Design of a Simple and Low-Cost Microcontroller Based Medicare Device for Heart Beat Monitoring

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Design of a Simple and Low-Cost Microcontroller Based Medicare Device for Heart Beat Monitoring

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ABSTRACT

Heart beat monitoring is vital to ensuring healthiness of the human cardiovascular system, but availability of a simple and low-cost heart beat monitoring device that does not require expert medical personnel to handle still remains a challenge especially in rural and semi-urban areas of developing countries like Nigeria. This paper describes the design and implementation of a simple, reliable, accurate and cost effective microcontroller based heart beat monitoring device with Liquid Crystal Display (LCD) and voice outputs. The heart rate of the subject is measured from the fingertip using optical sensors and the rate is then displayed on a text based LCD and voice outputs in English language and two Nigerian indigenous languages (Hausa and Yoruba).

Keywords: Heartbeat, Fingertip pulse rate, Microcontroller, Heart rate monitor (HRM), Voice output.

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1. INTRODUCTION

Science and technology by way of inventions and innovations has made life easier for everybody in all spheres of life. One of such is in medical sciences where medical personnel are now able to acquire vital medical data from patients. Two of the most important are the measurement of heartbeat rate and temperature [1]. The Human Heart Rate Monitors (HRM) are devices that allow the user to gain a real time measurement of their heart beat. They consist of a transmitter which detects the heartbeat by measuring the number of times the heart beats per minute and a receiver that determines the heart rate on receiving signals from the transmitter [2].

The first wireless Electrocardiography (ECG or EKG) heart rate monitor was invented in 1977 by Polar Electro. It was invented for the Finnish National Cross Country Ski Team to aid them in training. The concepts of "Intensity Training" became a buzz throughout the athletic world in the eighties, and in 1983 which lead to the introduction of the first wireless heart monitor [3] [2]. By the 1990s, attention shifted from heart rate monitors for intensify and quality training needs to normal individual everyday fitness needs [2]

Human Cardiovascular System consists of the heart, blood vessels and approximately five litres of blood that the blood vessels transport [4]. Heart rate measurement indicates the soundness of the human cardiovascular system. Heartbeat rate is one of the very important parameters of the cardiovascular system. The measurement of heart rate is used by medical professionals to assist in the diagnosis and tracking of medical conditions.

It is also used by individuals, such as athletes, who are interested in monitoring their heart rate to acquire maximum efficiency. According to [5], there is a dramatic increase in incidents of heart and vascular diseases as a result of the lifestyle and unhealthy eating habits. Consequently, heart problems are on the increase on younger patients. Statistics shows 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. In a clinical environment, heart rate is measured under controlled conditions like blood measurement, heart beat measurement, listening to heartbeats using Stethoscope and Electrocardiogram (ECG), but these methods are expensive and need to be carryout by an experience medical personnel. Therefore, there is a great need that patients are able to measure the heart rate in the home environment as well.

Reference [6] defines heart rate monitor (HRM) as a simple device that takes a sample of the heartbeat signal and computes the heart rate in beats per minutes (bpm) so that the information can easily be used to track heart conditions. The HRM devices employ electrical and optical methods as means of detecting and acquiring heart signals. ECG and blood pressure monitor are amongst a few medical devices that display heartbeat readings digitally. However, ECG is the only medical device that extracts heart beat signals and displays it in graphical form [7].

Drawbacks with ECG method are: too many sensors and cables connections, fluctuations in the ECG signal baseline, power line noise, and interference due to muscular activities and high cost of procurement. More so, ECG is not suitable for continuous monitoring on burnt victims and the conduction gel used may cause discomfort and inflammation on the skin.

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The average heart beats is between 60 and 100 times per minute. If your heart beats below 60 times per minute, this is *bradycardia*. If it beats more than 100 times per minute, is *tachycardia*. The rate of heartbeat is measured in beat per minute (bpm) [8].

