Design and Implementation of Microcontroller Based Mobile Heart Monitoring System for Bio-medical Diagnosis

Ayodeji James Bamisaye*, Olugbenga Oloniyo

Department of Electrical and Electronics Engineering, The Federal Polytechnic, Ado-Ekiti, Nigeria

Abstract

Heart related diseases are increasing day by day and there is a need for an accurate and affordable heart rate monitoring system for diagnoses. However, most heart rate measuring paraphernalia and environments are expensive and do not follow ergonomics. The proposed Heart Rate Measuring (HRM) system is economical, user friendly and uses optical technology to detect the flow of blood. The system is designed to sense and measure the pulse by clipping sensors on one of the fingers and then displaying the result on an Organic Light Emitting Diode (OLED) and synchronized with a software application at the medical personnel side. The paper explains how a single-chip microcontroller can be used to analyze heart beat rate signals in real-time and provide the information of bradycardia and tachycardia of heart rates, logged the details at interval and broadcast the information to the medical personnel if the heart rate exceeds the threshold. Qualitative and quantitative performance evaluation of the device on real signals shows accuracy in heart rate estimation. This system can be employed in the hospitals/clinics/ research and medical centers especially in developing countries to reduce the rate of death caused by cardiovascular related diseases.

Keywords

Cardiovascular, Arduino, Pulse, Diagnosis, Bradycardia, Tachycardia

1. Introduction

Cardiovascular disease is one of the main causes of death in many countries and thus it accounts for over 15 million deaths worldwide. In addition, several millions of people are disabled by cardiovascular disease [1]. The delay between the first symptom of any cardiac ailment and the call for medical assistance has a large difference among different patients and can have critical consequences. One critical inference drawn from epidemiological data is that deployment of resources for early detection and treatment of heart disease has a higher potential of reducing fatality associated with cardiac disease than improved care after hospitalization [2]. Hence novel strategies are needed in order to reduce time before treatment. Monitoring of patients is one possible solution. Also, the trend towards an independent lifestyle has also increased the demand for personalized non-hospital based care. Cardiovascular disease has shown that heart beat rate plays a key role in the risk of heart attack [1-3]. Heart disease such as heart attack, coronary heart disease, congestive heart failure, and congenital heart disease is the leading cause of death for men and women in many countries [3]. Most of the time, heart disease problems harm the elderly person as shown in figure 1 [4] because old age is a risk factor for heart disease. In fact, about 4 of every 5 deaths due to heart disease occur in people older than 65years [5]. The rate at which the heart works reduces with increase in Age (figure 1).
The heart's walls may thicken and arteries may stiffen and harden, making the heart less able to pump blood to the muscles of the body. Based on these changes, the risk of developing cardiovascular disease increases with age [6]. Because of their sex hormones, women are usually protected from heart disease until menopause, when their risk increases.

Early models consisted of a monitoring box with a set of electrode leads which attached to the chest [7]. The first wireless electrocardiogram (ECG) heart rate monitor was invented in 1977 as a training aid for the Finnish National Cross Country Ski team and as 'intensity training' became a popular concept in athletic circles in the mid-80s [1, 8]. In old versions of the monitor, when a heartbeat is detected a radio signal is transmitted, which the receiver uses to determine the current heart rate. This signal can be a simple radio pulse or a unique coded signal from the chest strap (such as Bluetooth or other low-power radio link); the latter prevents one user's receiver from using signals from other nearby transmitters (known as cross-talk interference). Newer versions of the heart rate monitor include a microprocessor which is continuously monitoring the ECG and calculating the heart rate, and other parameters [9]. Modern heart rate monitors usually comprise two elements: a chest strap transmitter and a wrist receiver or mobile phone (which usually doubles as a watch or phone). In early plastic straps, water or liquid was required to get good performance. Later units have used conductive smart fabric with built-in microprocessors which analyses the ECG signal to determine heart rate. More advanced models will offer measurements of heart rate variability, activity, and breathing rate to assess parameters relating to a subject's fitness. Sensor fusion algorithms allow these monitors to detect core temperature and dehydration [1, 10]. The digital heartbeat monitor and alert systems provides a more unique, effective and efficient means of real-time monitoring of a patient's health parameters and has ever since witnessed an unprecedented tremendous advancement as researchers keep searching for better ways to make these monitoring and alert systems more flexible, portable, and efficient.

