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THE DEVELOPMENT OF WIRELESS HEART RATE AND TEMPERATURE MONITORING SYSTEM USING BLUETOOTH LOW ENERGY

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ABSTRACT
Health monitoring system is commonly implemented to continuously track human health condition. Heart rate and body temperature are two important parameters to maintain a vital life. In this study, a wireless monitoring system by using Bluetooth low energy device called Bluno is developed to monitor both parameters. The entire system comprises of several parts which are heart rate sensor using photoplethysmography (PPG) and temperature sensor that are connected to Bluno, and a computer for a graphical user interface to display the measurement. The suitability of two different types of PPG sensors which are visible greenlight and infrared sensors for heart rate detection is also been compared in this study. The comparison was done on the skin of the fingertips and the result shows that both sensors give a similar heart rate reading when applied to the fingertips simultaneously. On the other hand, the temperature sensor is tested on the respondents to evaluate the time taken for the system to capture the right skin temperature. Based on the result, it shows that the temperature sensor needs about 35 second to read a stable body temperature.

Keywords: health monitoring, photoplethysmography, visible light, infrared light, temperature, bluetooth low energy.

INTRODUCTION
Nowadays, health monitoring system can be used to continuously monitor our health condition to ensure the human body is constantly maintained in good condition. Heart rate, body temperature, body weight, blood pressure and glucose level are some of the vital parameters that should be observed continuously for this purpose [1]. These parameters can give some important indicator of the body health condition. For example, high temperatures might indicate a fever while the unstable heart rate might indicate a heart problem. This early sign is a good indicator to see the physician for further check-up. In this study, a monitoring system is developed for both heart rate and temperature by using Bluno board that support Bluetooth Low Energy (BLE) connectivity.

Body temperature is one of the important parameter to understand human body condition. Body temperature can be measured in many locations on human body by using a thermometer. The most common location to place thermometer is in the mouth, ear, armpit, and rectum [2]. In this study, we are measuring the skin temperature of the body by placing the temperature sensor on the fingertips, close to the heart rate sensor in use. The temperature measurement unit that commonly being used is either degree Celsius (°C) or degree Fahrenheit (°F) depending on the country region**.**

The average temperature reading of resting human body is normally around 37.0°C. The physiological damages and fatality will occur when there is a difference for more than ±3.5°C from the normal body temperature [2]. According to Khan *et.al.* [3], the temperature value might be shown differently from different parts of human body, thus there is no single number that represents an exact value of normal temperature for different person under different condition There are a few intrinsic factors that affect human body temperature, such as ovulation, circadian rhythm, age, exercise and thyroid hormones. While for the skin temperature, the measurement also affected by the ambiance.

Similar to the body temperature, every person has a different resting heart rate, depending on their daily activity, fitness, age, gender, body condition and medications that they take [2]-[4]. A normal resting heart rate for adults has ranged from 60 to 100 beats per minute (bpm) [4].

Photoplethysmography (PPG) is an optical technique to be used in this study to capture the heart rate measurement. This technique can also be used to monitor several different types of health parameters such as pulse oximeter, blood volume variation on cardiovascular tissue and glucose readings [5]. The basic PPG requires an LED as a light source to illuminate the skin and a photodetector to measure the light intensity of the reflection [6]. The depth of the light penetration is depending on the wavelength of the light emitted as when the blood absorption is high; the depth of penetration is short.

Previously, PIC microcontroller is used as a processing platform of the heart rate reading to be displayed by using an LCD display. The reading is measured from the finger by tightly placing the sensor on the tips of the finger and on the ring position [7]. In this study, a health monitoring system with the implementation of Bluetooth communication is designed by using a Bluno board. The BLE 4.0 is used as a communication data transfer from device to the computer in order to display the reading value on the PC monitor. Compare to classic Bluetooth communication, BLE provides considerably lower power consumption and lower cost while maintaining a similar communication, and it is able to transfer a data from more than 100 m distance.

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Two different types of PPG sensors are also compared in this study which is visible greenlight and infrared (IR) sensors. These two sensors are using a different wavelength to read the heart rate. This light source is projected directly to the skin and it does not give any side effect to the skin and safe to be used in daily basis.

