30th Annual International IEEE EMBS Conference
Vancouver, British Columbia, Canada, August 20-24, 2008

A Wireless Sensor Network Compatible Wearable U-healthcare Monitoring System Using Integrated ECG, Accelerometer and SpO_2

Wan-Young Chung, Young-Dong Lee and Sang-Joong Jung, *Member, IEEE*

Abstract— **This paper presents the design and development of a wearable ubiquitous healthcare monitoring system using integrated electrocardiogram (ECG), accelerometer and oxygen saturation (SpO_2) sensors. In this design, non-intrusive healthcare system was designed based on wireless sensor network (WSN) for wide area coverage with minimum battery power to support RF transmission. We have developed various devices such as wearable ubiquitous sensor network (USN) node, wearable chest sensor belt and wrist pulse oximeter for this system. Low power ECG, accelerometer and SpO_2 sensors board was integrated to the wearable USN node for user's health monitoring. The wearable ubiquitous healthcare monitoring system allows physiological data to be transmitted in wireless sensor network using IEEE 802.15.4 from on-body wearable sensor devices to a base-station which is connected to a server PC. Physiological data can be displayed and stored in the server PC continuously.**

I. Introduction

Recent years, the number of applications for wearable technologies grow considerably [1]. Usually, these applications are focused on sensing human body and continuous monitoring of physiologic and acceleration parameters which are extremely useful in wearable ubiquitous healthcare application. The existing medical devices used for sensing and monitoring of human body are invasive, uncomfortable to wear [2].

This paper presents a prototype wearable device which is non-invasive, comfortable, and continuous. This means that patient may not feel the existence of the wearable devices when they are attached on patient's body. The main advantage is that these wearable sensor devices are able to offer the patients wireless communication based on IEEE 802.15.4. The devices used for this purpose should be small in its dimension and have low power consumption. Therefore, we propose u-healthcare system, which is attached to the body for sensing, monitoring and communication using wearable devices (chest sensor belt and wrist pulse oximeter).

This paper proposes a pervasive network system. Wearable USN nodes with attached devices are used to measure multiple physiologic parameters of human body. These wearable USN nodes form a wireless sensor network among themselves and other entities which are external to the human body. Wireless sensor network is the most suitable option for this system because a wired network requires laying wires around the human body, which are not desirable. This enables real time healthcare monitoring through wireless sensor network under active condition. Chest sensor belt has two electrodes in the belt and 3-axis accelerometer to acquire ECG signal and acceleration signal. Wrist pulse Oximeter consists of SpO_2 module, wearable USN node and probe to acquire SpO_2 value, heart-rate and photoplethysmograph (PPG) from user's finger. Wearable USN node collects physiological data and transmits all data to the base-station connected with server PC for continuous monitoring. In this area, the objective of communication is to transmit all measured data from sensor nodes to server without packet losses. One of the major components of this application is the monitoring of physiological data. The monitoring system was implemented using Matlab & LabVIEW programs.

Manuscript received April 7, 2008. This research was financially supported by the Ministry of Commerce, Industry and Energy(MOCIE) and Korea Industrial Technology Foundation(KOTEF) through the Human Resource Training Project for Regional Innovation.

Young-Dong Lee is with Dept. of Ubiquitous IT, Graduate School of Design & IT, Dongseo University, Busan 617-716, South Korea (e-mail: ydlee2@gmail.com).

Sang-Joong Jung is with Dept. of Ubiquitous IT, Graduate School of Design & IT, Dongseo University, Busan 617-716, South Korea (e-mail: jangels3497@yahoo.co.kr).

Wan-Young Chung is with Division of Computer Information Engineering, Dongseo University, Busan 617-716, South Korea (phone: +82-51-320-1756; fax: +82-51-327-8955; e-mail: wychung@dongseo.ac.kr).

II. Wearable U-healthcare Monitoring System

Fig. 1 shows the overall system architecture of wearable monitoring system for u-healthcare. The proposed wearable monitoring system for ubiquitous healthcare consists of two parts: wearable sensor devices part and server part. The wearable sensor devices include wearable USN node, chest sensor belt and wrist pulse oximeter, which send data to a base-station and measure physiological data from human body.

