrusive sensors for the care of the elderly, restricted by a user-centered protocol that guarantees their privacy and facilitates their acceptance by the user.

Keywords: Healthcare monitoring, Telemonitoring, Smart home

I. INTRODUCTION

The rapid aging of the world's population [1,2,3] will generate in near future profound implications for planning and delivering health and social care [4]. As a person ages, diseases that gradually deteriorate the physical and mental health can cause functional limitations, disability and dependency. For the elderly living alone, the detection of these problems can delay response times, diagnoses and treatments. Therefore, public policies are being developed in various countries to promote early intervention programs for the elderly population [5].

Inside the home, the elderly are exposed to various issues that could deteriorate their health. For example, there are studies that relate the indoor air pollution with wheezing, breathlessness, cough, phlegm, asthma, COPD, lung cancer and even lung function decline [6]. Another permanent risk in older adults are falls [7,8], that can lead to various problems, such as pressure ulcers, osteopenia, loss of muscle mass with its subsequent functional impact, dehydration, hypothermia, pneumonia and even death [9]. In addition to this kind of accidents, there are certain signs that are relevant to detect within a home, as they could lead to health problems. A relevant example of this is nocturia, which is the need to wake up at night at least one or more times to go to the bathroom [10]. Nocturia is more common in the elderly population, and these continuous nocturnal transits can cause sleep disorders [11,12] that can lead to reduced concentration, cognitive decline, poor levels of energy, and overall, negative effects in the quality of life [13,14]. Moreover, it is known that people

with nocturia are exposed to falls, due to the state of drowsiness in the night [15].

To deal with this kind of issues, a patient-centered care model is recommended, where not only emergency cases are taken, but the patient is actively committed to their care and therapeutic processes [16,17]. The current advance in technology and the reduction in hardware costs allow us to address the problems of older adults through information technology (IT) from a preventive and non-reactive perspective, before the consequences on health are irremediable. The non-invasive monitoring of older adults allows to observe their evolution, the appearance of early symptoms of neurodegenerative diseases and the generation of treatments, plans and programs geared to this age group needs. In this context, the concepts of *smart home* and *IoT for health* emerge, that is, equipping homes, objects and machines with technological elements (sensors, microcontrollers, etc.) to monitor actions or events of the users, as well as environmental conditions of the place, in order to detect emergencies early and reduce the times in the decision making [18,19,20].

Nowadays, the sensors can be classified in: wearable-based systems, camera-based systems, and environmental devices [21,22,23]. These kind of devices generate numerous sensitive data related to health and behavior of user/patients. Therefore, in Section II we propose a user-centered protocol that regulates the types of sensors and data collection that can be used in both smart homes solutions based on telemonitoring ADL (activities of daily living) platforms. Next, in Section III we propose a telemonitoring platform based on non-intrusive sensors for the care of the elderly, regulated by the previous protocol. These sensors allow to monitor environmental conditions (air quality, humidity, temperature and carbon monoxide), accidents (falls), and patient's health status (wandering, nocturia). The guarantee of the privacy facilitates the acceptance of the platform by the user.

II. USER-CENTERED PROTOCOL

In order to improve the healthcare and quality of life of the elderly, we propose to develop a sensor-based telemonitoring platform, based on the concept of smart homes. We consider a user/patient-centered care model, in which the elderly have a

large support team, made up of their close family, the hospital and their family health center, but also specialized emergency teams (e.g. firefighters or civil protection) (see Fig. 1). Nevertheless, before thinking about which sensors will integrate the platform, as well as which software components are required to collect, distribute and store the data, we must consider two critical requirements: the non-intrusiveness and privacy of the system.

