Integration of Smart Home Technologies in a Health Monitoring System for the Elderly

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Abstract

Among older adults, the challenges of maintaining mobility and cognitive function make it increasingly difficult to remain living alone independently. As a result, many older adults are forced to seek residence in costly clinical institutions where they can receive constant medical supervision. A home-based automated system that monitors their health and well-being while remaining unobtrusive would provide them with a more comfortable and independent lifestyle, as well as more affordable care. This paper presents a smart home system for the elderly, developed by the Technology Assisted Friendly Environment for the Third Age (TAFETA) group. It introduces the sensor technologies integrated in the system and develops a framework for the processing and communication of the extracted information. It also considers the acceptability and implications of this technology from the perspective of the potential occupants.

1. Introduction

Canada is facing a fundamental shift in its demographics with an unprecedented growth in its elderly population. Health Canada estimates that by 2021 there will be 6.7 million Canadians over the age of 65, representing 18% of the population [1]. As the members of this population age, their needs for costly healthcare monitoring increase. Many hospitals and nursing care facilities across the country are already reaching their financial limits and their personnel is exceeding the expected workloads [2]. Furthermore, because of shortages of services and/or nursing home beds in many areas of the country, up to 15 % of acute care hospital beds are filled with clients that no longer require acute care, but are waiting for these alternative services [3]. There is therefore a growing demand for technology that could aid in the care of the elderly, whether in health institutions or in their own homes. The biomedical engineering community, along with organizations such as Health Canada and various academic institutions, is attempting to respond to this need by developing smart home technologies that could provide automated monitoring of the health and well-being of seniors [4]-[7]. This could provide the elderly person with a higher degree of independence and quality of life, while decreasing the financial burden on the healthcare system. A recent review of studies on the telemonitoring of heart failure found not only high acceptance by patients, but a reduction of readmission rates and length of hospital stays [8].

Carleton University is currently involved in a joint Ontario-based project entitled Technology Assisted Friendly Environment for the Third Age (TAFETA). The co-lead in this project is the SCO Health Service, one of Canada's largest providers of continuing care for the older adult, rehabilitation, palliative care, and primary care. The project's other members include other healthcare institutions, schools, and industry partners in Ontario, Canada. Its primary mission is to identify and develop technology that will provide a safe living environment and be responsive to the health needs of the elderly [9].

The objective of this paper is to introduce TAFETA's current smart home research. It describes the various sensing technologies presently under investigation in the group's 'Independent Living Apartment' laboratory, shown in Fig 1. Approximately 50 patients have used the apartment facilities to date,

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however formal patient data collection has not yet begun. The paper intends to investigate the benefits and limitations of the sensors under consideration and to describe the integration of these technologies into a health monitoring system for the elderly.

The paper begins with a description of the different types of sensors in Section 2. The methodology for data acquisition and processing follows in Section 3. In Section 4, an Artificial Intelligence (AI) expert system is introduced, as well as the communication of the system's decisions. Section 5 considers the patient acceptability and implications of the smart home, and Section 6 concludes the work.

Fig. 1. Views of the bedroom, bathroom and kitchen in the TAFETA 'Independent Living Apartment' laboratory, located in the Elisabeth Bruyère Health Centre in Ottawa, Canada.

2. Intelligent Sensors

The smart home concept developed by the TAFETA research team includes various types of intelligent sensors. Several of these have been incorporated into the prototype apartment at the Elisabeth Bruyère Health Centre of the SCO Health Service, such as magnetic switches, motion sensors and pressure sensitive mats. Others are undergoing experimentation in the Digital Signal Processing lab at Carleton University, such as microphone arrays, smart grab bars and an electronic nose. The sensors currently under consideration are described in the subsections that follow.

2.1. Magnetic Switches

Doors throughout the home can be equipped with magnetic switches which output the binary state of 'open' or 'closed'. This is useful in monitoring the entry and exit from the various rooms of the home. The sensors are also useful in determining the interaction with kitchen appliances, such as the oven, refrigerator, or dishwasher.

2.2. Thermistors

Thermistors reading environmental temperature can periodically check each room temperature to assure proper heating and cooling of the living space. When placed on appliances, thermistors can provide information regarding stove or oven status, as well as faucet water temperature. Adding thermistors to the bed could also provide the patient's body temperature. An increase in this reading could indicate a fever, whereas a decrease could signal a lack of circulation throughout body extremities.

