Simultaneous Measurement of Respiratory Rate and Heart Rate by using Body Conduction Sound Sensor

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Abstract

In recent years, according to the causes of death ranking, heart disease and pneumonia are on the top of the rank. Heart disease and pneumonia cause the changes of respiratory rate and heart rate respectively. Thus, it is necessary to measure our heart rate and respiratory rate at an early stage. The purpose of this research is the development of the equipment that can measure anyone's heart rate and respiratory rate by using a body conduction sound sensor. The body conduction sound sensor is composed of electret condenser microphone, acrylic case, and filler. This sensor acquires the sound of the heartbeats and respiratory sounds by attaching the sensor on the left side of the body. As the obtained sound from our body has high-frequency noises, an analog filter is used to remove and filter the noise. After filtered, the obtained sound is transferred as an input to the microcomputer. Then, heart rate and respiratory rate is derived by signal processing. To confirm the effectiveness of the device, an experiment is performed by comparing the value of the heart rate and respiratory rate of the device with the value from self-check.

Keywords: respiratory rate, heart rate, body conduction sound sensor, microphone.

1. Introduction

In 2015, according to the causes of death ranking in 370,131 people, heart disease is ranked second with 195,933 cases and pneumonia is ranked third with 120,846 cases⁽¹⁾. Heart disease is a generic term for a disease that

occurs in the heart. An example of the main heart trouble includes coronary heart diseases such as angina and myocardial infarction⁽²⁾. As heart disease develops in our body, changes in our heart rate and respiratory rate occur. On the other hand, pneumonia is a disease related to the respiratory system. The development of pneumonia in our body causes the changes in our respiratory rate⁽³⁾. The chronic stage of either heart disease or pneumonia leads to death⁽⁴⁾. Thus, it is necessary to measure our heart rate and respiratory rate at an early stage.

Until now, doctors commonly measure the heart rate by manually counting the heartbeat sound from hearing through a stethoscope or using electrocardiogram device (ECG)^(5,6). Moreover, the respiratory rate can be measured from the hearing of respiratory sound through a stethoscope. Even though there are developed medical devices to calculate the respiratory rate and heart rate such as a bedside monitor and electronic stethoscope, these methods are not commonly used for daily basis^(7,8).

Regarding this problem, a system of a simultaneous measurement of the respiratory rate and heart rate using body conduction sound sensor is proposed. The method used for measuring the respiratory rate and heart rate is by calculating the respiratory sound and heartbeat sound using a body conduction sound sensor attached directly to the body skin below the left armpit. From the proposed system, the monitoring of respiratory rate and heart rate can be commonly used.

2. Proposed System

2.1 Summary

The sensor used in this paper to measure the respiratory rate and heart rate is called a body conduction sound sensor. The body conduction sensor is connected to an electric circuit and a microcomputer for the signal processing and value display. In this research, the system is designed on several algorithms in order to measure the respiratory rate and the heart rate of a human. The algorithms for this system will be explained in chapter 3.

2.2 Body Conduction Sound Sensor

The body conduction sound sensor uses an electret condenser microphone (EM289 made by Primo Corporation, known as ECM) as the main component. The ECM is fixed to the acrylic resin case and the surface is filled with polyurethane elastomer (product by Exseal cooperation, known as filler). The body conduction sound can be achieved by attaching this sensor to the surface of the body. The image of the body conduction sound sensor is shown in Fig. 1 and the structure of the body conduction sound sensor is shown in Fig. 2.

2.3 System Device

In this paper, to achieve the system objectives, the body conduction sound sensor is incorporated with others component to build the proposed system device. The input signal of the body conduction sound is achieved and operated by a programmed microcomputer called mbed (product by ARM Company). To display the result of the

Fig. 1. Body conduction sound sensor.

Fig. 2. Structure of the body conduction sound sensor.

measurement, the proposed system used a small LCD (Liquid Crystal Display) connected with the microcomputer. The proposed system device is powered by a 3.7 V lithium polymer battery and used a 3D printed housing for the device body. The image of the proposed system device is shown in Fig. 3.

3. Detection Measurement

3.1 Measurement Condition

The measurement condition is shown in Fig. 4. The body conduction sound sensor is placed directly on the subject's skin below the armpit or specifically on the left side of the 6th rib of the body. On a rest condition, the body conduction sound is lightly pushed onto the main body to gain a better body conduction sound signal. The sampling frequency of the body conduction sound sensor is 66.67 Hz and the number of sample taken is 1024 data. Therefore the measurement period is about $1024 / 66.67 \text{ Hz} = 15.36 \text{ s}$.

3.2 Fourier Analysis

The example of the measured signal of the body conduction sound is shown in Fig. 5. From the result of the measurement, the pattern of the sound of the heartbeat and the respiratory sound can be seen. However, to measure a precise respiratory rate and heart rate, the identification of the respiratory sound and the heart sound need to be done.

Fig. 3. Proposed system device.

Fig. 4. Measurement condition.

After collecting the data from the sensor, the data undergoes the Fourier analysis to determine and analyze the range frequency for respiratory rate and heart rate. In this paper, discrete Fourier transforms (DFT) is used for the analysis of the signal frequency⁽⁹⁾.

A normal respiratory rate for a person is 0 to 30 times, thus the frequency is 0 Hz to 0.50 Hz. For the heart rate, the normal adult heart rate is 51 bpm to 120 bpm, thus the frequency is between 0.85 Hz to 2.00 Hz. The result of the discrete Fourier transform of the measured data and the identification of the respiratory rate and heart rate frequencies is shown in Fig. 6.

After the ranges of the frequencies of the respiratory rate and heart rate have been identified, the result in Fig 6 is then converted to its wave signal separately by using the principle of inverse discrete Fourier Transform (IDFT)⁽¹⁰⁾.

