

DEVELOPMENT OF A LOW-COST PORTABLE HEARTBEAT MONITOR USING AN INFRARED SENSOR AND A MICROCONTROLLER-DIGITAL STETHOSCOPE

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ABSTRACT: *The problem of shortage of medical devices in rural areas of Nigeria, cause a budget to be limited and constrained. Therefore, developing medical devices at low cost is one solution. This paper proposes an improvement, portability, and cost-effectiveness of the heart rate measuring devices being applied in the Rural Local medical in Akure South Local Government Area of Ondo State of Nigeria; through the development of a Low-Cost Portable Heart Beats Monitor using an Infrared Sensor and a Microcontroller. The development of the prototype is to function as an assisting device for a user which has a busy lifestyle to monitor the heart rate at any place in the real-time condition. This report contains the detailed procedures involved in designing the heartbeat monitoring circuit, developing the circuit design, and carrying out the performance evaluation of the system developed. In this project, Infrared LED and photodiode have been used as a sensor to measure a heart rate and a PIC16F876A microcontroller acts as a controller to process the input and output of the device. The development of the prototype starts with designing the sensor circuit, signal conditioning circuit, voltage regulator circuit, microcontroller circuit, and dual power supply unit. After the functionality test, these circuits were integrated with the output display. The prototype design is able to display the heart rate measurement in beats per minute (BPM) and the condition of heart rate either low, normal, or high heart rate on a 16x2 matrix Liquid Crystal Display (LCD).*

KEYWORDS: heartbeats, monitoring, low-cost, infrared sensor.

INTRODUCTION

The condition of the human heart could be determined via heart rate measurement. The human heart rate varies from person to person depending on three major factors which include age, the person's physical and activity conditions. The human's heart rate for an adult that is healthy is

around 60-100 beats per minute (George, 2003). While for an athlete, his/her heart rate is slower than an active adult's (Valusamy et al., 2005). For the baby, on the other hand, the heart rate is higher which is around 120-160 bpm, and for children's heart rate, it is around 75 to 110 bpm (Eyinnaya, 2008). Abnormal heart rate such as lower heart rate than the normal rate is called bradycardia whereas a higher heart rate, which is higher than the normal, is called tachycardia (Chime, 2010). The traditional heart rate is measured by putting finger above pulse artery and count pulse rate within 30, and heart rate can be found by multiplying by 2 (Sharief, 2011). This method is easy but inaccurate, especially when artery pulse state is in high rate. The most accurate method to measure heart rate is by using an electrocardiogram machine (ECG) but this equipment is expensive and not affordable by individuals. Moreover, the ECG heart rate monitoring method has other drawbacks such as too many sensors and cable connections, fluctuations in the ECG signal baseline, power line noise, and interference due to muscular activities. The condition of the human heart could be determined via heart rate measurement. The human heart rate varies from person to person depending on three major factors which include age, the person's physical and activity conditions. In addition, the ECG is not suitable for continuous monitoring on burnt victims and the conduction gel used may cause discomfort and inflammation on the skin (Saritha and Sukanya, 2013).

Hence, the need to develop a low-cost and effective heart rate monitoring device on which this project is based on. This device "Microcontroller based heartbeat monitor" can be used in hospitals and also for patients who can be under continuous monitoring while traveling from place to place. Since the system is continuously monitoring the patient, and in case of any abnormality in the heart rate of the patient, the attention of the patient's relatives and the concerned medical doctor could be immediately called for. This project design utilizes a sensor unit which consists of an infrared (IR) light emitting diode (LED) and a photodiode. The IR LED and photodiodes will be used in this design because the sensors are designed for low power measurements and offer high sensitivity and low noise, enabling them to detect very low light levels. The IR diode functions as a transmitter that transmits an infrared light into the fingertip (placed over the sensor unit), while the photodiode functions as a receiver which senses the portion of the light that is reflected back. The intensity of the reflected light depends upon the blood volume inside the fingertip. So, each heart beat slightly alters the amount of reflected infrared light that can be detected by the photodiode. With proper signal conditioning, this little change in the amplitude of the reflected light can be converted into a pulse. The pulses are then counted by the Microcontroller to determine the heart rate and the result is displayed on a 16x2 LCD. The PIC16F876A Microcontroller will be used in the design because it has an inbuilt amplifier capable of raising the magnitude of the pulses at the output of the photodiode so that it can be sensed directly by the Microcontroller. This project is designed to run on a Dual power supply unit (DC and AC). This Dual power supply unit utilizes a 220V/12V, 300mA step-down transformer, a bridge rectifier circuit, filtering capacitor, a 9V battery, a 12V/10A relay, and a voltage regulator. It is expected to deliver the necessary voltage level needed by the Microcontroller and the other devices.

REVIEW OF RELATED WORKS

Human Heart Rate monitors have been widely used around the world. The devices allow the user to have a real-time measurement of their heartbeat. The first ECG accurate wireless heart rate monitor was invented by Polar Electro in 1977 as a training tool for the Finnish National Cross Country Ski Team. The concept of intensity training by heart rate swept the athletic world in the eighties, and in 1983 which led to the introduction of the first wireless heartbeats monitor (Rapheal, 2012). However, below are the summaries of some of the related works done in the past

George, (2003) proposed a heartbeat monitoring system for the Detection and Classification of five cardiac conditions. He used signal processing techniques and Artificial Neural Network (ANN) to implement real-time processing, intelligence, cost-effectiveness and efficient use of the ECG diagnostic system. He suggested the use of remote diagnostic medical systems for diagnosing at homes for further research.

Velusamy et al., (2005) have presented the design of a system that monitors the temperature at various locations on the Field Programmable Gate Array (FPGA). This system is composed of a controller interfacing to an array of temperature sensors that are implemented on the FPGA fabric. Such a system can be used to implement dynamic thermal management techniques. They cross validate the sensor readings with values obtained from Hotspot, a pre-RTL architectural level thermal modeling tool.

Enyinnaya, (2008) proposed a Heart Rate Monitor and Arrhythmia Detector which uses a low power Microcontroller MSP430FG4816 manufactured by Texas Instruments for signal analysis. The device was intended for use by medical practitioners in developing countries. The system is low cost, low power, portability, and capable of acquisition, amplification, and interpretation of biological signals (ECG), as well as notification whenever cardiac conditions such as *tachycardia* and *bradycardia* are experienced. Her main focus was on creating an ECG monitoring and alert system that detects cardiac abnormalities like *tachycardia*, *bradycardia*, etc. However, it requires expert medical practitioners to use.

