Measurement of Motion Activity during Ambulatory Using Pulse Oximeter and Triaxial Accelerometer

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Abstract

An ambulatory pulse oximeter system based on wireless sensor network is designed and integrated to the wearable sensor node. The system is developed to measure motion activities using pulse oximeter and triaxial accelerometer sensor during in motion. The input signals are pulse oximeter and triaxial acceleration signals which are acquired from a finger. However, motion artifact is originated a result in a distorted PPG signal which may cause between the skin and sensor during physical activity. Therefore, motion artifacts prevent their broad in wearable, ambulatory pulse oximeter system. The measurement of those signals, such as the PPG and the electrocardiogram (ECG) requires being still tight during the measurement in order to get the accurate result preventing noises caused by the casual movement. In this paper, we calibrate the distorted PPG signal with the motion activities by measuring PPG and motion signals by using triaxial accelerometer as a reference signal. The system allows PPG signals to be transmitted in wireless sensor network from the pulse oximeter to a base-station connected to server PC via IEEE 802.15.4. The experiments were performed by using wearable ECG, accelerometer sensor and ambulatory pulse oximeter for measuring in different scenarios such as resting, swing, walking, etc.

1. Introduction

Pulse oximetry has gained wide spread clinical acceptance in the latter part of the 21st century. This is in part due to the development of the microprocessor, better patient sensor design, and better data processing algorithms. Virtually every patient, whether in the hospital, chronic care center or at home, that has oxygen or mechanical ventilation requirements would benefit from pulse oximetry. This may be in the form of continuous monitoring or intermittent diagnostic testing. Continuous and ambulatory monitoring systems such as ambulatory ECG are therefore needed to detect the trait. In medicine, an ambulatory ECG (Holter monitor) is a portable device for continuously monitoring the electrical activity of the heart for 24 hours or more. An ambulatory electrocardiogram (EKG or ECG) records the electrical activity of your heart while you do your usual activities. There are several researches on ambulatory system. N.J. Holter is developed the ambulatory ECG (Holter) device as one of the most widely accepted ambulatory monitoring systems [1]. Bellet also devised a continuous 2-hour tape recording system using a similar device [2]. Yamashita, et al. [3] attempted to develop a simple telemetry device for monitoring pulse at a finger. Wrist watch-type pulse oximetry and blood pressure sensors have been developed and commercialized by several companies including Casio (BP-100 and JP200W-1V) and Omron (HEM-608 and HEM-609). Many technical issues still need to be solved for clinical use [4].

In this paper, we propose measurement of motion activities using pulse oximeter and triaxial accelerometer sensor during in motion. The ambulatory pulse oximeter monitoring system based on wireless sensor network is designed and tested. We calibrate the distorted PPG signal with the motion activities by measuring PPG and motion activities by using triaxial accelerometer as a reference signal. The system allows PPG signals to be transmitted in wireless sensor network from the ambulatory pulse oximeter to a base-station connected to server PC via IEEE 802.15.4.

2. System Architecture

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The proposed ambulatory pulse oximeter monitoring system is consists of two parts: wearable sensor devices part and server part. The wearable sensor devices are wearable sensor node and PPG module, those are connected to a base-station and measured physiological data from human body [5]. The measured physiological data are transmitted to a base-station via IEEE 802.15.4. At server side, shows the output waveforms of accelerometer and PPG sensor. Fig. 1 shows overall system architecture of the ambulatory pulse oximeter for u-healthcare monitoring system.

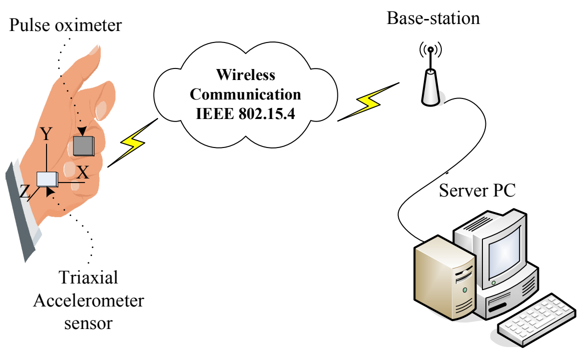


Figure 1. Architecture of healthcare system.

2.1 Basic measurement principles

The ambulatory pulse oximeter relies on spectrophotometric measurements of changes in blood color to determine oxygen saturation. This method is based on Beer-Lambert's law which relates the concentration of a solute to the intensity of reflected light through a solution. Knowing the intensity and wavelength of reflected light, spectrophotometric measurements are achieved by the reflection of light at two different wavelengths through tissue bed by light emitting diodes (LEDs) and measuring the light not absorbed by the tissue by a photodiode. This method exploits the fact that deoxyhemoglobin (Hb) has a higher optical extinction in the red region of the light spectrum around 660 nm compared to oxyhemoglobin (HbO_2). In the near-infrared region of the light spectrum around 940 nm, the optical absorption by Hb is lower compared to HbO_2, as shown in Fig. 2.

