Design and Fabrication of Arduino Based Heart Rate Monitoring System Using Reflectance Photoplethysmography

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ABSTRACT

This project is carried out to design and develop a low-cost Arduino based Heart beat monitoring system by applying the principle of reflectance mode Photoplethysmography (PPG). PPG is a non-invasive diagnostic method, that provides the information about the variations in cardiac activity through changes in blood volume using a light source and detector. As the heart beats, the blood is pumped throughout the body, resulting in rate change of blood volume inside the finger and wrist artery. Optical sensing mechanism is used to detect the variations of blood around the fingertip and wrist. The developed system goes through three phases. In the first phase, the sensor detects the pulse through the fingertip and wrist, and in second phase, the signal is sent for amplification, filter and then digitizing. The final Phase is where the Arduino Uno receives the digitized signal through serial port communication, where the heart rate is calculated, and BPM measured will be displayed as a result. The proposed system uses two sensors for detection, SEN-11574 and designed ADC circuit of different wavelengths of light sources, i.e. 560 nm, and 910 nm (Green and Infrared LED) and the performance was compared over the finger and wrist. It was concluded that Green LED could be used at finger site and infrared LED at wrist site for measurement. For wireless communication protocol, Bluetooth HC-05 module was used to send the data packets (BPM) to an android device, where the results are displayed. The proposed monitoring system gave fair BPM values when compared with standard heart monitoring device. By and large, the system gives an accuracy of 92 % with accurate and precise measurement values.

INTRODUCTION

1.1 Overview

The following chapter gives a brief introduction about the heart rate monitoring systems and bioelectrical signals in the industry of biotelemetry and telemedicine. It mentions out the different types of technologies or ways that can be build or implemented to monitor health status of human being. Moreover, short description is given about the quality of signals generated from the heart beat. Along with this, the problem statement of the project is reported, followed by the objectives of the project have been stated that will overcome the challenges caused in heart monitoring systems. Lastly, for the development of the project, the scope of the project is illustrated including the organization of the thesis.

1.2 Background

Over the past years, heart rate has been becoming an essential parameter which is linked with the cardiovascular system of the human beings. There are several ways of measuring the heart conditions of the people; i.e. through the ECG waveform or pulse generated from different body parts. The basic theory behind the cardiovascular system is the rhythmic expansion and contraction of an artery as blood is forced through it by the regular contractions of the heart. Heart rate, which is also known as pulse, is the number of times a person heart beats per minute. The heart rate is dependent on the condition of one's heart, size of the body, age, the person doing any activity or being at rest etc. Any of these actions would cause the variability of heart beat rate. Result shows the average adult heart beat ranges from 60-100 bpm.

However, researchers are making an extensive effort to find the best solution for the monitoring of the heart. Moreover, wireless heart rate monitors based on the photoplethysmography (PPG)

have been immensely contributing in diagnostic of health, as an important asset in hospitals, clinics and homes. The following (PPG) technology have an advantage in the detection of heart disorders and for the treatment of the people who suffers from various types of diseases. These include, diabetes, arrythmia, and blood pressure. The following **figure 1.1**, shows the hospital setup for monitoring health status of a patient where the hub shows the parameters being measured.

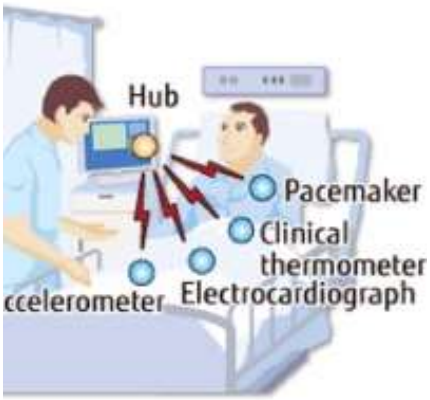


Figure 1.1: Hospital setup for monitoring Heart Rate

One of the advantages of the wireless health monitoring devices is that it reduces the cost and primarily setup at hospitals. Moreover, the need for having a visit to the hospital can be minimized by having portable heart rate monitors. It gives the advantage to an individual to have a pre-checkup anywhere without visiting the hospital.

1.2.1 Project Implementation

The driving force behind this project is to contribute beneficial effort to improve the healthcare monitoring devices where the patient can use these instrumentation devices independently and comfortably at their own home or workplace. The main purpose is to provide a medical device that can benefit society to a relatively large extent.