Chime, (2009) proposed a heart rate monitor using a low-cost Microcontroller, AT89C52, from Atmel Corporation for his design. He measured heart rate from the fingertip using an infra-red transmitter and receiver sensor box. The rate is then averaged and displayed on a text-based LCD but does not have voice output to aid visually impaired persons.

Sharief and Abdel-khair, (2011) also proposed a Microcontroller based heart rate monitor using fingertip sensors. The design uses optical technology to detect the flow of blood through the fingertip. The microcontroller is programmed to acquire the signal, eliminate the zero-crossing problems of the digitized signal by Fourier transformation and display the heart rate on an LCD. A local audible alarm is also provided to indicate heart rate status. The device, however, requires expert knowledge to use and is also not so economical.

Saritha and Sunkanya, (2013) presented the design and development of an integrated Microcontroller based device for measuring heart rate using fingertips. The design uses three

phases to detect pulses on the fingertip namely: pulse detection, signal extraction, and pulse amplification. They also used optical methods to develop the heart monitor. Finally, the performance of the HRM device is compared with ECG and the manual pulse measurement of a heartbeat. The device, however, gives only an alphanumeric visual output on the LCD.

After going through the literature and their limitations, it was decided to design and develop a Microcontroller based heartbeat monitoring system using an Infrared (IR) sensor with the incorporation of a 16x2 matrix Liquid Crystal Display (LCD) for digital readout of the measured heartbeat. In addition, a dual-mode power supply unit would be built so that the device can be powered by both A.C (mains supply) and D.C (battery).

METHODOLOGY

Design procedure

The heart rate is measured when a fingertip is placed over the sensor unit. The sensor unit consists of an Infrared (IR) LED and a photodiode, placed side by side as shown in figure 1. The IR diode transmits an infrared light onto the fingertip (placed over the sensor unit), and the photodiode senses the portion of the light that is reflected back. The intensity of the reflected light depends upon the blood volume inside the fingertip. So, each heartbeat slightly alters the amount of reflected infrared light that can be detected by the photodiode. With proper signal conditioning, this little change in the amplitude of the reflected light can be converted into a pulse. The pulses are then counted by the Microcontroller to determine the heart rate. The IR LED and Photodiodes are used in this design because of the following inherent advantages:

- (i) The sensors are designed for low power measurements;
- (ii) They offer high sensitivity and low noise, enabling them to detect very low light levels.

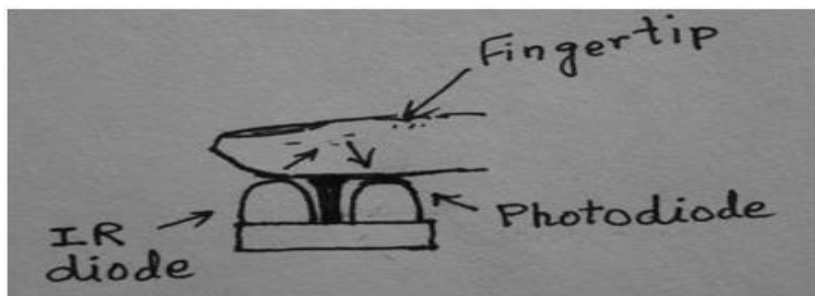


Figure 1: Fingertip placement over the sensor unit

The signal conditioning circuit consists of two identical active low pass filters with a cut-off frequency of 2.5Hz. This means that the maximum measurable heart rate is about 150bpm. The filtering is necessary to block any higher frequency noise present in the signal. It should be noted that the signal conditioning circuit discussed above is in-built in the PIC16F876A Microcontroller used for this project. The filter/amplifier circuit that connotes the signal conditioning circuit also functions to amplify the detected train of pulses at the output of the photodiode to appropriate voltage levels so that the pulses can be counted by the Microcontroller. The Microcontroller is programmed to display the measured heart rate over a period of time (3 seconds) on a 16x2 matrix Liquid Crystal Display (LCD).

Design and implementation

The heart rate measurement system uses optical sensors to measure the alteration in blood volume at the fingertip with each heartbeat. The block diagram of the overall design is shown in Figure 2. The overall design consists of the following units

- (i) The sensor unit comprising an infrared LED which functions as the transmitter and a Photodiode-which functions as the receiver;
- (ii) The signal conditioning circuit (Amplification and filtering unit- inbuilt in the Microcontroller);
- (iii) The Microcontroller unit (PIC16F876A);
- (iv) The 4MHz crystal oscillator unit
- (v) The dual (AC and DC) power supply unit;
- (vi) The Liquid Crystal Display (LCD) unit;
- (vii) The overall casing; and
- (viii) The Firmware section is the device software.