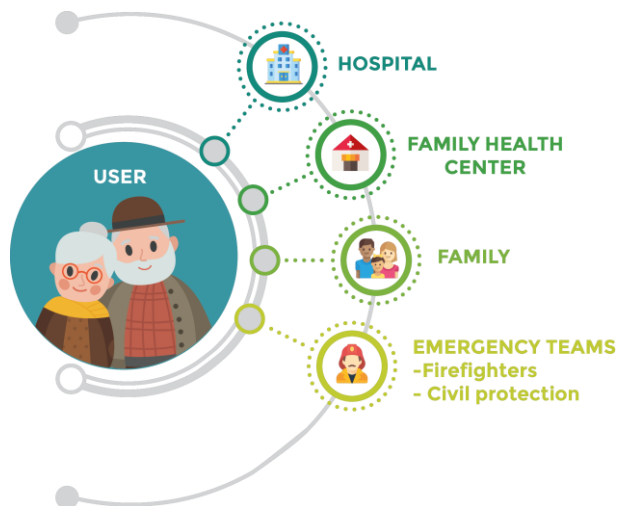


Figure 1. User support team

The platform must be non-intrusive, in such a way that the presence of the sensors does not intervene in the daily life of the users. In this sense, it is recommended discrete sensors, so that users can continue to make their lives without feeling monitored. The user may forget the feeling that she or he is being monitored, but it is important that she or he knows that is being monitored. Therefore, it is recommended that the sensors are not completely hidden, and that the user knows from the beginning where each of them will be located. To guarantee this ethical commitment with the user, the developer team must install the devices in the presence of the house users, and sign an informed consent document, previously approved by an ethics committee (service usually provided by universities and other types of organizations). Through this document, it must also be ensured the security of the data collected and the privacy of all the user's activities within the home.

Given the above, the proposed platform is intended for older adults with the following exclusion criteria:

- Patients with dementia.
- Patients with a history of alcoholism or substance abuse.
- Patients who are unable to understand or sign the informed consent document.
- Patients who do not wish to participate in the project.

The proposed solution also considers the following additional requirements, for the purposes of the data samples:

- The user must be over 65 years old (value that can vary according to the life expectancy or retirement age of each country).
- The user does not have a higher medical morbidity that leads to a life expectancy of less than 6 months.

For technical reasons of the sensors use (see Section III), the following requirements are also included:

- The user must live alone most of the time (although she/he may receive occasional visits).
- The user should not live with pets that move inside the house, such as dogs or cats.

Regarding the type of sensors, although wearable-based systems (e.g. watches, necklaces, bracelets, key rings, etc.) are very useful for outside, they are not as recommendable for inside the home, because they are a bit more invasive and constitute an idea of constant vigilance for the user. On the other hand, the proposed solution does consider camera-based systems and environmental devices, under certain restrictions that we shall see in what follows.

III. MONITORING SYSTEM DESCRIPTION

We propose to implement a multifactorial platform for continuous monitoring of the adult's daily activities, that allows to detect risk events inside home and thus improving the quality of life of the elderly. The aim is to provide them with the necessary tools to safely live their autonomy and independence, keeping their privacy (see Fig. 2). The novel monitoring system is installed in the homes of the elderly (A), with non invasive non intrusive components of nocturia sensors (B), falling sensors (C), humidity and carbon monoxide sensors (D), and an emergency button to call his/her contacts (E). The system is connected with emergency and firefighter department (F) by a platform which generates early warnings (1), collects medical and environmental data which goes to medical team and offers more information to give better diagnosis (2), and provides care and companionship (3). In what follows the system's hardware and software components are detailed.

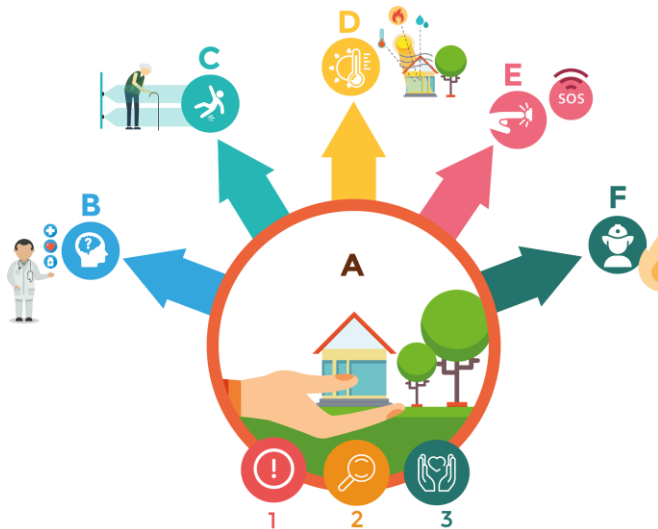


Figure 2. The proposed solution.