According to [8] having *bradycardia* (pronounced as *Bray-dee KAR-dee-uh*) means that your heart beats slower than normal. For majority people, heart rate of between 60–100 beats per minute is considered normal while at rest. Heart beats less than 60 times a minute, is slower than normal. Slow heart rate can be normal and healthy or it could be a sign of problem with the heart's electrical system. For some people, slow heart rate does not cause any problem. It can be a sign of being very fit. Healthy young adults and athletics often have rates of less than 60 beats a minute. In other people, *bradycardia* is a sign of a problem with the heart. "It means that the heart's natural pacemaker is not working right or that the electrical pathways are disrupted" [8].
Men and women aged 65 and older are most likely to develop a slow heart rate that needs treatment. As a person ages, the electrical system of the heart often does not functions normally, hence needs to be monitored frequently and regularly [9] .

Resting Heart Rate (RHR) is the rate at which your heart beats when you are at rest after 10 minute. Though, the best time to measure RHR is right after you naturally wake up in the morning. Generally, the lower a person's RHR, the more fit that person is because the heart need not work hard. Resting heart rate can be decreased due to consistent physical training and exercise [10]. However, RHR varies depending on the age and health condition of a person and time of the day as shown in Table 1.

Table 1: Resting Heart Rate [9]

Resting Heart Rate	
Infant up to age 1	100 – 160 bpm
Older Children ages 1-10	70 – 120 bpm
Teenage Children 11-17	60- 100 bpm
Adults	60 – 100 bpm
Average of Sex	
Male	70 bpm
Female	75 bpm
Active athletes	40 – 60 bpm

In this work, a novel low cost microcontroller based heartbeat monitoring device which uses optical sensors to measure the alteration in blood volume at fingertip is proposed and developed. The device gives the heart beat rate and status in two output form: Alphanumeric visual output and voice output in English and two other Nigerian indigenous languages, Hausa and Yoruba. The work is an improvement on the work done by [11].

2. RELATED WORKS

The Human Heart Rate monitors have been widely used around the world. The devices allow the user to have a real time measurement of their heart beat.

Reference [12] proposed a heartbeat monitoring system for Detection and Classification of five cardiac conditions. He used signal processing techniques and Artificial Neural Network (ANN) to implement a 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.

Reference [13] 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, portable, 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 practitioner to use.

According to [14] certain disorders, involving heart valves cannot be diagnosed from ECG. Other diagnostic techniques such as angiography and echocardiography can provide information not available in ECG.

Reference [15] 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 infra-led 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.

Reference [5] also proposed a microcontroller based heart rate monitor using fingertip sensors. The design uses the 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 expertise knowledge to use and also not so economical.

Reference [11] described the design of a simple low-cost PIC16F84 type microcontroller based heart rate measuring device with LCD output. The heart rate is measured from the fingertip using optical sensors and displayed on text based LCD, though the device can be used by non professional, it however does not have a voice output and cannot display warning of abnormalities on the LCD.

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Reference [16] presented the design and development of an integrated microcontroller based device for measuring heart rate using fingertip. The design uses three phases to detect pulses on the fingertip namely: pulse detection, signal extraction and pulse amplification. They also used optical method to develop the heart monitor. Finally the performance of the HRM device is compared with ECG and manual pulse measurement of heartbeat. The device however gives only an alphanumeric visual output on the LCD. In this work, a Simple low-cost Microcontroller Based Heart Rate Monitor is proposed. The microcontroller will measure the heart rate from the fingertip via the photodiode sensor and display the rate on an LCD with status information like: ***Rate Low (Bradycardia) Please See Doctor, Normal Heart rate*** and ***Rate High (Tachycardia) Please See Doctor***. A voice report of the heart rate is also provided hence no expertise is required to use the device which makes it suitable for use.

3. METHODOLOGY

The heart rate is measured when a fingertip is placed over the sensor unit. The sensor unit consists of an 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 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 a 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 the sensors are designed for low power measurements and offer high sensitivity and low noise, enabling them to detect very low light levels.

