A Low Cost Digital Heart and Respiratory Rate Monitoring System

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Abstract— **This project aims to design a low cost and portable heart and respiratory rate monitoring system. The proposed monitoring system was combining both the heart and respiratory rate in one system. The heart rate monitoring system was using an infrared LED and photodiode for the pulse sensor while the respiratory rate monitoring system was using a thermistor as a sensor. The system has been tested for a group of students with an age between 20 to 25 years old for the functionality test. The data were recorded and has been compared with the standard heart and respiratory rate measurement for the same group age. Both heart and respiratory rate shows a normal measurement where the heart rate result was between 60 to 100 beats per minute (BPM) and the the respiratory rate result was between 12 to 18 breaths per minute (BPM). It shows that this proposed system are able to produce a reliable measurement data for both heart and respiratory rate monitoring system.**

***Keywords*— heart rate, respiratory rate, arduino, infrared LED, photodiode, thermistor, beats per minute, breaths per minute.**

INTRODUCTION

Heart and respiratory rates in human body system are important and frequent become a first signal for critical health problem to occur. Both of them are scientifically related with each other. To produce energy, the human body uses oxygen that was supplied through the bloodstream. This automatically will affect the human's heart and respiratory rate when they were doing physical activities because the flow of the blood in the bloodstream will change depends on the activities of the human's body. The heart and respiratory rate was measured in beats per minute (BPM) and breath per minute (BPM) respectively. Usually, the average normal resting heart rate is 60 to 100 beats per minute while the average normal resting respiratory rate is 12 to 18 breaths per minute[8]. However, it is also depends on the age and the physical fitness of a person. Different age and physical fitness will affect their normal heart rate and respiratory rate.

One of the common medical devices that were used to measure the human's heart rate is electrocardiogram (ECG). An ECG has more various functions other than measure the heart rate such as determine the position and size of the heart chamber and check any heart's damages. It has several electrodes that can be attached to the several human's body part such as the chest, the wrists, the shoulder and the ankle[1]. Another common device that was used for measuring heart rate is heart rate monitor watch. This device is very user friendly where the user just need to wear the heart rate monitoring watch at their wrist and the watch will show the user's heart rate. Athlete used this kind of heart rate measuring device usually during their training exercises such as jogging, running and cycling.

This paper proposes a system that consists of both heart rate and respiratory rate monitoring system with an implementation of Arduino microcontroller. The device is portable, small size and user friendly where everybody does not have to do a complex procedure or installation to monitor their heart and respiratory conditions. The basic concept of this design is using an infrared LED and photodiode as a pulse sensor for heart rate system and thermistor as a sensor for respiratory rate. By analyzing the change of reflection of the infrared light that was projected to the photodiode through the fingertip, the heart rate data can be taken. Meanwhile, by analyzing the change of the temperature from the human's breath that was detected from the thermistor, the respiratory data can be taken.

METHODOLOGY

A. Overall system

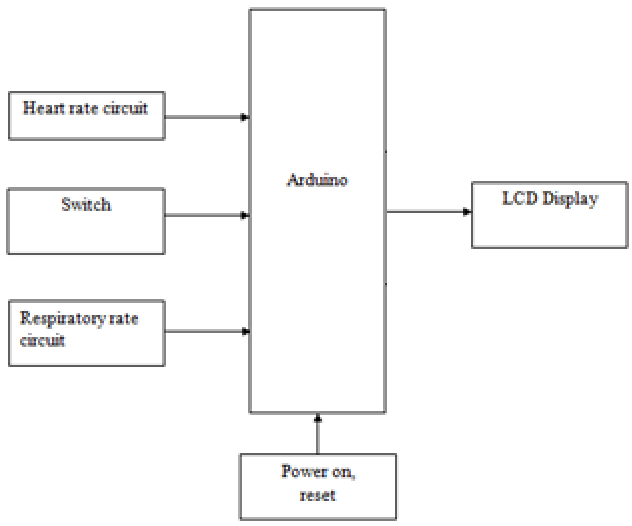

Fig. 1. The block diagram of the system

Fig. 1 shows the block diagram of the digital heart and respiratory rate monitoring system where the heart rate count circuit, the respiratory rate count circuit and the switch were the input for the Arduino, while the LCD display was the output of the system. The heart rate count circuit consists of pulse sensor that detects the pulse of the user while the respiratory rate count circuit consists of thermistor that detects the temperature during breathing and will send the signal to Arduino microcontroller. The function of the switch is to choose either to operate the heart rate circuit or respiratory circuit so that it will save the power consumption of the system. The input from the heart and respiratory rate circuit will produce an output of LCD display that will display the heart rate and respiratory reading.