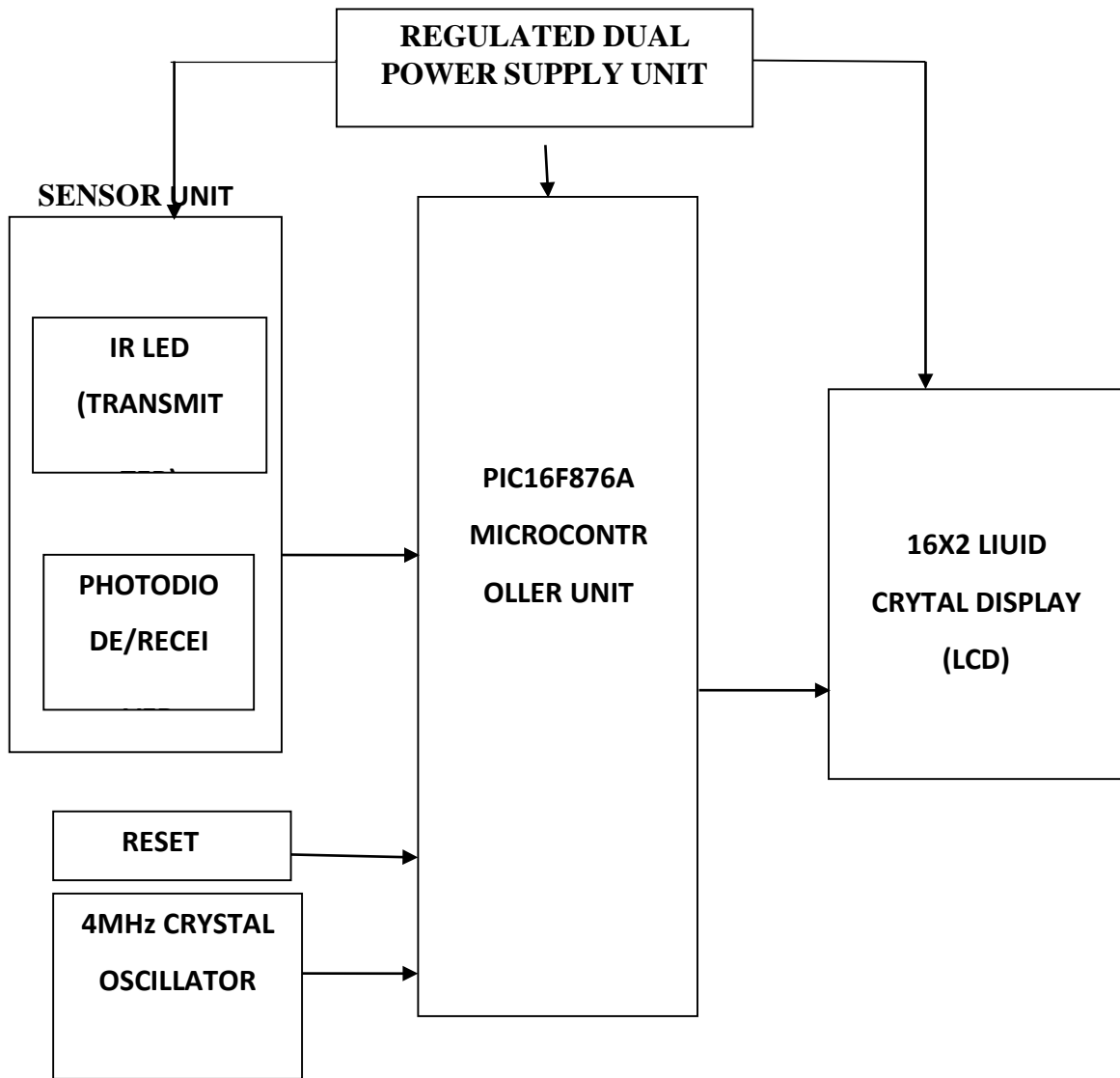


Figure 2: Block diagram of the designed Heart rate monitoring module

Device hardware circuits development

The overall circuit diagram of the device hardware is shown in figure 3.

Sensor Circuit

The sensor unit consists of an IR diode and a photodiode as shown in Figure 4. The IR diode transmits an infrared light into the fingertip and the photodiode senses the portion of the light that is reflected back. The intensity of the reflected light depends on the volume of blood pumped to

the fingertip by the human heart. Each heartbeat slightly alters the amount of reflected infrared light that can be detected by the photodiode. With the help of the signal conditioning circuit, this little change in the amplitude of the reflected light is converted into a pulse. The pulses are then counted by the Microcontroller to determine the heart rate

