SICE Annual Conference 2008
August 20-22, 2008, The University Electro-Communications, Japan

The Three-Lead Wireless ECG in Sensor Networks for Mobile Patients

Visarut Nopparat and Phongsak Keeratiwintakorn

Department of Electrical Engineering, King Mongkut's University of Technology North Bangkok,
1518 Pibulsongkram Rd, Bangsue, Bangkok, THAILAND, 10800
getto_8@hotmail.com and phongsakk@kmutnb.ac.th

***Abstract*— Telemedicine is a future trend of medical care due to the increasing cost of treatment and the aging of population around the World. Several telecommunication technologies are proposed for transferring medical data between a point of care and a hospital; however, full mobility of patients needed to be attached with wired monitoring devices is not provided. In this paper, we proposed a wireless three-lead electrocardiogram (ECG) device using a mote-based Wireless Sensor Network (WSN) to transfer heart signals from a patient to a personal computer for monitoring and storing. Our device is designed using low-cost, low-power components, and provides full mobility to patients by eliminating noise from patient's movement.**

***Index Terms*— Telemedicine, Electrocardiogram (ECG), EKG, Wireless Sensor Network, TinyOS, Telos, Heart Monitoring**

I. Introduction

WIRELESS technologies today are advanced, widely used, and more accepted as a reliable communication. With the advantage of using no wire, the adoption of wireless communications grows rapidly not only in commercial buildings, but also in medical care units. Due to the increasing cost of medical care and the aging of the Japanese and European population [1], several efforts have proposed ways to reduce the cost; for example, E-health services or Telemedicine where personal medical information (PMI) is digitized and stored in a database residing in a hospital intranet that can be remotely connected by physicians or medical experts. The PMI can be retrieved directly from patients using special sensing devices such as electrocardiogram (ECG) devices and forwarded to the hospital intranet via several telecommunication technologies such as Personal Area Network (PAN), Broadband Wireless Access (BWA), the Internet or World Wide Web, Cellular networks, and satellite communications.

Traditionally, to transmit PMI between a hospital and a point of care, a telemedicine system utilizes wired communications such as telephone ISDN, ADSL or cable modem. The system, therefore, is limited to a fixed point and cannot provide services to patients with mobility such as those in emergency incidents or those who are treated outside hospitals. Therefore, mobile telemedicine services have increasingly drawn attentions for several medical applications such as telecardiology or telepathology to combine those with wireless technologies such as personal area networks.

Personal Area Networks (PANs) are defined as wireless networks whose coverage is around a human body or less than 10-50 meters. The PAN was originally proposed for soldiers in battlefields to monitor vital life signals by connecting body sensors wirelessly. It is also used in wearable computers where all peripheral devices are wirelessly connected. Several research groups have proposed to use PANs for e-health and telemedicine. PANs are used to reduce the medical care cost to monitor and to record vital bio-signals that the monitoring and recording can be done at home or outside hospitals.

The requirements for PANs are a low-cost and low-power device that can transmit around few hundreds kilobytes per second. In addition, for telemedicine the accuracy of the monitoring and recording should be sufficient for medical doctors or nurses to diagnose a problem. The interference is also a concern when using in hospital environments where other medical devices should not be interfered by PAN deployment. Due to the increased need for telemedicine, it is also required that the PAN interoperates with hospital networks using other wireless technologies such as Wireless Local Area Network, e.g. IEEE 802.11 (or Wi-Fi), Cellular Networks, e.g., GPRS, EDGE, UMTS, and BWA Networks, e.g., IEEE 802.16 (or Wi-Max).

Our propose work offers the use of IEEE 802.15.4 [2] technology or Wireless Sensor Networks (WSNs) with multiple-hop communications as a PAN to transfer biomedical data, the ECG signals, from multiple patients to a personal computer for monitoring and recording. Our work is designed with very low energy consumption in mind, and utilizes the TinyOS as an operating system for WSNs. In addition, we use commodity hardware for our device; therefore, our device has a very low cost with high accuracy.