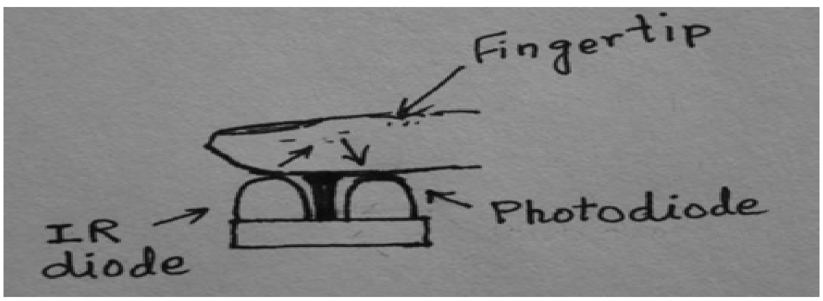

Figure 1: Fingertip Placement over the Sensor Unit Source - [17]

The signal conditioning circuit consists of two identical active low pass filters with a cut-off frequency of about 2.5 Hz. This means the maximum measurable heart rate is about 150 bpm. A voice chip (APR9600) is integrated into the circuit that allows the device to indicate to the user the measured values from the microcontroller. The operational amplifier IC used in this circuit is LM358, a dual OpAmp chip from Microchip. It operates at a single power supply and provides rail-to-rail output swing. The filtering is necessary to block any higher frequency noises present in the signal. The gain of each filter stage is set to 101, giving the total amplification of about 10000. A 1uF capacitor at the input of each stage is required to block the dc component in the signal. The microcontroller (PIC16F648A) was programmed to display the heart rate over a period of time. An LM 7805 voltage regulator was used to regulate the 9v to 5v.

This work also demonstrates a technique to measure the heart rate by sensing the change in blood volume felt at the fingertip by the microcontroller via the photodiode while the heart pumps the blood. The project consists of an infrared Light Emitting Diode (LED) that transmits an Infrared (IR) signal via the fingertip, reflected by the blood cells.

The reflected signal is detected by a photo diode sensor. The change in the blood volume with heartbeat results in a train of pulses at the output of the photo diode, the magnitude of which is too small to be detected directly by a microcontroller, hence the use of a two-stage high gain, active low pass filter designed using two Operational Amplifiers (OPAMPs) to filter and amplify the signal to appropriate voltage level so that the pulses can be counted by a microcontroller. The heart rate of the subject is measured from the fingertip via the photodiode and the corresponding result is displayed on a liquid crystal display (LCD).

4. DESIGN AND IMPLEMENTATION

The heart rate measurement system uses optical sensors to measure the alteration in blood volume at fingertip with each heartbeat. The design consists of a sensor unit with an infrared light-emitting-diode (IR LED) and a photodiode, the amplification and filter unit, the microcontroller unit, the display unit, the power supply unit, the voice output unit, and the firmware section. The block diagram is as shown in Figure 2 below.

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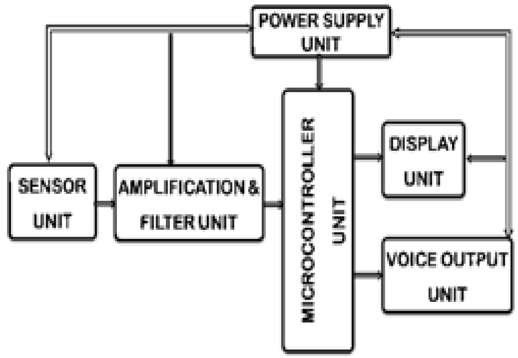

Figure 2: Block diagram of design

4.1 Device Hardware

The hardware is categorised under the following headings:

Sensor Unit**:** The sensor unit consists of an IR diode and a photo diode, see Figure 3. 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 heart beat slightly alters the amount of reflected infrared light that can be detected by the photodiode. With the help of LM358, an operational amplifier (OpAmp), 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.