A. Hardware components

The following sensors can coexist to detect actimetry, falls, nocturia, air quality (carbon monoxide), humidity and temperature. The platform is considered to be modular, so that the sensors are independent modules that can be integrated successively. If one module stops working, the others can continue to work. Furthermore, this modularity approach also allows the integration of new components. The monitoring systems considered are the following:

- *Monitoring of environmental conditions:*

To avoid accidents such as fires, explosions and inhalation of carbon monoxide, sensors will be used in sources that can emanate harmful gases such as the kitchen, stove, heater, etc., in order to alert in case of abnormal concentrations in environment. Concretely, it is proposed a the MQ-9 sensor for the detection of gases harmful to health. It can detect concentrations of these gases from 100ppm to 10000ppm.

In addition, a DHT22 sensor will be installed to measure humidity and temperature. This sensor has a range for temperature from -40°C to 125°C with 0.5°C of precision, and from 0% RH to 100% RH with 5% accuracy for humidity. Moreover, it has a sampling rate of 0.5 [Hz] (it delivers one measurement every 2 seconds).

- *Monitoring accidents:*

To detect falls, infrared radiation sensors will be used to capture the heat of objects within their field of vision, transforming it into a temperature value. We propose a sensor model AMG8833 of low resolution (8x8 pixels in a viewing angle of $60^{\circ}\times 60^{\circ}$), in order to keep the privacy of the user. These sensors will be located in each room and will be distinguished by an "id". An ODROID C1+ minicomputer is used to

process the information, which is connected to the sensors through an ATMEGA328P microcontroller (see Fig. 3). This module will be used to detect possible falls with an accuracy of 90%, by means of artificial intelligence algorithms (SVM, LSTM, GRU and BLSTM) already used in [21].

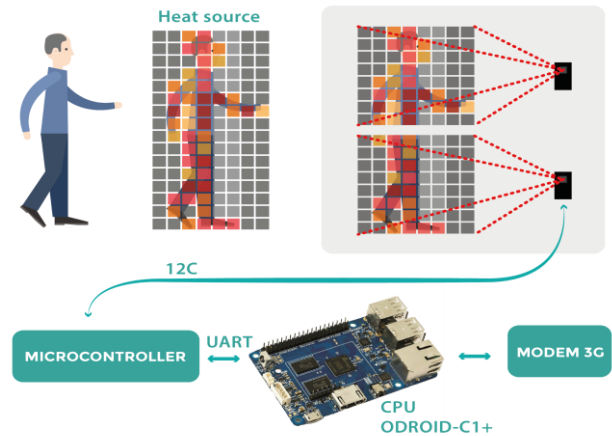


Figure 3. A privacy-friendly thermal sensor of low resolution

- *Monitor of the patient's health status:*

To detect wandering in the elderly, we need first to classify the daily activities carried out by the elderly. This can be done by using the same thermal sensors of low resolution used to detect falls and mentioned before. Thus, for example, if the user at lunchtime goes to the kitchen, it is assumed that she/he is having lunch. At the beginning of the monitoring, the user's activity profile will be constructed. Then, through a probabilistic model based on Markov chains, wandering can be detected as anomalies in the user's general behavior pattern.

In order to detect nocturia, a sensor attached to the toilet is used to measure a voltage proportional to the conductivity present in the water in the toilet. This information is stored in a MicroSD memory card. Nocturia is detected when the sensor starts to activate frequently during the nights.

