A Context-Aware Healthcare Architecture for the Elderly

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Abstract. In order to provide dependable healthcare services for the elderly, it is necessary to have a patient-centric system in which service automation dominates through the use of context-awareness. Healthcare service automation has the virtues to overcome the disadvantages arising from the disabilities that are inherent in the elderly population, physically challenged, and those who live in remote areas. In order that patients trust the healthcare services provided by the system, the creation of healthcare services must be founded on accurate model of patients, and must be delivered by experts through dependable medical devices and secure channels. Motivated by this goal, we propose a healthcare architecture based on a generic Context Awareness Framework (CAF) adapted to the elderly. The automation aspects of healthcare services based on this architecture are discussed.

Keywords: Health care · Elderly population profiles · Context awareness · Healthcare model · Healthcare determinants

1 Introduction

A survey in US [1] has revealed that most US citizens believe that old age actually starts at age 68, with some of them pegging it at as high as 74. In 2012, the population of the elderly made up 11 % of the world's population and was projected to reach 22 % by 2050, with 68 % of the world's population over 80 living in Asia and Latin America and the Caribbean [2]. At the moment, one in six Europeans can be regarded as elderly [3]. It is estimated that by 2020, China will have 230 million elderly people, thereby making it the largest population of elderly worldwide, while India will come next with about 158 million old people [4]. This study also asserts that by the year 2030, the number of people aged 18 across the world will be lower than the ones over age 65, with the number of those aged 85 and above being 8.5 million [5]. From these reports it is evident that the proportion of care givers to the elderly will be decreasing, while the cost of giving care for the elderly will be increasing. An effective solution to this problem is 'healthcare service automation', which can provide services whenever and wherever they are demanded. It can maximize the health

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service utilization and minimize service cost. In this paper, we have focused on creating a context-aware architecture for implementing healthcare system from bottom up.

We have chosen to focus on the elderly due to the numerous vulnerabilities and healthcare needs they face, especially personal care in daily living which could range from taking care of personal hygiene to feeding themselves. When an elderly person's nutritional requirements are not met, it could result in malnutrition and degrading health conditions [6]. A health condition that can result out of poor nutrition is diabetes which has been found to lead to higher rates of premature death. Stroke is a common illness that can coexist with diabetes [7]. Since sedentary lifestyle, social isolation, loneliness, or depression can lead to malnourishment, and depression medications can also change how nutrients are absorbed or how food tastes, caring the dietary needs of elderly is paramount. For the chronically ill elderly, for example those suffering from arthritis [8] who also have a recurring episode of osteoarthritis [8], care needs to be given in multiple dimensions. It has been reported that about 20 % of those who are 55 years and older experience mental disorders such as anxiety disorders, severe cognitive impairment and mood disorders which are not part of normal aging [9]. Mental illness is very difficult to address as many seniors are either unwilling or unable to report their situations. Most elderly people lack knowledge about the causes or symptoms behind their health problems and assume their health problems are simply due to their aging [10]. A survey [4] has revealed that 96.0 % of the elderly have never utilized any of the geriatric welfare services because of lack of awareness. Elderly also go through physical, psychological and financial vulnerabilities [11], become dependent on others which exposes them to societal dangers [12] such physical and psychological assaults, and financial exploitation [13]. The different vulnerable situations and the health conditions discussed above can be related to specific contexts thereby creating a need for context-aware solutions.

1.1 Context Awareness

Context is very important to our day-to-day living. It is how we interpret and interact with the environment. For example, we use context to sense and react to cases of impending danger. However, this innate ability does not automatically translate when we interact with computer systems. While it is easy for a health provider to interpret the current health condition of a patient, a computer system needs to be modeled in such a way that it makes use of certain tag values in making relevant and accurate decisions.

Context can be defined as any information that can be used to characterize the situation of an event [14]. A situation occurs when multiple entities around an event are assigned values. In ubiquitous computing context is regarded as any circumstance or condition surrounding a user that is considered relevant to the interaction between the user and the ubiquitous computing environment [15]. Therefore, a context-aware healthcare architecture intends to make use of the situations around a patient to make better decisions with the overall goal of improving the patient's health conditions.

A context-aware healthcare system makes use of sensors to perceive context and actuators to realize its decisions. Sensors are entities that provide measurable responses to changes in a system's environment. Example include hardware devices such as GPS Sensor [16]. Actuators usually work by subscribing to events and getting instructions included in the event [17]. For example, an *Emergency Service* can request to be notified when an elderly patient requires such services.