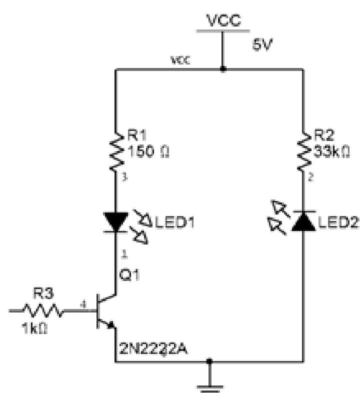

Figure 3: Sensor Unit

Amplification/Filter Unit: 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. The signal conditioning circuit consists of two identical active low pass filters. The OpAmp Integrated Circuit (IC) used in this circuit is LM358 see Figure 7, a dual OpAmp chip from Microchip Inc. The symbol, pin configuration and unit gain of the OpAmp is as shown in figures 4, 5 and 6 respectively. It operates at a single power supply and provides rail-to-rail output swing. The filtering is necessary to block any higher frequency noises present in the signal. A 1µF capacitor at the input of each stage is required to block the dc component in the signal. The two stage amplifier/filter provides sufficient gain to boost the weak signal coming from the photo sensor unit and convert it into a pulse. Equations 1 and 2 below show the Gain, *A* and the Cut-off Frequency, f_c respectively:

$$Gain\ of\ each\ state, A = \frac{R_f}{R_i} + 1 \quad \text{..} \quad (1)$$

$$Cut-off\ Freq, f_c = \frac{1}{2\pi R_f C_f} \quad \text{...} \quad (2)$$

Equations for calculating gain and cut-off frequency of the active low pass filter

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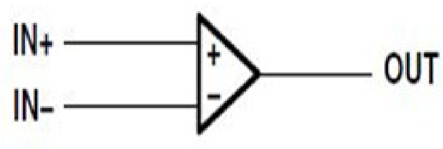

Figure 4: Symbol of an amplifier

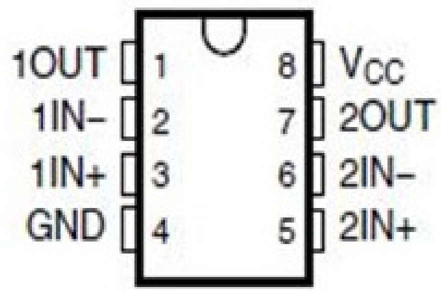

Figure 5: Pin configuration of LM358

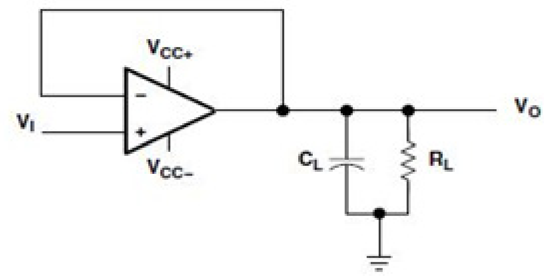

Figure 6: Unit gain of LM358

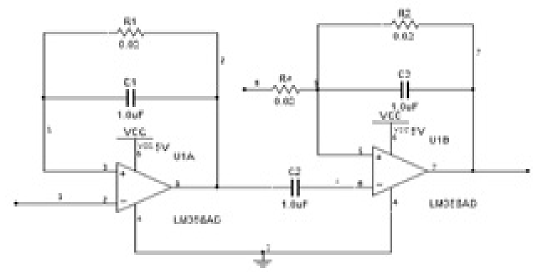

Figure 7: Amplifier/Filter Unit

The output signals from the sensor unit is very small hence required amplification for the microcontroller to process. The filter section is used to remove unwanted signal like noise, distortion due to the amplifier as well as interference from other devices.

Microcontroller Unit: This unit basically handles all processing and coordination of other components, hence the brain of the Heartbeat Monitor. The microcontroller used in this work is PIC16F648A, an 18-pin Flash- based, 8-bit CMOS Microcontroller with nano Watts Technology. PIC16F648A is considered because of the design requirements for compactness, portability, low-cost and high-performance and also since memory requirement of this device is really not much. Figure 8 shows the pin configuration of the PIC16F648A microcontroller unit (MCU).