In overall, this paper has four sections including this section and the rest is structured as follows. The next section discusses on the material and methods that are related to the proposed system. Then, results and discussions are briefly explained based on two experiments that have been conducted and the last section is the conclusions.

MATERIAL AND METHOD

Processing board

The Bluno development board is a combination of Arduino UNO with BLE module. By using this ideal prototyping platform, hardware and software developers can easily go wireless with their design. Real time low energy communication can be easily made by using this BLE technology as CC2540 BT 4.0 chip is already integrated on this embedded systems device of Bluno board. It can perform wireless programming through BLE, supports Bluetooth HID, and supports AT command to set up the BLE. Any project that made with Arduino UNO can go wireless by using Bluno since it is also compatible with all Arduino UNO pins. In short, Bluno can be used with any Bluetooth 4.0 enabled devices and has functions like master and slave settings, wireless transmission, and Bluetooth HID connection to the computer between devices. Figure-1 shows the image of Bluno microcontroller board.

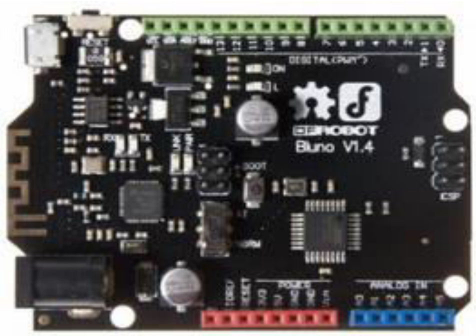


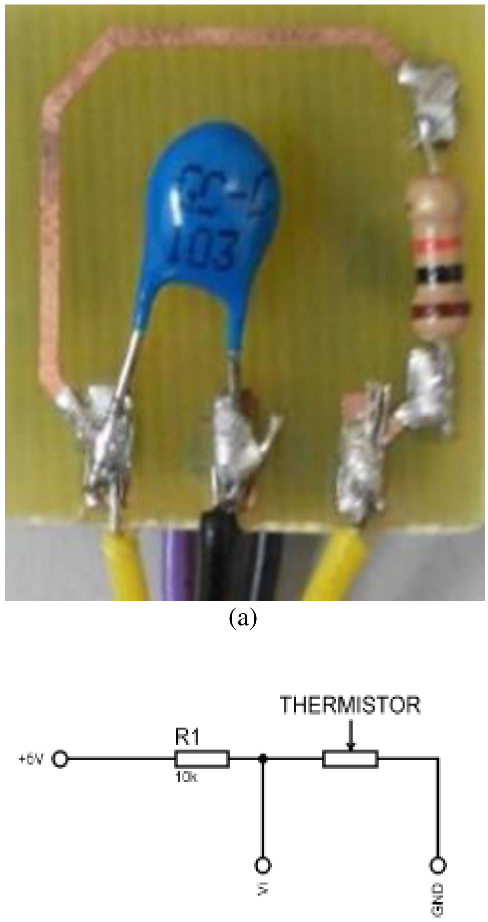
Figure-1. Bluno microcontroller board.

Circuit diagram of temperature sensors

The temperature sensor used in this study is NTC 10 kΩ thermistor as shown in Figure-2(a). The thermistor changes its resistances when there is a change in temperature that has a direct contact to the sensor surface.

Figure-2(b) shows the schematic diagram of voltage divider circuit for the body temperature sensor circuit. A fixed resistor of 10 kΩ is connected in series with the thermistor. The body temperature value, T is calculated by referring to equation 1.

$$\frac{1}{T} = \frac{1}{T_o} + \frac{1}{\beta}\ln\left(\frac{R}{R_o}\right) \qquad (1)$$



(a)

(b)

Figure-2. (a) Temperature sensor (b) Circuit diagram of temperature sensor.

where T_o is a room temperature, β is beta coefficient of the thermistor that is set to be 4000. R_o is the resistance at room temperature and in this case is 10 kΩ. The unit temperature measurement use of this equation is in unit Kelvin and can be easily converted into the final value for the display purposes. The unknown value of resistor, R from the thermistor can be defined as in equation 2 based on Arduino ADC value.