The paper is organized as follows: We briefly survey the current technology-based solutions in Sect. 2. We provide a brief introduction to context awareness concepts in Sect. 1.1. Following that we present the entity model of our proposed healthcare architecture in Sect. 3. In Sect. 4, the healthcare architecture is discussed. We conclude the paper in Sect. 5 with remarks on our ongoing work in a prototype implementation and testing of the healthcare architecture.

2 Related Systems

We first review a few existing context-aware healthcare architectures for the elderly. Next we comment on their inadequacies in meeting the daily care and protection of the elderly.

University of Rochester, Georgia Tech, Massachusetts Institute of Technology (MIT) and TIAX, LLC all have smart living projects where they combine context-aware and ubiquitous sensing, computer vision-based monitoring and acoustic tracking through the use of infrared sensors and video cameras in laboratories in order to monitor health information for long periods of time [18]. Another wearable sensor-based mobile healthcare system that reads context-based information such as motion and location of an elderly is *CarePredict* [19]. *CarePredict* transmits data through wireless communication service to remote servers from where experts can examine the information in order to detect any acute deviation, such as restless sleep patterns and changes in eating patterns of the elderly which can then be isolated and investigated further. In addition, *Codeblue* developed by University of Harvard is a healthcare system heavily reliant on context awareness [20]. *Guardian Angel Service*, developed for the Symbian OS platforms, provides active context-aware monitoring for medical stakeholders about elderly facing chronic conditions [21]. It uses context-aware sensors to read vital signs like heart rate and skin temperature in order to help the patient avoid hazardous health conditions. *CareMerge* is an enterprise mobile healthcare system that helps provide real time information about the health of the elderly to their healthcare providers and family [22]. It offers communication with and notification to family members, tracking and sharing of health information and automatic reminders. *Virtual Health Pet* system, developed in Brazil with Java Micro Edition (J2ME) technology, sends out alarm to remind the elderly on medication, as well as alerting emergency services. *GetMyRx* system attempts to simplify the administrative task behind the elderly people in getting their prescriptions [23]. It involves scanning and sending of paper prescriptions with name and address of the patient to a local pharmacy for delivery.

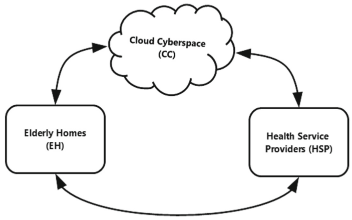

Fig. 1. Entity model

Doctors are also able to send prescriptions directly to pharmacies from the comfort of their offices. *Chinese Aged Diabetic Assistant*, developed by Microsoft in China, is a smart-phone-based support system for elderly diabetics patients that provides recommendations and guidelines for patients in taking insulin and oral medications. *Mobile HIV/AIDS Support* assists healthcare workers in rendering quality services in the developing world by providing reliable medical information for use while the health staff are in the field. *EpiSurveyor* is an easy to use open source software developed by Washington-based non-profit software company *DataDyne* that helps in the creation and sharing of surveys for development of policies by healthcare authorities.

From the above review above it is clear that the current systems are more advantageous to the medical staff than to patients. Most elderly patients lack skills to interact with many current mobile healthcare systems, because the systems do not provide easy to use interfaces. In spite of some of the advantages they offer to patients, an elderly patient may have to use more than one system depending upon her medical situation. Moreover, collectively they do not adequately address the daily health needs and the vulnerabilities of the elderly.

3 Entity Model

In this section, we present the entity model of our healthcare architecture. Below is an informal explanation of the entities shown in Fig. 1.

- *Elderly Home (EH)*: The entity *Elderly Home* represents a smart physical accommodation for elderly people where they are managed and monitored by primary caregivers through the use of sensors. An elderly can be under multiple care givers in a particular elderly home, since a caregiver might just be responsible for a particular type of health condition and an elderly can have multiple health conditions. Electronic communication in the Elderly Home is often done through a mobile terminal which is simply a mobile device such as a phone or personal display assistant that has an application running on its operating system acting as a hub to record the data coming in from all the sensors and actuators. It usually stores temporary information in a local database and then sends data to the Cloud Cyberspace through network technologies, such as 3G and WLAN over Hypertext Transfer Protocol (HTTP).