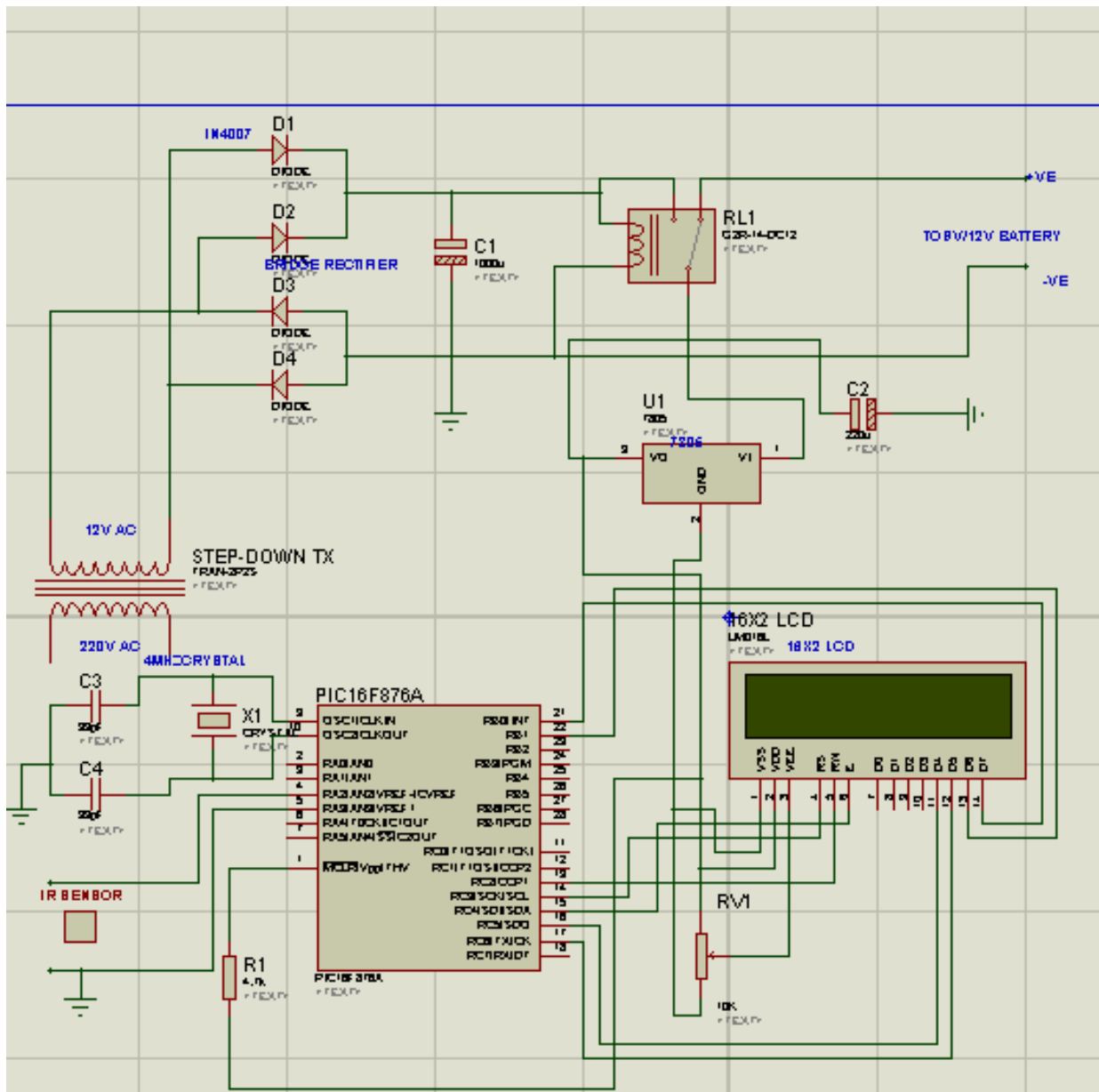


Figure 3: Circuit diagram of the device

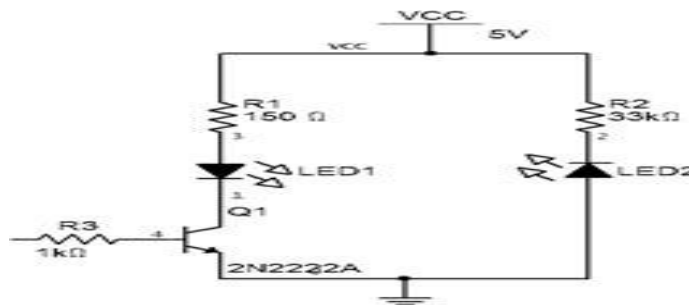


Figure 4: Sensor circuit

$$\text{Current through the LED1} = \frac{V_{cc}}{R_1} = \frac{5}{150} = 33mA$$

$$\text{Current through the LED2} = \frac{V_{cc}}{R_2} = \frac{5}{33 \times 10^3} = 0.15mA$$

Signal conditioning circuit

A major challenge in the design of a system like this is acquiring and measuring very small electrical signals in the presence of much larger noise components. However, the PIC16F876A Microcontroller used in this project design has a principal advantage over its fellow PIC series in that it has an inbuilt signal conditioning circuit that performs both amplification and filtering functions. The filtering is necessary to block any higher frequency noises present in the signal while the amplification provides sufficient gain to boost the weak signal coming from the photosensor unit and convert it into a pulse.

Microcontroller Unit

This unit basically handles all processing and coordination of other components; hence it could be regarded as the brain of the heartbeat monitor. The Microcontroller used in this work is PIC16F876A, a 28-pin Flash-based, 10-bit ADC CMOS microcontroller with nano Watts Technology. PIC16F876A is considered because of the design requirements for compactness, portability, low cost, and high performance and also because the memory requirement of this device is not much. Figure 5 shows the pin configuration of the microcontroller.

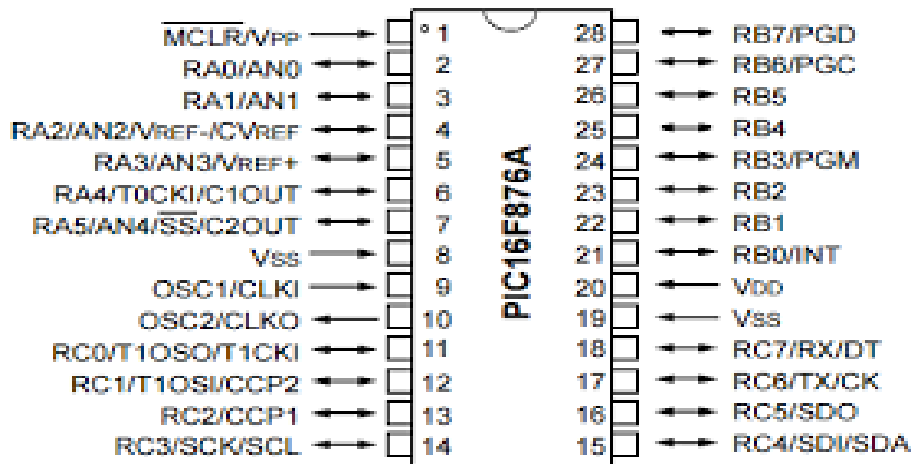


Figure 5: Pin configuration of PIC16F876A Microcontroller (Source: Datasheet)

Salient Features of the PIC16F876A Microcontroller

The PIC16F876A Microcontroller has a host of features that maximize system reliability, minimize cost through elimination of external components, provide power-saving features and offer code protection. Some of these features include the following: Reset (power-on Reset, power-up Timer, oscillator start-up Timer, and brown-out Reset)

Interrupt (Watchdog Timer with independent oscillator for reliable operation), Programmable code protection, ID Locations, Low-voltage and In-circuit serial programming via two pins, In-circuit Debugger, RB6 clock pin and RB7 data pin, an operating frequency of 20MHz. The PIC16F876A Microcontroller has two timers that offer necessary delays on power-up. One is the Oscillator Start-up Timer (OST), intended to keep the chip in Reset until the crystal oscillator is stable. The other is the Power-up Timer (PWRT), which provides a fixed delay of 200ns (nominal) on power-up only, designed to keep the part in Reset while the power supply stabilizes. There is also circuitry to reset the device if a brown-out occurs, which can use the Power-up Timer to provide at least a 200ns reset. With these three functions on-chip, most applications need no external Reset circuitry. The sleep mode is designed to offer a very low-current Power Down mode.

Crystal Oscillator Circuit

Considering the fact that the PIC16F876A Microcontroller has a DC operating frequency of 20MHz, an external 4MHz crystal oscillator is coupled to the Microcontroller to enable enhanced performance. This crystal oscillator generates a frequency of 4MHz which is used as the clock frequency for the Microcontroller. The crystal oscillator circuit consists of a 4MHz crystal and two 33pF capacitors connected in parallel. Its equivalent circuit is shown in Figure 6.