2.3. Accelerometers

By placing accelerometers in the chairs, couches and flooring throughout the apartment, high impacts could be detected. Impacts with the sitting furniture could represent a lack of muscular strength or control over time. Impacts with the floor, however, could represent the occupant losing their balance and falling, which may require immediate attention.

2.4. Radio Frequency Identification (RFID)

A common problem of patients with early stages of Alzheimer's or dementia is forgetting where they have placed commonly used objects. This can have less serious effects, such as the misplacement of television remote controls, or more serious consequences, such as the misplacement of medication bottles. RFID tags can be placed on commonly misplaced objects to allow their retrieval should they be lost in the home.

2.5. Infrared Motion Sensors

In order to track the presence and motion of the resident throughout the apartment, infrared motion sensors can be installed in each room. An extensive stay in one room may indicate a problem with the resident's mobility. Illogical wandering or sporadic changes in the direction of motion may indicate signs of mental anxiety or confusion.

2.6. Microphone Arrays

Microphone arrays have been used in a variety of sensing and multimedia applications [10]. In the smart home, they can transmit the sounds within the residence to a monitoring station. This is useful for both the detection of abnormal noises or calls for help, as well as a form of communication with the occupant.

2.7. Smart Grab Bars

There are several uses for grab bars in the home. The most evident may be in the bathroom. Grab bars are often used as an aid for the entry and exit from the shower and bathtub, as well as transfers on and off the toilet. Grab bars equipped with pressure sensors can monitor changes in force applied over time, which could signify either improvements or deteriorations in strength and balance.

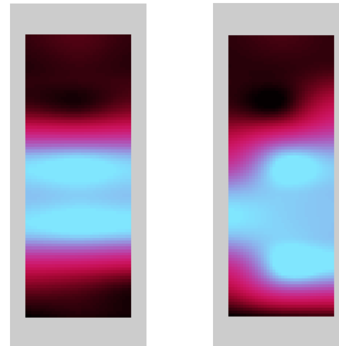
2.8. Pressure Sensitive Mats

Pressure sensor arrays such as the Tactex Controls Inc. Bed Occupancy Sensor (BOS™) can be installed under the bed mattress to monitor the patient's condition at rest. The BOS consists of an array of 8 x 3 sensors, which produces readings of the pressure exerted on each of the 24 taxels. This output can be viewed in the form of a visual image, which shows the patient's presence and posture while lying down [11], or the pressure exerted by the hands and torso when getting in and out of bed. Fig 2 displays an example of the shifts in pressure exerted on the BOS as a patient pushes downward with their hands to aid in exiting their bed. Changes in bed entry and exit patterns can signify changes in the physiological condition of the occupant. Their recognition could lead to the prevention of falls and hip fractures, a common occurrence amongst the elderly [12].

The output can also be viewed in the form of 24 separate time-signals, which allow the extraction of various additional parameters such as respiratory rates, restlessness and movement [13], [14]. Similarly, the arrays can be placed on chairs throughout the home to monitor presence and sitting posture, or incorporated into the flooring to monitor motion and gait analysis [15].

2.9. Electronic Noses

Electronic noses have various benefits throughout the smart home. The Cyranose 320 e-nose system, from Smith Detection, can be used to acquire the smell in different parts of the home and determine its classification [16]. Once it is trained to recognize normal smells, it could then detect unusual odors related to forgotten garbage, burning food, expired refrigerator contents, or to the occupant's personal hygiene.



(a) (b)

Fig. 2. BOS pressure images of subject during 2 stages of bed exit. (a) thighs are exerting uniform pressure while in sitting position (b) pressure shifts to torso and hands.

3. Data Acquisition and Processing

Suitable data acquisition parameters such as sampling rates and amplification levels will be individually determined for all sensors throughout the prototype apartment. The data from each sensor will then be collected on a continual basis to allow both real-time notifications and pattern recognition over time. The test subjects will be patients at the Elisabeth Bruyère Health Centre, who are deemed capable of living independently in the smart home environment.

Before being input into the decision-making system, the sensor outputs will undergo various preprocessing steps. They will first be converted into data formats which are readable by the processing software. The formatted data will then go through a procedure of normalization, segmentation, signal enhancement, and data fusion. The parameters of interest for each sensor will then be extracted and stored for use in the expert system.

The signals acquired from the intelligent sensors, as well as the data processing involved, will be distributed across two sites: the processing unit within the home and an externally located central monitoring facility. It will therefore be necessary to investigate data storage needs, transmission bandwidth, and the reliability of this distribution.