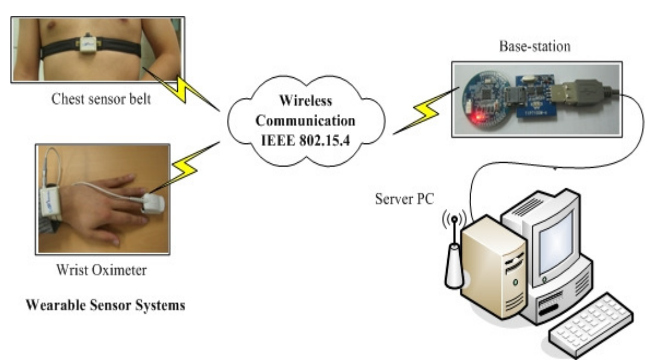

Fig. 1. Wearable USN node.

The measured physiological data are transmitted to a base-station via IEEE 802.15.4. The server PC displays the output waveforms of ECG, accelerometer and SpO_2 sensor.

A. *Wearable USN node*

The wearable USN node was developed by our laboratory for u-healthcare monitoring system as shown in Fig. 2, which features an ultra low power Texas Instruments MSP430 micro-controller with 10KB RAM, 48KB flash memory and 12-bit A/D converter. It supports several low power operating modes, consuming as low as 5.1uA in sleep mode and 1.8mA in active mode. The CC2420 wireless transceiver in the USN node is IEEE 802.15.4 Zigbee compliant. It has programmable output power, maximum data rate of 250Kbps, and hardware provides PHY and some MAC layer functions. The CC2420 is controlled by the MSP430F1611 through SPI port and a series of digital I/O lines. The USN node uses M25P80 is an 8Mb (1 Mbit * 8) serial flash memory with write protection mechanism, accessible from SPI bus. To minimize the size of wearable USN node, we have made the USB programming board as a separate module. This module is needed only when nodes are connected to the server PC either for application download or when the node acts as a base-station.

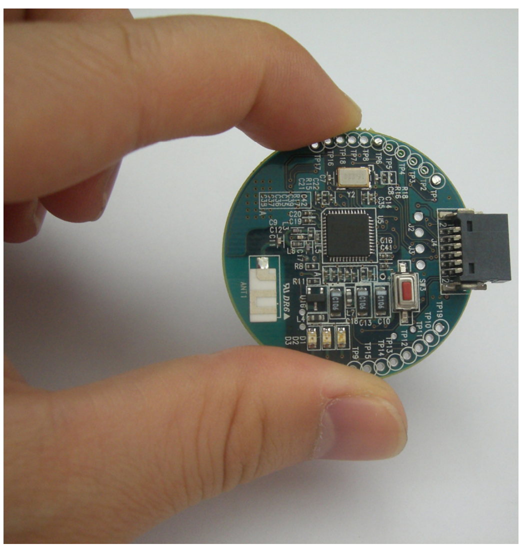

Fig. 2. Wearable USN node.

Fig. 3 shows a sensor board to integrate to the wearable USN node which consists of an ECG and a three-axis accelerometer sensor. In the sensor board, ECG signals from the electrodes are amplified with a gain of 300 (24.8 dB) and filtered with the cut-off frequencies of 0.05 Hz and 123 Hz. An ECG electrode has two electrodes which are integrated within the sensor belt. In addition, the sensor board has also a three-axis accelerometer sensor (MMA7260Q, Freescale) to measure acceleration signals.

TABLE I
SPECIFICATION OF THE WEARABLE U-HELAHTCARE SYSTEM

		Specification
Accelerometer (MMA7260Q, Freescale)		3-axis
ECG (2 electrodes)	Gain	300 (24.8 dB)
	Cut-off frequency	0.05 ~ 123 Hz
A/D converter (embedded with MSP430F1611)	Resolution	12 bits
	Sampling rate	200Hz
Wireless transceiver (CC2420, Chipcon)	Frequency band	2.4GHz~ 2.485GHz
	Sensitivity	-95dBm
	Transceiver rate	250 Kbps
	Current draw	Rx: 18.8mA, Tx: 17.4mA Sleep mode : 1uA
Power	Battery powered	3.3V

B. *Wearable U-healthcare Sensor System*

We developed two types of wearable u-healthcare sensor system: a chest belt type sensor system (Chest sensor belt) and a wrist type sensor system (Wrist oximeter). Fig. 3 shows a wearable chest sensor belt which has a chest sensor belt with conductive fabric electrodes, an ECG and accelerometer sensor. We have the same two-layer PCB board, a wearable USN node was placed on top and sensor board with an ECG and accelerometer was placed at the bottom layer. The wearable USN node connects to the wearable chest sensor belt using a push button connector.