The rest of this paper are as follow. In Section II, we describe related work of telemedicine using other wireless technologies. In Section III, we describe the requirements of ECG devices and our proposed work for ECG signal amplifier. In Section IV, we describe our Wireless ECG

PR0001/08/0000-2308 ¥400 © 2008 SICE

Sensor Network for patient monitoring, and we show our experiment results in Section V. We conclude our work and our future work in Section VI.

II. Related Work

In [3], a prototype of mobile teletrauma system is proposed to use 3G cellular networks. Traumatic patients are attached with Wireless ECG devices. ECG data are then transferred to a tablet PC for storing and forwarding to a hospital using 3G cellular networks. In [4], the medical data are multiplexed over the UMTS channels for higher and more reliable data transfer between an ambulance and a hospital.

In [5], a mobile health care system is proposed to connect a wireless PAN to a health care service provider using GPRS or UMTS technology. The system utilizes Bluetooth or IEEE 802.15.4 devices to form the wireless PAN. Similar work, CodeBlue [6], aims to provide a uniform telemedicine services for emergency response using WSNs. CodeBlue project proposes a common protocol and a software framework to integrate sensing devices such as a pulse oximeter and a two-lead ECG with a handheld computer and a location-tracking tag to provide first response services.

In corporate with CodeBlue, AID-N project [7] is proposed to provide emergency response services using a decentralized electronic triage system. Electronic triage sensors are deployed to monitor vital signs of patients and raise an alarm when a patient needs immediate medical attention. The AID-N project deploys IEEE 802.15.4 wireless technology for the electronic triage tags that form a WSN in an ad hoc manner.

In [8], a portable device for wireless patient monitoring using Wi-Fi technology is proposed. The sensing devices including a three-lead ECG device, a oxygen saturation meter and a heart rate monitor are connected to a Personal Digital Assistant (PDA) for date transferring from PDA to a computer system via Wi-Fi technology.

Reference [9] proposes a backbone system for telemedicine using Wi-Max-based broadband access networks to provide quality of services and also the mobility of the telemedicare units such as ambulances.

Several wireless technologies are available for PANs. Bluetooth or IEEE 802.15.1 standard is commonly used for commercial application for cable replacement, and it is widely available in most cellular phones. In [10], Bluetooth is used as a medium to transmit biomedical data from a patient to a cellular phone to forward the data to a hospital intranet. The method utilizes the existing and widely used technologies to realize the real application. However, this method requires paid cellular services and an expensive cellular phone for data transfer. Furthermore, the services can be interrupted by phone services. Additionally, Bluetooth devices are not designed for very low power consumption. The IEEE 802.15.4 or WSN is designed for very low-power consumption and very low-cost. In several situations that need a very long battery life, WSN is commonly used as a PAN to support mesh networking.

III. Heart wave Amplifier

A. Characteristics of Biosignal Amplifier

With each heartbeat, an electrical impulse or wave travels through the heart. This wave causes the heart muscles to squeeze and pump the blood to from the heart. In general, the magnitude of the wave is about 1 mV, and the frequency response is ranged from 0.05 – 100 Hz. In order to see the full wave, we need an amplifier only in that frequency range. The characteristics of our proposed bio-signal amplifier are as follow.

High Input Impedance. The wave is obtained from an electrode that is attached on skin. The attachment between the electrode and the skin has high impedance; thus, the input impedance of the amplifier needs to be higher to decrease the signal loss from the attachment.

High Common Mode Rejection Ratio (CMRR). Due to the marginal amplitude of the heart wave, it is vulnerable to any kind of noise signals. Therefore, we use the amplifier with high CMRR that a gain in differential mode is high to amplify the heart signal and that in common mode is low to reject noise signals.

Highly Sensitive Low-frequency Response. The heart wave has a very low frequency (0.05 Hz) near DC signals; thus, it is sensitive to DC offset that comes from the body movement or the change of the impedance around the electrode attachment area. Without any correction, the DC offset is, therefore, amplified with the heart signal. With the high CMRR, the DC offset can be amplified up to 500 or 1000 times. A typical DC offset of 300 mV (AAMI standard) could saturate the amplifier such that there is no gain for heart signals. Our proposed amplifier utilizes the negative DC feedback circuit to the input to eliminate the DC offset from the body movement. Therefore, our proposed amplifier can be used with a patient with mobility such as walking or doing regular activities.