- *Cloud Cyberspace (CC)*: The *Cloud Cyberspace* represents the server where all incoming medical information from the elderly home will be received, stored, and made available to healthcare service providers. It is usually installed at the hospital or a wireless service provider when the system is expected to share patient's personal health information with multiple clients. It runs a web server such as Apache and IIS which is used for processing and persisting data usually in a database like MySQL or SQL Server. The Cloud Cyberspace (CC) also analyzes medical information for predefined states and executes the corresponding response as stated by the healthcare providers. For example, a doctor might specify to alert emergencies services through email when the blood pressure of an elderly has remained above a safe level for some period of time.
- *Service Providers (SP)*: *Service Providers* represents the generic actuators in the system that provide healthcare services to patients. A variety of actuator types may exist in the system. Actuators receive instructions from the *Cloud Cyberspace (CC)* and then execute them. A good example is "a pharmacist actuator" acting on a drug delivery request. Entities like government health agencies, health insurance companies, and medical research groups that are not directly involved in the treatment of the patient can make use of the information to provide other services to the patient.

4 Architectural Design

Figure 2 shows the detailed design of our architecture. We specialize it based on the Generic Context Awareness Framework in [16] to a detailed architectural design for elderly healthcare applications with focus on fulfilling the healthcare needs of such patients. The architecture is discussed in details below:

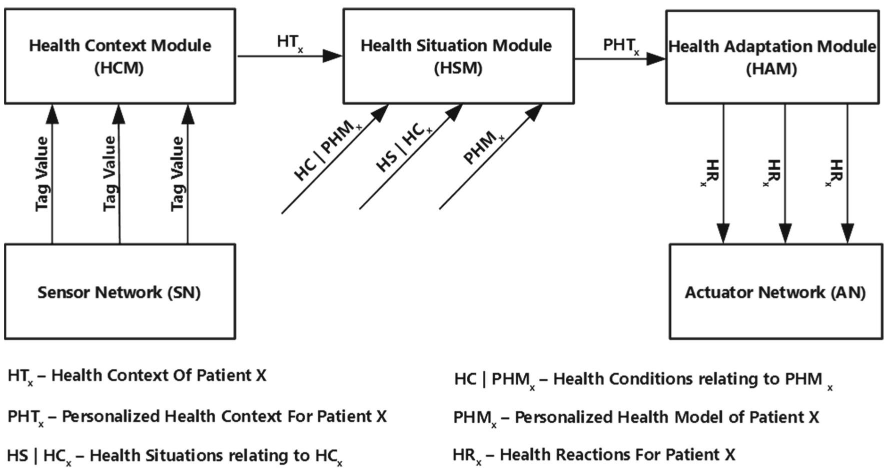

Fig. 2. Detailed architectural design

4.1 Basic Concepts

In this section, we present basic healthcare terminologies that we used in our design.

- *Health Determinants (HD)*: By *Health Determinants*, we refer to factors that affect the health of an individual. These factors can be used to create a personalized health model for that patient, thereby assist in making decisions that will ultimately lead to the improvement of the patient's health status. A patient's health model can further be enhanced by including his desired privacy policies. Examples of *Health Determinants* include biological, environmental and physiological factors. Health determinants can be represented as either atomic or tuples or a collection of atoms and tuples where an atomic representation refers to a tag-value pair with specific data types and units. The values can be monitored initially, at specific intervals or even continuously especially when they are critical to the health of the patient. An example is heart rate.
- *Health Conditions (HC)*: The term *Health Condition* refers to the medical diagnosis of a patient done by healthcare professionals. For example, based on the medical tests, a patient's health condition may be determined as 'depression' or 'dementia'. It is important to note that a patient can have multiple health conditions and can also be at risk of developing additional health conditions that can result from one or more of existing health conditions. We intend to categorize health conditions in terms of the health determinants that can be monitored to assess a patient's health progress over a period of time.
- *Health Context (HT)*: We use the term *Health Context* to denote the continuous monitoring through sensors that is being done for each patient taking into consideration time and other useful information that can be useful in making better decisions. It is important to constantly evaluate a patient's *Health Context* in order to derive the appropriate current *Health Situation* existing for the patient's *Health Condition* and ultimately execute the appropriate adaptations for that patient in an intelligent manner.
- *Health Situations (HS)*: We use *Health Situations* to represent states of interest to the healthcare application in our architecture. Usually, for each health condition, there will be a certain set of health situations that are important for consideration. For example, the *High* health situation is realized when a patient diagnosed with a *diabetic* health condition records a blood sugar level of 10.5 mmol or above. *Health Situations* can have relations between each other. For example, an *Emergency* situation usually follows a *Danger* situation. It is important to note that *Health Situations* are constructed by the medical experts, based on medical knowledge and clinical experience. As such, a health situation is domain-dependent and context-sensitive.
- *Personalized Health Context (PHT)*: We use *Personalized Health Context* to represent the the complete information set that can be used to perform adaptations by the system. This set consists of the current and past relevant *Health*