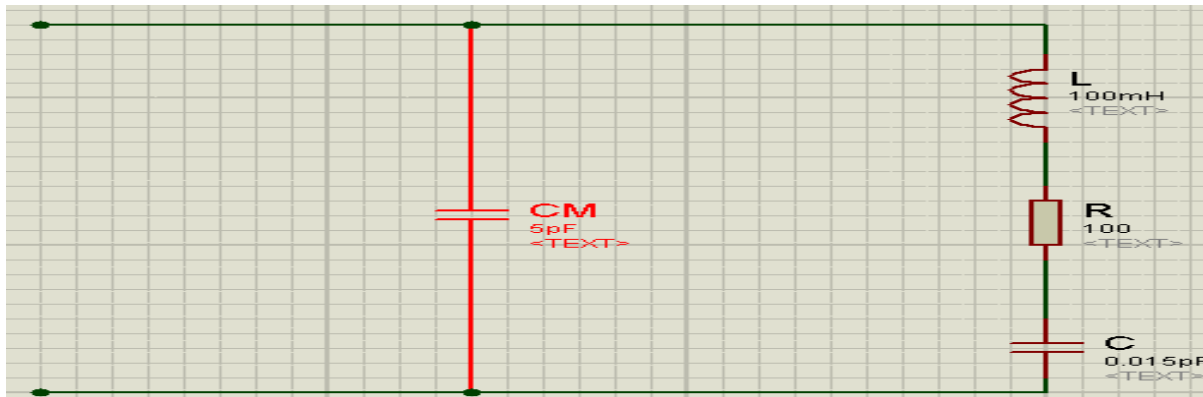


Figure 6: Equivalent circuit of the 4MHz Crystal Oscillator used

C_M = mounting capacitance,

R-L-C = electrical equivalent of vibrational characteristic of the crystal

As shown in the circuit diagram of Fig3.7, typical values for a 4MHz crystal are:

L=100mH, C= 0.015pF, R= 100Ω, and $C_M = 5pF$

Operating frequency of the crystal oscillator, $f_s = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(100 \times 10^{-3} \times 0.015 \times 10^{-12})}}$

$4.11 \times 10^6 \approx 4MHz$

Dual Power Supply Circuit

The device was designed to run on a dual (AC and DC) power supply. This implies that it can be powered by either the AC Mains supply (220V) or a 9V/12V battery source to deliver the necessary voltage needed by the Microcontroller, the sensor, and LCD. Figure 7 shows the circuit diagram of the dual power supply unit.

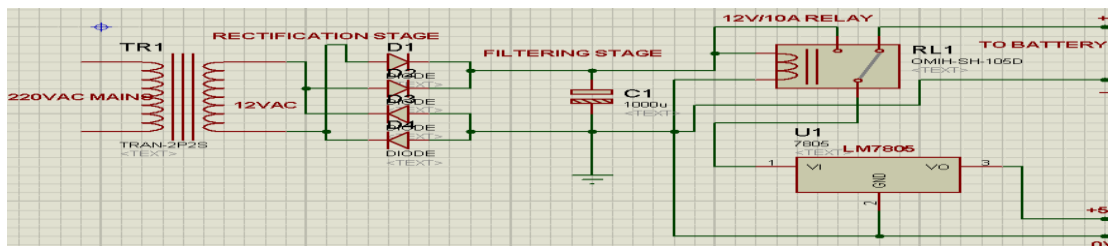


Figure 7: Circuit diagram for the dual power supply unit

Calculation of the value of the filtering/smoothing capacitor

Load current going into the LM7805 (i.e maximum current required by the power supply),

$$I_{MAX} = 0.5A$$

Capacitor voltage before discharge = $V_{MAX} = 12V$

Capacitor voltage after discharge = $V_{MIN} = 5V$

Discharge time of reservoir capacitor for half-wave rectifier, $T_H = \frac{1}{F} = \frac{1}{50Hz} = 20ms$

Discharge time for a full-wave diode bridge rectifier, $T_F = \frac{T_H}{2} = \frac{20ms}{2} = 10ms$

$$C >= \frac{I_{max} \times T_F}{V \text{ before discharge} - V \text{ after discharge}}$$

$$C_{min} = \frac{0.5 \times 10 \times 10^{-3}}{12-5} = 714 \times 10^{-6} = 714\mu F$$

Therefore, a close value of **1000uF** was chosen

The Display Unit

The display unit consists of a Liquid Crystal Display (LCD) which displays the information measured by the Microcontroller. The LCD used in this project is a 16x2 matrix line character. This implies that it can display 16 characters in 2 rows totaling 32 characters in all. Figure 8 shows the pin configuration of the LCD.



Figure 8: Pin configuration of the 16x2 matrix LCD

LCD pin description

VSS is for the -5V

VDD is for the +5V

RS is for the register select

RW is for the registered right reprogram

VEE is for screen brightness control/contrast control

E is enabled for automatic reset whenever there is a wrong connection

D0-D7 represents data pins.

It should be noted that data pins D0-D3 are not used and may be grounded or left alone.

Overall circuit implementation procedures

In order to minimize cost, ensure portability and reduce the complexity of the circuitry, the signal conditioning circuit, the microcontroller unit, the dual power supply circuit, the crystal oscillator, and the display unit are all incorporated on a single Printed Circuit Board (PCB) which is designed from the scratch. Hence, the Heart Rate Monitoring (HRM) device comprises the following sections:

- (i) The main control PCB;
- (ii) The IR sensor unit;
- (iii) The overall casing design; and
- (iv) The Transformer for the power supply

Step-by-step Procedures Used in Designing the Main Control PCB

A printed circuit board (PCB) mechanically supports and electrically connects electronic components using conductive tracks, pads, and other features etched from copper sheets laminated onto a non-conductive substrate. A printed circuit board has pre-designed copper tracks on a conducting sheet. The pre-defined tracks reduce the wiring, thereby reducing the faults arising due to loosen connections. One simply needs to place the components on the PCB and solder them. The procedures involved in designing the PCB on which the entire main control circuit components are soldered are discussed below.

Soft version design on proteus: This entails circuit implementation on both the design and the schematic platforms of the proteus simulation software. Figure 9 below shows the circuit layout side of the PCB.