Due to the differences in extinction coefficients, the light absorbed due to Hb and HbO_2 can be determined and used to calculate the ratio R, which correlates to oxygen saturation.

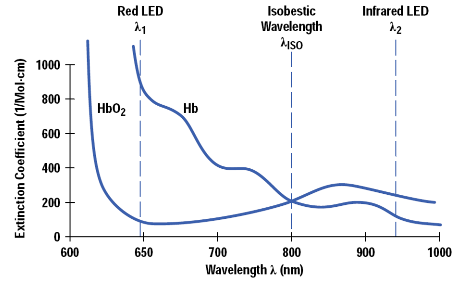


Figure 2. Absorptivity spectrum of Hb and HbO2 in the visible and near-infrared swavelength region.

2.2 Wearable sensor node

The wearable sensor node is developed by our laboratory for u-healthcare monitoring system as shown in Fig. 3 (a), which features an ultra low power Texas Instruments MSP430 micro-controller [6] with 10KB RAM, 48KB flash memory and 12-bit A/D converter. It supports several low power operating modes and consumes as low as 5.1uA in sleep mode and 1.8mA in active mode. The CC2420 wireless transceiver is IEEE 802.15.4 Zigbee compliant and has programmable output power, maximum data rate of 250Kbps and hardware provides PHY and some MAC layer functions [7].

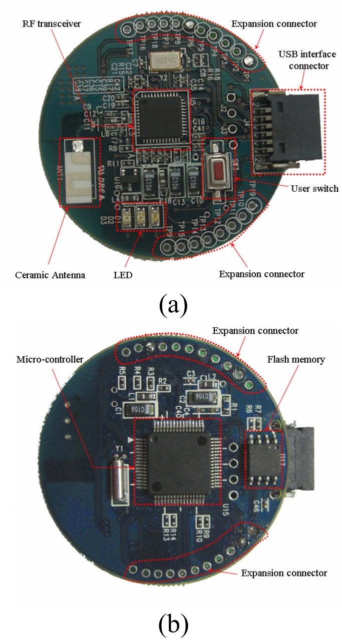


Figure 3. Wearable sensor node (a) front view, (b) back view.

Table 1. Specification of the wearable sensor node

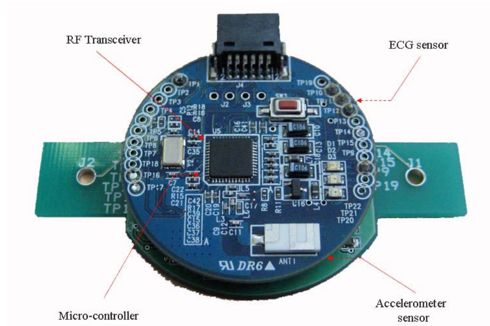
Species of Device	Specification Item	Specification
Accelerometer (MMA7260Q, Freescale)		3-axis
ECG (2 electrodes)	Gain	300 (24.8 dB)
	Cut-off frequency	0.05 ~ 123 Hz
A/D converter (embedded with MSP430F1611)	Resolution	12 bits
	Sampling rate	200Hz
Wireless transceiver (CC2420, Chipcon)	Frequency band	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

The CC2420 is controlled by the MSP430F1611 through SPI port and a series of digital I/O lines. The M25P80 is an 8Mb (1 Mbit × 8) serial flash memory with write protection mechanism, accessible from SPI bus. To minimize the size of wearable sensor node, we have made the USB programming board as a separate module which is needed only when nodes are connected to the server PC either for application download or when node act as base-station.

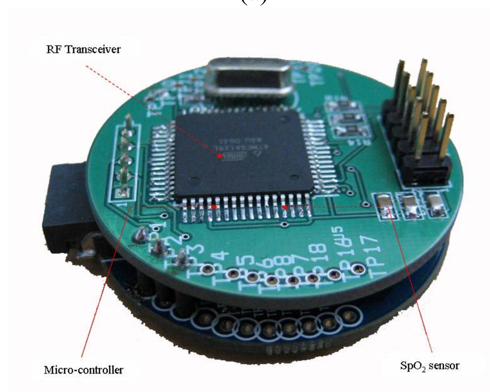
2.3 Wearable sensor devices

We developed two types of wearable u-healthcare sensor devices: a wearable sensor device with ECG and accelerometer sensor and a PPG module (the ambulatory pulse oximeter). Fig. 4 (a) shows a wearable sensor devices which has ECG and accelerometer sensor and can be used to a chest sensor belt with conductive fabric electrodes. We have the same two-layer PCB board, a wearable sensor node was placed on top and sensor board with an ECG and accelerometer was placed on the bottom layer. The wearable sensor node connects to the wearable chest sensor belt using a push button connector. To obtain ECG signal from human skin, we used the wearable sensor which contain conductive fabric electrode (size 8cm). As well as ECG signal, an acceleration signal obtains from wearable sensor node.

