Estimation of Breathing Rate and Heart Rate from Photoplethysmogram

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Abstract—**Photoplethysmograph (PPG) is a simple and cost effective method to assess cardiovascular related parameters such as heart rate, arterial blood oxygen saturation and blood pressure. PPG signal consists of not only synchronized heart beats, but also the rhythms of respiration. The PPG sensor, which consists of infrared light-emitting diodes (LEDs) and a photodetector, allows a simple, reliable and low-cost means of monitoring the pulse rate. In this project, PPG signals are acquired through a customized data acquisition process using Arduino board to control the pulse circuit and to obtain the PPG signals from human subjects. Using signal processing techniques, including filters, peak detections, wavelet transform analysis and power spectral density, the heart rate (HR) and breathing rate (BR) are be obtained simultaneously. Estimations of HR and BR are conducted using MATLAB algorithm developed based on the wavelet decomposition techniques to extract the heart and respiration activities from the PPG signals. The values of HR and BR obtained using the algorithm are similar to the values obtained by manual estimation for seven sample subjects where the range of percentage errors are small about 0 - 9.5% for the breathing rate and 2.1 - 5.7% for the heart rate.**

Keywords— Photoplethysmograph, breathing rate, heart rate, wavelets decomposition

I. Introduction

Breathing rate (BR) is defined as the number of breaths taken within a period of one minute and measured when a person is at rest. Heart rate (HR) is measured as the number of heart contractions within one minute and it usually depends on the age and level of physical fitness. Normal resting HR is between 60-100 beats per minute (bpm) [1]. BR measured in the similar way to the HR, with the average rate between 12-20 breaths per minute [2]. BR and HR are vital signs, thus they are important in predicting the signs of chronic diseases such as heart attack or pneumonia [3]. The decrease and increase in BR and HR can be a sign that something is wrong in our body. Increased BR (tachypnea) can be caused by fever, dehydration, asthma and lung infections, while the possible causes of decreased BR (bradypnea) can occur due to the use of narcotics, alcohol, sleep apnea and brain conditions [3]. Therefore, monitoring of BR and HR is very important to monitor the health condition of individuals.

Respiratory measurement is usually carried out using the tools and techniques such as spirometers, pneumotachometry and capnography. This equipment cannot be used in all situations and condition of the patient as these devices can cause inconvenience to the person using it or it may disrupt normal breathing. Thus, measurement of respiratory rate from physiological signal is more suitable to be used such as electrocardiogram (ECG) [4] and photoplethysmogram (PPG) [5] which is always highly recommended by medical experts. Allen 2017 has highlighted that PPG is one of the best method to obtain cardiovascular related data based on the variation of the blood volume related to the heart [6]. PPG signal contains a lot of information about the body systems including the cardiovascular system, respiratory system and central nervous system. Thus by monitoring the PPG signal, two signals, which is measurement of BR and HR can be generated [7].

As the PPG signals have hidden rhythms of breathing movements, estimation of BR and HR from PPG signals can be achieved through many steps of signal processing including filtering, peak detections, wavelet transform analysis and power spectral density analysis. Other researchers evaluated BR based on ECG R-peak amplitudes, respiratory sinus arrhythmia and baseline wander [4] and some did it using principal component analysis (PCA) and empirical mode decomposition (EMD) on PPG signals, [8]. In this paper we evaluated wavelet transforms on PPG signals and the estimation of BR and HR are based on the power spectral density of the wavelets.

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II. Methodology

Initially, the preparation of finger pulse sensor device is carried out by the construction of an integrated PPG circuit. A microcontroller Arduino is used as a necessary tool in the development of the integrated circuit. PPG signals are acquired from the index finger using the pulse sensor. The acquired PPG signals are then filtered to remove the noise signals and further processed using wavelet decomposition technique. Next, the power spectral density is used to determine the level of breathing and heartbeat waves that have been separated. In the final stage, an algorithm is develop to display the two estimated readings of heart rate and respiratory rate.

A. PPG Integrated Circuit

The system is generated using a 5V power supply incorporating the use of a finger pulse sensor. The sensor operates in reflection mode with infrared (IR) LED and the light detector placed adjacent to the LED. The sensor is backed with dark strip covering the finger, thus no external influence of bright light intensity during the process of data recording. Finger pulse sensor is connected to the input pin positive (+) operational amplifier (OpAmp) circuit which is LM358 as a data input to the system. The final part of this circuit is alternating current (AC) gain stage using non-inverting OpAmp LM358. The capacitor that is connected to R2 is used to block DC signal component and allow only AC signal passing through the circuit. An output signal of the gain stage AC will be read by the analog-to-digital converter used on Arduino boards as a controller circuit.

