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Delivering home healthcare through a Cloud-based Smart Home Environment (CoSHE)

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HIGHLIGHTS

- Presents a Cloud Based Smart Home Environment (CoSHE) for home healthcare services.
- CoSHE includes a smart home, a wearable unit, a private cloud, and a robot assistant.
- CoSHE provides human's contextual information and monitors the vital signs.
- A case study of body hydration monitoring with help from the robot assistant.

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ABSTRACT

The dramatic increase of senior population worldwide is challenging the existing healthcare and support systems. Recently, smart home environments are utilized for ubiquitous health monitoring, allowing patients to stay at the comfort of their homes. In this paper we presented a Cloud-Based Smart Home Environment (CoSHE) for home healthcare. CoSHE collects physiological, motion and audio signals through non-invasive wearable sensors and provides contextual information in terms of the resident's daily activity and location in the home. This enables healthcare professionals to study daily activities, behavioral changes and monitor rehabilitation and recovery processes. A smart home environment is set up with environmental sensors to provide contextual information. The sensor data are processed in a smart home gateway and sent to a private cloud, which provides real time data access for remote caregivers. Our case study shows that we can successfully integrate contextual information to health data and this comprehensive information can help better understand caretaker's health status.

1. Introduction

According to a world report on aging and health released in 2015 [1], the elderly population is rapidly increasing worldwide, and most people can expect to live more than 60 years for the first time. However, human functionalities are more likely to be impaired at an older age, which can lead to various diseases such as heart problems, stroke, respiratory disorders, and dementia. Surveys conducted in the United States [2] and Europe [3] showed that patients or older adults tend to prefer living in their own home with home-based care services rather than being hospitalized. As a result, building a smart home environment that can deliver medical services has recently become a main research focus. As indicated in the National Health Expenditure Projections 2012–2022 [4], the total expenditures for home healthcare are expected to increase from US$99.5B in 2016 to US$144.9B in 2021.

A smart home environment provides ample contextual data related to a resident's health, which allows more accurate health monitoring than only using physiological signals. It is clear that the context of residents, such as what they do, or where they are in the home, can provide important information for health assessment. For example, the time spent in sedentary behaviors, such as sitting or lying, may be an indicator of cardiovascular disease [5]. Another application can be for patients recovering from a stroke where monitoring of re-learning everyday living skills such as eating, using the bathroom, and dressing can facilitate evaluation of rehabilitation and accelerating the recovery process [6].

In this paper, we presented a Cloud-Based Smart Home Environment (CoSHE) that enables accurate health monitoring by providing both the resident's physiological signals and the associated behavior/location context. The paper is organized as follows: Section 2 gives a review of recent smart home healthcare projects. Section 3 presents an overview of our CoSHE architecture. Section 4 describes the context recognition algorithms. Section 5 presents a case study on body hydration monitoring and robotic assistance. Section 6 gives the conclusion and future work.

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2. Literature review

Advances in the development of telehealth and portable hospital-grade technologies allow healthcare providers to deliver in-home medical services that were previously available only in hospitals [7]. According to Grönvall et al. [8], older adults with severe heart conditions can conduct self heart diagnosis by measuring their weight, blood pressure, pulse, and cardiac activity and report to the hospital through online questionnaires. Hospital nurses will contact patients if something unexpected happens. However, the significant amount of work required from the nurses reduces the system efficiency. The ACCENT (Advanced Component Control Enhancing Network Technologies) Home Care System [9] is another system for telehealth and telecare. Even though this system has been originally designed for general applicability, its idea and architecture cover most of the essential components needed for telecare services in home environments. This system was developed with the following issues in mind: management, conflicts, policies, and interface of home care. The recent technical innovations have led to the development of smart sensors, cloud computing, and big data analysis, which have been applied to home healthcare. Real-time tele-monitoring of diverse bio-signals and video consultations are two main growing approaches for home-based care, both in research and commercial systems [10]. The existing smart home projects often combine environmental and wearable sensors. For example, environmental sensors may include PIR (Passive Infrared Sensor), RFID (Radio Frequency Identification), ultrasonic, camera, microphone, or pressure sensors. Wearable sensors are often used in smart healthcare applications for measuring body temperature, respiration, cardiac activity (ECG — Electrocardiogram), blood oxygen saturation (SpO2), perspiration (GSR — Galvanic Skin Response), muscle activity (EMG — Electromyogram), brain activity (EEG — Electroencephalogram) and motion (accelerometer and gyroscope).

