A Design and Analysis Ubiquitous Healthcare Monitoring System over Wireless Sensor Network

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Abstract

Radio Frequency Identification (RFID) and Wireless Sensor Network (WSN) had drawn a lot of attention as methods for realizing a ubiquitous society. RFID and WSN are two important wireless technologies that have a wide variety of applications and provide limitless future potentials. RFID facilitates detection and identification of objects that are not easily detectable or distinguishable by using current sensor technologies. However, it does not provide information about the condition of the objects it detects. Sensors, on the other hand, provide information about the condition of the objects as well as the environment. Hence, integration of these technologies will expand their overall functionality, capacity, and efficient wireless communication substrate for medical devices that addresses ad hoc or fixed network formation, naming and discovery, transmission efficiency of data, data security and authentication, as well as filtration and aggregation of vital sign data need to be study and analyze. This paper proposed an efficient architecture for ubiquitous healthcare monitoring system that possesses the essential elements of ubiquitous healthcare monitoring system architecture to improve the reliability and accuracy of analyzing and diagnosis, it also collects context-aware information on the patient activity integrated with existing medical practices and technologies in real-time tracking and monitoring.

Keywords: RFID, WSN, u-Healthcare, Monitoring System

1. Introduction

In recent years, in almost every country in the world, substantial financial resources have been allocated to the health care sector. Technological development and modern medicine practices are amongst the outstanding factors triggering this shift. Developed countries like South Korea, Japan, and China are currently facing a middle-and older-aged marketplace from a predominantly youth-driven marketplace. This trend is resulting in a greater demand for health care-related services and greater competition among health care providers.

In order to provide more detailed information on our paper, we conducted a research about the population growth of adults who are prone to illness. According to the U.S. Bureau of the Census based on International Data Base (IDB) [1], the number of adults age 65 to 84 is expected to double from 35 million to nearly 70 million by 2025 when the youngest Baby Boo-

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mers retire. One example was based on a recent study that almost one third of U.S. adults, most of whom held full-time jobs, were serving as informal caregivers – mostly to an elderly parent.

Providing patients with convenient health facilities at a low cost has always been a great challenge for health service providers. Moreover, the fast changing life style of the modern world and the problem of aging society pose an urgent need to modernize such facilities. This involves devising cheaper and smarter ways of providing healthcare to sufferers of age-related diseases. In addition, emphasis has to be paid on providing health monitoring in out-of-hospital conditions for elderly people and patients who require regular supervision, particularly in remote areas. Future trends in national healthcare services are expected to include shorter hospital stays and better community care.

Another main concern of our society nowadays is the significant number of elderly patients head to nursing homes. We conducted thorough studies in order to find solutions to this problem and we found out that it is very important to build a remote u-healthcare monitoring system that can continuously, automatically, accurately, and cost effectively monitor patient’s condition such as ECG and vital signs in order to provide a fast and efficient medical analysis and medication.

Our paper offers an efficient architecture for ubiquitous healthcare monitoring system wherein, we integrate RFID and WSN. We based our goals and objectives in the previous related works and studies that focused on u-Healthcare system at the hospital, home, offices, and while the patient is travelling. There are several contributions we proposed in this paper.

We design an efficient architecture for ubiquitous healthcare monitoring system architecture using RFID over WSN. Wherein, the patient is capable to scan his/her medical status by using RFID body sensor and wirelessly transmit at store his/her medical data to local workstation, then transmit it to the central database server. The workstation queries the central database which contains the proper administration for the giving medical prescriptions or medication. In case or emergency with regards to the status of patient, they will be alerted on their wearable device or they can receive messages to their smartphones or healthcare devices. Additionally, the medical staff manning the workstation will also receive an alert message indicating that the patient status needs attention. The medical staff will take an action depending on the alert level status of the patient, whether they send a medical prescription and medication or personally check and apply medication to the patient.

We group various ubiquitous healthcare services depending on its functions and identify the crucial requirements for further enhancement. After thorough studies and analyzing the crucial requirements and related works, we have come up with a conceptual design for ubiquitous medical service management architecture using RFID over wireless sensor network by integrating various ubiquitous healthcare services and system application. Further detailed explanation was illustrated and discussed on proposed architecture section.

2. Related Work

Research about u-Healthcare system which enables us to monitor patients’ status and receive medical services is being conducted. The most significant limitations of wireless networks are the slow data transfer rate and lack of a single connectivity standard that enables devices to communicate with one another and to exchange data.
2.1. Design issues

Other limitations include wireless devices, which are still in their infancy stages. The current medical systems are merely providing medical services when a patient who has already a bad health status visits medical facilities.