Fig. 3. The developed wearable chest belt type sensor system.

To obtain ECG signal from human skin, we used the wearable chest sensor belt which contains a conductive fabric electrode (size 8cm). As well as ECG signal, an acceleration signal obtains from wearable USN node.

Fig. 4 shows the wrist type sensor system which has SpO_2 sensor to measure SpO_2 values. We used the Nonin OEM Module (Nonin, USA) as SpO_2 sensor that has the size of 53 mm * 20 mm * 15 mm. The optical components used include red LED, infrared LED and photodiode, operating by transmittance light. The SpO_2 values can be obtained by calculating the ratio of both lights, depending on absorption of light. The wrist oximeter performs data acquisition 5 bytes per 1 second containing photoplethysmographic (PPG) data sampled at 75 Hz and SpO_2 values.

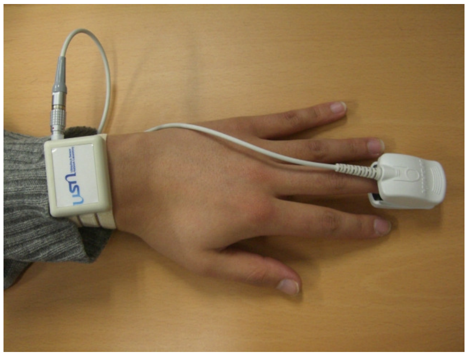

Fig. 4. The developed wearable wrist type sensor system.

C. *Wearable Ubiquitous Sensor Network*

Fig. 5 shows a person wearing the chest belt type sensor system and wrist type sensor system. The chest sensor belt is attached on the chest to measure ECG and acceleration signal, and the wrist oximeter is attached on the wrist using probe which contains LEDs and photodiode to measure SpO_2 value. Both devices can communicate to each other via wireless sensor networks. All measured physiological data from wearable sensor system can be stored in a packet for transmission and sent to a base-station with low packet collision and low power operation through wireless sensor network. Then, the monitoring program can be used to display the physiological data and stores the data in the server.

III. EXPERIMENT RESULTS

Experiments were performed for different places by wearing chest sensor belt and wrist oximeter as shown in Fig. 5.

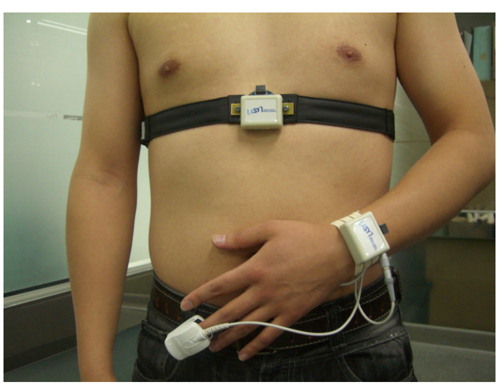

Fig. 5. Person wearing the wearable ubiquitous healthcare sensor system.

In this experiment, the ECG and accelerometer signals were monitored continuously and recorded each minute for 10 minutes on a treadmill. Fig. 6 shows the treadmill exercise at the sports center of Dongseo University. The person wore a wearable USN node to monitor ECG and accelerometer signals during exercise on a treadmill.

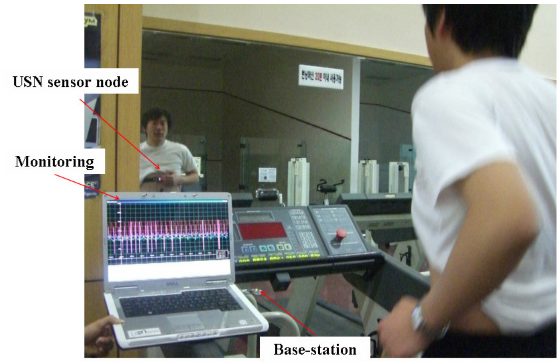

Fig. 6. Exercise on a treadmill by wearing the wearable sensor system.