Fig. 4 (b) shows the ambulatory pulse oximeter which have PPG module to measure PPG signal. The SpO_2 values can be obtained by calculating the ratio of both lights, depending on absorption of light. PPG module has been designed to permit to manage almost of all processing (e.g. analog signal processing, signal collection and calibration, etc.) in a module. It is based on a low power 8-bit ATmega128L microcontroller operating in 3V. Low power operating PPG module is integrated to wearable sensor node for user's physiological parameters monitoring system.



(a)



(b)

Figure 4. Wearable sensor devices: (a) ECG and accelerometer sensor, (b) PPG Module.

The wearable sensor devices should be small and light and attached to body tightly to reduce noise effect and feel comfortable to wear. The ambulatory pulse oximeter is attached to the wrist as shown Fig. 5. The size of PPG module is same with wearable sensor node as a 40mm diameter respectively.

The ambulatory pulse oximeter performs data acquisition 5 bytes per 1 second containing PPG data, SpO_2 values and heart rate. Raw data acquired by the PPG module are transmitted to a PC via wireless sensor network. On the PC, a LabVIEW interface displays and stores these data to a file, after then a MATLAB program loads the data and applies the algorithm.

Figure 5. The developed ambulatory pulse oximeter system.

3. Experimental Results

Experiments were performed by using wearable ECG, accelerometer sensor and ambulatory pulse oximeter for measuring in different scenarios as shown in Fig. 6. Acceleration signals provide valuable information about individual's activity with PPG data through some scenarios. SpO_2 value and heart rate are received from PPG data.

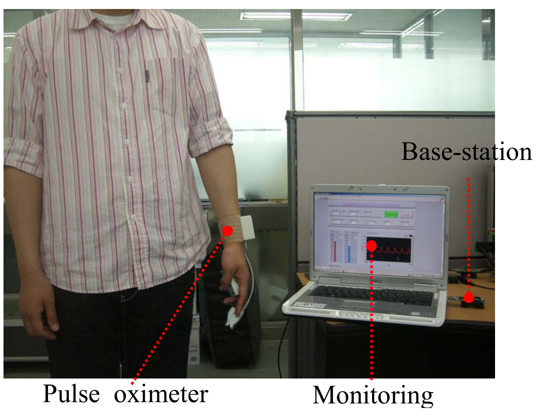


Figure 6. Wearing of the ambulatory pulse oximeter for ambulatory monitoring.

Motion artifacts are known to affect the accuracy and reliability of wearable sensors. These measurements indicate that motion patterns following movements with PPG and accelerometer. Accelerometer has been suggested as motion references for preserving physiological signals in motion patterns. Fig. 7-10 shows output waveforms of accelerometer and PPG signals, when person is resting, sitting and standing, swing and walking by wearing wearable sensors.

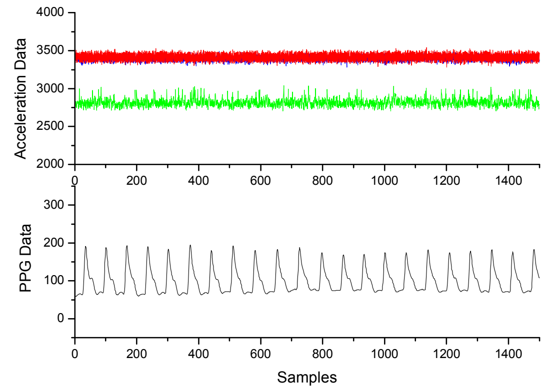


Figure 7. Resting data during ambulatory monitoring.

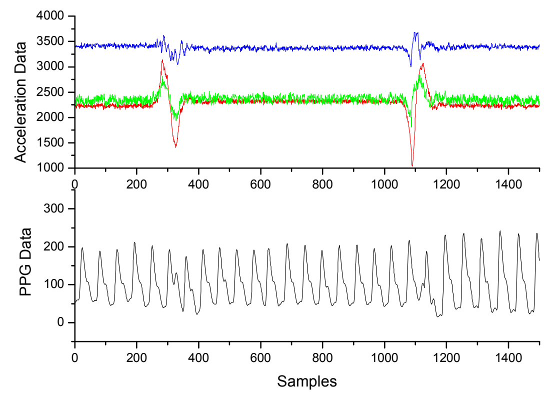


Figure 8. Sitting and standing data during ambulatory monitoring.