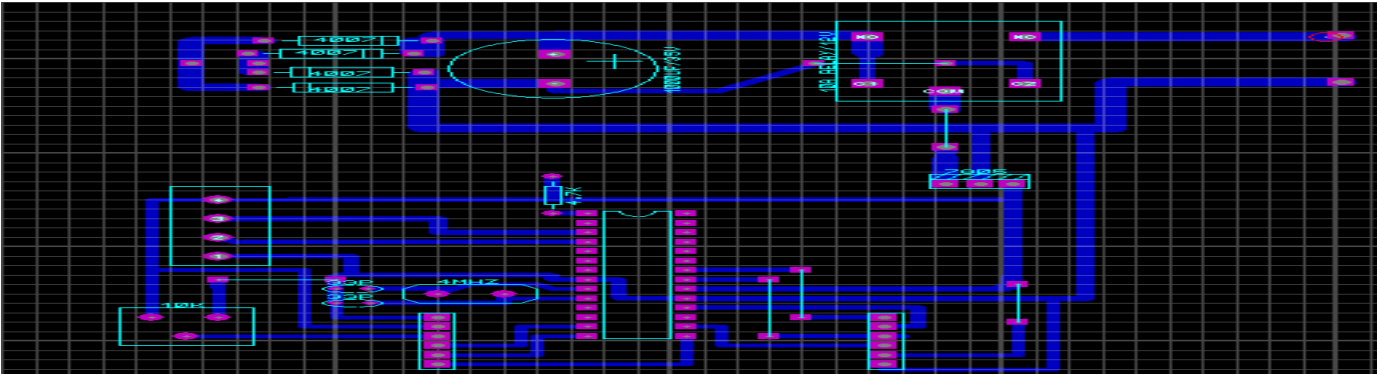


Figure 9: Circuit Layout side design of the PCB using proteus

Double-sided printing: This entails the printing of both the SCHEMATIC and CIRCUIT LAYOUT sides of the PCB.

Measurement and cutting-out of the required board size: This entails the use of a ruler and engineering knife to measure and cut out the required board dimension from the PCB sheet.

Surface cleaning and smoothening of the board's surface: This is done to remove dirt and any unwanted pattern from the board's surface. It is done using a small smoothening sponge (or alternatively a piece of clean cloth) soaked in a little quantity of petrol. After cleaning and smoothening, the board is carefully placed on the print-out soft version and wrapped with the edges properly covered up using paper tape.

Lamination (Engraving): This is done with the aid of a laminating machine (or alternatively using a pressing iron) to transfer the features (SCHEMATIC AND CIRCUIT LAYOUT) on the soft version to the board. The resultant board after lamination with the paper coverage is then soaked inside water for a few minutes to facilitate easy removal of the paper coverage. The paper coverage removal is done using the palm of the right thumb and care must be taken to avoid scratching the board surface with the finger.

Etching: The etching chemical used is “Ferric Chloride solution” with the chemical formula- $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$. The laminated board is placed in the solution contained in an open container for a few minutes and carefully stirred to ensure uniformity. The resultant PCB after etching often referred to as “green board” is then sun-dried for a few minutes.

Spraying: The PCB is then sprayed with the anti-rust agent to prevent the possible occurrence of rusting.

Drilling: PCB mini drilling machine is used with the drilling bit that ranges from 0.8mm to 1mm

throughout the design. 0.8mm bit is used for fixing of IC sockets and the resistors that are 0.25w. 1mm drilling bits are used specifically to drill relays, diodes, and big electrolytic capacitors holes. The drilling bit is fixed and fastened into the drilling machine. It is then pressed firmly to the copper track that is labeled for the component pad. When the drilling machine is pressed on the PCB, it drills the holes for the components.

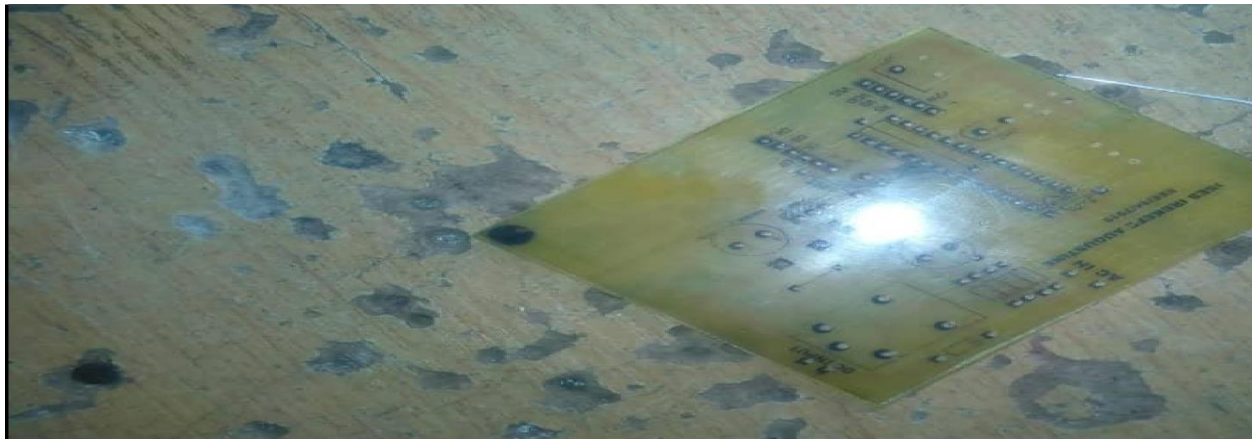


Figure 10: Schematic side of PCB after drilling of holes



Figure 11: Circuit Layout side of PCB after drilling of holes

Components mounting and soldering: This entails fixing each component in their appropriate positions on the schematic side of the PCB and the corresponding soldering on the circuit layout side.



Figure 12: Components mounting and soldering on the PCB

Testing: The completed main control PCB is then tested to examine its functionality

Assembling and Interconnection of various Sections

This entails coupling of the transformer for the dual power supply, fixing of the PIC16F876A Microcontroller into its socket soldered on the PCB, connection of the IR sensor and the LCD modules to their corresponding pins/connectors soldered on the PCB plus the soldering of the power supply cable

Overall Casing Design

The designing of the casing is the last stage in the device hardware implementation. In order to construct a very good casing for the device, a flat steel plate was cut out according to the dimensions shown in figure 10 below. The spaces for the A.C mains plug, DC source connecting wires, IR sensor module flex, and the LCD were then drilled out. The cutting and drilling were done using electric G-Saw and electric twist drill respectively and this was followed by bending of the cut-out plate design using a bending machine. After getting the desired case form (Rectangle), the painting of the casing was performed for proper outlook and finishing. The following materials were used for painting the device casing:

Thinner, Slow Thinner, Hardener, Clear Coat Oil, Primer, Base Smooth Zap Paper

The above materials were mixed in the right proportion and poured into a spraying machine cup for painting the casing.

Device software development

The firmware handles all the control and computation operations. The firmware was developed using MikroC PRO for the PIC compiler. The MikroC PRO for PIC is a powerful feature-rich development tool for PIC microcontrollers. It is designed to provide the programmer with the easiest possible solution to developing applications for embedded systems, without compromising performance or control.

