Application of Wireless Sensor Networks in Health Care System

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Abstract

Recent, advances in wireless networks and electronics have led to the emergence of Wireless Sensor networks (WSNs). WSNs have been considered as one of the most important technologies that can change the future[16]. These networks consist of small battery–powered motes with limited computation and radio communication capabilities. Each sensor in a sensor network consists of three subsystems: the sensor subsystem which senses the environment, the processing subsystem which performs local computations on the sensed data, and the communication subsystem which is responsible for message exchanges with neighboring sensors. WSNs comprise tiny wireless computers that sense, process, and communicate environmental stimuli, including temperature, light, and vibration.

WSNs have been under rapid development and has become essential in such domains as industrial operations (factory, production, supply chains), health care (home monitoring, biomedical, food safety), environmental (agriculture, habitat preservation), infrastructure (energy, traffic and transportation, flood gauges, bridge stress, power grids, water distribution), and military, as well as for research and development.

Advances in wireless sensor networking have opened up new opportunities in healthcare systems. Sensor-based technology has invaded medical devices to replace thousands of wires connected to these devices found in hospitals. This technology has the capability of providing reliability in addition to enhanced mobility. In the future, we will see the integration of a vast array of wireless networks into existing specialized medical technology.

This paper will investigate the application of current state-of-the-art of wireless sensor networks in health care systems and will address how WSN concepts are integrated in our computer engineering program.

Introduction

Globally, the elderly population is growing and the general population is aging. Life expectancy continues to increase with new advancements in health care. Subsequently, the length of retirement is increasing. Concurrently, more are living with chronic diseases such as heart disease, cancer, Alzheimer's, and other forms of dementia, placing larger burdens on healthcare systems. Today, more than 850 million people in the world who suffer from chronic diseases are using up to 85% of the healthcare dollars[1]. In the United States, this amounts to more than $1.5 trillion dollars per year. According to the US Centers for Medicare and Medicaid Services (CMS), the national health spending in the United States in 2008 was estimated to be $2.4 trillion dollars[19]. The cost of heart disease and stroke takes around $394 billion[19]. Consequently, the US health care system is facing daunting future challenges. The current situation is likely to worsen

with the first baby boomers reaching retirement age in the next decade. For the first time, the elderly are expected to outnumber the young, not only in the United States but worldwide.[1]

Throughout the world, the over age 65 population is projected to more than double from 357 million in 1990 to 761 million by 2025.[2] In 1950, the total European elderly population (age 65+) approximated 45 million; by 1995 had already more than doubled to 101 million; and by 2025, is anticipated to exceed 173 million[3]. The American data follows similar trends. The total United States population in 1975 was 216 million. By 2050, the US population is expected to climb to 350 million. As the general population increases, however, the percentage of the population age 65 and under will decrease, and the percentage of the population age 65 and older will increase from 10.6% in 1975 to 18.2% in 2025. Older adults already account for as much as 20% of the population of many nations in Western Europe as well as Japan. Japan is one of the most aged societies in the world. In Japan, the ratio of elderly 65 and older to the rest of population was 18.6% in December 2002, and it is estimated to increase to 35.7% in 2050[17].

Longevity has given rise to increasing understanding of age-related disabilities and diseases, which can leverage large economical burdens. The expense of these diseases extends beyond financial, however. A 1997 study found that almost one-third of United States adults, most of whom also held full-time jobs, served as informal caregivers – most commonly to an elderly parent[4]. The 1997 cost of replacing this assistance to older Americans was estimated at $45 billion.

Continuing the status quo clearly is not the answer for healthcare systems. It is imperative to devise a new way of providing care to a rapidly expanding population of older adults while shrinking unsustainable healthcare costs. Andy Grove, former CEO of Intel, described the U.S. health care situation as follows:

> *Healthcare is the largest segment of the economy in the U.S., and…it is becoming too expensive to deliver. We're still living in the 'mainframe' era of healthcare….We can't, as a society, afford to devote any more of our economy to it…What we need is…the healthcare equivalent of the low-cost PC*[5].