This paper aim at designing and implementing a portable and affordable system that can detect, transmit and monitor the heartbeat, analyze and log the information at intervals of time and broadcast the information to doctor or medical personnel in-charge for monitoring in case of any abnormality that will require urgent attention.

The objectives are to:

i. Measure the heartbeat of patients by using sensors as analog data, later converted into digital data using analog to digital converter (ADC) which is suitable for wireless transmission.

ii. Use Micro controller device for temporary storage of the transmission data. This signal is processed using the microcontroller to determine the heart beat rate per minute.

iii. Log the data of the signal being processed from time to time and

iv. Display the processed signal on OLED at the patients’ side and synchronized with a software application at the medical personnel side.

The paper is divided into different sections: Section 1.1 reviews the heart rate; section 1.2 presents the hardware design and connections while software design and configurations is presented in section 1.3; section 1.4 describe the test conducted and the performance analysis of the system; the system operation and conclusion drawn are presented in sections 1.5 and 1.6 respectively.

HEART RATE: The heart is the organ that is responsible for pumping blood throughout the body. It is located in the middle of the thorax, slightly offset to the left and surrounded by the lungs basically; the human heart is composed of four chambers which are two atriums and two ventricles. The right atrium receives blood returning to the heart from the whole body. That blood passes through the right ventricle and is pumped to the lungs where it is oxygenated and goes back to the heart through the left atrium, and then the blood passes through the left ventricle and is pumped again to be distributed to the entire body through the arteries [11]. Figure 2 [12] shows the human heart and how blood flows all-round the human heart.
The heart rate or heart pulse is the speed of the heart beat measured by the number of times the heart pounds per minute, i.e. beats per minute (bpm). Heart rate varies as the body needs to absorb oxygen and excrete carbon dioxide changes during exercise or sleep. This can be used by the medical expert in diagnosis and monitoring the health condition of a patient [2]. The average resting human heart rate is about 70 bpm for adult males and 75 bpm for adult females [8]. Heart rate varies significantly between individuals based on fitness, age and genetics. This is shown in Table 1 [13] for men and women of different ages. Lower than normal heart rates are usually an indication of a condition known as bradycardia, while higher than normal heart rates are known as tachycardia [3].

### Table 1. Resting Rate Chart for Men and Women [13].

<table>
<thead>
<tr>
<th>Age</th>
<th>Excellent</th>
<th>Good</th>
<th>Above Ave</th>
<th>Ave</th>
<th>Below Ave</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-25</td>
<td>56-61</td>
<td>62-65</td>
<td>66-69</td>
<td>70-73</td>
<td>74-81</td>
<td>82+</td>
</tr>
<tr>
<td>26-35</td>
<td>55-61</td>
<td>62-65</td>
<td>66-70</td>
<td>71-74</td>
<td>75-81</td>
<td>82+</td>
</tr>
<tr>
<td>36-45</td>
<td>50-56</td>
<td>63-66</td>
<td>67-70</td>
<td>71-75</td>
<td>76-82</td>
<td>83+</td>
</tr>
<tr>
<td>46-55</td>
<td>49-61</td>
<td>64-67</td>
<td>68-71</td>
<td>72-76</td>
<td>77-83</td>
<td>84+</td>
</tr>
<tr>
<td>56-65</td>
<td>46-56</td>
<td>62-67</td>
<td>68-71</td>
<td>72-75</td>
<td>76-81</td>
<td>82+</td>
</tr>
<tr>
<td>65+</td>
<td>50-55</td>
<td>56-61</td>
<td>62-65</td>
<td>70-73</td>
<td>74-79</td>
<td>80+</td>
</tr>
</tbody>
</table>

An electrocardiogram (ECG), also called an EKG, is a graphic tracing of the voltage generated by the cardiac or heart muscle during a heartbeat. It provides very accurate evaluation of the performance of the heart [14]. The heart generates an electrochemical impulse that spreads out in the heart in such a fashion as to cause the cells to contract and
relax in a timely order and, thus, give the heart a pumping characteristic. An actual voltage potential of approximately 1 mV develops between various body points [15].

In measuring heart rate, there are various ways to measure such as by using pulse oximeter, heart rate monitor, an electrocardiograph, and ECG strap. The beat per minute is differ for many people which depend on the ages, body physical condition and environmental factor [16].