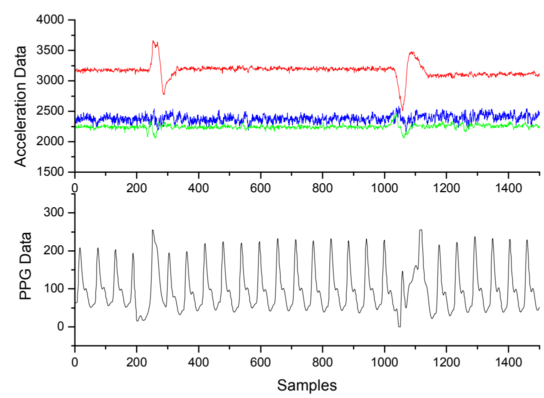


Figure 9. Swing data during ambulatory monitoring.

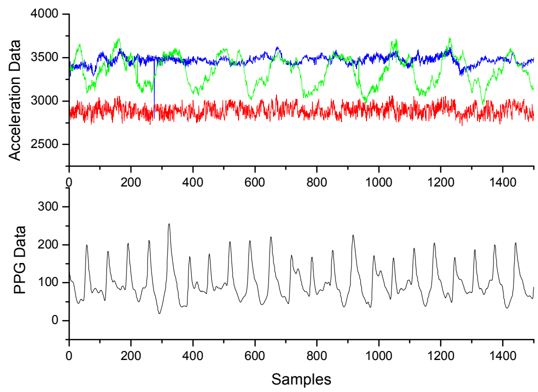


Figure 10. Walking data during ambulatory monitoring.

During the resting state, physiological data are stable readings. However, when the scenarios were sitting & standing, swing, and walking, the recorded data dropped significantly at several instances since the wearable devices determined that motion artifacts are included in these data. These measurement points, which were caused by the motion generated by activity, were revealed to indicate that no usable signals were being detected. Motion artifacts can be detected from accelerometer and PPG signals using scheduled scenarios previously. Each scenario occurred to different motion artifact signal which has deviated peak. These signals during scenario can lead to heart rate estimation depending on the measured peaks. These deviated peaks should be considerate.

Fig. 11 shows the screen capture of the SpO_2 monitoring program. This program was designed with LabVIEW. It monitors the PPG signal by drawing the pulse waveform at server PC connected base-station as soon as it receives the SpO_2 value (%) and heart rate from the ambulatory pulse oximeter. This system acts as a continuous event recorder, which can be used to follow up patients at home. ECG, acceleration and SpO_2 value can be measured on the wearable sensors, and all measured data are saved in server wirelessly. It can make correct diagnosis even under situations where the patient is unconscious and has the ability to carry out daily activity. The bio-signals of patient can provide informative details to the doctors using of the wearable sensors for monitoring. The goal was to provide a capability to monitor at server PC for real time measurements of multiple physiological parameters (ECG, Acceleration, and PPG data) through some scenarios.

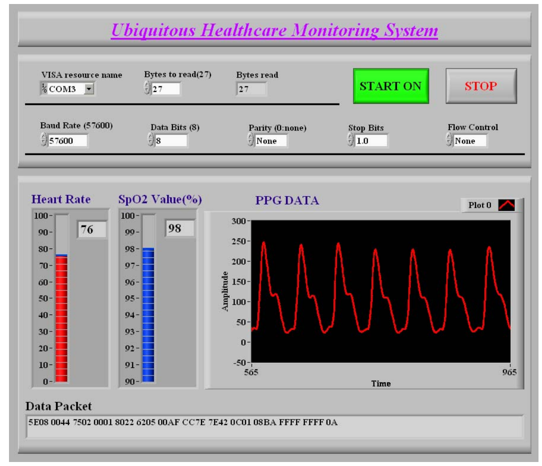


Figure 11. Pulse oximeter monitoring program at server PC.

4. Conclusion

An ambulatory pulse oximeter system based on wireless sensor network is designed and integrated to the wearable sensor node for u-healthcare monitoring system. The system has been demonstrated to operate successfully in u-healthcare system according as measurement, communication, and monitoring with scheduled scenarios in ambulatory. The distorted signals included motion artifacts can be obtained using pulse oximeter and triaxial accelerometer sensor. The acceleration signals allow obtaining a reliable measurement even in presence of motion artifacts. Thus, this paper proposed that it provide a capability to develop the wearable sensors, communicate physiological data and monitor at server PC for u-healthcare monitoring system during motion activities.

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