Wireless Sensor Networks

Rapid advances in the areas of sensor design, information technologies, and wireless networks have led the way for the proliferation of wireless sensor networks[18]. A wireless sensor network consists of a large number of wireless-capable sensor devices working collaboratively to achieve a common objective. A WSN has one or more sinks (or base-station) which collect data from all sensor devices. These sinks are the interface through which the WSN interacts with the outside world[22]. The basic premise of a WSN is to perform networked sensing using a large number of relatively unsophisticated sensors instead of the conventional approach of developing a few expensive and sophisticated sensing modules[21]. The potential advantage of networked

sensing over the conventional approach, can be summarized as greater coverage, accuracy and reliability at a possibly lower cost.[21]

"WSNs are composed of individual embedded systems that are capable of

1. interacting with their environment through various sensors,
2. processing information locally, and
3. communicating this information wirelessly with their neighbors. "[19]

A sensor node (embedded system) usually consists of three components which are[19]:

- Wireless modules or motes – key components of the network which consists of a microcontroller, transceiver, power source, memory unit, and may contain few sensors. Examples: Mica2, Cricket, MicaZ, Iris, Telos, SunSPOT, and Imote2.
- A sensor board which is mounted on the mote and is embedded with multiple types of sensors. Examples: MTS300/400 and MDA100/300.
- A programming board (gateway board) – provides multiple interfaces including Ethernet, WiFi, USB, or serial ports for connecting different motes to an enterprise or industrial network or locally to a PC/laptop. These boards are used to program the motes or gather data from them. Example: M1B510, M1B520, and M1B600.

In a wireless sensor network, tens, hundreds, or even thousands of sensor nodes are scattered throughout a physical environment. Each device is capable of monitoring-sensing-and/or displaying-actuating-information. A sensor node is capable of gathering sensory information, processing it in some manner, and communicating with other nodes in the network[21].

When wireless sensor networks are designed for medical applications they are often referred to as wireless medical sensor networks (WMSNs). Wireless medical sensor networks have delivered significant improvements to the healthcare industry in the 21st century[6]. Wireless medical sensors are arranged on a patient's body and can be used to closely monitor the physiological condition of patients. These medical sensors monitor the patient's vital body signs (e.g temperature, heart rate, blood pressure, oxygen saturation, etc.) and transmit the data in a timely fashion to some remote location without human intervention. A doctor can interpret these sensor readings to assess a patient's condition. Thus patients could benefit from continuous long-term monitoring after being discharged from the hospital[6]. WMSNs will continue to play a central role in the future of modern healthcare as continuous and ubiquitous monitoring becomes increasingly important in order to shorten the amount of interaction needed between physicians and their patients to facilitate reduction of costs.

The term wireless medical sensor networks was recently coined to unite researchers to form interdisciplinary teams with expertise in bioengineering, electronics, computer science and engineering, medicine, among others. Wireless medical sensor networks differ from traditional wireless sensor networks (WSNs). Traditional WSNs are independent and automatic, utilized in

a large scale in either a fixed or distributed manner. Their data rates are limited by the applications. WMSNs, however, involve direct human involvement (i.e., patient, doctor, nurse, other providers, etc.), are utilized in a small scale (i.e., depending on usability), must support mobility in order for the patient to be able to carry the device, and demand high data rates, with reliable communication and multiple recipients. WMSNs carry the promise of quality-of-care across wide variety of healthcare applications as they can be wearable, implantable, portable, and integrated on many types of wireless communication motes[6].

Wireless sensor networks have emerged as a feasible technology for a myriad of applications, including many different health care applications. WSN technology can be adapted for the design of practical Health Care WSNs (HCWSNs) that support the key system architecture requirements of reliable communication, node mobility support, multicast technology, energy efficiency, and the timely delivery of data[10].

The application of the Wireless Sensor Networks in healthcare systems can be divided into three categories:

1. Monitoring of patients in clinical settings
2. Home & elderly care center monitoring for chronic and elderly patients
3. Collection of long-term databases of clinical data

Monitoring of Patients in Clinical Settings

Wireless medical sensor networks are becoming increasingly important for monitoring patients in the clinical setting. There exists an overwhelming need for continuous and benign monitoring of more and more physiological functions in a hospital setting. Sensors today are effective for single measurements, however, are not integrated into a "complete body area network", where many sensors are working simultaneously on an individual patient. Mobility is desired, but in many cases sensors have not yet become wireless. This creates the need for the implementation of new biomedical personal wireless networks with a common architecture and the capacity to handle multiple sensors, monitoring different body signals, with different requirements. The type and number of sensors must be configured according to monitoring needs related to different diseases, treatment, and the patient treatment life cycle[12].