$$R = (10k)\ /\ \left(\frac{1023}{ADC-1}\right) \qquad (2)$$

where ADC is the value from Arduino serial terminal. ADC value also can be obtained from the value of the voltage that entering to Arduino by using equation 3.

$$ADC\ = Vi\ x\ \left(\frac{1023}{Vcc}\right) \qquad (3)$$

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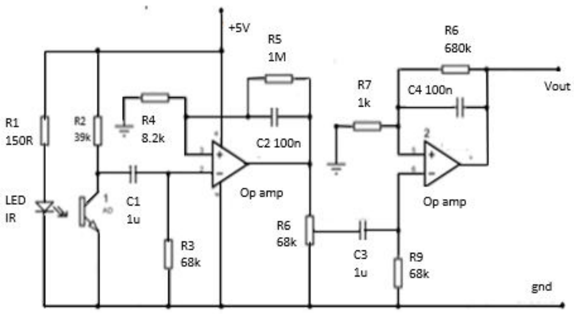
where V_{cc}=5V and V_i is the voltage divider value that being connected to the analogue input on the Bluno board. This can be measured by using a multimeter.

Circuit diagram of PPG sensors

There are several types of LED with a different wavelength that is suitable to detect the heart rate. In this study, the difference of the signal produce in between visible light and IR is demonstrated. The wavelength of the visible greenlight PPG ranging from 495–570 nm is normally being used due to the reason that it had shown to have a minimal influence from motion artefacts [9]. In this study, the visible greenlight of 550 nm wavelength is used as shown in Figure-3(a) [8].

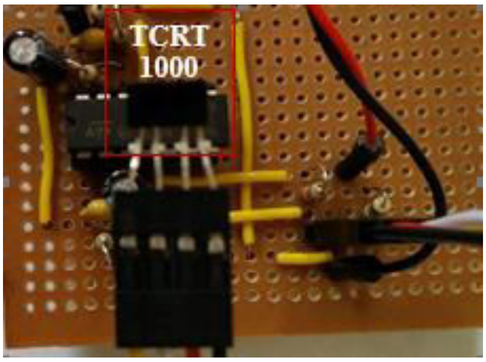
IR is an invisible light that cannot be seen directly by human eyes. It has a longer wavelength than visible light which is around 700 nm-1 mm, and it frequencies is lower than a visible light. IR is also commonly used to record the arterial heart rate directly from the skin. Figure 4(a) shows the IR sensor [8] model TCRT 1000. The wavelength of this sensor is 950 nm [9].

(a)

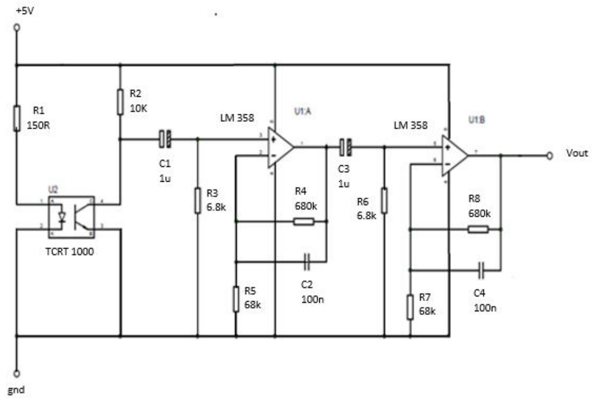


(b)

Figure-3. (a) Image of visible greenlight sensor (b) Conditional circuit for visible greenlight sensor.



(a)



(b)

Figure-4. (a) TCRT 1000 IR sensor (b) Conditional circuit for IR sensor.

Figure-3(b) shows the conditional circuit of the visible greenlight sensor and Figure 4(b) is a conditional circuit for IR sensor. This conditional circuit consists of amplifiers and band pass filter as a voltage gain and DC signal filtering respectively. This conditional circuit is important in order to enhance the heart rate signal while suppressing all the unwanted noise.

