2010 Fourth International Conference on Sensor Technologies and Applications

Real-Time Monitoring and Detection of "Heart Attack" Using Wireless Sensor Networks

Kala John Kappiarukudil
Amrita Centre for Wireless Networks and Applications
AMRITA Vishwa Vidyapeetham (Amrita University),
Kerala, India
e-mail: p2wna09009@students.amrita.ac.in

Maneesha Vinodini Ramesh
Amrita Centre for Wireless Networks and Applications
AMRITA Vishwa Vidyapeetham (Amrita University),
Kerala, India
e-mail: maneesha@am.amrita.edu

***Abstract*- The main purpose of this research work is to develop a wireless sensor network system that can continuously monitor and detect cardiovascular disease experienced in patients at remote areas. A wearable wireless sensor system (WWSS) is designed to continuously capture and transmit the ECG signals to the patient's mobile phone. The fastest alert will be issued to doctors, relatives, and hospitals, using the proposed data processing algorithm implemented in the patients mobile phone. The complete data from WWSS will also be transmitted to a central station, which provides a service to the doctor to view his patient's record and provide his prescription remotely, on his request. A heterogeneous wireless network design is also proposed for the continuous transmission from WWSS to a Central Data Center (CDC). The proposed system is integrated with a dynamic data collection algorithm that collects the ECG signals at regular intervals, according to the health risk perceived in each patient. Employment of this system will contribute in reducing heart diseases, leading to death of a patient, and also act as an effective health care service to patients in rural area. This continuous monitoring system will provide effective, efficient, and fast health care service to patients at risk, even if the doctor, relatives are not near the patient and also during the non availability of the cellular network.**

Keywords-wireless sensor network; real-time monitoring; cardiovascular disease; heart attack; cellular network

I. INTRODUCTION

In the recent years, world is experiencing high rate of heart diseases. Heart diseases have become one of the leading causes of death, and World Health Organization (WHO) states that cardiovascular diseases are the world's largest killers, claiming 17.1 million lives a year [5].

India having a population of approximately 1.17 billion people (estimate for July, 2009), more than one-sixth of the world's population, experiencing heart disease as the single largest cause of death in the country with heart attacks being responsible for one third of all deaths caused by heart diseases. According to a projection by the World Health Organization (WHO) and the Indian Council of Medical Research (ICMR), India will be the heart disease capital by 2020 [6].

Angina, Arthrosclerosis, Convective heart failure, Coronary artery disease, Heart attack, Cardiac dysrhythmia, Ventricular fibrillation, Tachycardias are the main cardiovascular diseases. These can be diagnosed by analyzing the changes in ECG pattern.

The emerging wireless sensor technology provides the capability to continuously sense, process and transmit the required signals to a control station. This capability can be used for real-time monitoring of cardiovascular patients, which will reduce the effects of diseases. Wireless sensor nodes are constrained of their available energy and memory. This limitation can be minimized by integrating other wireless network technologies with the current wireless sensor network.

Mobile phones are one of the most common devices available with each and every individual in this world. The recent mobile phones have enough available memory, energy, and processing power. So these advantages of mobile phone technology can be utilized to overcome the constraints of wireless sensor network technology for transmission, processing, and buffering of the sensed data.

This work proposes a wireless sensor network design for real-time monitoring and detection cardiovascular disease. This system incorporates wireless sensor network technology with other wireless technologies such as cellular network, wireless LAN, and broadband network, for efficient and fast delivery of health alerts. This proposed system consists of a wearable wireless sensor system, control system, heterogeneous wireless network system, two phase real-time data analysis and visualization system, and the warning system. All these together will provide the ECG signal analysis of a cardiac patient, remote monitoring, delivery of warning to a doctor, relative, and the hospital, and an extended service of transferring the ECG signals and previous records of the patient to his doctor in a remote location. This system can be used for providing enhanced healthcare services to the rural areas of the developing countries that are facing shortage of efficient specialized doctors. Thus the cardiovascular disease causing the death of patient can be reduced immensely by the implementation of this proposed system, in both rural and urban areas.

Section II describes the related work. Section III discusses architecture for wearable wireless cardiovascular disease monitoring system. Section IV discusses wireless network algorithm for monitoring and detecting cardiovascular disease. Section V describes the implementation and validation. Section VI describes the conclusion and future work.