If the number of pulse count in time T is n, then the heart rate per minute (i.e., 60s) is given by

$$N = 60n/T$$

If the duration of the measurement is 1 second, then the heart rate is calculated thus:

$$N = 60n$$

The operation of the software is described below in Program Description Language (PDL)

BEGIN

```

Initialize I/O ports;
Configure I/O ports;
Display ready!!! Please press Start
button;Find Heart Rate;
Display rate in LCD;
If
Pulse count>70, display on LCD high Rate;
Else If
Pulse count is <60, display on LCD Low Rate;
Else
Display on LCD Normal Rate;

```

END IF

```

Pulse rate=0;
Calculate
Pulse count=pulse rate* 60

```

END EXECUTION

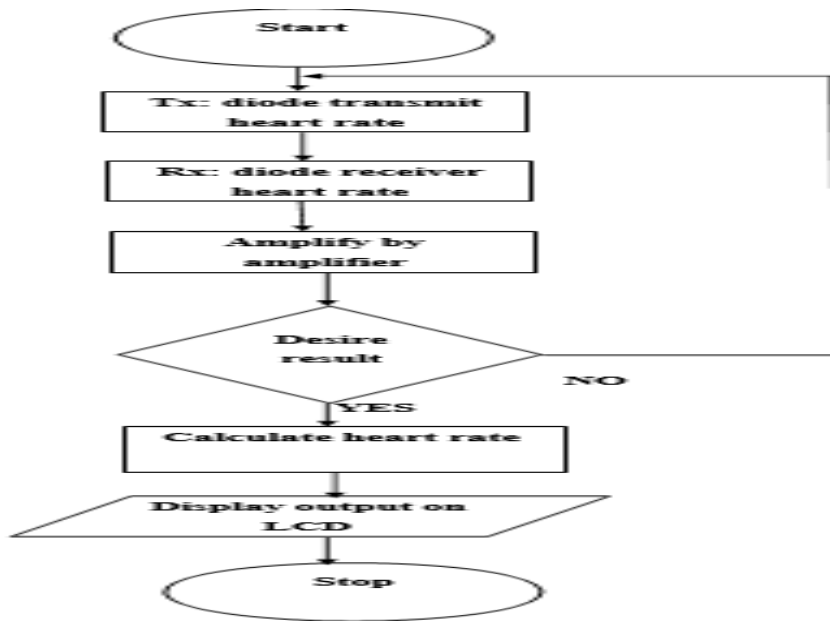


Figure 13: A snapshot of the competed and cased HRM device

RESULTS

At the first phase of the device, the optical receiver and transmitter were constructed and tested. The output of the receiver was connected to an oscilloscope to obtain the heartbeat signal shown in figure 14.

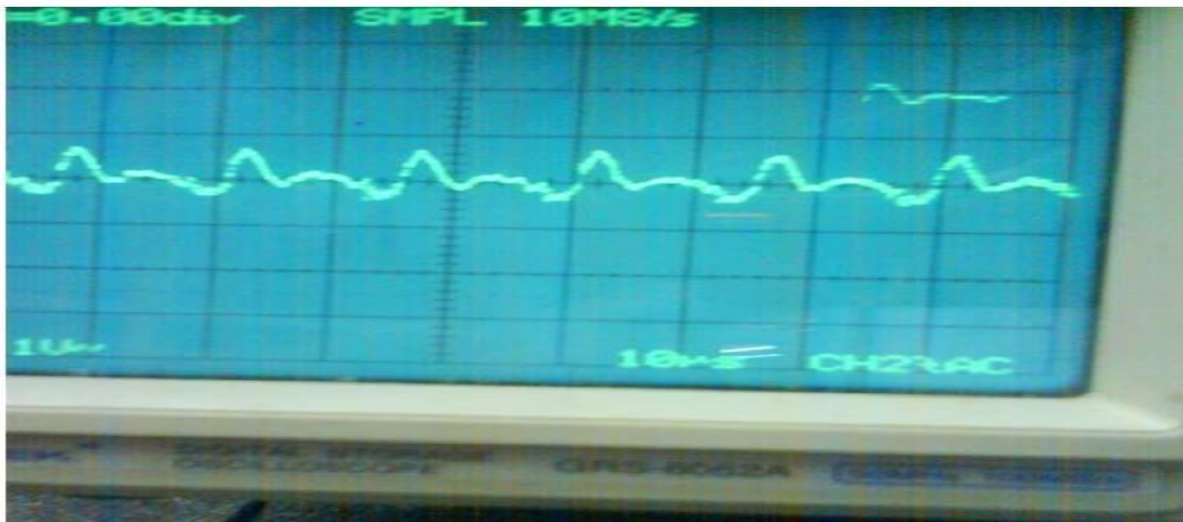


Figure 14: Output heartbeat signal from the sensor

A bandpass filter was used to filter the noise from the heartbeat signal and the output obtained after removing the noise in the heartbeat signal is shown in figure 15.

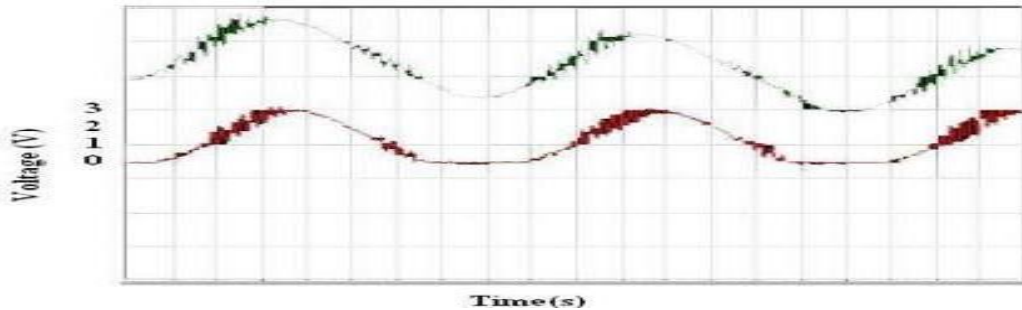


Figure 15: Filtered output heartbeat signal

The amplified output signal is shown in figure 16.