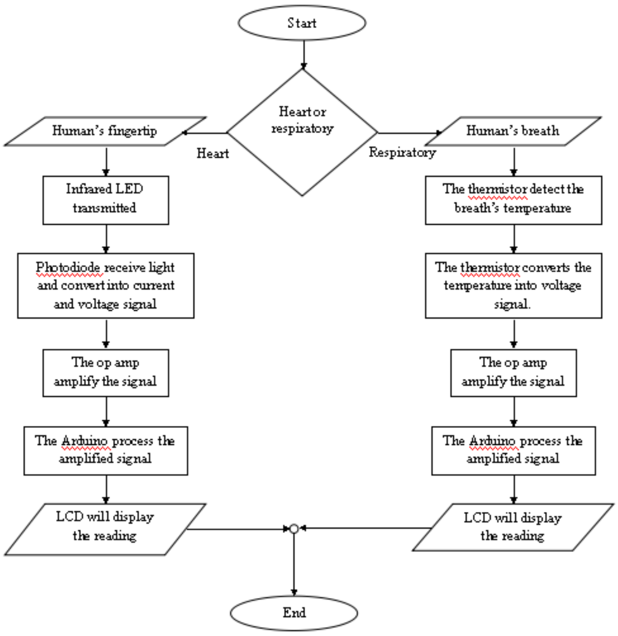

Fig. 2. Flow chart of the operating system

Fig. 2 shows the flow chart of this project's operation system. It starts by detecting the human's pulse by using the infrared LED or detecting the breath's temperature by using the thermistor. For detecting the human's pulse, the infrared LED will transmit an infrared light through the human body part and act as a sensor. Humans are labeled as semi transparent where most of the lights were absorbed or reflected by the organs and tissues such as skin, bone, muscle, and blood. When blood is pumped through the body, it gets squeezed into the capillary tissues, and the volume of those tissues increases very slightly. Then, between heartbeats, the volume decreases [5].

So, by using this theory, the infrared LED can act as a pulse sensor to detect heart rate by detecting the change in volume that affects the amount of infrared light that will transmit through. The small changed of transmitted infrared light will be detected by photodiode, which is a light detector. The photodiode will strongly detect the light from infrared LED and generate generate a small voltage and current when it is blasted with the Infrared LED[2].

The next process is to amplify the small signal that produced from the photodiode. This circuit consist of Op Amp that capable of amplify the input signal. Finally, the Arduino will process the pulse sensor circuit that act as an input with the completed programming coding using the Arduino language to display the output at the LCD display.

For detecting the human's respiratory rate, the thermistor will detect the temperature of the human's breath and convert the temperature into voltage signal[7]. As we know, the human's breath also produce heat. Since the output voltage is very small, an op-amp circuit was used to amplify the signal. Then, the temperature's data of the breath's temperature were collected and sent to the Arduino microcontroller. By using a proper coding, the data will be compared and analyzed to display the respiratory rate at the LCD display.

B. Heart Rate Module

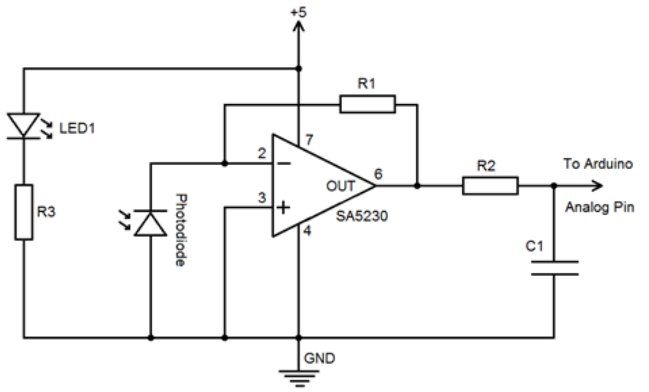

Fig. 3. Schematic diagram for heart rate circuit

This circuit using a low pass filter concept as shown in Fig. 3 which is consists of op amp OPA177GP that can perform with a voltage supply as low as 3V or as high as 18V. The infrared LED has peak wavelength of 940 nm and the photodiode has peak wavelength of 850 nm. The feedback resistor R1 is equal to 1MΩ while the value of both R2 and R3 are 100Ω. Lastly, the capacitor C1 is equal to 4.7µF. The output of this circuit is connected to the Arduino analog pin.