WMSNs systems have several advantages over traditional wired systems such as ease of use, reduced risk of infections, reduced risk of failures, reduced user discomfort, enhanced mobility, increasing the efficiency of treatment at hospital, and lower cost of delivery[7].

At the Interventional Center, Oslo University Hospital, they have developed, implemented and tested a biomedical wireless sensor network (BWSN). The BWSN allows simultaneous use of six different sensors. The following six different sensors were integrated[12]:

- Memscap - Wireless Pressure Transducer

- Millicore - DigiVent Pulmonary Air Leakage
- Novosense - CardioPatch ECG sensor
- Novelda - Medical UWB-IR radar
- VTT - Heart Monitoring Accelerometer
- SINTEF - SpO2 & Temperature sensors

Their BWSN matched performance of the state of the art wired advanced medical monitoring platforms. Their new wireless system facilitated more aggressive and early patient ambulation and unrestricted mobility. This applies to post procedure monitoring of patients, as length of hospital stays are shortening due to minimally invasive procedures[12].

The BWSN was implemented using a commercial sensor integration platform from Imatis, and was able to overcome several technical barriers such as sensor synchronization and noise handling. There are other challenges that have yet to be overcome including the design of improvements to extend mobility outside the operating room, to improve security handling, and to monitor several patients simultaneously[12].

At University of Texas at Dallas, they have designed a BWSN for monitoring patient vital sign data in a hospital setting. They are using Crossbow MICAz motes to design a mesh network that routes the patient data to a remote base station within the hospital. A hospital care giver can access the patient's data at any point in time and doesn't have to be present in the patient's room to examine the readings. The nodes of the network are self-powered and get its energy from overhead 34 W fluorescent lights using solar panels. The network nodes can be interfaced to different vital sign sensors like electrocardiograms (ECGs), blood pressure (BP), and pulse-oximeters. They have tested their system by interfacing a commercial BP/heart-rate monitor (BPM) to a node. The sensor node controlled the BPM to initiate a reading and collecting data and forwarded the data to the base station. They also designed a graphical user interface (GUI) to store and display data on the base station PC[14].

University of Paris-Est Creteil Val de Marne (UPEC) in collaboration with the Henri Mondor University Hospital Center in France have designed a WSN system to monitor patients' physiological parameters as well tracking their location within the hospital. The first objective of their project was to monitor the pulse oximeter parameter (SpO2) of patients from the time that they leave their rooms and move within the hospital (for example going to operating room or for an X-ray). The real-time collection of SpO2 parameter will allow the caregivers to monitor the variation of the patients oxygen levels and to intervene when the collected values goes below certain level. The second objective of their system was to track patients' as they are moved within the hospital. With this system they can collect valuable data for scheduling the operating room. For example, they can track the patient as they enter the operating room and the time that they exit the operating room. Their experiments' results were encouraging and their system improved the healthcare services quality[15].

The implementation of wireless medical sensor networks technology will lead to reduced hospitalization time due to more rapid mobilization, as well as improved documentation by stored, digitized signals. The result will be improved decision making for diagnostic, observation and patient treatment.[12]

Home & Elderly Care Center Monitoring for Chronic and Elderly Patients

It is of utmost importance to provide affordable, high-quality healthcare to the elderly while enabling them to live independently. At-home healthcare can help address the social and financial burdens of an aging population. At-home healthcare can be achieved by using WMSNs. The general problem of acquiring physiological and behavioral data from patients for diagnosis, monitoring, or chronic disease management can be addressed using WMSNs. These wireless sensors can be installed in a patient's home environment to provide real-time and extended monitoring of activity and wellbeing. When coupled with communications technologies such as mobile phones and the Internet, the sensor network can keep family, caregivers and physicians informed, while also establishing trend and detecting variability in the health of the patient. Following are examples of initiatives by different groups to use WSNs technology in home health care and elderly care centers:

Hongwei Huo and et al have developed a prototype of Wireless Sensor Network, an interconnection platform, and a service management platform to support distance healthcare at home. Their system is capable of automatically measuring and collecting home parameters and body parameters, and sending the data to the central server over different public networks, wired or wireless. The central server makes data analysis, generates a report about the elder's activity and health states, and activates or an emergent alarm when a dangerous event occurs. The central server has the ability to automatically send the message to the end-users by a voice telephone call, SMS or E-mail etc. A series of experiments showed that their system is reliable[7].