However, a u-Healthcare system with sensor network enables patients to receive medical services from caregivers through mobile devices and remote clinic services anytime, anywhere. At the same time, the caregivers can provide medical services to prevent diseases by discovering the symptoms in advance through monitoring the patient continuously before her/his status is worsened. As examples of existing u-healthcare system based on sensor networks, a Location-Based Medicare Service (LBMS) was implemented in Taipei Medical University Hospital which used RFID tags to locate both patients and hospital assets with successful results [2]. The infrastructure of this system can be seen in Figure 1.

![Figure 1: Taipei Medical University Hospital LBMS Infrastructure](image)

Exavera’s eSheperd uses RFID over WLAN to track patients, staff, and supplies, including medication dispensed to patients by the staff [3]. The infrastructure of this system can be seen in Figure 2.
En-Vision America has created a new way to provide prescription information to the user using RFID with their product, ScripTalk, seen in Figure 3 [4]. When a patient using a ScripTalk reader submits a prescription, the pharmacy software prints and programs an auxiliary smart label using a dedicated, small-footprint printer. The smart label, which stores prescription information, is placed onto the prescription container by the pharmacist. In the home, the patient uses a hand-held ScripTalk reader that speaks out the label information using speech synthesis technology.
Unfortunately, the first two of these systems do not put the actual medication intake into the hands of the patient; they all rely on staff dispensing. Additionally they require WLAN access points and an expensive communication infrastructure. While the last system mentioned does put medication administration into the hands of the patient, it is not part of a network and therefore cannot be supervised by staff.

2.2. Challenges in wireless healthcare

In ubiquitous healthcare applications, the most significant limitations of wireless networks are the slow data transfer rate and lack of a single connectivity standard that enables devices to communicate with one another and to exchange data [4]. Security of sensor networks is also one of the major problems in wireless healthcare, in which security of sensor networks is a complicated task, mostly due to the limited resources of sensor units. The first line of defense, i.e. encryption and authentication, is useless if an attacker has entered the system, and it is also vulnerable to side-channel attacks. Thus, a second line of defense, known as Intrusion Detection, must be added in order to detect and eliminate attacks. In the recent past, various solutions for detecting intrusions have been proposed. Most of them are able to detect only a limited number of attacks. Further, the solutions that deploy machine learning techniques exhibit higher level of flexibility and adaptability. Yet, these techniques consume significant power and computational resources [5]. Other limitations include wireless devices, which are still in their infancy stages and therefore slower in speed than desktop computers, high initial costs involved in setting up wireless systems and lack of real-time connectivity due to device mobility.

In order to achieve efficiency gains in the ubiquitous healthcare setting, three major issues in wireless development need to be addressed:

* Appropriate development methodology must be developed to enable proper integration of new solutions with existing wireless solutions.
* Data access, communication and synchronization issues between mobile devices and existing data bases must be resolved.
* Suitable user interfaces must be designed in order to capture and access data accurately and timely.
While many prototypes of healthcare solutions have been found to be successful, they have also suffered from limitations with regard to code, integration with existing applications, user interfaces and data transmission. To allow flexibility, code is often written as generic as possible and parameters are kept as variables. During real-time testing, some of these parameters have caused run time errors, as the compiled code has not been able to resolve certain data types prior to the run. This has created the necessity to re-visit the code and examine every instance of the run in order to fix the problem. Also integration with existing applications has caused concern, as the healthcare industry lacks uniform standards [6].

Different types of healthcare sensors require different sampling rates and reliability requirements. Linear, or waveform-independent, healthcare data, such as body temperature, blood pressure and oxygen content, require a lower sampling rate and lower reliability than waveform-like, that is, waveform dependent data, such as ECG or EKG. Since waveform-like data do not need continuous data transfer, data transfer can be initiated only when desired by the monitoring side or in periods of finite duration. On the other hand, in critical and emergency situations, waveform-like data require long-term data transfer.

Some prominent reasons for energy wastage in wireless networks include retransmission after packet loss by collusion, overhearing, and idle listening and over emitting. In a healthcare application, however, recovery of lost packets through retransmission is not necessary, because health data have to be real time. Any lost packet must be replaced by the most recent update in the next transmission. Retransmission of packets also requires more storage memory at the motes, which is generally limited in size. For most cases, the data field in each packet is between 8 bytes and 40 bytes and the sampling rate is between 100/sec and 360/sec, and the data size is 2 bytes in ECG or EKG measurement in our study. Thus one packet lost means 4 or 20 sampling data lost form ECG or EKG signal [7].