2. Method

The method adopted in this research is divided into two aspects: the hardware design and connections; and the software design and configuration

2.1. Hardware Design and Connections

The block diagram is shown in figure 3 which is made up of two aspects:

![System block diagram](image)

**Figure 3. System block diagram.**

**2.1.1. The Master**

This is the receiver device which is made up of Arduino Uno, NRF24L01+, NRF25L01 and Antenna. It serves the purpose of interaction with a computer system and communicate received signal from the Transceiver to the Real Time Monitoring Environment on the computer system as shown in Figure 4.

![Picture of the receiver after connection](image)

**Figure 4. Picture of the receiver after connection.**

**2.1.2. The Slave**

This is the transmitting and main device that carries out the operation of conversion of the pulse received from the sensor to digital signal. It is made up of Arduino Nano, MAX30102 pulse oximeter and heartrate sensor, NRF24L01+ Transceiver, 0.96” OLED display, Lithium Battery, DPDT switch and lithium battery charger.

The MAX30102 and OLED Screen were connected to the Arduino Nano. Both the OLED display and the MAX30102 breakout board need 4 wires connected to the Arduino board: Ground; VCC; SDA; SCL. The data lines for the I2C interface will depend on the specific version of the Arduino board being used. In this case A4 for SDA and A5 for SCL was used, as these are the hardware dedicated pins for the Uno and Nano. The NRF24L01 breakout board is then connected to the transmitter and the pin configurations are: Vcc – 3.3v; GND – GND; CSN – 7; CE – 8; MOSI – 11; MISO – 12; SCK – 13, while on the receiver the pin configuration is: Vcc – 3.3v; GND – GND; CSN – 7; CE – 8; MOSI – 51; MISO – 50; SCK – 52. The connections were displayed in figure 5.

Three of these pins (MISO, MOSI and SCK) are for the SPI
communication and they need to be connected to the SPI pins of the Arduino, but each Arduino board have different SPI pins. The pins CSN and CE can be connected to any digital pin of the Arduino board and they are used for setting the module in standby or active mode, as well as for switching between transmit or command mode. So once the NRF24L01 is connected, modules to the Arduino boards are ready to be assigned codes for both the transmitter and the receiver.

![Figure 5. Picture of the transmitter after connection.](image)

The MP1405 lithium battery charger is connected to the battery with B+ terminal to battery positive terminal and B- to the battery negative terminal while the OUT+ was connected to DPDT switch pin 1 and OUT- was connected to pin 4 of the switch figure 6.

![Figure 6. Complete Hardware assembling of the Transmitter.](image)

### 2.2. Software Design and Configuration

There are several software tools that have been used to program the system. The microcontroller needs to be programmed using its own software before the system operates. The Hardware works on the C++ programming language. The IDE used is Arduino Sketch which is used to edit Cpp codes of all hardware incorporated with the Arduino Board. Other used software are: Arduino Sketch, Proteus, Code Block, Visual Basic.

All cpp codes are sketched up using code block and after verification it’s compiled to the microprocessor using the Arduino sketch. Proteus is used to draw and simulate the circuit of the system, while Visual Basic is used to design the real time monitoring software using cpp programming language. Once the three devices (Arduino, OLED display and MAX30100 sensor board) are connected, the code to the Arduino board is uploaded. The algorithms for the receiver and transmitter are shown in figure 7 and 8 respectively.

![Figure 7. Algorithm for the receiver.](image)