An external LED is placed on the OpAmp output to act as a detector that blinks according to the person's heart rate. A resistor 1k ohms is used to limit the current flow and thus prevent damage to the LED. The blinking LED, ease up detection of the PPG signal. Then the signal amplified by the operational amplifier is transferred to a computer using an Arduino microcontroller board using its built-in analog-to-digital converters. Analog values can be read directly in the software Arduino via serial monitor. The values displayed will be recorded and stored in .txt files for further processing by Matlab programming.

B. Extraction Of Respiration And Heart Rhythm Signals

Extracting the respiration and heart rhythms signals from the PPG signal is the most important process in this project. The process of extraction will identify both the heart rate and respiration waveforms from the PPG signal. In this project, the method used to extract these signals is by using the wavelet decomposition and power spectral density analysis.

C. Wavelet Decomposition

Wavelet decomposition is a technique of signal processing that allows signals to be decomposed into different levels of frequency signals. Thus, in order to facilitate the extraction of the heart and breathing waveforms, the PPG signal undergoes wavelet decomposition. The BR and HR can be computed based on the frequencies required for breathing and heart rate, respectively. In the process of decomposition of the wave, low-pass filter (LPF) and a high pass filter (HPF) are utilize to decompose the incoming signal into different scales. LPF coefficients are referred to as "approximation" which is defined for identity and HPF referred to as "detail", which is defined for signal delivery. Thus, the decomposition process is a repeated process that lead to the wavelet decomposition tree. An example of block diagram for four stages of decomposition is shown in Figure 1, where the approximation coefficient is described by the coefficient A and the detail described in coefficient D.

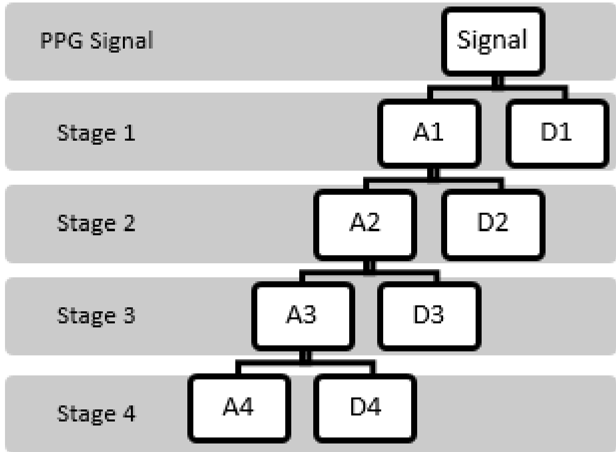

Fig. 1. Wavelet decomposition stage

After decomposition of the signal waveforms, the level of detail (D) coefficients showing breathing and heartbeat signal are extracted from the PPG signal. Figure 2 shows a 10-level signal decomposition for each detail PPG signal acquired. Based on the frequency of the signals, the coefficient D8 represents breathing signal and the coefficient D6 represents the heart signal. Using the detail coefficients corresponding to breathing and heart rhythm signals, an analysis of the power spectral density (PSD) is used to obtain the main frequency of the PSD which corresponds to the breathing rate and heart rate values.

PSD indicates where the frequency variation is strong and weak. Unit PSD is the energy per frequency and it can show the energy in a particular frequency range. This method will show the range of frequencies where it is strong to determine the main frequency of the signal waveform. Through this method, each wave that has been extracted will be analyzed to determine the frequency of the signal obtained. After the analysis is done, the PSD on the level of detail, D6 indicate the frequency range of around 1Hz, and this proves that the level at detail D6, the resulting wave is the heartbeat signal which is around 60 bpm. In the D8, the frequency obtained from the PSD shows the frequency range is about 0.2-0.35 Hz. According to Kiran et. al [4], the frequency range of 0.2-0.33 Hz is a respiratory signal of 12-21 breath per minute, and this shows that the level of detail D8 is the waveform that corresponds to the respiration.