Anuroop Gaddam and et al have designed a novel home monitoring system which is based on cognitive sensor network and is intended for elder-care application. The smart system consists of an optimum number of cognitive wireless sensors which are used to detect usage of electrical devices, bed usage pattern, flow of water, etc., and also incorporates a panic button. The cognitive sensors provide information that can be used for monitoring the elderly by detecting any abnormality pattern in their daily activities around the house. The system generated and sent an early warning message to the care giver, when an unforeseen abnormal condition occurred. Even though this system used a limited number of sensors, it was capable of capturing the abnormality in a person's daily routine by recognizing the use of appliances necessary for daily living. Their system could be installed and maintained in residential environments with ease[8].

N. K.Suryadevara, et al have designed and developed an intelligent home monitoring system based on ZigBee wireless sensors to assist and monitor the elderly people. The performance of their developed system was evaluated by running the system at four different elderly houses and recording the data and simultaneously performing the activity recognition in real time. The houses were equipped with the wireless sensor network with the fabricated sensor units attached to various house-hold appliances. Six electrical sensors are connected to appliances Microwave, Toaster, Water Kettle, Room Heater, TV and Audio. Four force sensors are connected to Bed, Couch, Dining chair and Toilet. One contact sensor is connected to grooming table and one temperature and humidity sensor to monitor the ambient environment readings. A laptop was installed with the developed intelligent software connected with ZigBee module acted as the coordinator associated with WSN to collect and monitor the elder's behavior[9].

Growth of the elder population has given rise to the increasing demand for long-term elder-care facilities. The majority of elders living in such facilities are suffering from multiple chronic illnesses. Due to theses illnesses, the elderly's physical and mental health is slowly declining. In order to detect these declines early, continuous tracking of the elders' daily activity is required. Chun-Cheh Hsiao, et al have integrated a 45-node WSN-based location system in NTUH-BH to automatically track the elder's daily mobility. They collected location traces and investigated the daily and long-term mobility of four volunteering elders for eight months. Following are the findings of their study:

1. "Each elder's daily mobility shows a reoccurring pattern. The pattern, however, differs from individual to individual.
2. The mobility level, the total distance the elder moves in the facility per day, shows a stronger variability. Not all elders show reoccurring patterns in mobility levels. Some of them are spontaneous moving from event to event."[4]

From these observations, it was concluded that long term location tracking, not just the mere quantity of mobility, allows discovery of the moving patterns and in turn making early detection of the elders' physical or mental problems possible[4].

Eleni Stroulia et al. have designed a Smart Condo. This project was an interdisciplinary activity at the University of Alberta. Their team included researchers from Rehabilitation Medicine, Pharmacy, Art and Design, Education, and Computer Science. They have developed a wireless sensor network with a variety of sensor types in an 850 square-foot condominium. Their sensor network records a variety of events and environmental parameters and feeds the related data into a web-based system. The web-based system was responsible for inferring high-order information about the activities of the condo's occupant and supporting the visualization in a 2D Geographic Information System (GIS) and a 3D virtual world (Second Life (SL)). They believe that one of the most innovative aspect of their project is the use of SL, a virtual world platform, for visualizing the activities of the condo tenant through an avatar[22].

Only 9% of physicians work in rural areas, however, almost 20% of the population of the US lives in rural areas[23]. There is a big shortage of physicians and specialist in the rural areas. Wireless Medical Sensor Networks technology has the potential to alleviate problematic patient access issues.