2.3. Contribution of proposed paper

As a result, data-centric approaches are better for waveform-like data most especially in wireless networks, where a query or command from the base-station initiates data transfer. Linear data can use either the data-centric approach or the event-driven approach, where data are transferred when an event is sensed. It is generally observed that linear data change gradually without any periodic sequences. So, sometimes only a change in amplitude is required to detect an abnormal event. Consequently, a threshold limit can be set to limit the amount of data transferred, and data transfer is initiated only if the value of sampled data exceeds the threshold.

In waveform-like data, any packet loss can be a serious problem, as it may lead to loss of useful information or may give a false impression of abnormality. Unlike typical wireless sensor environments, where many sensors are used to sense the same event simultaneously, each sensor in a healthcare application senses a different event. This characteristic has the practical consequence that the query model for a healthcare system can be simpler in design that that for an industrial system.

In order to implement a u-Healthcare system with a sensor network, there are a few issues to be considered. Firstly, correction technique of vital signs error caused by wireless transmission is needed. Secondly, augmenting signal technique of a sensor node having limited transmission signal strength is needed. Thirdly, since it is difficult to analyze a large number of vital signs collected from sensor network with mobile devices having limited processing ability, a technique to solve that problem is required.
This paper presents ubiquitous healthcare system architecture for designing and implementing an efficient ubiquitous healthcare system for continuous monitoring of patients under their natural physiological states or elderly persons with chronic diseases. Especially our proposed system architecture is designed for monitoring of the elderly who live in country side or small rest home without enough support from caregivers or doctors, instead of patient monitoring in big hospital environment. Further insights into the natural cause and progression of diseases are afforded by context-aware sensing, which includes the use of accelerometers to monitor patient activities, or by location-aware indoor tracking based on ultrasonic and RF sensing. Moreover, indoor location tracking provides information about the location of patients in their physical environment and helps the caregiver in the provision of appropriate support.

3. Proposed System Architecture

Wireless healthcare monitoring in a sensor network has different requirements and priorities than environmental, agricultural and industrial monitoring. This section discusses some of the software design issues that must be addressed when implementing query-driven healthcare monitoring, as well as the effects that the varying sampling rates and packet sizes required by different medical sensors have on network performance.

3.1 Ubiquitous System Architecture over WSN

A key requirement for ubiquitous healthcare system is the ability to operate continuously over a long period of time and to periodically update the data on the database for efficient real-time data analysis. Generally speaking, the primary objective of a wireless sensor network is to maximize the node/network lifetime, while performance metrics are secondary objectives. On the other hand, the main aim of a wireless healthcare system should be reliable data transfer with minimum delay [8].

Our proposed system architecture does not require an expensive communication infrastructure, instead it will use several ad-hoc wireless sensor networks integrated with existing medical practices and technologies in real-time, remote monitoring in giving medication, and patient status tracking system assisted by embedded wearable wireless sensors. Patient’s wears RFID chest belt with EKG sensor to allow continuous, real-time monitoring and capturing of multiple physiological signals, including ECG, body temperature, respiration rate, blood pressure and acceleration. After capturing patient’s medical status, it will be transmitted and stored temporarily at the near local workstation using Smartphone, this data will also be transmitted to the central medical database server to store and update the data of patient’s (see figure 4). Medical professionals can check and analyze the medical status of the patient at the hospital by using central medical monitoring system or they can also do it outside the hospital (e.g. at the office, home, while traveling or attending meetings and conferences) through Smartphone/PDA using mobile based medical monitoring system which is connected to Wi-Fi/WiBro.
By referencing the database it will be determined if the status of the patient is good or bad, and to check the status of medication whether it should be taken or not, or it should be change. If the medication should not be taken, for any reason, the patient will be alerted through their mobile or embedded wearable sensor device monitor. Additionally, an alert will appear on the staff supervised central workstation citing the patient, the time of the incorrect application, and what the medication was. The sensors will utilize multi-hop communication so that they can communicate with the workstation even when they are out of transmission range. In addition, the devices can be mobile, such as emergency devices, or fixed, such as temperature sensors, etc. Some of the main characteristics of a networked sensor are: (1) small physical size, (2) low power consumption, (3) limited processing power, (4) short-range communication capability and (5) small storage capacity.

