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Development of a wearable health monitoring device with motion artifact reduced algorithm (ICCAS 2007)

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Abstract: In this paper, a real-time, wearable and motion artifact reduced health monitoring device is represented. A finger band, wearable health monitoring device, is consists of photoplethysmography (PPG) sensor, 3-axis accelerometer, microprocessor and wireless module. The PPG sensor acquire distorted heart beat signal due to motion artifact. The finger movements are detected using the accelerometer, and major motion directions causing of the noise are researched by comparing each directional motion signals and distorted PPG signal. Two directional motions are significantly related to noise, therefore, these two directional active noise cancellation algorithm was applied to reconstruct the noise added heart beat signal. Low order (4th order) NLMS (normalized Least Mean Square) adaptive filter is employed for small size wearable device. The finger band device is experimented in daily body motion condition (1–3 Hz), and reduce distortion rate less than 5% by active noise cancellation algorithm. The motion artifact reduced finger band sensor can offer continuous health monitoring without daily motion artifact.

Keywords: real-time, wearable, photoplethysmography, motion artifact, active noise cancellation

1. INTRODUCTION

Vital signal measurement devices and techniques are important research fields for health care monitoring and an emergency health alarm system for patients and the aged. These person who has weak vital signal, should monitor their bio-signal, such as pulsation, continuously and alarm to others when their signal is weaker. Among various vital signals, pulsation is adequate to health monitoring device since it can be measured easier and it needs simple devices than others.

Photoplethysmography (PPG) is a noninvasive heart beat, pulsation, measurement instrument, which has a potential to be developed into a portable device due to its relatively small size. Heart beat affect to blood pressure and it change the volume of the vessel and rate of blood flow. These volume and flow change can be detected using near red and infrared wave length light source and detector. Using these properties, pulsation, which is related to heart beat, can be measured by gathering detector's signal.

The instrument has been developed for, monitoring and diagnosis patient not only in the hospital but also at home. However, for portable and ubiquitous health care system, the real-time measurement, wireless and motion artifacts problems should be worked out. In particular, motion artifact reduction is the most challenging issue. To reduce the problem many methods were researched this hindrance; one is sensorless approaches, which extract the pulsation's frequency component using frequency and time domain feature analysis [2, 3] without any other sensors. Another is the sensor approach, which obtain pulsation signal by removing the motion noises, using body movement information from other motion acquisition sensors. The most well-known method about this approach is active noise cancellation algorithm with an adaptive filter [4, 5]. But most of their research is off-line analysis, large program size which is not adequate to wearable and portable device, and experiments are not mostly wireless system.

This paper presents a real-time, wireless and wearable device with a motion artifact reduction algorithm. The device has an applicable small programming size for portable devices.

2. SYSTEM SETUP

2.1 Hardware Description

Fig. 1.Finger band sensor

The wearable sensor device should be small and light and attach to body tightly to reduce noise effect and feel comfortable to wear. Additionally, wireless communication device also reduces motion artifact by reducing effect of the data cable inertia.

The finger band sensor, wearable PPG sensor, is attached to the finger base, as shown in Fig. 1. The size and weight is 25 x 30 mm^2 and 16.8g, respectively. The PPG sensor is located on the inner layer of the band, and the accelerometer is on the circuit.

The finger band device is divided into two parts; the sensor device and the host analysis computer. In detail, the sensor device part can be divided into three parts, as shown in Fig.2.

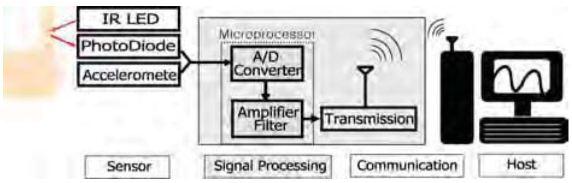

Fig. 21 Block diagram of photoplethysmography

The first sensor part consists of a light source, a photo sensor for PPG and an accelerometer for motion detection. A 940 nm wavelength, a surface mounted type Infrared LED, and a photo-diode are used to acquire the PPG signal. Although a more detailed explanation follow in the next chapter, motion is considered to be directly related to noise, so to measure and analysis the body motion and a noise source, a 3-axis accelerometer is used.