The present technology consists of electrical and optical heart monitors. One of the methods is the attachment of bulky strap around one's chest. On the other side, optical monitors require no use of strap around the chest and is more convenient in terms of comfort/measurement than the electrical method. However, the best way of measuring heart rate is through the pulse, which uses the concept of LED and photo-sensors. More research must be made to avoid the obstacles in sensing the heart i.e. using the (PPG) technology, which over the last few years is being promoted to make the technology reliable and efficient. The focus is to have a system installed in hospitals where the measurement of different health parameters can be measured, and the data be transferred wirelessly to a distant receiver (for hospitals: Nurse room) as shown in **Figure 1.2**.

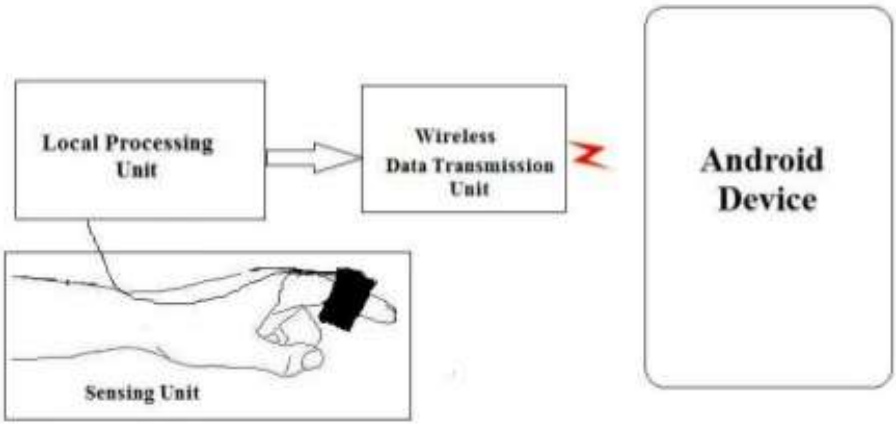


Figure 1.2: Proposed Wireless and portable system for health monitoring

1.2.2 Monitoring process

Bio signals are measurable signals produced by the body that can be monitored and related to the health and status of bodily organs. Despite the diversity in the electronics devices used for sensing bio signals and communication platforms employed in transmitting them, almost all wireless wearable monitors have the same working method as illustrated in **Figure 1.3**. A typical wearable device goes through the following steps to achieve monitoring:

• **Sensing:** The bio signal of interest is detected, and a proportional electrical response is produced.

• **Amplification:** The small electrical response generated by the sensing component is amplified to a level suitable for analysis.

• **Digitization and Storage:** The amplified bio signal is digitalized with an analog to digital converter and then stored in a memory device.

• **Data Transmission:** The stored data is transmitted over a wireless communication platform.

Figure 1.3: Steps involved in bio signal monitoring

1.3 Problem statement

With the advancements in biotechnology, the standard heart rate monitoring system have raised great attention in terms of its use in hospitals and clinics. However, the use of this concept gives rise to portable heart rate monitors (HRM). On contrary, there are several issues in the field of biotelemetry, one of which is the brainstorming of bioelectrical signals generated from the (HRMs). The heart signals obtained from such portable devices might not be that accurate compared to the standard at hospitals. Another problem arises in optical heart monitors, is the accurate placement of the sensors around the body parts, i.e. knowing which part of the body gives the greatest or least amplitude of the pulse. Furthermore, the interferences such as noise, skin tone, the crossover problem gives bad results in optical HRMs. When compared to standard heart monitors, the performance of wearable pulse oximeters lacks in terms of calculating heart rate giving huge errors in detection.

1.4 Objectives

The main objective of the project is to build an improved Arduino based heart rate monitor using Bluetooth communication for sending data wirelessly, which will be helpful for the individuals by using it anywhere easily at hospitals, home, office, schools etc. as an alert before any serious issues.

The aim of the project is to study and perform research in the department of biotelemetry devices, i.e. (PPG) and other principles related heart monitor systems. By and large, the main objectives of the project are stated below:

- To design and develop improved heart rate monitor using two different modules; standard Pulse sensor and IR pulse module.
- To design and develop wireless communication system between heart rate monitor and mobile phone using Bluetooth HC-05 module.
- To analyze and study the performance of the sensor placement on different sites of body: index finger and wrist, under two conditions i.e. Rest and Exercise.