At-home care can provide many advantages in terms of financial benefits, improved quality of life for patients, and more effective fall detection prevention or monitoring of many long-term chronic diseases.[20]

Collection of Long-Term Databases of Clinical Data

Sensors link the physical with digital world by capturing and revealing real-world phenomena and converting these into a form that can be processed, stored, and acted upon. The data that is gathered by the sensors in a WMSN can be used in two ways[20]:

1. Healthcare applications that leverage wireless sensor networks analyze the data gathered by sensors to infer and make decisions about the state of a patient's health and wellbeing. By improvement in monitoring consistency, continuous monitoring enhances data quality and precision for decision support leading to better titration of therapeutic interventions.
2. The continuous gathered data can be analyzed utilizing computational intelligence techniques to find solutions to the unsolved problems in the healthcare system.

Integration of WSN concepts in Computer Engineering Curriculum at UVU

Wireless Sensor Network is a broad and ever-developing technology. This field has attracted leaders in technology and has become essential in many areas. There are emerging applications for Wireless Sensor Networks. New technologies are developing in this field rapidly, and industry is in an increasing need of well-trained and skilled graduates. Since WSN has huge potential, many leading universities have included it as a component in their curriculum. The authors have done a study on how various institutions of higher education have integrated WSN concepts in their computer science and engineering programs[13].

Utah Valley University

Utah Valley University (UVU), with a Fall 2012 student headcount of over 31,500 students, is located in the Orem/Provo community, Utah's second largest urban area with a population of about 530,499 (U.S. Census, 2011 est.). The Computer Science department at UVU offers a Bachelor's Degree in Computer Science with two areas of specialization, including Computer Science (traditional) and Computer Networking. It also offers a Software Engineering degree as well as a Computer Engineering degree. The curriculum content for the Computer Science degree is based on the 2008 ACM Curriculum Report. The Computer Science degree at UVU was accredited by Accreditation Board for Engineering and Technology (ABET) in 2002 and currently has more than 500 students.

Prior to June 2012, the UVU Computer Engineering program was limited to an area of specialization in the computer science department. No formal engineering program existed. In 2012, our computer engineering (CE) program was approved by the Board of Regents resulting in the development of UVU's first engineering program. The new curriculum established for the CE program requires two embedded systems courses. In the second of these courses, wireless sensor network concepts will be introduced. Computer Engineering students are also required to take a Senior Design course; some of our students are doing their senior design projects on WSNs. Integration of the WSNs concepts in a required course (Embedded Systems II) guarantees that our students are going to become familiar with this important area before graduation. It is of utmost importance that computer engineering students be exposed to the design issues of WSNs and be prepared to design future WSNs for the society.

Summary and Concluding Remarks

Today, there is an increasing interest in developing technical solutions, by academia and industry alike, to address problems with healthcare delivery. While it is difficult to accurately predict the future of any field, the global aging population presents steep challenges for the healthcare industry to deliver services to all who need it while adapting to a new environment that demands cutting costs of healthcare services. In fact, the future of healthcare in our increasingly aging world will oblige ubiquitous monitoring of health with minimal physical interaction of doctors with their patients. Low-cost technologies are expected to aid in the delivery of services while simultaneously reducing costs. Wireless sensor networks have the potential to assist in meeting some of these future challenges, by simplifying use of medical equipment, advancing at-home medical care, and displaying health and wellness information to both providers and patients. The design of better wireless medical sensor networks seems to be a good solution to part of the problem. As a result, wireless sensor networks are becoming increasingly important for monitoring patients both in the clinical settings as well as home.

This paper studied the application of WSNs in the healthcare system. The application of the Wireless Sensor Networks in healthcare systems was divided into three categories: monitoring of patients in clinical settings, home and elderly care center monitoring for chronic and elderly patients, and collection of long-term databases of clinical data.

This study revealed that the existing application of WMSNs in the healthcare system have some shortcomings that need to be addressed. The WSN research community has done an admirable job of addressing some of the limitations that currently exist for healthcare-related applications; however, improvements are still needed regarding security and privacy issues in addition to further upgrades to wireless communication.

As educators in the field of engineering and computer science, it is essential to expose our students to the emerging field of WSNs. As the industry is constantly involved in the development of technology and products to solve issues with WSNs, tomorrow's computer

scientists and engineers must be educated on the Wireless Sensor concepts. It is our job to integrate these concepts into the undergraduate curriculum of these fields.

Wireless Sensor Networks applications in healthcare are being researched and deployed all over world. With the rise of these applications, implications will also arise.

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