As healthcare applications commonly handle several types of waveform data, the application of wireless sensor network technology to ubiquitous healthcare is rather more demanding than its application to other real-time systems monitoring such factors as temperature, humidity, acoustics, light and pollution [9, 10].

Figure 4. RFID-based u-healthcare monitoring system architecture over WSN
3.2 System flow

Figure 5. System Flowchart

Figure 5 shows the system flow of our propose system architecture. It uses the unique ID transmitted by RFID with EKG sensor as a key to information stored in database. The Smartphone reads the data from RFID chest belt with EKG sensor then, the Smartphone check if the patient has records using u-healthcare monitoring system; if the patient doesn’t have records the system will prompt a message to patient to create patient ID, else if the patient has records the system will update and store patient medical data in local workstation temporarily for local backup purposed, at the same the local workstation send the patient medical records to the central data server which serves as the central repository of all the patients. This central database is located at the hospital wherein the medical professionals can check and analyze the patient’s condition and early symptoms detection. If the patient current condition is not stable, the medical professional who analyzes the medical data of the patient will send an alert message regarding his/her current condition; it also includes the medical advice and medication prescription.

In addition heart diseases can be detected by means of analyzing electrocardiograms (ECG). However, heart rate can be affected by such activities as walking, running and falling, which
makes it very important for continuous health status monitoring to record patient activities along with the ECG data. Fusion signal monitoring combines a health parameter and a physical condition [11] to enhance the accuracy of health or cardiac event monitoring. Thus, ECG and activity data are continuously recorded and simultaneously analyzed in a wireless sensor network environment with a built-in automatic alarm system for giving early alarm signals to the treating physician or other caregivers.

3.3 Applications of the proposed system

Our proposed system can be applied in private and public hospitals, homes, offices, and even while travelling. We designed the system for fast and accurate healthcare service by integrating RFID and WSN technology. Our system consists of five major components: (1) RFID chest belt with EKG sensor for health monitoring, activity monitoring and patient information and location tracking, (2) a Smartphone functioning as a local processing unit or monitoring tool, (3) a local workstation functioning as a local database server for temporary storing patient data’s, specifically in urban areas which are far from the hospitals, (4) a central database server which is the central storage of patient’s medical records, (5) a central medical monitoring system which functions is for the medical professionals to study and analyze patient’s status, and also we have ubiquitous medical monitoring system using Smartphone/PDA for checking and analyzing patient’s status while travelling or out of the hospital. This system has several features and capabilities that are already present in existing u-healthcare systems. However, unlike other systems, our proposed system was developed mainly for elderly persons or patients with chronic diseases living at home and in urban areas. It measures patient activities, while working, exercising, travelling, and even while sleeping. This context information helps to provide further insight into the natural cause and progression of the patient’s condition and enhances the accuracy of early symptoms detection.

3.4 Wearable Healthcare System Architecture

Recent advances in sensor technology allow continuous, real-time ambulatory monitoring of multiple physiological signals, including ECG, body temperature, respiration rate, blood pressure and acceleration [12]. This section presents a wearable wireless node for the ubiquitous monitoring of ECG, activity and SpO2. Capable of obtaining physiological data from a wearable wireless sensor node, the system then transfers the data wirelessly to a base-station connected to a server PC in an ad-hoc network using IEEE 802.15.4 or LR-WPANs.
3.5 Ubiquitous Healthcare Services Management Architecture

We have come up with a conceptual system architecture based on the identified requirements on the ubiquitous healthcare service systems. The architecture tells what components have to been considered in the implementation of a ubiquitous medical service system in terms of data and information processing aspects. As shown in Figure 7, the proposed architecture has been organized with the consideration of ubiquitous medical center which is the central information processing server for ubiquitous servers, user front-end which takes care of collecting healthcare-related data and providing services for the users such as patients, physicians, personal healthcare people, and healthcare experts, external systems which might interact with the ubiquitous medical center, and communication networks covering wired and wireless communication channels.
Figure 7. Ubiquitous Healthcare Service Monitoring Management Architecture

The user based system is implemented in the ubiquitous healthcare service client platform which could be a mobile handheld device, a wired communication terminal, and a sensor node with sufficient resources such as computing power, battery and communication capability. The client platform is expected to have communication interface module, sensor interface module and user interfaces modules. The communication interface module plays the role to provide the client applications with communication channels to the u-Medical center over the wired or wireless networks.