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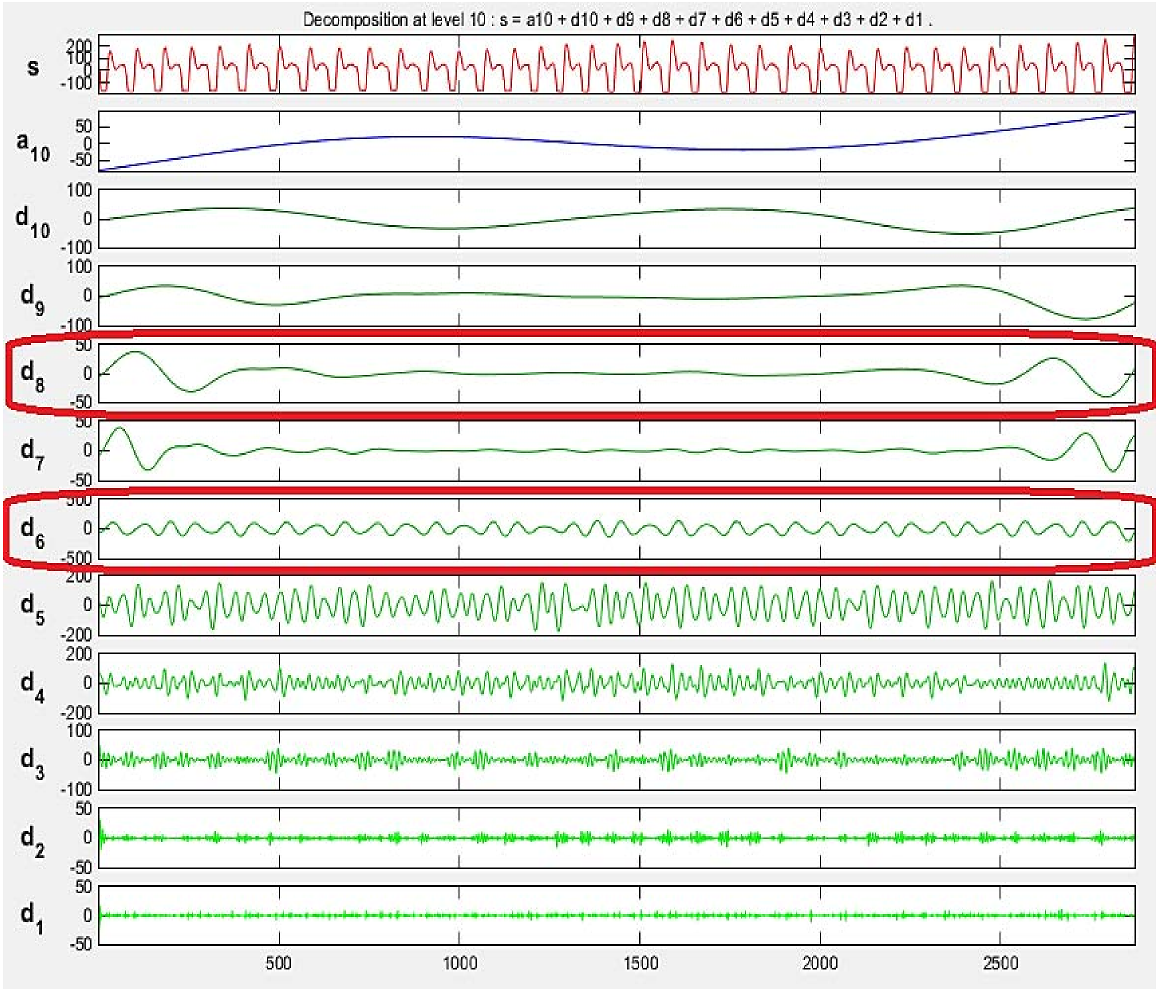

Fig. 2. Wavelet decomposition detail levels

D. Algorithm For Breathing Rate And Heart Rate Estimation

At this stage, an algorithm has been developed to display the estimated individual readings for BR and HR. This algorithm has been built based on peak detection technique. Equation 1 and 2 show the calculation of the duration in seconds and minutes, respectively.

$$Duration\ in\ second, T(s) = \frac{Length\ of\ the\ signal, N\ (Hz)}{Sampling\ frequency, Fs\ (Hz)} \tag{1}$$

$$Duration\ in\ minute, T(m) = \frac{Duration\ in\ second, T(s)}{60} \tag{2}$$

The wave peaks obtained for both the breathing and heart waveform are used for the calculation of the total rate in a minute as in equation 3.

$$Total\ rate\ per\ minute = \frac{peak\ count}{Duration\ in\ minute, T(m)} \tag{3}$$