There are several types of Arduino but for this project, Arduino Uno was used. The Arduino Uno consists of 14 digital input/output pins and 6 analog inputs which is quite limited number of component that can be use for a certain project but just enough for this project.

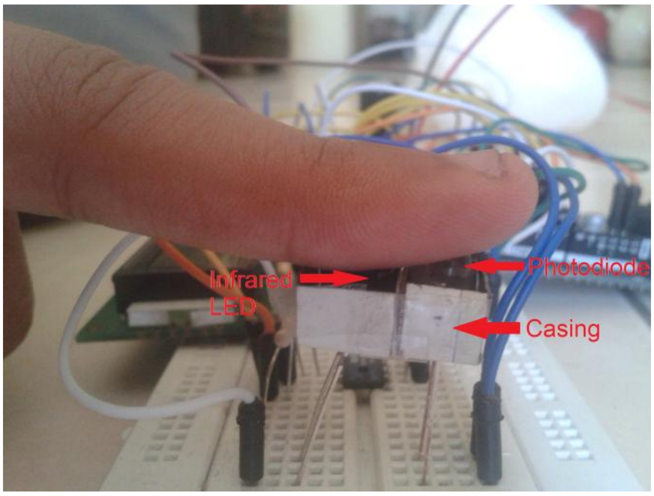

Fig. 4. The example of placing the fingertip for heart rate count

The input of the heart rate module is the fingertip of the user. The fingertip was placed at the top of both infrared LED and photodiode as shown in Fig. 4. Both infrared LED and photodiode were covered with a casing so that the photodiode will not be interrupted with other light at the surrounding.

The value of the output that connected to the analog input pin of Arduino will be converted to voltage value. The output of the heart rate circuit was connected to analog pin named A0 at the Arduino.

The arduino will read the A0 pin by using the command analogRead. The value of the analogRead will be multiplied with the reference voltage, which is equal to 5V and will be divided with 1023. The value of 1023 is a maximum analog reading that can be reached by Arduino.

$$Voltage = (analogRead(A0) \times 5) / 1023. \quad (1)$$

C. Respiratory Rate Module

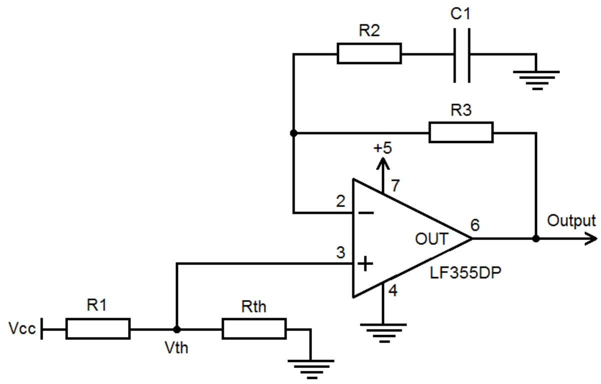

Fig. 5. Amplifier part for the respiratory system

The respiratory rate circuit has two important part that is the amplifier part and the comparator part. The circuit in the Fig. 5 shows the amplifier part of the respiratory system. This circuit also uses the high pass filter concept that consists of op-amp LF355DP. To measure the respiratory rate of the user, the thermistor was mounted inside the mask, which is worn by the user. When the user breathe inside the mask, the temperature of the user's breath will change the resistance (R_{th}) of the thermistor that will also change the voltage (V_{th}) of the thermistor.

The change of the voltage (V_{th}) will be amplified through the op amp circuit because the value is too small. The value of R1, R2 and R3 are 1kΩ, 10kΩ and 30kΩ respectively while the value of C1 is 2200µF.

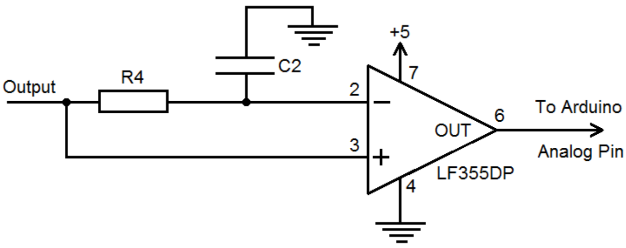

Fig. 6. Comparator part for the respiratory system

The output of this amplifier circuit will goes to the analog comparator circuit as shown in Fig. 6 so that it can be compared with the reference voltage. Different user will have a different breathing temperature especially the user with different ages. A younger user will have less respiratory rate compared to the older user[9].