1.5 Project scope

The foremost focus area of the project is to undergo a deep research about the cardiac monitoring based on the principles of photoplethysmography (PPG) and knowing the other related methods for heart monitoring. After this brainstorming step, the main scope of the project is to design and simulate the heart beat sensor using Proteus as a simulation software. After the simulation step, the development of heart rate monitors will be done through suitable programmed coding in Arduino. Two PPG based monitoring circuits will be implemented for sensing heart Beats per minute (BPM). First method will mainly consist of standard pulse sensor that uses Green LED as a light source whereas the second method uses an infrared light emitting diode (IR LED) and a phototransistor instead of Green light source for detection of pulse. However, both of these circuits will be interfaced with an Arduino microcontroller. The next step is the programming of an Arduino with the help of suitable coding to operate the circuit.

Furthermore, performance of the pulse sensor would be compared and analyzed in terms of the accurate placement of the sensor and the difference of using Green LED or IR LED. For the signal analysis, the performance of the device will be tested by placing the sensor on finger and wrist of the subject. Moreover, the conditions set for measuring pulse are: the subject (Person) being at rest and then performing activity.

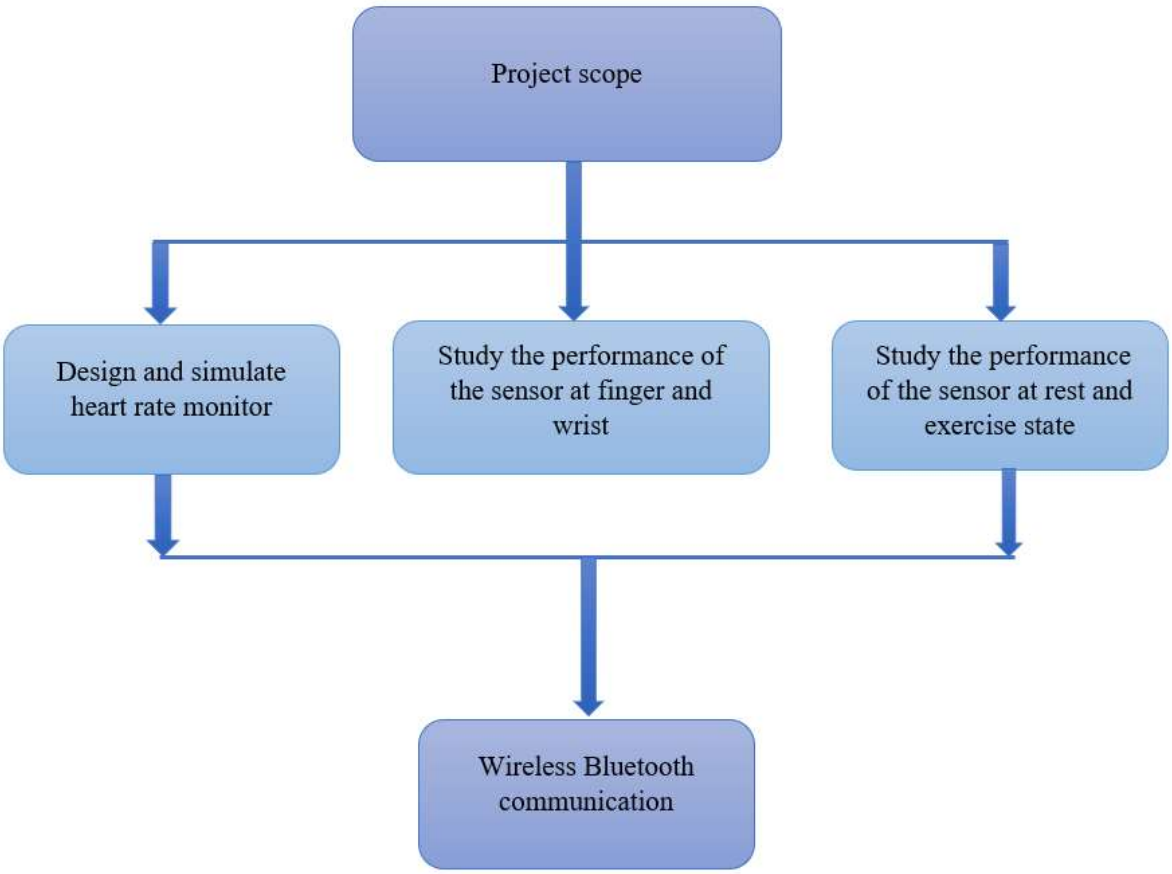
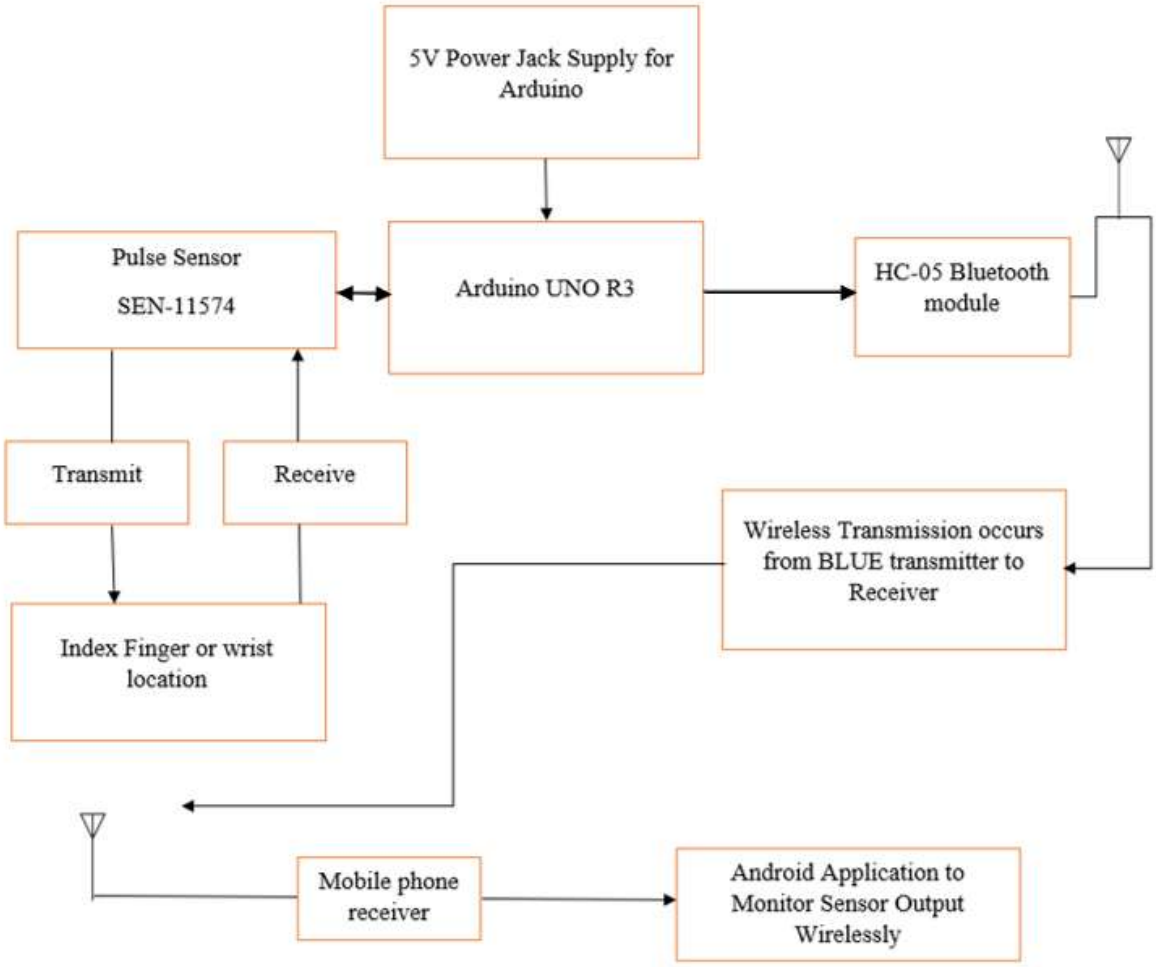


Figure 1.4: Work Breakdown Structure (WBS)