Fig. 7-9 shows output waveforms of ECG, accelerometer and SpO_2 sensor when the person was walking, running and resting on a treadmill. The ECG signals provide a record of electrical events occurring within the heart. Acceleration signals provide valuable information about individual's activity such as walking, running, resting and falling. SpO_2 and heart rate are received from PPG data.

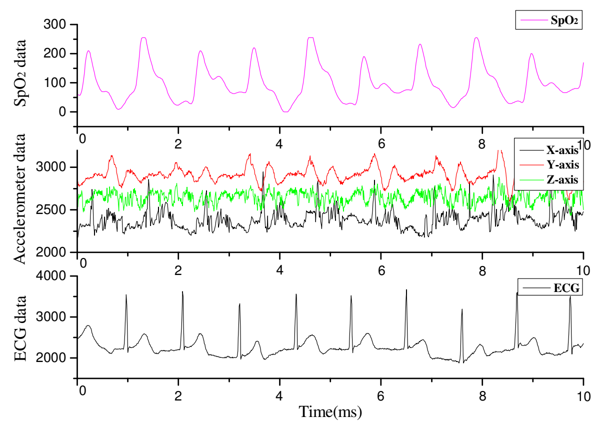

Fig. 7. Walking data on a treadmill.

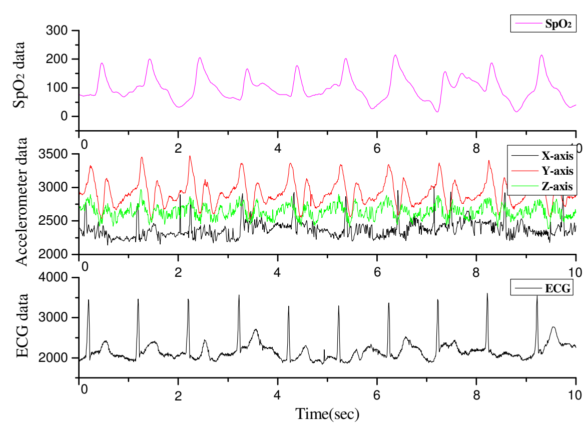

Fig. 8. Running data on a treadmill.

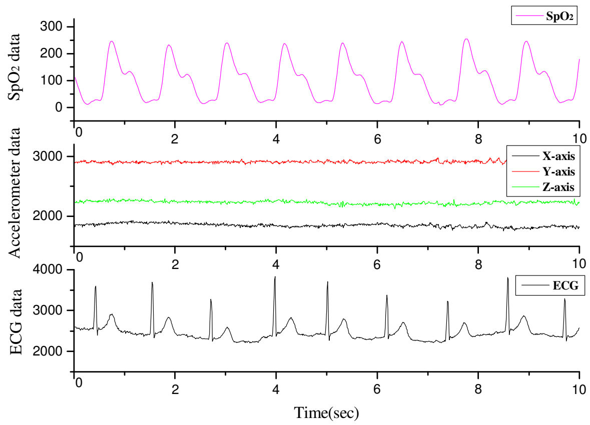

Fig. 9. Resting data on a treadmill.

Fig. 10 shows a screen capture of the SpO_2 monitoring program designed with LabVIEW. It monitors the SpO_2 wave signal by drawing pulse waveform on the server PC connected with base-station as soon as it receives the SpO_2 value (%) from portable sensor. This system acts as a continuous event recorder, which can be used to follow up patients at home, as they lead a normal life. Although the SpO_2 value is calculated by the module, measured data are saved on the server. It can reach a correct diagnosis even under situations where the patient is unconscious and has the ability to carry out daily activities. To enhance the informative content of the recorded data, this type of real-time measurement of SpO_2 values needs to be combined with action or activity monitoring data.