978-0-7695-4096-2/10 $26.00 © 2010 IEEE
DOI 10.1109/SENSORCOMM.2010.99

II. RELATED WORKS

A home-based mobile cardiac monitoring solution is described in [1], which incorporates a design of an integrated electrocardiogram (ECG) beat detector, supported by the PDA version of Personal Health Information management System (PHIMS) and Facilitated Accurate Referral Management System (FARMS) through wireless network. This system is designed to use in a home environment whereas the proposed system is capable to be used for continuous monitoring of the patients at different environments such as home, hospital, work place, and practically anywhere.

A wearable cardiac monitor for continuous and real time monitoring of user's cardiac condition is introduced in [2]. The proposed device is composed of 3 main components: a disposable electrode, a controller, and personal gateway (e.g., cellular phone, PDA, and smart phone, etc.). The ECG signal is recorded according to the surface Laplacian of the body surface potential. WHAM shows enough feasibility and has advantages as a wearable ambulatory monitoring device in that the hardware is miniaturized enough small to integrate on a small region, thereby no wire leads need. This system is developed to monitor the ECG of the patient if the patient is not mobile. Whereas the proposed system is capable to continuously monitor patients in all states such as mobile or immobile.

Gimenez et al. introduces a new system for Integral community cardiac rehabilitation based on technological platforms for the LCSS's (Lifestyle Change Supporting System). The LCSS is based on a control and decision support system (tablet-PC). The system has the following characteristics: personalized cardiac rehabilitation program, automatic support in establishing and modifying care program, risk factor, monitoring access for the patients, intensive cardiac monitoring with automatic alarms, support self care programs and continuous information of the therapy results. The system described in [3] is developed for the cardiac rehabilitation purpose, whereas the proposed system is used for continuous monitoring and real-time warning of any cardiac problems for patients at any risk level.

Hoff et al. present a dedicated ultrasound system to monitor cardiac function continuously during and after cardiac surgery. The system uses miniature 10MHz transducers sutured directly to the heart surface. The ultrasound measurements are supported by synchronous ECG and pressure recordings. The system developed in [4] uses a new method for the measurement of ECG. The proposed system uses existing method for measuring of ECG, but brings in innovative data collection and alert dissemination according to risk level each patient. This proposed system provides the capability of the doctor to prescribe medicine, by being anywhere in the world.

Romero et al. describe the evaluation and optimization of a beat detection algorithm that is robust against high levels of noise. An evaluation protocol is defined in order to study four different characteristics of the algorithm: non-rhythmic patterns, different levels of SNR, exact peak detection and different levels of physical activity. The proposed system is used to save human life by disseminating alerts when the cardiac problem arises. This proposed system also provides the capability to locate the patient at risk and provide the necessary health care with minimum delay.

III. KEY CONTRIBUTION

The proposed system is capable for real-time, continuous monitoring of cardio vascular disease, detecting life threatening heart attacks, and disseminates the alert to the doctor, relatives, and patient. The currently available wearable cardiac monitoring system requires connectivity to either cellular network or wireless network to disseminate the alert. But in the current scenario, cellular or wireless network is not available continuously. Due to this non-availability of the network connectivity, alert dissemination will be delayed, increasing the risk of the patient. Even if the cellular network is unavailable, the proposed system is capable to disseminate the alert to the patient through his mobile phone as high beep alarms or as audio messages. On reception of the high beep, the patient will become aware of his/her health status and the required action will be initiated.

An innovative two phase alert dissemination is designed to provide the health care with minimum delay, contributing to the reduction of threat to human life. Patient data is collected, aggregated, and disseminated according to his health risk. This will contribute in providing effective data traffic management.

The proposed system is provides the capability to monitor the patient present at their workplace, home, hospital, and where ever the patient wishes to be. However the above mentioned capability of the system brings in new complexity of locating and tracking the patient. The proposed system provides the solution for locating the patient in real-time, that will enhance the capability of the system in providing the required health care with minimum delay.