Project Framework



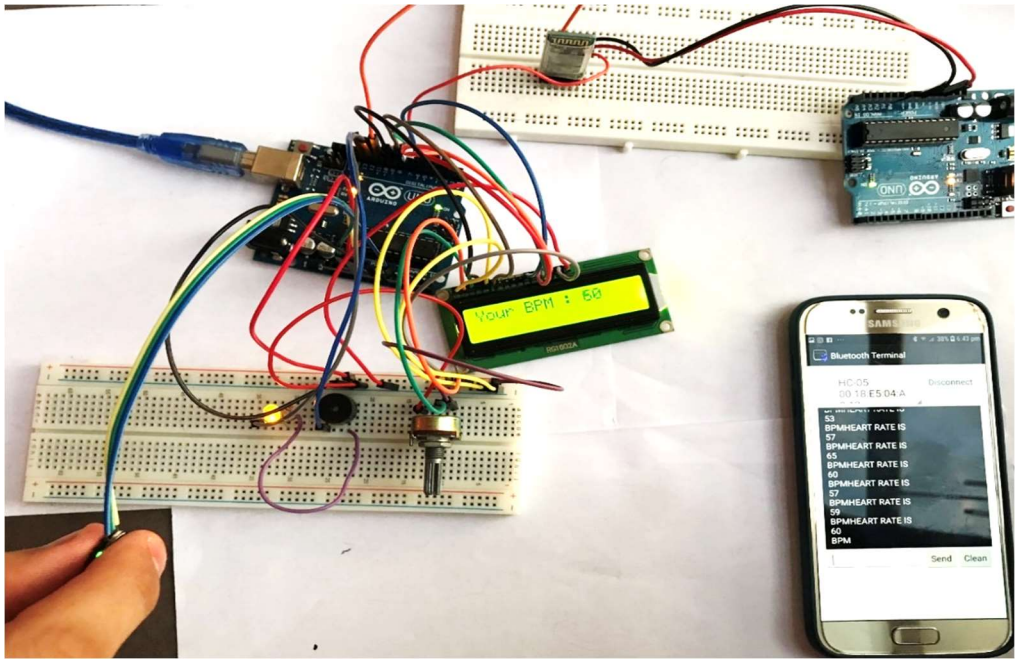


Figure 4.13: Demonstration of Finger Placement (Design 1)

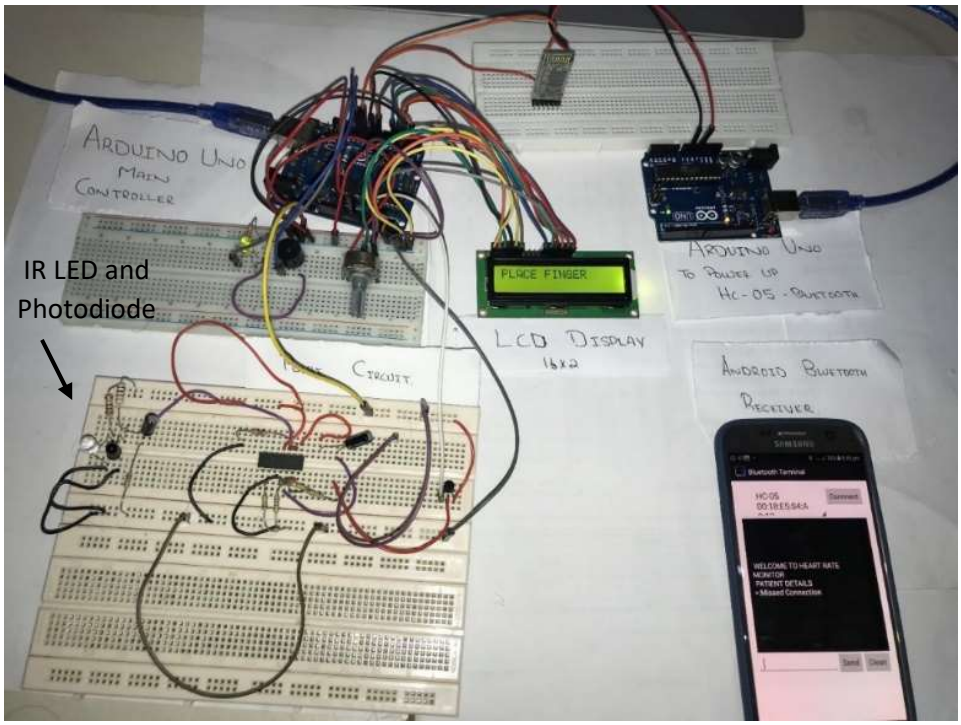


Figure 4.12: Hardware Setup for Design 2 Heart Monitor System

Conclusion and Recommendation

Overview

This chapter is classified into two main sections, i.e. Conclusion and Recommendations. The first section gives an overview of the project objectives achieved and the obstacles that were tackled. Likewise, the second section proposes, several work and researches are recommended to make the system more enhanced.