4. AI Expert System and Communication

One of the major components of the smart home project is the development of an AI expert system. This system will correlate information from all of the sensors throughout the home and make decisions regarding the resident's status and physiological condition.

Older adults with mobility issues and slight memory problems are at high risk of falls during the night, especially as they make trips from the bedroom to the bathroom. In the prototype lab, the research team is experimenting with two commercial systems that integrate a small number of sensors to this effect: the Pathways Lited Pathway™ and the Austco DCS-2000 Dementia Care System. The Lited Pathway consists of a light strip placed along the door frame between the two rooms. The light strip is activated by a motion sensor in the bedroom as the resident gets up during the night and approaches the bathroom. When the resident returns to bed, the system waits for a predetermined amount of time before turning itself off. The Austco system combines a bed exit sensor, a door reed switch and passive infrared sensors to monitor the resident's behavior around the bedroom. It compares the actions of the resident to one of 16 predefined behavior profiles and reports any detected variations. It also provides intelligent light cuing to assist the resident to the bathroom or back to their bed.

In the current project, the work of the above two commercial systems is extended to integrate various sensors from different parts of the home to create a more comprehensive analysis of the resident's status. The AI expert system extends the monitoring capabilities to consider various options as to the person's behavior after exiting the bed and provides corresponding alerts or alarms.

4.1 AI Expert System

The expert system will implement adaptive architectures to allow the modeling of daily behavior as well as the response to changes observed over time. If, for example, the system learns that during the night the occupant usually exits their bed between 2 am and 4 am for approximately 10 to 20 minutes, the system can provide alerts as to bed exits at times outside this interval or exits of unusually long durations. The information provided by the various sensors introduced in Section II can then be fused together to make an analysis of the situation. Should the person not return to bed within the expected time, the motion sensors located throughout the home can provide information as to the person's trajectory since their exit from the bed. The magnetic switches on the refrigerator door along with the thermistors and electronic nose in the kitchen can detect that the patient is simply preparing food. Alternatively, if the person sat on their living room couch and fell asleep, the pressure sensitive mats located under the cushions could verify this action. Potential falls while getting up from the toilet could also be detected by the smart grab bars and falls while walking could be detected by the accelerometers embedded in the furniture and flooring. Finally, any expressions of pain or cries for help by the patient could be monitored by the microphone arrays located throughout the home.

Different pattern recognition and classification algorithms will be explored, such as decision trees, Bayesian classifiers and neural networks. The expert system will detect pattern abnormalities in real time, reported through a 4-tier alarm system as follows:

Tier 1) Mild Abnormality: This may be a small difference in daily patterns, such as an unusually high number of bed exits throughout the night or the omission of a daily shower. While this abnormality will be reported to a caregiver, human intervention remains optional with Tier 1 alarms.

Tier 2) Caution: The caution alarm is slightly more serious than Tier 1, like a refrigerator door left open or a water faucet left running for an extended period of time. Tier 2 alarms would usually recommend human intervention, either as a call or visit by a caregiver or family member.

Tier 3) High Alert: When two or more parameters extracted from the sensors are shown to be a cause for caution, the high alert alarm will be activated. This indicates that the occupant is in danger of harm and should be watched more closely. An example of this may be the combination of an abnormal movement in bed, followed by an abnormal bed exit and subsequently abnormal gait as the patient attempts to walk. This alarm level will always recommend a visit by a caregiver or family member.

Tier 4) Emergency: The fourth tier is the most severe of the four, with a direct line to emergency services. This could be the detection of a hard fall, a burning scent, or a stop of respiration during sleep.

4.2 Communication

There will be two levels of communication at the output of the AI expert system:

1) Online Database: An internet-based database containing real-time patient statistics will be created such that it can be accessed by doctors, specialists, caregivers and the next of kin. The displays will be visual and audio displays controlled by the privacy level assigned to the user. The doctors will have full access to all medical data and sensor outputs, while the next of kin will be given only information regarding the general state of the occupant.

2) Automated Alarms: These will be transmitted through e-mails, cell phones, pagers, or 911 calls, depending on the severity of the detected abnormalities. For Tier 1 and 2 alarms, the communication will only reach the immediate caregivers. The next of kin will be added to the communication of Tier 3 alarms, provided they have requested this in advance. In the case of a Tier 4 emergency, paramedic services, all members of the occupant's medical team, and the next of kin will receive immediate notification.