Contexts, the *Health Conditions* of the patient, the current *Health Situations* for the patient based on the current *Health Contexts* and the personalized health model for that patient.
- *Health Adaptation (HA)*: *Health Adaptation* is the set of predefined execution plans usually provided by healthcare experts for a patient taking account of each health situations that can occur for that patient as well as the patient's context history and personalized health model. Our architecture considers past histories of context to cater for cases where a particular context might need to occur for a number of times before its associated *Health Adaptation* can be triggered. An example of a *Health Adaptation* is sending an email to emergency ambulance services to pick up a dementia patient who is currently experience a health situation indicative that he or she is lost.

4.2 Architecture Modules

In section, we present information about the modules in our architecture.

- *Sensor Network (SN)*: The *Sensor Network* is the combination of sensors with the sole purpose of measuring entity tag values. In the healthcare field, sensors are usually wearable or implanted photoelectric and connected in a star topology through wires and short-range wireless techniques such as IEEE 802.15.1/Bluetooth or IEEE 802.15.4/ZigBee, or a combination of the two [24]. Each sensor acquires data, converts it into an electrical signal and amplifies it for communication with other modules for interpretation. For example, a diabetic patient can require different sensors to measure his or her glucose level and body mass index continuously.
- *Health Context Module (HCM)*: The *Health Context Module* is responsible for the generation and validation of health context based on the aggregated tag values from sensors. For each tag value, there is an expected range of values that can be regarded as valid which is known as the input range for that parameter. For example, the input range of a temperature sensor could be between −30 and 100 degrees Celsius. The *Health Context Module* is responsible for filtering out values outside the input ranges of these sensors. Different sensors in the *Sensor Network* might also be responsible for monitoring the same tag value. An example is the case study of a patient whose location is required to be continuously monitored. The tag value of the location can either be determined using a GPS sensor or any other sensor with Internet Protocol (IP) reporting capabilities. The *Health Context Module* is then responsible for picking the most accurate and relevant value from the numerous available tag values.
- *Health Situation Module (HSM)*: The *Health Situation Module* is responsible for generating *Personalized Health Context* of the patient being monitored. When the health context comes in from the *Health Context Module*, the *Health Situation Module* searches for the personalized health model for a patient with the associated *Health Conditions*. The *Health Situation Module* then uses the health context to fetch the appropriate *Health Situations* corresponding to the

Health Conditions for that patient. This information is then forwarded to the *Health Adaptation Module* as the *Personalized Health Context*.
- *Health Adaptation Module (HAM)*: The *Health Adaptation Module* is responsible for generating the appropriate *Health Adaptations* or *Health Reactions* and picking the right actuators relevant to the chosen reactions. The privacy policies provided by the patient in the healthcare model is also used here to restrict how much information is made available to the actuator. This module is also responsible for logging adaptations as feedback in order to improve the personalized health model for the patient later.
- *Actuator Network (AN)*: The *Actuator Network* is a network of actuators similar to the *Sensor Network*. An actuator is a device to convert an electrical control signal to a physical action, and constitutes the mechanism by which an agent acts upon the physical environment [25]. Actuators could also be software-based [16]. In healthcare, a good example of an actuator is an insulin pump that can receive an instruction to either increase or decrease its rate of flow. In our architecture, most of the actuators are human. For example, caregivers, doctors and pharmacists can use certain devices that are part of the architecture for providing better healthcare services to the patient.

5 Conclusion

This paper has proposed a context-aware architecture that can be used for constructing a smart living system for the elderly. We have established the various population profiles, health needs and vulnerabilities of elderly people in order to establish why we need this architecture, which was specifically adapted for old people. We also surveyed existing health care systems and architectures for elderly people. We developed an entity model for the architecture and discussed a detailed architectural design.

Currently, we are working on developing the set of health determinants, situations and contexts for several health conditions such as dementia and care giving for lonely depressed elderly people. We are investigating data and communication security issues along with patient's privacy concerns that are necessary for mobile healthcare applications. We will integrate security and privacy policies in the architecture that we have developed and implement a prototype of the system.

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