Next part is the pre-signal processing, circuit part, which contains an analog signal processing part, amplifiers, filters, and analog to digital converters (ADC). Since the raw signal on the sensor signal (especially the AC component) is so small and distorted, signal processing is demanded before being sent to a communication system. The raw signal demands a low pass filter for reducing high frequency noise and high pass filter for rejecting a DC component to enhance the AC component. As filters, second order active analog high and low pass filters (Sallen-Key Filter) are used. Filtering signals are amplified to enhance and acquire discriminable signals by a thousand times.

The last part is digital signal processing. High order filtering has good performance to extract wanted signal, but more number of components are required to increase filtering order. Therefore, digital filtering is employed to satisfy both circuit size and filtering performance. The filters are designed as a 0.5 – 3 Hz band pass filter, and totally fourth order analog active filter and digital filter are used in this signal processing.

The following part is the communication system. To transmit obtained data from the sensor device to the host computer, the microcontroller converts data into communication language, an 8bit digital signal. Then it transmits the data through a wireless device, Bluetooth. It is a widely used device, especially for portable devices such as in MP3 players or cellular phones. The device has up to 30m communication distance, and size of the device is 20 x 18 mm^2. The operation voltage is 3.7 V.

Labview software from National Instrument obtains transmitted data and display by graph on the host computer. Also, digital filtering and analysis algorithm are programmed

2.2. Motion artifact reduction algorithm

Active noise cancellation algorithm is used to reduce motion artifact. This is a signal filtering algorithm from a noise added pulsation signal and body motion signal to noiseless pulsation signal. The distorted PPG signal contains motion signal components and using adaptive filter, heart beat signal is extracted from various noise signal components.

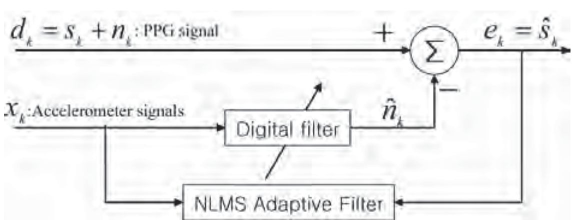

Fig. 3. Block diagram of the active noise cancellation algorithm

Fig. 3 shows a block diagram of an active noise cancellation algorithm, which reconstructs a raw pulsation signal (s_k) from the corrupted signal (d_k), using measurable noise signal (x_k). Here, PPG and body motion data correspond to d_k and x_k respectively. This research predominantly used 3-axis accelerometer signals (x_k) for body motion data (n_k).

In this study, NLMS (Normalized Least Mean Square) adaptive filters were employed due to their fast processing and low order filter coefficients [6]. In the equation (1), w(n), the digital filter coefficient is computed from products of step size (μ(n)), input data (x(n)) and error data (e(n)). Instead of fixed step size in LMS algorithm, the step size are changed and normalized by the energy of input data vector. Step size, μ, are computed with the coefficients a, b and input data as equation (2), and the role of the coefficients are prevent the step size not to fluctuate excessively. Thorough this various step size condition, in NLMS cases, more flexible and stable signal processing is possible, which is appropriate for real-time and wireless sensors.

$$\mathbf{w}(n+1) = \mathbf{w}(n) - \boldsymbol{\mu}(n)\mathbf{x}(n)e(n) \quad (1)$$

$$\boldsymbol{\mu}(n) = \frac{b}{a + \mathbf{x}^{\mathrm{T}}\mathbf{x}} \quad (2)$$

3. EXPERIMENT

PPG signals are measured at not only moving left finger but also right finger in fixed pose, as a reference signal. Pre-experiment resulted that longitudinal axis and rotational direction to finger directional movements are strongly related to motion artifact. Therefore, two directional active noise cancellation algorithms are applied to reconstruct the pure PPG signal. The experiments are progressed in that various frequency movement conditions are experimented during 30 sec in finger longitudinally and 20-cm-long hand waving. The range of the frequency is similar to daily body motion, 1.5~2.5 Hz. Zero-crossing (Z.C) peak counting method are used as an evaluation method.