Numerous smart home research projects have been conducted in the US, Europe and Japan with many of them focusing on different approaches to providing healthcare [11–17]. The Aging In Place project at the University of Missouri started in 2000, and it has been constantly developed with the main goal of meeting the desire of older adults to remain independent in their own home [11]. An integrated sensor network is installed to monitor health and enhance safety of older adults. Additionally, functionalities are added to supplement registered nurses by giving an alert when abnormal changes in the health signals of an older adult are detected [18]. Smart Medical Home is another project conducted by University of Rochester, which is set up in a five-room house equipped with environmental sensors, bio-sensors, and a video camera system. It is designed to maintain health, diagnose and treat disease. Other projects such as the Aware Home at Georgia Institute of Technology [12], the Gator Tech Smart House at University of Florida [13] and the CASAS at Washington State University [14] are all aimed at designing a smart home-based health monitoring platform. These kinds of projects are often equipped with typical devices such as a motion tracking system, an ultrasonic location tracking system, a smart floor, and a smart bed, along with a software system providing artificial intelligence to assist the elderly. They can track the location, recognize the activities of the resident, assist those with cognitive difficulties, or help with diabetes management. There are many other smart home projects including the CareLab in Germany, ProSafe in France, ENABLE in Netherlands, CareNet in UK and Ubiquitous Home in Japan [15]. Recently a project called VictoryaHome was funded by the European Ambient Assisted Living Joint Program [16] which is focused on assisting older adults and care givers in their homes. This system can help older adults live more independently by providing services including monitoring health, safety and facilitating social contact. The system can serve as a medication reminder, check activity, and detect falls by using a wearable smart belt-clip. Other functions such as virtual visit are achieved using a robot named Giraff [17]. This enables older adults and their remote care givers or relatives to make video calls, and the care givers can remotely control the robot to move around and check the older adult through the robot's camera. The VictoryaHome Cloud was established to facilitate telecommunication and data transmission for all the previously mentioned functions. However, no environmental and medical sensors are used in the VictoryaHome, and as a result it cannot monitor real-time health status and context information.

The above review of existing systems, which is summarized in Table 1, shows that many of them can only provide a limited amount of information regarding the resident's health condition. Some of them lack the ability to provide health monitoring or healthcare delivery. Some projects do not equip either physiological or home sensors. Essentially, complete information is critical to accurately assessing the patient's health condition. This can be achieved by developing a comprehensive system which integrates wearable physiological sensors to collect bio-signals, a smart home environment with unobstrusive environmental sensors to understand the person's daily activities and a cloud platform to aggregate the data and provide analytics. CoSHE is built as a comprehensive system which supports all of the above mentioned functions and further provides a platform for health monitoring, early detection and prevention of different health problems. With a robot assistant integrated, CoSHE also opens an opportunity for healthcare delivery via interaction between the robot and the human.

3. System architecture

The proposed CoSHE consists of four major components: a smart home setup, a wearable unit, a private cloud infrastructure, and a home service robot. Environmental sensors are used for collecting motion and activity information of the human subject. The wearable unit is used to collect physiological and body activity information through non-invasive, wearable sensors. Data from the environmental sensors and wearable sensors are processed by a home gateway where pre-processing, indoor localization and activity recognition algorithms are implemented. The comprehensive physiological data with contextual information are then sent to the private cloud for storing and both local and remote access purposes. The home service robot is able to access the information from the cloud to get understanding of the human context, and thus it can interact properly with the human. The following subsections detail the four major components of our system architecture as shown in Fig. 1.

3.1. Smart Home

The Smart Home environment consists of a 4.87 m by 6.7 m mock apartment testbed equipped with environmental sensors, a human subject with mobile devices such as smartphone and a home gateway. The floor plan and overview of the smart home testbed are shown in Fig. 2. The environmental sensors include a network of Passive Infrared (PIR) sensors and Grid-EYE thermopile array sensors. These sensors are distributed on the ceiling of the mock apartment in a regular pattern and the data are transmitted to the home gateway through the ZigBee protocol. Our experimental setup uses the OptiTrack Camera system as shown in Fig. 2 to evaluate our context recognition and classification algorithms. The smart home setup, sensor placement, sensor calibration, and operation can be found in [19].