![Figure 8. Algorithm for the Transmitter.](image)
The sketch code for the OLED display is shown below:

```c
#include "U8glib.h"
U8GLIB_SSD1306_128X64 u8g(U8G_I2C_OPT_NO_ACK
void setup()
{
    fpa_image();
    intro_display();
}

void draw(void){
    u8g.firstPage();
    do {
        u8g.setFont(u8g_font_gdr17r);
        u8g.setPrintPos(20,20);
        u8g.print("Federal");
        u8g.setPrintPos(0,41);
        u8g.print("Polytechnic");
        u8g.setPrintPos(14,64);
        u8g.print("Ado-Ekiti");
    } while( u8g.nextPage() );
    delay(2000);
}

void fpa_image()
{
    u8g.firstPage();
    do {
        u8g.setFont(u8g_font_gdr17r);
        u8g.setPrintPos(20,20);
        u8g.print("Federal");
        u8g.setPrintPos(0,41);
        u8g.print("Polytechnic");
        u8g.setPrintPos(14,64);
        u8g.print("Ado-Ekiti");
    } while( u8g.nextPage() );
    delay(2000);
}

void intro_display()
{
    u8g.firstPage();
    do {
        u8g.setFont(u8g_font_unifont);
        u8g.setPrintPos(0,10);
        u8g.print("Heart Monitoring");
        u8g.setPrintPos(36,24);
        u8g.setFont(u8g_font_5x7);
    } while( u8g.nextPage() );
    delay(2000);
}

void loop()
{
    // picture loop
    u8g.firstPage();
    do {
        u8g.setFont(u8g_font_unifont);
        u8g.setPrintPos(34,22);
        u8g.print("HRTB:");
        u8g.setFont(u8g_font_gdr17r);
        u8g.setPrintPos(74,23);
        u8g.print("71");
        u8g.setFont(u8g_font_unifont);
        u8g.setPrintPos(100,24);
        u8g.print("BPM");
        u8g.setFont(u8g_font_5x7);
        u8g.setPrintPos(0,34);
        u8g.print("Developed by");
    } while( u8g.nextPage() );
    delay(1000);
}
```
3. Test and Result Analysis

The screen test is first conducted by uploading the sketch code for the OLED display. After the uploading, the display comes up as shown in figure 9.

![Figure 9. Pictures of the display output during screen test.](image)

After the screen test, the pulse oximeter and transceiver were tested and the result was observed through the serial monitor of the Arduino sketch in figure 10.

![Figure 10. Arduino Sketch Environment Interface.](image)

At the completion of the tests, all codes were compiled together and the sketch was uploaded to both the Transmitting device and Receiver device of the heart monitoring system. The heart monitor system software provides the interface for inputting the minimum and maximum heart rate, in which when the heart beat per minute
falls or rise beyond the set limit triggers the alarm and the details is logged per minute which can be viewed from time to time. The real time test and logging per minute are shown in figure 11 and 12 respectively. The program will send the monitored data wirelessly and interfaces between the Heart rate Monitoring software and the hardware.

4. Discussion

It can be observed from figure 3 that the Heart rate monitoring system comprises of components such as MX30102 pulse oximeter and heart rate sensor, Arduino Nano, Arduino Uno, OLED display, Lithium battery and charger, NRF24L01 transceiver, push button and 3.5mm Audio jack and socket. The Heart rate monitor works on the principle of capturing of pulse through the flow of blood in the body. This is
accomplished by using the pulse oximeter and heart rate sensor (MX30102) to capture the pulse on the fingertip in relation to the mechanism of the heart blood pumping activity. When the finger is placed on the sensor, a light emitting diode (LED) shines light on the vein which transmits the blood to the finger and a reflected pulse is captured by the photodiode present in the MX30102 pulse oximeter and heart rate sensor. The captured pulse being an analog signal is sent to an Arduino board (Arduino Nano) which serves as a microprocessor and handles the software coding of the entire activity of calculation of heartbeat per minute (BPM), converts the analog signal to digital data which is interpretable by the display module. The processed signal from the Arduino board is transmitted via a Transceiver (NRF24L01) which serves as a sender at the sensor end and at the Real Time Monitoring end as a receiver. The signal received from the transceiver is processed by the Arduino Board (Arduino Uno) which is responsible for the real time conversion and logging of the data and sent to a computer system via a USB cable where it can be monitored from time to time.

5. Conclusion

The system presented in this paper has been integrated with modern technology to help in regularizing the health condition of most individuals by keeping track of their heartbeat rate condition. Thus, alerting the medical personnel on the patient’s real time health situation using RF transmission and reception mode of communication interfaced with NRF24L01 technique. The heartbeat of the patients is measured by using pulse oximeter and heart rate sensor, converted into digital data using microcontroller device and for temporary storage of the data used for transmission. This signal is processed using the microcontroller to determine the heart beat rate per minute. The data of the signal being processed is logged from time to time on the real time heart monitoring software. The processed signal is displayed on OLED at the patients’ side and synchronized with a software application at the medical personnel.

References