The proposed system provides freedom of movement for both the patient and the doctor, by providing the alarm at their fingertip. This system also provides extra services to the doctor for detailed analysis of the available data and prescribing the medicine by online, on his request. This system also provides accessibility of the patient's historic records by any doctor selected by the patient.

IV. WIRELES NETWORK ACHITECTURE FOR MONITORING AND DETECTING CARDIOVASCULAR DISEASE

The complete architecture for a real-time monitoring cardiovascular system is shown in Figure 1. The architecture consists of:

- **Wearable Wireless Sensor System (WWSS):** The wearable wireless sensor system is used to

continuously sense the ECG of a patient. WWSS consists of lead chest electrodes, blood pressure sensors, respiratory sensors, interfacing and signal processing circuit, and the transmitter.

Electrical signals initiated from the heart are captured by the lead chest electrodes, amplified and filtered using the interfacing and signal processing circuit. These ECG signals are transmitted to the mobile phone using Bluetooth technology.

A blood pressure and respiratory sensors will also be incorporated with the system. The data from these sensors will be monitored when an ECG variation is noted. Correlation between these three data will be used to produce an alarm.

- **Mobile Control System (MCS)**

The signals transmitted from the WWSS are received by the patient's mobile phone. This mobile phone act as the control system, which process the ECG signals, generate the initial warning, and transmit the data and warning to the doctor, relative, and patient's mobile phone, and also to the specified hospital. The warning message with warning alarm will be send by the GSM/GPRS module of the mobile phone. In order to locate the position of the patient, his location, from the GPS module in the mobile phone, and the time stamp will be sent along with each data packet transmission. Time stamp can also be used for determining the event continuum.

- **Heterogeneous Wireless Network System (HWNS):**

The warning alert and the sensed data can be transmitted to the doctor, relative, and patient's mobile phone, and also to the specified hospital using heterogeneous wireless network system. The components of the HWNS differ according to the location of the patient. If he is outdoor, he can choose ad-hoc mode in his processing software, and hence the data will be transmitted through the cellular network. If the patient is in his house or in the hospital, he can choose infrastructure mode, in which the data can be sent through wireless LAN, broadband network, or satellite network. The infrastructure mode will allow high data transfer, and more frequent sampling of the sensors, while the cellular network will allow low data transfer, with reduced sampling rate, compared to infrastructure mode. These networks can also be used for providing the enhanced service to a doctor such as delivering patients old records and current signals for further analysis and diagnosis for a remotely located doctor.

- **Two Phase Real-time Data Analysis and Visualization System (RDVS):**

The two phase real-time data analysis and visualization software is used to deliver fast and efficient warning/alerts of cardiovascular patients to doctor, relatives, and hospital. The first phase is implemented in the mobile control system that will process the current ECG signals and send real-time warnings, if required. The second phase is implemented in the central data center. This phase will do extensive complex analysis of current ECG signals with the available historic signals of a patient, to diagnose the probability of a heart attack, or any other cardiovascular diseases. This phase is also capable to transmit the data analysis results along with the ECG images to a doctor's mobile phone, on his request, at near real-time.

- **Warning System (WS):**

The warning system is integrated in the mobile control station and also in the central data center (CDC). The mobile control system provides the fastest warning, whereas the central data center will provide extensive warning about any prospective cardiovascular disease. The warning alarm can be either a message or a special music stored in the music library of the concerned person's mobile phone, or a combined technique.