Proposed health monitoring system

The block diagram of the entire development system is shown in Figure-5. The systems consist of a heart rate sensor, skin temperature sensor, and Bluno development board that connected to the computer through BLE communication. The device interface program on the computer monitor will display the heart rate and body temperature in beat per minutes and degree Celsius respectively. The graphical user interface (GUI) design is developed using Window based application that is executed and work perfectly on Windows 8 and Windows 8.1 operating systems platform.

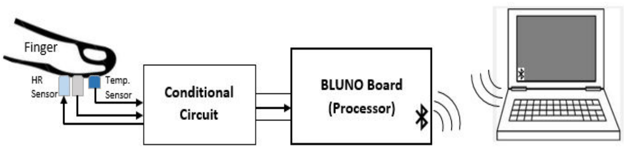


Figure-5. Block diagram for device system.

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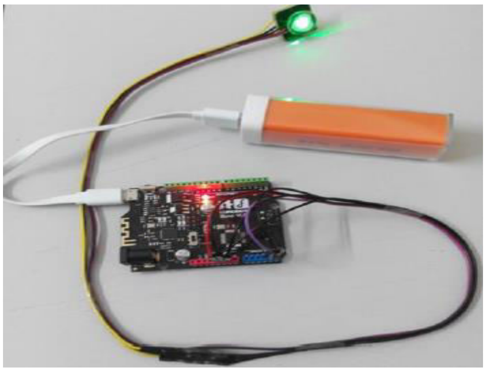
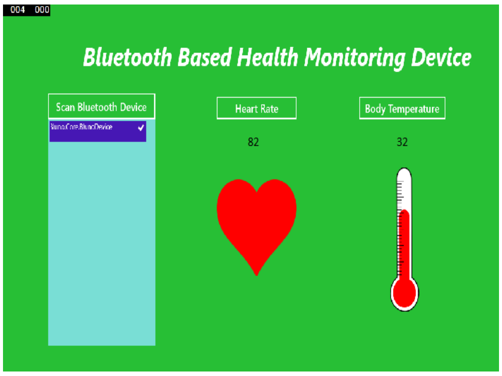
Figure-6(a) shows the hardware of the device. As can be seen in the Figure, a portable battery is used to power up the device. Figure-6(b) shows the GUI display of the window application on the computer monitor. Before the heart rate and the temperature reading can be displayed on the application, the Bluetooth connection in between the computer and the Bluno board need to be established first. Once the connection is established, the heart rate and the temperature value will be displayed and updated continuously.



(a)



(b)

Figure-6. (a) Device connection. (b) GUI design.

RESULT AND DISCUSSIONS

There are two different experiments that have been conducted on the entire developed systems. The first experiment is conducted in order to analyse the differences between the output signal produce by IR sensor and visible greenlight for heart rate reading. Second experiment is done to evaluate the temperature response of the sensor by using the monitoring system that have been designed and the differentiation of the heart rate reading between manual calculation and developed system monitoring display.

Evaluation of heart rate signal of both visible Greenlight and IR sensor

In this experiment, the output signal is measured by using Data Acquisitions (DAQ) and then the signal is analysed using Matlab. Both IR and visible greenlight sensor is placed on the fingertips on the same subject and at the same time in resting condition while the readings is taken. The set up can be seen in Figure-7.

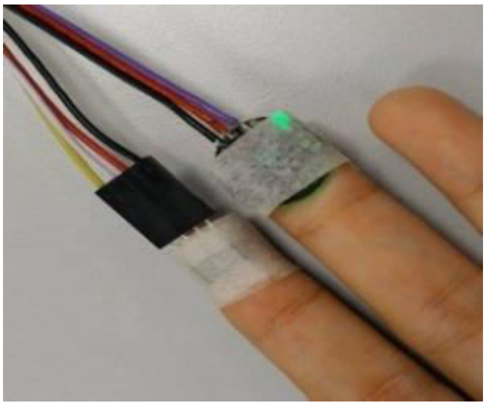


Figure-7. Sensors placement while taking the readings.

Figure-8 shows the heart rate reading for visible greenlight and IR respectively. It indicates that both of the signals are simultaneous and given a similar heart rate value but visible greenlight show smoother output signal of heart rate. In addition, the peak voltage output for both signals are different as this value is depending on the conditional circuit that being used together with the sensor.