Conclusion

The main aim of the project was to study and research about the biotelemetry technologies in order to make the cardiac systems more enhanced. It integrates the design and problem-solving skills of engineering with biomedical sciences to improve wearable heart monitors what could help the heart patients to improve the quality of health in daily lifestyle and can serve them as alert call for any serious heart issues. Moreover, such systems can also be implemented at hospitals or clinics for continuous monitoring of the patient by using wireless communication system.

Three main objectives were selected for this project to have improved heart rate detection system. The first objective was to design and develop heart rate monitor using two different properties of sensing methods, i.e. Pulse sensor SEN-11574 and Signal conditioning circuit that uses (Infrared LED and photodiode for pulse detection). Furthermore, to have a constant programming system the Arduino Uno is used as a microcontroller that controls the working of the circuit.

The heart monitor system uses photoplethysmography (PPG) principle in the project to detect the Beats per minute (BPM) values. For the Pulse sensor SEN-11574 with LED of (520-560 nm wavelength), biomedical test sensor was installed and used in software, whereas, the potentiometer is used to control the voltage level at sensor. This concept is then related to the hardware working concept of SEN-11574 sensor, as it gives the output value when the sensor detects the pulse in finger or wrist. Likewise, the signal conditioning circuit was designed, that uses Infrared LED (910-940 nm wavelength) and photodiode as a pulse detector, LM 324 operational amplifier for filtering and amplifying the signal, and lastly NPN-2N3904 transistor for the output signal.

This is achieved by programming the code in Arduino IDE software. Additionally, once the coding is programmed, the 'Proteus' software is used for simulating and testing the system. Once the circuits were interfaced with Arduino, the output BPM value was diagnosed. The hardware prototype was made successfully by giving the BPM value, when the finger and wrist was placed over the sensor area. By compiling suitable coding for heart rate detection into Arduino board, the results depicted that heart rate can be detected from variations of blood flow rate through finger or wrist. However, the project achieved its first objective by having simple improved heart monitoring system.

To develop a wireless communication system for heart monitor, low power (3.3V) Bluetooth HC-05 module is used to create a connection with Android device. HC-05 Bluetooth module is interfaced with the heart monitor through the coding in Arduino, where it acts as an interpreter between a heart monitor and Android device. Lastly, the data from the heart monitor is sent wirelessly to an android receiver by establishing serial communication through HC-05 module. The system had a range of 10 meters between the transmitter (heart monitor) and receiver (Android). However, the second objective of the project was accomplished.

Subsequently, the results were compared and analyzed between the heart monitor using Green LED and infrared LED as source. Additionally, the experimental study is carried out by placing the sensor on finger and wrist, where the performance of the sensor is analyzed.

It has been concluded from the experiment performed that by using LED of wavelength 520-560 nm, i.e. Green Led on the index finger for pulse detection gives accurate values. Whereas the wavelength of 910 nm, i.e. infrared LED can be used at the wrist giving more pulsation information. However, the readings and signals recorded from the PPG based heart monitoring system, the amplitude of output PPG signal gets affected by two processes. The first process includes the reduction factor of back reflected light, where the light is reflected by the tissues and backlights superficial artery. Hence, the larger diameter of the artery, the less light reflects to the sensor.

Furthermore, the second process includes the reflection of light by the arterial wall. This means that more light is reflected by the arterial walls which causes in the attenuation of the signals. That is why the shape of the PPG signal mainly rely on the effect of these two processes. On the other side, the PPG signal gets affected by the respiration, that is why the magnitude of PPG signal is influenced. Temperature could also reportedly affect the PPG signal and the ABP values. When the temperature of the hand was decreased to a low level, the blood pressure of the radial artery would increase as well as its diameter. Lastly, the component ratio and amplitude of signals are affected by the change in light wavelength. Later this affect causes change in coefficient correlation of pulse rate and heart rate.

By and large, the developed heart monitor showed accurate and precise and the percentage error is 8.1%, resulting in the accuracy of 91.9%.

Recommendations

For future development, there is a lot of scope to improve the heart monitoring systems. Moreover, some of the suggestions for the system enhancement are:

- The acceleration sensor should be added to the system, where it can remove the motion artifacts.
- The system should be made lighter by miniaturizing into PCB and make commercially available for public use.
- Number of health parameters should be added such as, blood pressure estimation, respiratory rate and body temperature etc., to make the system more valuable.
- To guarantee the system accuracy, number of testing should be performed on people of different ages and health conditions.
- More advance technology should be used for the communication. Such as Wi-Fi, ZigBee or Radio frequency.