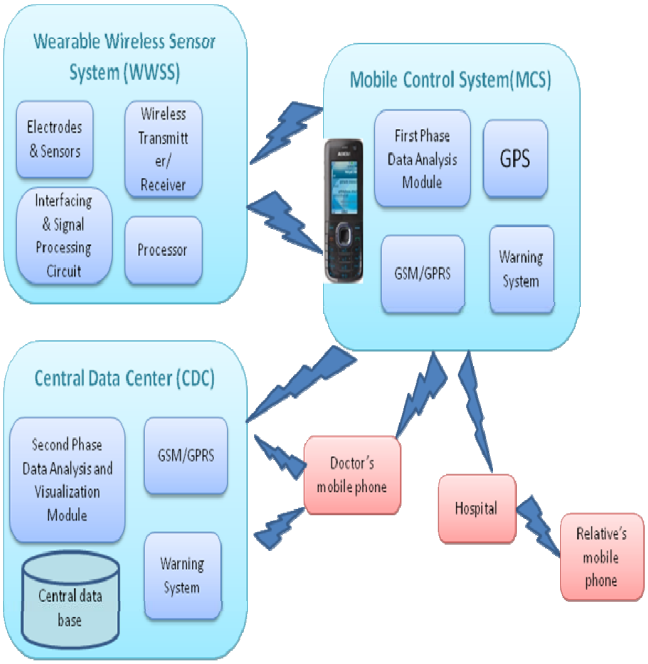

Figure 1: Wireless Network Architecture for Heart Attack Monitoring System

This architecture can be used for continuous monitoring of cardiovascular patients of multiple doctors.

This architecture allows the patient to change his doctor at any time. One of the main advantages of this system is the availability of the patient's historic data to the new doctor. This will help in faster and effective diagnose of the disease.

V. Wireless Network Algorithm Principles for Monitoring and Detecting Cardiovascular Disease

Different wireless network algorithms are designed for processing the received signals. These algorithms are implemented in the mobile control station and in the central data center. The different algorithms are given below.

(a)Algorithm for processing ECG signal

Signal collected by the chest electrode has to be processed to get ECG signal. This processing of the ECG signal can be done in WWSS or in MCS based on the power available to the WWSS. Dynamic sampling rate will be set according to the health risk of the person.

(b)Algorithm for analyzing ECG

ECG signals received from the WWSS will be analyzed in the MCS to determine the pattern changes that contribute to a particular cardiovascular disease. Any change in pattern will trigger the feedback system to switch on the pressure and respiratory sensor. Correlation analysis of data from these three sensors will be done. Any positive outcome from the analysis will show a warning level. A respective warning/alert message will be send to the doctor, relative, patient, and the hospital.

(c)Risk Based Data Transmission Algorithm

The sensor data transmission requirement for each patient will be different according to their health risk. The health risk will be more, if a patient has already experienced a heart attack or having a major cardiovascular disease. Each doctor has provided with the capability to set a minimum data transmission frequency in the MCS, according to his patient's health risk. Otherwise the central data center will dynamically set a minimum data collection frequency according to the patient's historic records. This minimum data collection frequency will be communicated to the MCS during the initiation of the network. The doctor can change the minimum data collection frequency according to his discretion and it will be communicated to the MCS in near real-time. The ECG signal from the MCS will be to send to the central data center according to previously set data transmission frequency.

(d)Time synchronization

ECG signals have to be analyzed in the MCS and in the Central Data Center (CDC) for determining the event continuum. This requires time synchronization with respect to the global time for effective data analysis. MCS and CDC should be global time synchronized. Time synchronization in WWSS is achieved by adjusting the MCS clock according to global time signals received from MCS, at frequent intervals.

(e)Locating the patient

Wireless network system provides the capability to monitor and locate the patient continuously. The knowledge of patient's location is necessary to provide the required and remedial action with minimum delay. This can be achieved by activating GPS module in the MCS.

VI. Implementation and Validation

This real-time wireless monitoring and detection system for cardiovascular diseases will be implemented, tested, and validated, in the available cardiac patients of Amrita Institute of Medical Sciences (AIMS), India. These patients will be attached with the WWSS to their body, on the upper arm or near to the heart. Their mobile phones will be enhanced with the software platform developed using the above discussed design, that will facilitate efficient and fast delivery of warnings.

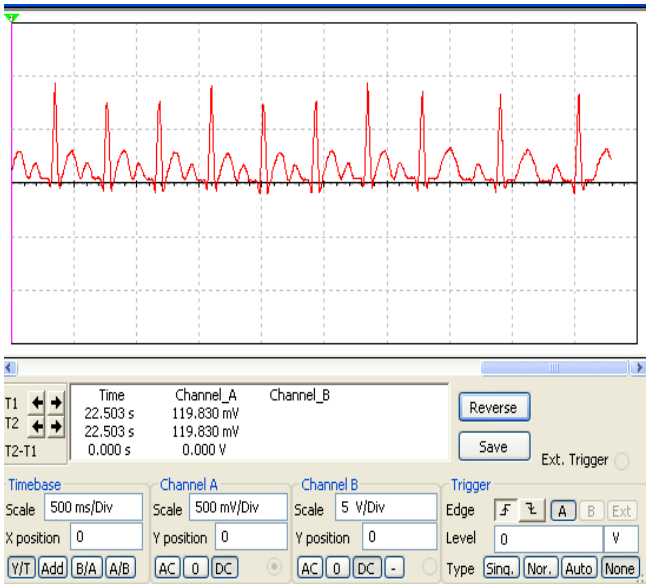

Figure 2: ECG signal obtained from the simulation.