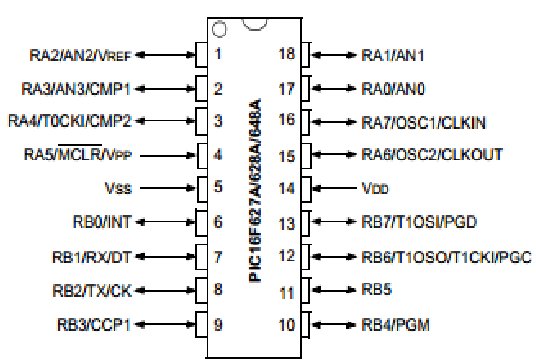

Figure 8: Pin Configuration of PIC16F648A [18]

The PIC16F648A MCU has host of features which maximize system reliability, minimize cost through elimination of external components, provide power-saving features and offer code protection. The following among others are some of these features: Reset (Power-on Reset, Power-up Timer, Oscillator Start-up Timer, and Brown-out Reset), Interrupts (Watchdog Timer with independent oscillator for reliable operation), Programmable code protection, ID Locations, Low-voltage and In-Circuit Serial Programming via two pins, RB6 clock pin and RB7 data pin.

The PIC16F648A 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 64ms (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 64ms 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 [18].

The Display Unit: The display unit consists of a Liquid Crystal Display (LCD), which displays the information measured by the MCU. The LCD used in this project is 20 x 4 line characters. This means that it can display 20 characters in 4 rows totalling 80 characters in all. Figure 9 shows pin configuration of the display unit.

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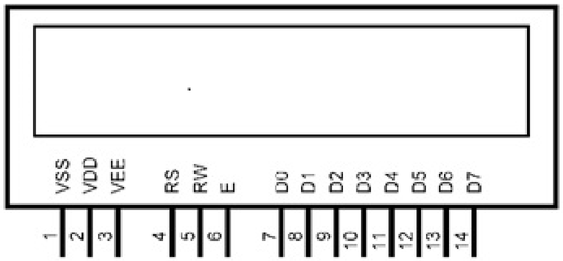

Figure 9: Display Unit

The Voice Output Unit: The voice chip used in this design is APR9600 see Figure 10, which offers true single-chip voice recording, on-volatile storage, and playback capability for 40 to 60 seconds. The device supports both random and sequential access of multiple messages. Sample rates are user-selectable, allowing designers to customize their design for unique quality and storage time needs. Integrated output amplifier and microphone amplifier greatly simplify system design. The device is ideal for use in portable voice recorders, toys, and many other consumer and industrial applications. APLUS integrated achieves these high levels of storage capability by using its proprietary analogue/multilevel storage technology implemented in an advanced Flash non-volatile memory process, where each memory cell can store 256 voltage levels. This technology enables the APR9600 device to reproduce voice signals in their natural form. It eliminates the need for encoding and compression, which often introduce distortion. The labels Rate low (RL), Normal rate (NR) and Rate high (RH) on Figure 10 indicates the connection points to the microcontroller for triggering the respective messages in the voice chip.

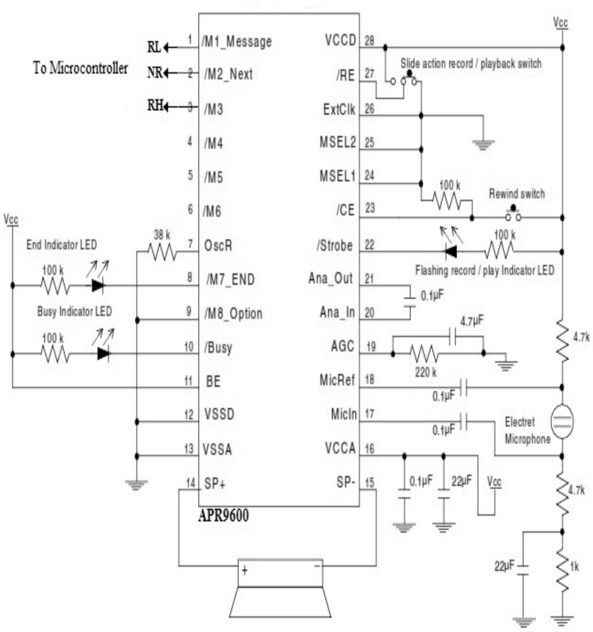

Figure 10: APR9600 voice chip circuit with pin out configuration [19]

The Power Supply Unit: This project is designed to run on a 9V battery source. It is expected to deliver the necessary voltage level needed by the microcontroller and the other devices. These devices required a 5V supply instead of the 9V, hence the need for a voltage regulator. The LM7805 chip is used to regulate the 9v to 5V supply for the whole design as shown in Figure 11.