To collect and manage the data of the previous sensors, the following hardware devices are proposed:

- *Local Processing Unit (LPU):* It processes the signals captured by the sensors inside the house. This minicomputer of the ODROID family is capable of executing artificial intelligence algorithms for the detection of actimetry and monitoring the concentrations of harmful gases, temperature and humidity in the environment every 5 minutes. This unit also has a 3G modem, which is used to send alerts to the centralized server, informing about events such as falls or abnormal concentrations of harmful gases. It is important to mention that LPU allows

processing the data within the user's home. This ensures that the data sent to the central databases of the system are not raw, but only send the alerts and summaries necessary for the monitoring of the elderly. The latter is a key point to ensure the privacy of the data.

- Central of Alerts: It receives and manages the information sent from the LPU. When receiving an emergency alert (drop, anomalous behavior, gas leak or inappropriate environment) it stores the information in a database and then it can be configured to send an alert message to the user's contacts.

Through the data collected by the sensors, daily, monthly and annual reports on the patient's situation at home and their daily activities will be made. By unifying information from several patients, it will be possible to perform advanced analysis through data mining, to find non-trivial patterns: characteristics of the evolution of old age, disability, dependency, among others, in order to guide treatments, plans, programs and policies.

B. *Software components*

Access to data will be given by two types of interfaces:

- Web application: To display data regarding follow-up of the elderly, alerts issued, and descriptive statistics of the evolution of the elderly. The only users that will use this view will be the clinical team in charge of the elderly (physician, nurse, physiotherapist), with read permissions, and the decision maker (director of the health center and/or the director of the municipal corporation, or a ministerial representative), with full access to the sections of the web application.
- Mobile application: It receives the alerts generated by the systems and display them in the cell phones of the contacts and the physician in charge. The recipients of this information are the family/caregiver and the clinical team of the elderly.

IV. CONCLUSION AND PERSPECTIVES

Nowadays, the patient-centered care model is fundamental to improve the quality of life of the elderly people. Advances in IoT have allowed the development of various sensors to monitor different variables within the home, which has led to the concept of smart homes. Each sensor gives rise to a system, in which there are actors and data involved, whose analysis favors the processes of decision making. This work propose a patient-centered care model in which is essential the interconnectivity of all these systems and environments of the user, favoring the crossing of information to improve patient care, detect emerging risks more quickly, and respond more efficiently when a fall or some other problem occurs. Moreover, it is proposed a protocol in which elderly

participants will be randomised in a 1:1 ratio to receive either a telemonitoring platform in their houses or standard health care protecting privacy and personal data of all patients.

This kind of platforms seeks to impact in the short and long term. On one hand, it allows detecting anomalies in the elderly and decreasing the time of post-fall care, which results in a decrease in both the psychological impact of the patient and the medical cost of care. On the other hand, it favors the generation of a social support network in the long term. In fact, it integrates health care centers within homes, and takes the patient's care to their daily environment, which includes their family, friends, neighbors, etc. It is interesting to mention that the implementation of a patient-centered care model also depends on socio-cultural factors that must be taken into account when setting up the system. In some countries, like Chile or France, for example, firefighters are the ones who deal with gas leaks in homes, instead of medical centers.

The current solution is not intended to be a definitive solution for the care of the elderly. On the contrary, there are still important open problems that will be treated as future work. For example, the possibility of considering homes with pets, or the reduction of sensor costs. Indeed, AMG8833 sensors are expensive, so it would be helpful to find better ways to distribute them in space without loss of information. It will also seek to reduce the ODROID in the house, as well as optimize the hardware in size and functionality. Another important problem is the detection of falls in the shower. Nowadays it is a blind spot and one of the places with the highest risk of falls in the home. Since it is not useful to include thermal sensors in the bathroom, a possible solution could be the use of ultrasound.

Finally, the integration of the system into the clinical records managed by the healthcare centers is in process. This is a complex issue, since it varies case by case, depending on the region and country where the patient lives. However, there are certain standards that could help us, such as the health data transmission standard, HL7.

ACKNOWLEDGMENT

This work was partially funded by FONDEF IDeA I+D #ID18I10212. This work has the approval of ethics (code CEC181-19) granted by the accredited scientific ethics committee of the Universidad de Valparaíso, Chile.

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