The result of IDFT of the respiratory rate range and the heart rate range is shown in Fig. 7 and Fig. 8 respectively.

3.3 Autocorrelation Function

From Fig. 8, the peaks of the heartbeat sound wave are not constant and needed to be correct. Therefore, the principle of the autocorrelation function is used to correlate the values of the heartbeat sound based on the others samples⁽¹¹⁾. The result of the autocorrelation in the heartbeat sound wave is shown in Fig. 9.

3.4 Respiratory Rate and Heart Rate Derivation

From the maximum period value of the respiratory wave in Fig. 7 and maximum period value of the heartbeat wave in Fig. 9, the value of the respiratory rate, RR and heart rate, HR can be derived by the following equation consecutively.

$$RR = \frac{60}{T_{RR}} \quad (1)$$

$$HR = \frac{60}{T_{HR}} \quad (2)$$

Where T_{RR} [s] is the highest sinusoidal period in the respiratory wave pattern and T_{HR} [s] is the highest sinusoidal period in the correlated heartbeat sound wave pattern.

4. Evaluation Experiment

4.1 Aim

The experiment was conducted to evaluate and

Fig. 5. Example of the measured signal.

Fig. 6. Result of the DFT and signal frequencies identification.

Fig. 7. Result of the IDFT for respiratory rate range.

Fig. 8. Result of the IDFT for heart rate range.

confirm the effectiveness of the developed device to calculate a person's heart rate and respiratory rate simultaneously on various people.

4.2 Environment and Methodology

The measurement condition of the subject is as stated in section 3.1. The subject's respiratory rate and heart rate was measured at a rest condition and was tested for 60 seconds on 10 subjects (from A to J). The subjects were 10 young and healthy male students at an age range from 22 to 25 years old. In consideration of the relation of heart rate to the body mass, the subjects are categorized based on their Body Mass Index (BMI) standardized by the World Health organization which is divided into standard weight, underweight and overweight. To evaluate the result of the system measurement, the respiratory rate and the heart rate of the subject was measured from the subject vital signs check simultaneously with the system.

4.3 Result and Discussion

The result of the evaluation experiment of the system and its comparison to the vital signs check reading is shown in Table 1 and Table 2.

From the standard weight and underweight category, as can be seen in Table 1, the maximum number of the difference of the respiratory rate of the proposed system and the vital sign check is one time. The vital sign check for the respiratory rate is the movement of the posture of the subject's stomach and chest when breathing. The difference of the measurement is caused by the difference of the starting point of the measurement of the proposed system and starting point of the subject's breathing by human judgment.

As can be seen in Table 2, from the standard weight

Fig. 9. Result of the autocorrelation function on the heart rate signal.

Table 1. Comparison of the measurement of the respiratory rate of the subject using the proposed system with vital signs check.

Subject Category	Subject	Respiratory Rate [times]	
		Proposed System	Vital Sign Check
Normal Weight	A	17	18
	B	18	18
	C	21	20
	D	16	16
Underweight	E	18	18
	F	19	18
	G	19	18
Overweight	H	16	16
	I	25	18
	J	22	20

Table 2. Comparison of the measurement of the heart rate of the subject using the proposed system with vital signs check.

Subject Category	Subject	Heart Rate [bpm]	
		Proposed System	Vital Sign Check
Normal Weight	A	75	76
	B	65	64
	C	89	88
	D	70	72
Underweight	E	98	100
	F	86	84
	G	71	68
Overweight	H	69	88
	I	77	64
	J	85	80

and underweight category, the maximum difference of the heart rate of the proposed system and vital sign check is 3 bpm on subject G. The difference is caused by the common error for vital signs check. For the heart rate, the vital sign check was performed by calculating the number of pulse rate per minute. However, as a pulse is a feel of increase of pressure over an artery following each heartbeat, the increase of pressure can be too low or too high and cause differences between heart rate and vital signs check. As the maximum difference between the heart rate and vital signs check is very low, the measurement of the heart rate of

proposed system can be assume effective on standard weight and underweight person.

On the other hand, for the overweight category, the maximum difference of the respiratory rate is 7 times and the maximum difference of the heart rate is 19 bpm both on subject I. The differences are caused by the high amount of body fat that obstructs the sound signal before obtained by the body conduction sound sensor. However, the differences can be reduced if subject leans their body to the left side to increase the pressure of the body to the body conduction sound intensity, thus receiving more precise signal⁽¹²⁾.

From the result of the evaluation experiments, both respiratory rate and heart rate values have a low difference from the vital signs check and precision of the measurement for the standard weight and low weight category. Therefore the proposed system can be assumed effective for the standard weight and lower weight person.

5. Conclusion

In this paper, in conjunction with the concern of the increasing of heart disease and pneumonia in people health, a system to measure our heart rate and respiratory rate at an early stage is needed. In relation to this problem, a system to simultaneously measure the respiratory rate and heart rate by using a body conduction sound sensor is proposed. The method of measuring the respiratory rate and heart rate is by calculating the respiratory sound and heartbeat sound using a body conduction sound sensor attached directly to the body skin below the left armpit. To determine the efficiency and compatibility of the system, an experiment was performed by comparing the measured results to vital signs check. From the result of the evaluation experiments, both respiratory rate and heart rate values have a low difference from the vital signs check and have a low problem of the precision of the measurement for the standard weight and low weight category. Therefore the proposed system can be assumed effective for the standard weight and lower weight person.

For future research, the measurement condition to measure the respiratory rate and heart rate effectively on an overweight person is targeted. A method using a highly sensitive ECM or another type of low-frequency microphone will be tested. The proposed system is hoped to be used widely in the society as a system for respiratory rate and heart rate monitoring for medical uses.

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