For the friendly and easy-to-use applications, the front-end (user/client) should have user-friendly interface components. The RFID/sensor interface module takes charge of handling various context-aware, wearable sensors and biometric sensors, if they are organized to be used in the service. If a WSN or a BSN is configured around the healthcare beneficiaries, the wired/wireless interface module is responsible for all networking tasks like configuration, routing, discovery, scheduling, and data collection. The WSN and BSN have been actively yet worked, and thus the architecture tells that such well-established sensor interface module should be employed in the healthcare service development. Depending on the types of services (i.e., client services, physician assistant services, personal healthcare services, and data interoperability services), dedicated client applications should be developed.

The ubiquitous medical service management center contains the components for communication interface, workflow monitoring, EMR (electronic medical record) database management, knowledge base management and decision support engine, and the components for client services, physician services, personal healthcare services and data interoperability services. The communication interface takes charge of establishing communication channels with client applications and external services systems over wired and/or wireless networks, enforces the security mechanisms and policies for data security and privacy protection, and provides event notification services via SMS, e-mail, etc. The EMR database component manages the medical and healthcare data collected from the user front-end and provides the interfaces for the services built on the server side. The knowledge base component compiles the expert knowledge for patient care and personal healthcare and provides the decision making module which automatically diagnoses the states of the healthcare beneficiaries and determines the actions to be taken based on the deduced states and the compiled knowledge.

Figure 8. Client Services

The client services are to care about patients in a remote manner and usually to contain the patient follow-up and patient status analysis modules along with the underlying architectural services.
The *physician assistant services* help the physicians and healthcare personnel take care of their patients/clients in effective ways. Therefore, they need client data management and medical/health diagnosis assistance, and medical treatment consultancy modules.

The *personal healthcare services* are used by the individuals to take care of their health and thus they contain the modules for healthcare schedule management and decision support and analysis.

The *data interoperability services* are implemented with the components for data import and export, data analysis, and data synchronization. In the architecture, a patient or a client
sends his/her medical or health-related data from the user based service to ubiquitous medical service management center (i.e., either client services or personal healthcare services), client’s status is automatically determined by the service and he/she is informed of it.

On the other hand, when client’s status needs a serious attention, his/her physician or healthcare personnel should be informed automatically. Sometimes, some back-end service like an emergency center should be informed in the case of emergency without failure. When client’s healthcare personnel are notified for serious attention to the patient or client, the personnel should be able to check her record at the moment in a ubiquitous way. These workflows should be run without failure and delay, therefore the architecture has to be equipped with the workflow monitoring component for critical mission follow-up and log management.

For the service effectiveness and efficiency, the ubiquitous healthcare service systems need to exchange their own data with external systems with the shared standard protocols like HL7 (Health Level Seven), DICOM (Digital Imaging and Communications in Medicine, MFER (Medical waveform Format Encoding Rules), and ISO/IEEE 1073 (Medical/ Health Device Communication Standards).

4. Conclusion

The emerging field of radio frequency identification and wireless sensor networks combines sensing, computation, and communication into a single tiny device. The power of wireless sensor networks lies in their ability to deploy large numbers of tiny nodes that assemble and configure themselves. One of the major challenges in wireless sensor network applications is remote continuous monitoring of patients or elderly persons staying at home or in hospital even though our system was developed in small size wireless sensor network environment for the elderly or patients with chronic disease who live with a few number of persons without caregivers or doctor’s attention in house or small nursing home. Because healthcare applications typically deal with several types of waveform data, the use of wireless sensor network technology to u-healthcare is much more demanding than the use of WSNs for other real-time monitoring tasks.

The proposed architecture we designed is to present new capabilities for both remote and real-time monitoring of patients. We have identified important characteristics required in ubiquitous medical service management systems in order to get some clues for ubiquitous healthcare service system architecture design. We identified the required components of a robust u-healthcare monitoring system and discussed the system components according to the categories of services such as, client services, physicians’ services, personal healthcare services, and data interoperability services. It tells which service modules are required for service infrastructure establishment, and which task-specific service modules are useful for each category of services. This proposed service management architecture possesses the essential elements of each future medical application that are integrated with existing medical practices and technologies in real-time, remote monitoring, in giving medication, and patient status tracking system assisted by embedded wearable wireless sensors which are integrated in wireless sensor network.
References


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