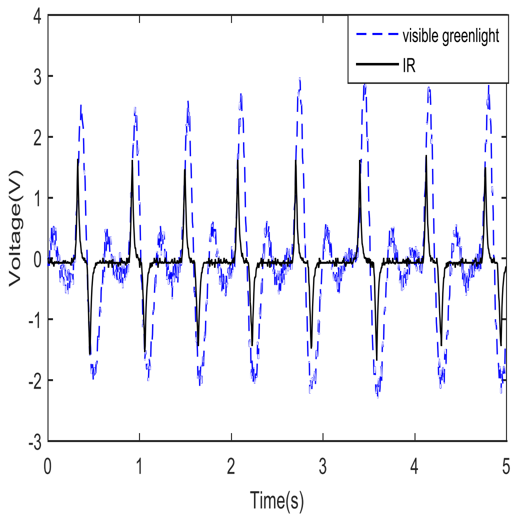


Figure-8. The output signal of the visible light and IR on the fingertips in experiment 1.

Evaluation of temperature and heart rate response

In this experiment, the temperature sensor response is being tested. To take the measurement, the temperature sensor was placed on the finger as shown in Figure-9.

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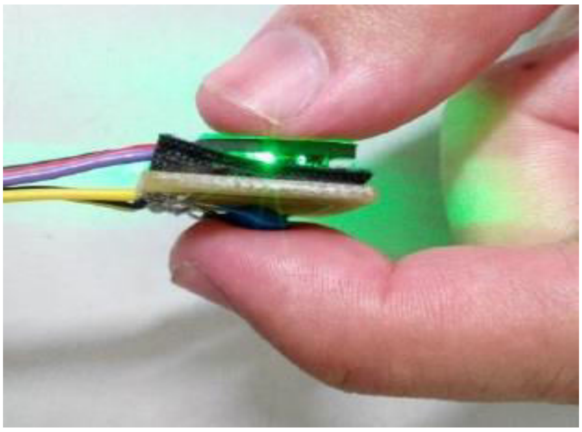

Figure-9. Placement of temperature sensor while taking a measurement.

This measurement is recorded every 5 seconds for 90 seconds and the measurement is repeated for three times. The room temperature while the experiment is carried out is 22°C measured by using a thermometer. The graph of the measurement is shown on Figure 10. It shows that the maximum temperature measured is 32°C which is the skin temperature of the body. For all of the repeated measurement, it shows a similar response of the temperature incremental and gets saturated when it reaches a stable skin temperature. The temperature sensor takes about 35 seconds to reach a stable temperature reading for these three experiments as shown in Figure-10. The environmental temperature can influence the measurement when the experiment is conducted as only one side of the temperature sensor touch the fingertips.

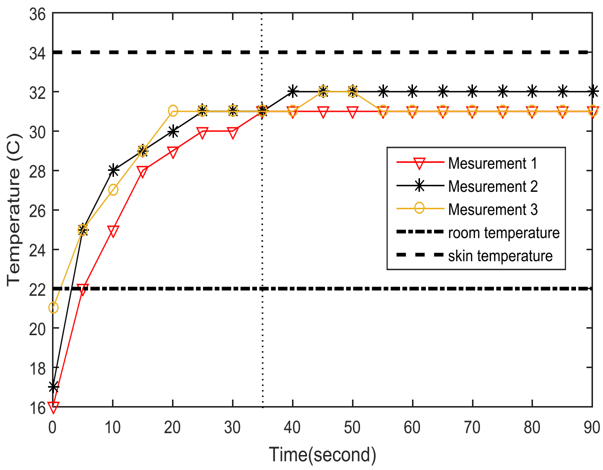

Figure-10. Temperature measurement.

The graph in Figure-11 is plotted based on the average heart rate calculation that being captured by using DAQ and also the heart rate value displayed on the GUI of the monitoring systems. This experiment is done in order to evaluate the algorithm used in the Bluno board to measure the heart rate is accurate. Both measurements are done simultaneously by recording the data in every five second for four minutes while the signal from the visible greenlight sensor is connected to both Bluno board and DAQ.