B. The Proposed Amplifier

Our proposed amplifier for heart signals for Electrocardiograph is shown in Fig. 1. The buffer circuit receives electrical signals of heart beats and breathing from electrodes or leads attached to a body. The measurement of signals is performed using the bipolar limb lead that needs four leads at the four positions, right arm (RA), left arm (LA), left leg (LL) and right leg (RL) as shown in Fig. 2. The right leg drive circuit is used to reduce noise. The bio-signal amplifier includes the amplifying circuit for gaining heart signals and the negative feedback circuit for eliminating the DC offset from body movement. The filter circuit is a low-pass filter to cut off the frequency at 100 Hz. Therefore, it is limited to the heart diagnosis with heart signal less than 100 Hz. At this point, the heart signal is clear and included both positive and negative levels. To input the signal into an analog-to-digital channel of MSP430, whose range is from 0 – 3V, we use a clamping circuit to convert the signal into only positive level between 0 – 3 V. The circuit also includes the high-pass filter with the frequency response at 0.05 Hz.

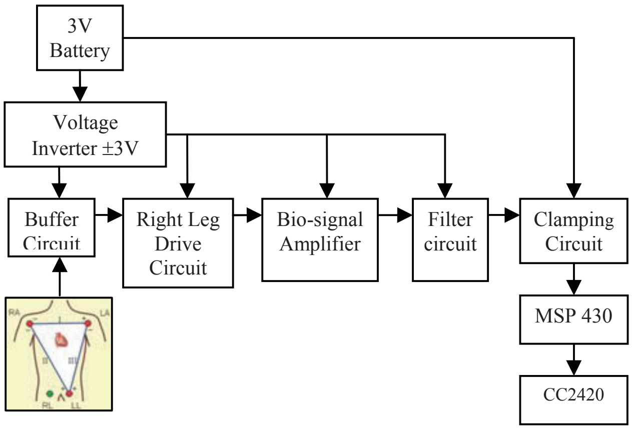


Fig. 1 . The block diagram of our proposed Wireless ECG

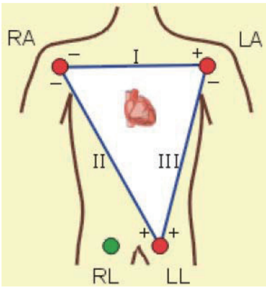


Fig. 2 . The position of leads for the bipolar limb lead measurement

C. *Wireless ECG Node*

Our wireless ECG node is consisting of the heart signal amplifier attached to the Telos B mote from UC Berkley [11]. The mote includes an MSP430 microprocessor and a CC2420 RF chip. The MSP430 is a 16-bit RISC, mixed-signal, and very low-power processor with a sleep current of less than 1 μA [12]. The CC2420 is a low-power 2.4 GHz RF chip with Tx/Rx current of less than 20 mA [13]. The CC2420 chip is also compliant to IEEE 802.15.4 standard for low-rate low-power PANs. Fig. 3 shows our amplifier board with Telos B mote.

IV. WIRELESS ECG SENSOR NETWORK

A typical wireless sensor network is composed of nodes and a gateway as shown in Fig. 4. The nodes are mobile nodes that are loosely connected together, and they are equipped with sensors, the three-lead ECG sensors, in our work. Each node is attached to each patient to take samples of heart waves. The samples are then broadcast and forwarded to other nodes in order to reach the gateway. The gateway is commonly attached to a more powerful node such as a personal computer or PDA. The samples are then forwarded to PC for data collection, monitoring, and display. The WSN can be set up in hospital environments where the gateway is in a nursing room for monitoring or alarming. A patient is attached with a mobile node with ECG sensors. For a large hospital area, forwarder nodes, nodes without sensors, are installed along the way to create transmission coverage throughout the hospital.