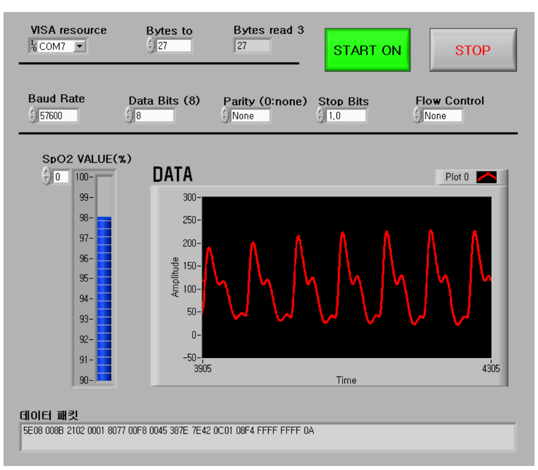

Fig. 10. Pulse waveform at server PC connected with a base-station.

IV. Conclusion

Particularly, the system of a next generation wireless sensor network compatible wearable devices for u-healthcare and activity monitoring has been presented here. The system has been demonstrated to operate successfully in u-healthcare system according to measurement, communication and monitoring without any disturbance to daily life of patient or elderly person. Such a system is composed of wearable u-healthcare sensors for the detection of ECG, acceleration and SpO_2 value detection, and a low-power wearable USN node. The USN node collects data provided by the sensors and sends these data to an acquisition unit which can be a server PC or internet by means of a personal server. Thus, the physiological data of a person under observation can be sent in real time to the server PC via several sensor nodes attached on the roof of house or hospital. With these, doctors could act immediately in case of anomalies in the vital parameters monitored.

References

[1] Guang-Zhong Yang (2006), *Body Sensor Networks*, Springer-Verlab London Ltd.

[2] Carten W. Mundt, Kevin N. Montgomery, Usen E. Udoh, Valerie N. Barker, Guillaume C. Thonier, "A Multiparameter Wearable Physiologic Monitoring System for Space and Terrestrial Applications", *IEEE Transactions on Information Technology in Biomedicine,* Vol. 9, No. 3, September 2005.

[3] IEEE-802.15.4, "PART 15.4: Wireless Medium Access Control (MAC) and physical layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs)," *The Institute of Electrical and Electronics Engineers, Inc.*, Tech. Rep., September 2006, IEEE Std 802.15.4-2006 (Revision of the IEEE Std 802.15.4-2003).

[4] Uwe Maurer, Anthony Rowe, Asim Smailagic, Daniel P. Siewiorek, "eWatch: A Wearable Sensor and Notification Platform", *Proceedings of the International Workshop on Wearable and Implantable Body Sensor Networks* (BSN'06).

[5] Lo BPL, Yang GZ, "Key technical challenges and current implementations of body sensor network", *Proceedings of the second International Workshop on Wearable and Implantable Body Sensor Networks*, pp1-5, 2005.

[6] J.Pan and W.J. Tompkins,"A real-time QRS detection algorithm, *BME-32*, pp.230-236., 1985.

[7] Aart Van Halteren, Richard Bults, Katarzyna Wac, Nicolai Dokovsky, George Koprinkov, Ing Widya, Dimitri Konstantas and Val Jones, "Wireless Body Area Network for Healthcare: the MobiHealth Project", Wearable eHealth System for Personalised Health Management, *Studies in Health Technology and Informatics*, 2004, Vol.108.

[8] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, "Electron spectroscopy studies on magneto-optical media and plastic substrate interfaces(Translation Journals style)," *IEEE Transl. J. Magn.Jpn*., vol. 2, Aug. 1987, pp. 740–741 [Dig. 9th Annu. Conf. Magnetics Japan, 1982, p. 301].

[9] MSP430F1611 micro-controller, http://focus.ti.com/docs/prod/folders/print/msp430f1611.html.

[10] Philip Levis, Sam Madden, David Gay, Joseph Polastre, Robert Szewczyk, Kamin Whitehouse, Alec Woo, David Gay, Jason Hill, Matt Welsh, Eric Brewer and David Culler, *TinyOS: An Operating System for Sensor Networks*, Ambient Intelligence. W. Weber, J. Rabaey, and E. Aarts (Eds.), Springer-Verlag, 2004.