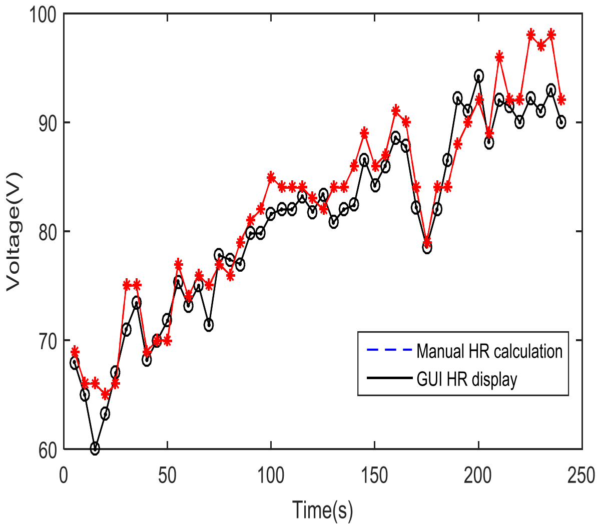

Figure-11. Comparison of heart rate measurement.

The value of the heart rate capture by using DAQ is calculated manually based on the signal being generated on Matlab plot. The resting heart rate of the subject starts at 68 bpm and the value is increasing to nearly 100 bpm while the reading is taken. Based on the figure mentioned, both of the plots show a similar characteristic with an acceptable value difference. This difference might be due to some effect of the noise and glitch while the experiment is conducted.

CONCLUSIONS

In this study, the monitoring system using Bluno board for heart rate and temperature measurement is presented. The signal generates by the visible greenlight and IR sensor is compared side by side and it gives a similar heart rate reading. The algorithm used to convert the signal into the heart rate reading is also compared with the manual measurement using DAQ and the result shows a similar characteristic of both signals with a very minimal difference. This monitoring system can be further developed in the future where the environmental effect on the output signal need to be reduced and more sensors can be added into the system for more functionality of specific application such as glucose monitoring systems and sleep monitoring systems.

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REFERENCES

[1] R. A. Ramlee, M. Azlishah, B. Othman, M. Ikhwan, and B. Abdul. 2014. Low Cost Heart Rate Monitoring Device Using Bluetooth," In Information and Communication Technology (ICoICT), 2014 2nd International Conference. pp. 42-46. IEEE.

[2] K. Parsons. 2014. The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort, and Performance. in Human thermal environments Crc Press.

[3] M. N. I. Khan, D. F. Noor, M. J. H. Pantho, T. S., Parveen, F. Abtahi, and M. I. H. Bhuiyan. 2013. A low cost optical sensor based heart rate monitoring system," In 2013 International Conference on Informatics, Electronics and Vision (ICIEV).

[4] Miah, M. A. Raihan, S. Basak, M. R. Huda and A. Roy. 2013. Low cost computer based heart rate monitoring system using fingertip and microphone port," In International Conference on Informatics, Electronics and Vision (ICIEV). pp. 1-4. IEEE.

[5] Y. Maeda, M. Sekine, T. Tamura, A. Moriya, T. Suzuki and K. Kameyama. 2008. Comparison of reflected green light and infrared photoplethysmography. In Engineering in Medicine and Biology Society. EMBS 2008. 30th Annual International Conference of the IEEE, 2008, pp. 2270-2272. IEEE.

[6] J. Lee, K. Matsumura, K. I. Yamakoshi, P. Rolfe, S. Tanaka and T. Yamakoshi. 2013. Comparison between red, green and blue light reflection photoplethysmography for heart rate monitoring during motion. In Engineering in Medicine and Biology Society (EMBC), 2013 35th Annual International Conference of the IEEE. pp. 1724-1727. IEEE.

[7] W. H. M. Saad, N. A. A. Salam, T. K. Leong and S. N. A. Bahrom. 2014. Verification of Heart Rate Monitor Using PPG Pulse Sensor". International Journal of Applied Engineering Research (IJAER)., Vol. 9, pp. 24369-24378.

[8] DataSheet: Subminiature Solid State Lamp: Green, 2013 KingBright.

[9] DataSheet: TCRT1000/TCRT1010, Vishay Telefunken.