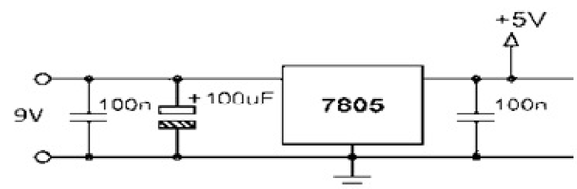

Figure 11: Power Supply Unit

From the circuitry in Figure 11, the 9V battery source is regulated to a 5V by LM7805, a voltage regulator. The capacitor is used to increase the transient response off the regulator.

4.2 Device Software

The firmware handles all the control and computation operations. The firmware was developed using MikroC PRO for 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 counts in time T is n, then the heart rate per minute is given by N,

Where N = 60n/T ……………… (3)

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

N = 60n ……………………….. (4)

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

BEGIN

Initialise I/O Ports;
Configure I/O Ports;
Display Ready!!! Please Press Start Button;
Find Heart Rate;
Display Rate on LCD/Voice Output;
If
Pulse Count is >70, display on LCD/voice out High Rate;
Else If
Pulse Count is < 60, display on LCD/voice out Low Rate;
Else
Display on LCD/voice out Normal Rate

END IF

pulserate = 0;
Calculate
pulsecount = pulserate * **60**;

END EXECUTION

The flowchart for the operation of the software is given below in Figure 12:

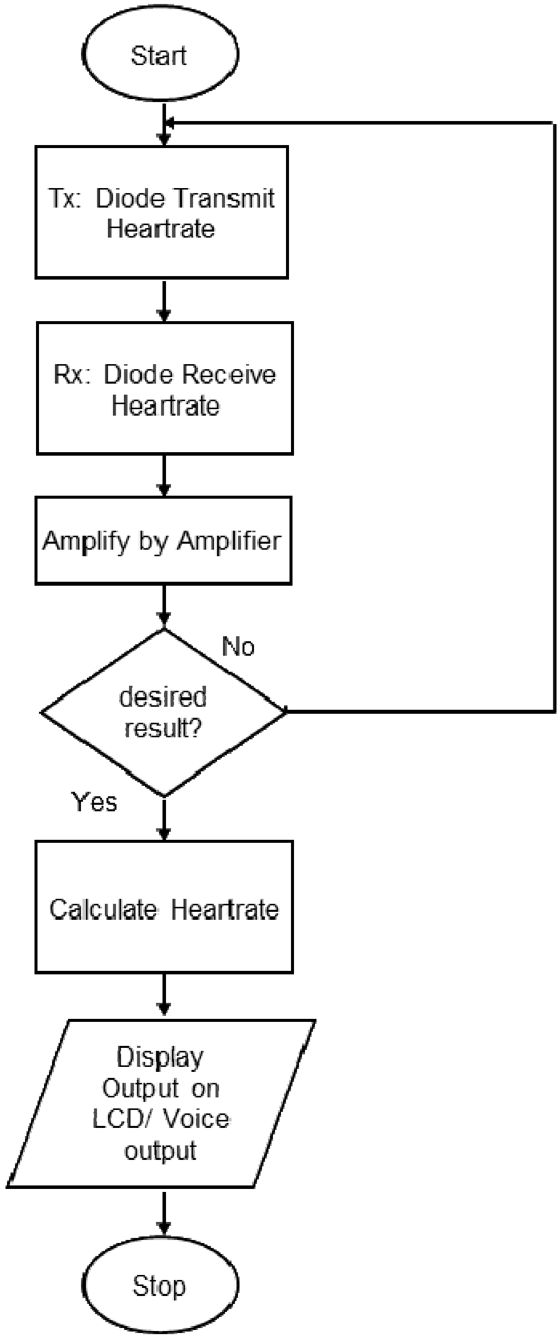

Figure 12: Flowchart of the Programme

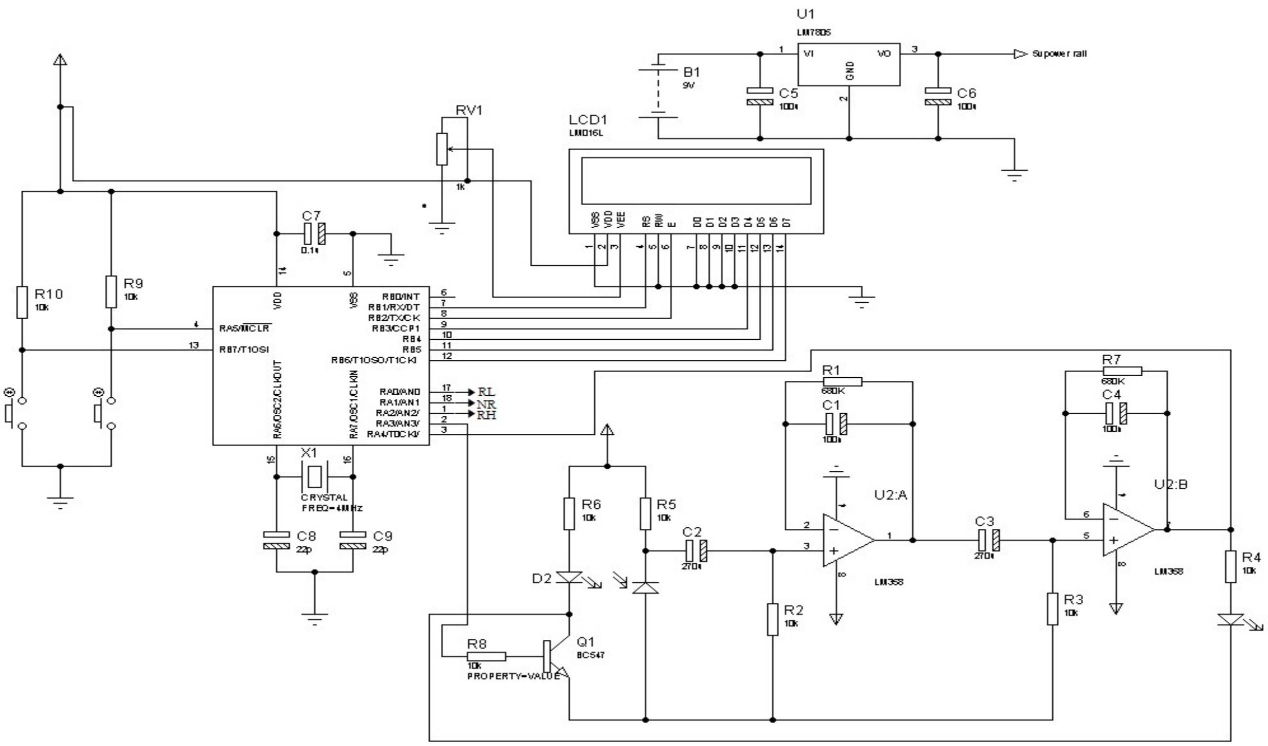

Figure 13: Circuit diagram of the device

5. CONCLUSION AND FUTURE WORK

In this paper, the design of a Simple and Low-Cost Microcontroller Based Medicare Device for Heart Beat Monitoring has been presented. The device is portable, durable, and cost effective hence could be used by any individual in the proposed region even if not a cardiologist. This device could be used in clinical and nonclinical environments. It can also be easily used by individual users, e.g. athletes during sporting activities. For future work, the device could be further improved by addition of the following features:

1. Monitoring device that could be used to detect the heart beat anomalies of physically challenged individuals without hands.
2. Also a graphical LCD can be used to display a graph of the change of heart rate over time.
3. 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.
4. It could be integrated with mobile technology for e-health cloud transmission to health care providers.

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Author's Brief

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