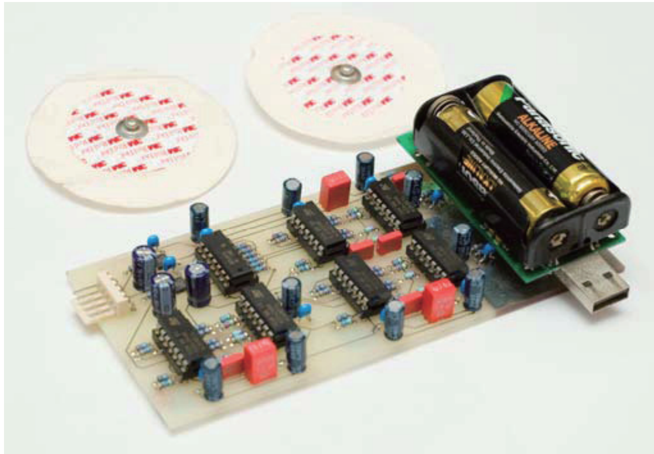


Fig. 3 . The signal leads, the bio-signal amplifier board, and Telos B mote

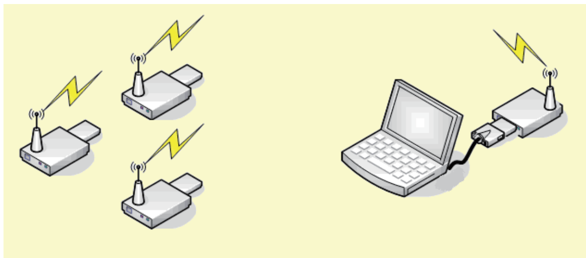
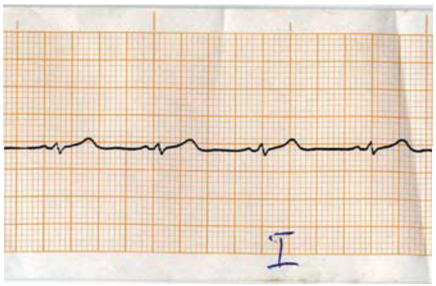


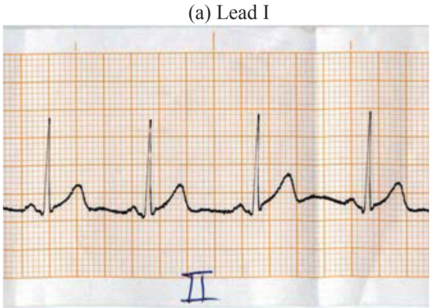
Fig. 4 . A Typical Wireless Sensor Network

V. EXPERIMENT RESULTS

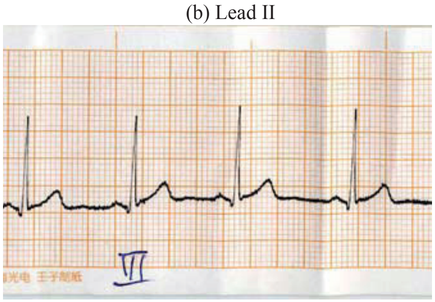
We set up our experiment using our three-lead Wireless ECG with a patient. The results are compared with a 12-lead commercial electrocardiography. In Fig. 5, the heart signals from (a) Lead I, (b) Lead II, and (c) Lead III of the commercial ECG are shown. Fig. 6 shows the signals from the same patient using our mote-based wireless ECG. From the top are the signals from Lead III, Lead II, and Lead I, respectively. The results show similarity between the signals from the 12-lead commercial ECG and those from our three-lead wireless ECG. Our wireless ECG can be attached to a patient with mobility with very little noise or distortion. Therefore, it is more suitable for telemedicine for patient with mobility.



(a) Lead I



(b) Lead II



(c) Lead III

Fig. 5 . ECG Signals from a commercial 12-lead Electrocardiography.

Fig. 6 . The sample of simultaneously readings from one patient with our 3-lead ECG device on a computer screen. From the top are the signals from Lead III, Lead II and Lead I.