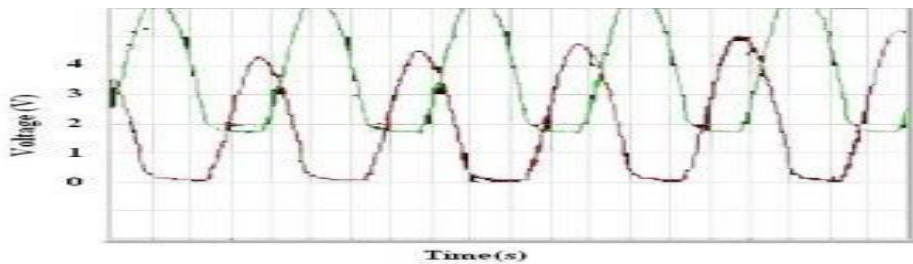


Figure 16: Amplified output signal

Accuracy comparison with an ECG

The performance of the designed HRM device is tested with the output signal Electrocardiogram (ECG) of the fingertip sensor on the oscilloscope for 9 patients. The percentage error rate (E) was calculated using the equation below.

$$E(\%) = \frac{[A - M]}{A} \times 100$$

Where **A**= actual heart rate (on an oscilloscope)

M= measured heart rate (using HRM device),

E= Percentage error rate, and

[A-M] = Absolute value of the error.

Table 1: Accuracy comparison with an ECG

Gender	Age(yrs)	HR on display (BPM)	HR on an oscilloscope (BPM)	Error rate (%)
Male	22	96	97	1.03
Male	22	81	83	2.41
Male	20	78	78	0
Male	22	87	90	3.33
Male	20	79	80	1.25
Female	22	77	77	0
Female	22	103	104	0.96
Female	19	75	75	0
Female	20	69	71	2.81

Mean Error rate (%), $E_m = \sum fx/n$

Where, $E_m = \text{mean error rate}$, $\sum fx = \text{sum of all the error rates and } n = \text{number of patients}$

$$E_m = \frac{1.03 + 2.41 + 3.33 + 1.25 + 0.96 + 2.81}{9} = 1.31\%$$

Heart rate measurement before and after exercise

Another experiment applied that ask two male volunteers to measure their heart rate after taking a rest for about two minutes and took another measure after running for five minutes. The results obtained for the device measurement compared with a manual measurement is done by counting pulse from the wrist are presented in Table 2.

Table 2: Heart rate measurement before and after taking exercise

Age(yrs)	Case	HR on display (BPM)	HR on an oscilloscope (BPM)
24	Before exercise	65	64
24	After exercise	90	88
15	Before exercise	91	88
15	After exercise	110	100

DISCUSSION

Comparing figure 14 and figure 15 above, it is observed that the high-frequency noise of 120Hz from ambient lights has been filtered out as expected. The filtered signal is required to have an SNR of 20dB or greater, to ensure that the amplifier is able to correctly convert the continuous signal to a higher amplitude signal form without producing false triggers due to noise. The filtered signal has an SNR of approximately 24dB and this allows the amplifier to properly amplify the heartbeat. This test shows the filter is able to remove high-frequency noise from the heartbeat signal.

The result obtained for the mean error rate shows that the HRM device has an average error rate of only 1.31% and hence, depicts its efficiency in measuring heartbeats in a cost-effective and ergonomic manner. In general, the heart rate of females is higher than males. But this is not true where differences in weight, daily life (i.e., kind of work, health, inheritance of heart disease, doing exercises... etc.), is put into consideration.

As obvious from the testing results presented in table 2, different kinds of people have different heart rates; the first volunteer was a boy who always takes exercise, his heart rate was the lowest. But the other volunteer was a fat boy, so his HR is the highest during rest and without doing anything. Before testing, all of them known heart rate was around 70 times/minute but taking that out of this range means health problem. After testing, the information was correct in that the safe range is between 60 to 120 bpm. Thus, providing more response information of body conditions such as heart rate is very important to users, which can help them to know healthy conditions and reduce disease.

IMPLICATION TO RESEARCH AND PRACTICE

Some severe diseases and disorders e.g., heart failure needs close and continual monitoring procedure after diagnosis, in order to prevent mortality or further damage as secondary to the mentioned diseases or disorders. Monitoring these types of patients, usually, occur at hospitals or healthcare centers. Heart arrhythmias for instance, in many cases, need continual long-term monitoring (UK's National Health Service, 2021). However, the patients are often too early released, owing to the need for a hospital bed for another patient on the waiting list, who needs to be hospitalized immediately. Hence, the development of a low-cost portable microcontroller-based heartbeats monitor would benefit the users to monitor their heart rate at home or any place.

There is a dramatic increase in incidents of heart and vascular diseases as a result of lifestyle and unhealthy eating habits. Consequently, heart problems are on the increase in younger patients. Statistics (UK's National Health Service, 2021) show that coronary heart disease is now the leading cause of death. Thus, any improvements in the diagnosis and treatment tools are welcomed by the medical community. This device "Microcontroller based heartbeat monitor using an IR heartbeat sensor" developed in this research project work can be used in hospitals and also for patients who can be under continuous monitoring while traveling from place to place. The project has developed a cost-effective heartbeat monitoring system that would be affordable to people of all categories.

CONCLUSION

In this paper, the development of a simple and low-cost microcontroller-based Medicare device for heartbeat monitoring has been discussed. The device is portable, durable, and cost-effective and hence, could be used by any individual in any place even if not a cardiologist. Finally, from the performance evaluation carried out, it was deduced that the developed HRM device has an average error rate of only 1.31% which in turn, depicts its efficiency in measuring heartbeats in a cost-effective and ergonomic manner.

RECOMMENDATIONS FOR FUTURE RESEARCH

The Heart Rate Monitoring device developed in this project could be used in clinical and non-clinical environments. It can also be easily used by individual users most especially athletes during sporting activities. However, for future work, the device could be further improved by the addition of the following features:

- (i) An APR 600 voice chip could be incorporated into the device so as to enable voice output in the English language and the two other Nigerian indigenous languages, Hausa and Yoruba.
- (ii) Monitoring device that could be used to detect the heartbeat anomalies of physically

challenged individuals without hand.

(iii) A graphical LCD can be used to display a graph of the change of heart rate over time.

(iv) A serial output can be incorporated into the device so that the heart rates can be sent to a personal computer (PC) for further online or offline analysis.

(v) Finally, it could be integrated with mobile technology for e-health cloud transmission to health care providers.

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