The hardware circuit for WWSS was designed and simulated using NI Multisim1.0. One of the simulation results is shown in Figure 2. Different heart conditions were modeled in the simulation by varying the frequency and voltage. A QRS detection algorithm was used to detect the variations in the QRS complex. When this variation crosses the threshold for the patient, a warning will be issued.

VII. Conclusion and Future Work

This paper presents a real-time wireless sensor network system for monitoring and detecting any upcoming cardiovascular disease. The system has the

capability to monitor multiple patients at a time, to deliver remote diagnosis and prescriptions, and also for providing fast and effective warnings to doctors, relatives, and the hospital. The system design consists of wearable wireless sensor node, mobile control unit, heterogeneous wireless network system, two phase data analysis and visualization system, and the warning system. The system is also capable to collect the data according to perceived health risk in each patient. Especially this system will be useful before, during, and after a cardiac arrest for continuous monitoring of a patient in the remote location. The system will contribute in the reduction of death due to heart attack and other cardiovascular diseases; also it can be used for providing health service by specialized doctors, to rural areas. Comparatively, this system can be produced in low cost, since it only needs to develop a wearable wireless sensor system, the software platforms, and the development of data storage capability. The system utilizes the available wireless network for the data transmission, which contributes to the cost reduction. In future, the current system will be tested and validated in Amrita School of Medical Sciences. The current system will be modified later, by incorporating other sensors, to monitor blood pressure, diabetes, and respiration process, to reduce false alarms.

ACKNOWLEDGMENT

I would like to express my gratitude to Amrita University for providing a very good motivation and environment for this research work. I would also thank Dr Venkat Rangan and Mr. Abishek Thekkeyil Kunnath, for their valuable contribution to this work.

REFERENCES

[1] K. W. Goh, J. Lavanya, Y. Kim, E. K. Tan, and C. B. Soh, "A pda based ECG beat detector for home cardiac care," 27th Annual Conference Shanghai, IEEE. Engg. in Med And Biology, China, pp. 375-378, September 1-4, 2005.

[2] K. Shin, H. T. Hwang, H. Y. Kim, J. P. Kim, H. S. Yeo, and W. Han, "WHAM: A novel, wearable heart activity monitor based on Laplacian potential mapping," 27th Annual Conference, IEEE. Engg. In Med and Biology, Shanghai, China, pp. 7361-7364. September 1-4, 2005.

[3] G. Gimenez, J. Guixeres, F. J. Villaescusa, J. Saiz, S. Merce, and R. Rodriguez, "A New System for Integral Community Cardiac Rehabilitation Based on Technological Platforms for the Lifestyle Change Supporting System," ISSN. Computers in Cardiology, pp. 845-848, 2006.

[4] H. Lars, E. Andreas, and I. Halfdan, "Cardiac Monitoring Using Transducers Attached Directly to The Heart," IEEE International Ultrasonic Symposium, pp. 749-752, 2008.

[5] R. Inaki, G. Bernard, and P. Julien, "Robust beat detector for ambulatory cardiac monitoring," 31 annual conferences of IEEE, EBMS. Minneapolis, Minnesota, USA, pp. 950-953, September 2-6, 2009.

[6] S. Nimmala, J. van de Molengraft, J. Penders, and B. Gyselinckx, "An intelligent wireless ECG patch for single-lead ECG monitoring," Journal of Electro cardiology, vol.41, 2008, issue 6, pp. 645–646, doi:10.1016/j.jelectrocard.2008.08.031.

[7] http://www.who.int/cardiovascular_diseases/en/. Last access date: 20/02/2010

[8] http://www.medindia.net/patients/patientinfo/HeartAttack.htm. Last access date: 25/01/2010