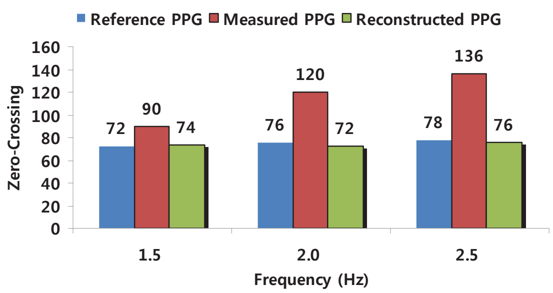

Fig.4. Pulsation counts from the Z.C. of the signals

The result, Fig.4, shows that the motion artifact reduction algorithm improve performance. The x, y axis represent frequency and represent number of zero-crossing during a minute, respectively. Lower than 1Hz condition, zero-crossing error between reference and distorted measured PPG signal are nearly zero. The number of reference pulsation is 72 to 78 bpm (beat per minute), from normal healthy subject, and That of measured signal is 90 to 136 bpm in 1.5~2.5 Hz hand waving conditions, the error rates increase as movement frequency is higher. However, that of the reconstructed signal with motion artifact reduced algorithm detected almost same number of reference signal.

Table 1 Error between signals on various frequency conditions

Signal comparison	Z.C. error (%)		
	1.5 (Hz)	2.0 (Hz)	2.5 (Hz)
Reference v.s. Measurement	25.00	57.89	74.36
Reference v.s. Reconstructed	2.78	5.26	2.56

Table 1 shows error rates between the numbers of each signal's zero-crossing in various frequency conditions. Error rates increase from 25 % to 75 % as the frequency is higher. However reconstructed PPG signal case have low error rate, averagely lower than 5%. Besides it is represented lower than 4 count on beat per minute unit. Especially, in the 2.5 Hz motion condition, the error rate between reference and measured signal is 74 %, but between reference and reconstructed signal is 2.56 %. It means that the designed device and algorithm reduce motion artifacts efficiently.

4. CONCLUSION

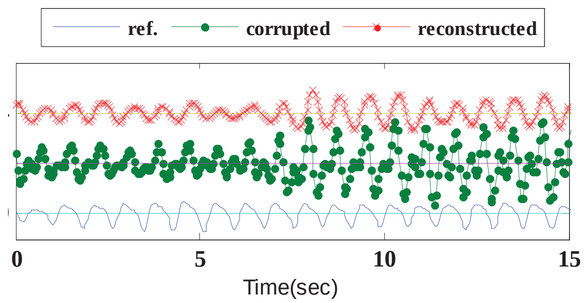

Fig.5. Reference (bottom), corrupted (middle) and reconstructed (top) signal in 2.5 Hz hand waving conditions

A real-time, wearable and wireless finger band sensor is designed with the motion artifact reduction algorithms. We obtain body motion data which is source of motion artifact using the accelerometer, and it is applied to active noise cancellation algorithm. As experiments, one directional hand motions which has difference frequency conditions are given. Fig.5 shows experimental signals; lower periodical signal is reference pulsation signal, middle complex signal is measured corrupted signal, and top smooth and periodical signal is reconstructed signal. On the graph also represent the performance is well-done. As a result, counting error of pulsation signal is reduced less than

5%.

The experimental frequency condition is similar to a hand's daily movement. For example as hand motions, running, walking [7], and hand gesture [8] have approximately 2 to 4 Hz frequency motion, and as finger motions, object exploration and texture scanning [9] have 0.8 to 2 Hz in table 2. But in hand writing, typing and tapping condition (4~7 Hz), they demand more high frequency artifact experiments and it remains future works.

Table 2 Frequency of daily hand movement

Motion		Frequency (Hz)
Hand motion	Run	3
	Walk	2
	Hand gesture	0 - 4
Finger motion	Object exploration	0.8 – 1.6
	Texture scan	0.8 – 2.2
	Hand writing Typing Tapping	4 - 7

Humans are moved more than remain fixed, relaxed pose on our daily life. Moreover, accidents and emergencies occur in movement condition. Therefore, wearable and portable health care device with motion artifact reduced algorithm techniques are demanded for continuous health monitoring. And the proposed device in this paper could have a potential to developing this portable and wearable device without daily motion artifact.

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