The algorithm for estimating the BR and HR has been applied on PPG signals for seven sample data recorded from seven different human subjects. Comparison of the BR and BR obtained using the developed algorithm and the estimated BR and HR obtained manually by clinical method have been made to identify the percentage of errors between the two methods. Equation 4 shows the general formula for calculation of the percent error for BR and HR between manual calculation method and system development based on algorithm estimation.

$$\%\ error = \frac{|manual\ calculation - algorithm|}{manual\ calculation} \times 10 \tag{4}$$

III. Result And Discussion

The display of estimated readings within one minute for BR and HR are in Matlab command window as shown in Figure 3. Estimation of the reading for both BR and HR are based on the respiratory waveforms and heart rhythm signals extracted from the PPG signals. Samples of PPG data are taken from seven individuals. Each individual has the estimated BR and HR from system development that are slightly vary from each other. The

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results of BR and HR are also compared to the values obtained by manual calculation in accordance to the clinically practise method where BR is estimated based on observation of movement up and down of the chest in a minute and HR is based on average number of radial pulse for ten seconds.

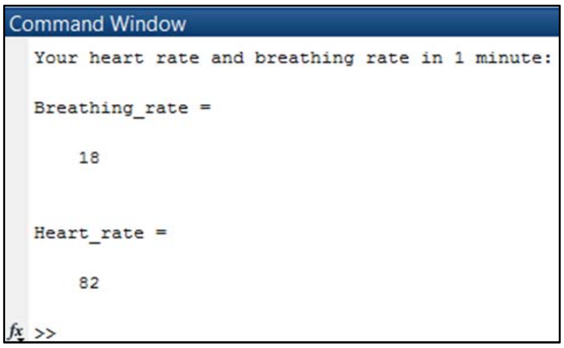

Fig. 3. Sample reading of heart and breathing rate

The estimated data of BR and HR for seven sample subjects based on clinically practised method and system development are shown in Table 1 and Table 2, respectively. For comparison, the percentage of error is used to evaluate how much the percentage of error based on the difference between system development using algorithm and manual method conducted according to clinical practice.

TABLE 1. BREATHING RATE FOR CLINICAL METHOD AND SYSTEM DEVELOPMENT ALGORITHM

Sample no.	Clinical method	System development	Percent error (%)
1	19	20	5.3
2	18	18	0.0
3	20	21	5.0
4	21	23	9.5
5	24	26	8.3
6	22	23	4.5
7	21	22	4.8

TABLE 2. HEART RATE FOR CLINICAL METHOD AND SYSTEM DEVELOPMENT ALGORITHM

Sample no.	Clinical method	System development	Percent error (%)
1	79	83	5.1
2	95	97	2.1
3	77	81	5.2
4	80	82	2.5
5	106	112	5.7
6	82	80	2.4
7	94	97	3.2

Based on the percentage of error shown in the table, the difference reading is acceptable because the range of percentage errors obtained is small. Comparison of breathing rate shows the minimum percentage error is 0% and the maximum error is only 8.7%. For the estimated heart rate, comparison of the two methods shows the minimum percentage error is 2.1% and maximum percentage error is 5.4%. This shows that the estimated values of BR and HR through system development using algorithm are similar to the estimated values through manual estimations using clinically practised method.

IV. CONCLUSION

In this paper we report the simultaneous estimation of BR and HR from PPG signal based on the previous studies which indicated that PPG signal contains not only the heart rhythms, but also respiratory signals. PPG signals are acquired through an in house PPG sensor integrated circuit being controlled by Arduino UNO board. The PPG signals are preprocessed and undergone wavelet decomposition into several frequency levels. Waveforms of coefficient D6 shows the characteristics of a heart rhythm and waveforms of coefficient D8 shows the characteristics of respiratory signal. PSD is used to obtain the main signal frequency and thus to estimate breathing rate and heart rate from the PPG signal. Analysis of the estimation of BR and HR on seven PPG sample data obtained from seven subjects has been conducted. The estimation results are also compared with the manual values obtained through common clinically practiced method. Based on the calculation of the percentage of errors made, the estimation of BR and HR obtained are almost equal to the values obtained through the manual method in which the range of the percentage of errors are small, about 0-9.5% for breathing rate and 2.1-5.7% for heart rate. Drawback of bulky clinical equipment such as using the spirometer can be overcame because the estimation of BR and HR from PPG signals is more suitable to be used as it will not disturb normal breathing of the user.

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