VI. Conclusion and Future Work

This paper presents a wireless ECG device for telemedicine using Wireless Sensor Networks. The networks include a mote-based node called Telos running an operating system, TinyOS. The wireless ECG device including a heart wave signal amplifier is designed using low-cost, low-power components. The device can measure up to three leads when attaching to a patient. The mobility of the patient is allowable since the sensor circuit is designed to eliminate noise from the patient mobility. The results of experiments show the similarity of ECG data obtained between our wireless ECG device and the wired 12-lead commercial ECG device. In our future work, we plan to incorporate the wireless ECG devices into a full monitoring system for a hospital environment where several patients are monitored at the same time using multiple-hop WSN.

References

[1] [ITU-D] ITU SG-2 Q14/2 Document 2/189-E, “The future of telemedicine implementation” by Japan, August 23, 2000. Available at http://www.itu.int/ITU-D/study_groups/SGP_1998-2002/SG2/Documents/2000/189E.doc [last accessed on Dec. 10, 2007]

[2] IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks— Specific requirements, Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs), IEEE Standard 802.15.4, 2006.

[3] Y. Chu and A. Ganz, “A Mobile Teletrauma System using 3G Networks,” IEEE Trans. Inform. Tech. Biomed., vol. 8, no. 4, Dec. 2004, pp. 456–62.

[4] J. R. Gallego et al., “Performance Analysis of Multiplexed Medical Data Transmission for Mobile Emergency Care over the UMTS Channel,” IEEE Trans. Info. Tech. Biomed., vol. 9, no. 1, Mar. 2005, pp. 13–22.

[5] D. Konstantas, V. Jones, and R. Herzog, “MobiHealth —Innovative 2.5/3G Mobile Services and Applications for Health Care,” Proc. IST Mobile and Wireless Telecommun. Summit ’02, Thessaloniki, Greece, 17–19 June, 2002.

[6] K. Lorincz, D. Malan, T. R. F. Fulford-Jones, A. Nawoj, A. Clavel, V. Shnayder, G. Mainland, S. Moulton, and M. Welsh., “Sensor Networks for Emergency Response: Challenges and Opportunities,” In IEEE Pervasive Computing, Special Issue on Pervasive Computing for First Response, Oct-Dec 2004.

[7] T. Massey, T. Gao, M. Welsh, and J. Sharp, “Design of a Decentralized Electronic Triage System,” in Proceedings of the American Medical Informatics Association Annual Conference (AMIA 2006), Washington, DC, November 2006.

[8] Y. H. Lin et al., “A Wireless PDA-Based Physiological Monitoring System for Patient Transport,” IEEE Trans. Info. Tech. Biomed., vol. 8, no. 4, Dec. 2004, pp. 439–47.

[9] D. Niyato, E. Hossain, J. Diamond, IEEE 802.16/WiMAX-based broadband wireless access and its application for telemedicine/e-health services, *IEEE Wireless Communications*, Vol. 14, No. 1, pp. 72-83, Feb. 2007.

[10] C. H. Salvador, M. P. Carrasco, M. A. G. de Mingo, A. M. Carrero, J. M. Montes, L. S. Martin, Cavero, I. F. Lozano, J. L. Monteagudo, "Bluetooth Telemedicine Processor for Multichannel Biomedical Signal Transmission Via Mobile Cellular Networks", IEEE Trans. On Information Technology in Biomedicine., vol. 9, n.1, March 2005.

[11] J. Polastre, R. Szewczyk, D. Culler, “Telos: Enabling Ultra-Low Power Wireless Research,” in proceedings of The Fourth International Conference on Information Processing in Sensor Networks: Special track on Platform Tools and Design Methods for Network Embedded Sensors, IPSN 2005: 364-369, April 25-27, 2005.

[12] *MSP430x1xx Family User’s Manual,* Doc. No. slau049f, Texas Instruments, Inc., Dallas, TX, 2006.

[13] *The 2.4 GHz IEEE 802.15.4 / ZigBee-ready RF Transceiver User’s Manual,* Doc. No. SWRS041B, Texas Instruments, Inc., Dallas, TX, 2006.