An overall view of the framework for the entire health monitoring system is shown in Fig 3.

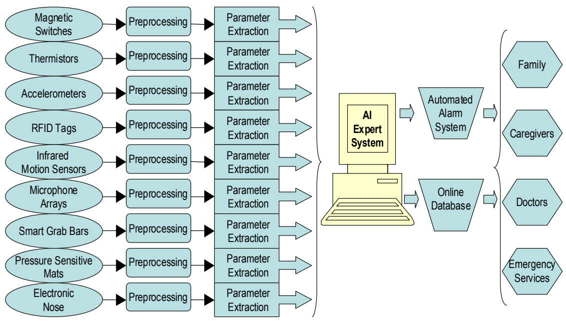


Fig. 3. Health Monitoring and Communication Framework.

The notification system will require the communication between several partners: the smart home processing unit, the central monitoring facility, the caregivers, the medical specialists, emergency services, and the next of kin. In view of this, the use of wireless technology will be investigated, along with the power requirements, data compression, and storage capabilities at each location. Issues of privacy and encryption will remain of prime importance throughout the consideration of all options.

5. Patient Acceptability and Implications

5.1 Advantages

Once the smart home technology and its support system are fully established, the elderly person who wishes to stay in their own home rather than in a healthcare institution may be able to live a more independent life. The automated decision and notification system could especially benefit those who require 24-hour supervision. They would no longer require additional people living in their home or intruding on their sense of privacy. This can have both physical and emotional benefits to the older adult, as they may feel more autonomous and self-sufficient. A recent study of 176 older adults living in community housing in the UK suggested that the majority of participants, whose average age was 76, would accept a system that monitored their falls at home [17].

The unobtrusive nature of the TAFETA apartment attempts to provide a reasonably natural standard of living. This may result in a calmer environment for the senior person to live in, which in turn may increase the accuracy of the parameters extracted by the monitoring system. It also may provide smoother transitions from lower to higher levels of monitoring, as the addition of supplementary equipment may go largely unnoticed by the occupant. In addition, this unobtrusive form of monitoring is intended to minimize the intimidation and fear often caused by being surrounded by complex equipment in the home.

With automated alarms in place for the detection of falls or abnormal behavior patterns, the quality of medical attention for the occupant of the smart home may increase. The patient's burden of asking for assistance is reduced, which is essential in the common case where the patient is incapacitated. Also, subtle changes over time, which may have previously been overlooked, become more detectable with this emerging technology. This may lead to the treatment or prevention of more serious illnesses.

The care of aging seniors can often be a significant financial burden on their families. This method of in-home care may provide a much more economic alternative by avoiding institution fees and constant human supervision. The decision of implementing automated medical supervision may also be less taxing mentally, knowing that their family member will remain in their own home rather than being sent away to unfamiliar surroundings.

5.2 Challenges

The thought of suddenly having their daily lives monitored through any means may be considered intrusive by the senior and thus met with much controversy and objection. These feelings may be compounded by the fact that unlike today's generation, those currently in the third age were not raised in a world of highly technical surroundings and therefore may be very uneasy relying on them for their well-being. It is consequently likely that some elderly people may choose to confront or reject the addition of this new technology in their homes. In the UK study mentioned earlier [17], 21% of older adults who had fallen in the last 12 months unexpectedly rejected a device to detect falls. It was also reported that monitoring with video cameras was less acceptable than monitoring without.

It is possible that after an extended time period of living in a smart home, the occupant may become very comfortable in their living environment and develop a false sense of security. As previously mentioned, the smart home can provide notification of a burning stove, open refrigerator, or a hard fall, subsequently providing the appropriate assistance. This may mislead the senior into believing that they in fact are successfully living on their own and decide they no longer require the monitoring devices, requesting to have them removed from their home. This dangerous effect may become compounded if the resident in fact has become completely dependent on the automated reminders and can no longer perform simple tasks without their assistance.

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6. Conclusions

This paper has provided an overview of the current smart home technology being developed by the TAFETA research group. It has described the sensors which are being integrated to form a health monitoring system and the resulting 4-tier alarm system which communicates any abnormalities found. It has also provided some insight into potential positive and negative reactions of the elderly occupants and their implications. Future work will look into the details of the different sensors, their outputs, the specific parameters of interest extracted from each, and their role in the expert system's pattern recognition and classification system.

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