So, this analog comparator circuit will compare each of the user's data with the reference voltage to achieve a constant average respiratory rate. The value of resistor R4 is 10kΩ and the value of capacitor C2 is 220µF. The output of this analog comparator circuit will be connected to the arduino analog pin.

The input of the respiratory module is the thermistor that was mounted inside a mask to avoid an interference of the temperature from the surrounding. The thermistor will only detect the temperature that came out from the user's breath directly as shown in Fig. 7.

Fig. 7. The example of wearing the mask

Same as the heart rate module, the values of the output also need to be converted into voltage value. The output of the respiratory rate was connected at analog pin A1 of the Arduino. So, the voltage equation for the respiratory rate will be the same as (1) except the variable is A1 instead of A0.

$$Voltage = (analogRead(A1) \times 5) / 1023. \quad (2)$$

D. Algorithm

By using an Arduino microcontroller, it can be programmed by using it's own software where all the condition can be initialized inside that software. For this system, it was divided into two subsystems, which is the heart rate system and the respiratory rate system. Both of them had the same algorithm but with a different condition.

For heart rate system, the first five data was used to find the highest output value to act as a reference voltage. For the next 160 data, the output voltage will be compared with the reference voltage to gets the number of beats. If the output voltage is the same or equal to the reference voltage, a beat is counted. The value of 160 was chosen because the highest value of heart rate is 160 BPM. For the respiratory rate system, all the process is the same except it only use 60 data instead of 160 data because the highest value of respiratory rate is 60 BPM.

RESULT AND DISCUSSION

The result shows the functioning of the developed system from the samples of 10 male students with a range of age between 20 to 25 years old. That range of age was chose because they were young and active people where they have a low possibility of having a critical disease such as high blood pressure that can affect the heart rate and respiratory rate measurement. Each of the students had taken a measurement for both heart and respiratory rate for three times. The average readings for both measurements were recorded.

The heart rate measurement of a person can be taken from their fingertip. Basically, there are other body part that can be used as a heart rate measurement such as the wrist and the temple area of the head but the best result can be obtained from the fingertip because it provides greater reflection and less absorption of light. The phalanx bone in the fingertip is less dense than radius ulna or carpal bones in wrist and temporal bones in the temple area [3].

TABLE I
AVERAGE HEART RATE FROM 20 TO 25 YEARS OLD STUDENTS

No.	Age	Heart Rate
1	22	71
2	21	61
3	24	82
4	23	86
5	23	64
6	25	74
7	20	61
8	20	67
9	24	71
10	22	81

Basically, most people have an average resting heart rate between 60 to 100 beats per minute (BPM). A moderately active people also will have an average normal resting heart as a normal people. But for professional athletes, they can achieve a heart rate as low as 40BPM[11].

Based on the experimented heart rate data, there are no professional athletes among the 10 people because the data was in the range between 60 to 90 BPM. The 10 people that was taken their heart rate measurement also were students where they were not focusing on athletics activities too much. But overall, based on the data was taken, all the 10 people are having a normal resting heart rate.

The detail classification of heart rate measurements for men between 20 to 25 years old are shown in Table II.

TABLE II
HEART RATE MEASUREMENT CLASSIFICATION

Athlete	49 - 55
Excellent	56 - 61
Good	62 - 65
Above Average	66 - 69
Average	70 - 73
Below Average	74 - 81
Poor	82+

From the data taken, there are two people that have 61BPM, which is an excellent heart rate measurement, and 1 person that has 64BPM, which is a good heart rate measurement[4]. They have a good and excellent heart rate measurement possibly because of they moderately active in physical activities. A people with an athlete level of heart rate measurement usually have consistent physical activities with a proper schedule. That's why an athlete can achieve 49 to 55 BPM. But for those who only moderately active just like 3 people from the samples, they can only achieve a good to excellent heart rate measurement.

The other 5 people have a below average to above average heart rate measurement which is between 66 to 81 BPM. This is a normal resting heart rate for a common people that doing their normal routine activities. They usually don't have ~~too~~ much physical activity and don't work out too much.

The remaining 2 people has a poor heart rate measurement which is 82 BPM and above. Usually people with a poor heart rate measurement because of poor health issues such as heart attack and high blood pressure[10]. For young people, the reason they have a poor heart rate is probably because of smoking habits and have a lot of stress in their daily lives. Other than that, it probably also because of their bad eating habits that cause them to overweight[6]. So, the data can be used as a first signal for them to proceed with detail health check because prevention is better than cure.

TABLE III
AVERAGE RESPIRATORY RATE FROM 20 TO 25 YEARS OLD STUDENTS

No.	Age	Respiratory Rate
1	22	14
2	21	20
3	24	12
4	23	14
5	23	12
6	25	16
7	20	15
8	20	18
9	24	15
10	22	16

The normal resting respiratory rate is 12 to 18 breaths per minute (BPM). The respiratory rate was measured during at rest condition because the measurement of respiratory rate was not accurate if the measurement was taken after the user walking around or doing any physical activities.

Based on the result above, all 10 people have a normal respiratory rate except for 1 person that have 20 BPM which is exceed the normal respiratory rate range. The increased and decreased respiratory rate is because of different factors. For a slightly increased respiratory rate just like a person from the sample, probably because of dehydration during taking the measurement due to hot weather or probably he has a history of smoking habits[9].

There are none of them has a decreased respiratory rate which below than 12 BPM. The decreased of the respiratory rate is usually because of some critical disease such as damage to the brain, strokes, head injury or effects of some medication. So, none of them has a sign of critical disease that affect their respiratory rate measurement.

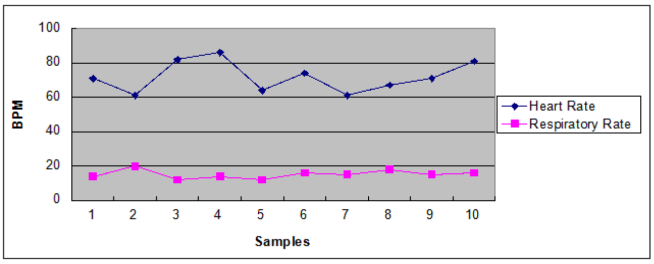

Fig. 8. Relationship Between Heart Rate and Respiratory Rate

Based on the graph in Fig. 8, the seventh sample has an excellent heart rate measurement and normal respiratory rate measurement. Compared with the second sample, he also has an excellent heart rate measurement but has a slightly abnormal respiratory rate measurement. The third and fourth samples have a poor heart rate measurement but have a normal respiratory rate measurement. The comparison between the best and the poor for both heart and respiratory rate was tabulated in Table IV and V.

TABLE IV
COMPARISON BETWEEN THE HEART AND RESPIRATORY RATE FOR EXCELLENT HEART RATE

No.	Heart Rate	Respiratory Rate
2	61	20
7	61	15

TABLE V
COMPARISON BETWEEN THE HEART AND RESPIRATORY RATE FOR POOR HEART RATE

No.	Heart Rate	Respiratory Rate
3	82	12
4	86	14

The inconsistent readings of the measurement may also caused of the hardware unstable, not because of the user's condition only. The heart rate circuit consists of infrared LED and photodiode as a pulse sensor. The photodiode is very sensitive to surrounding light that could affect the reading during the heart rate measurement. The photodiode should only receive the reflection infrared light from the infrared LED through the use's fingertip to get an accurate heart rate measurement. The errors could occur during taking heart rate measurement where the surrounding light leaked through the photodiode and cause the heart rate reading becomes inconsistent. However, the errors did not affect too much where the reading still can be used as a reference.

For respiratory rate measurement, errors are hardly to occur because the respiratory rate circuit uses a thermistor as a sensor and the thermistor was mounted inside a mask so that it can detect the breath's temperature directly from the user's mouth. Furthermore, the thermistor did not affected by the surrounding temperature because it was mounted inside the mask. That's why the data for respiratory rate measurement is more consistent compared with heart rate measurement.

CONCLUSION

As a conclusion, the proposed Digital Heart Beat Rate and Respiratory Rate Monitoring System using Arduino is a system that using a low cost material to monitor the heart rate and respiratory of a person. By using this system, the heart rate and the respiratory rate of a person can be manually monitored by themselves anywhere. Therefore, this project is expected to operate effectively without having any problem can be commercialized to help the growth of technology in the medical field.

For a future work, the system should be focusing on improving the stability of the heart and respiratory rate measurement. It could have multiple inputs that can be attached to several body part to get a better analysis about the heart and respiratory rate. This system also could be improve by having a stored data system where the measurement of the heart and respiratory rate can be stored for each person so that the monitoring system can be more efficient.

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