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DEVELOPMENT OF A MICRO-CONTROLLER BASED HEARTBEAT MONITORING DEVICE

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Heartbeat, Amplifier, Heart monitor, Peak Signal, Beat per Minutes, Filtering

ABSTRACT

Interest in solving heart related issues technologically brought about the aim of this innovative research to design and implement a portable microcontroller-based heartbeat monitor. The design considerations are medical practitioners in developing countries who have very limited medical infrastructure. Hence, low cost, power, portability and ease of use are factors that are considered at every stage of the design. The main challenge is amplification of the desired weak signal in the presence of noise from related muscles and electrical sources. The design and construction of the heart monitor involved affordable amplifier and filtering components coupled with a (PIC 16F84A) and a 7 segment displays. A typical heart rate ranges from 50 beats per minute to 200 beats per minute, with a normal one in the range of 70bpm-72bpm. Most readings obtained were higher (100bpm-150bpm) than the normal ones which do not conform to the normal readings expected. The heart rate results were obtained by measuring the time between peak signals and comparing it with predetermined value programmed in the PIC. The beats per minutes (BMP) results were displayed on the multiplexed 7-segment displays.

INTRODUCTION

The heart beats as a result of 'commands' passed in the form of bioelectric impulses and a series of rapid and successive pattern of depolarization and re-polarization across the cardiac muscle, generating electrical signals. The electrical activity of the heart can be detected on the skin by the use of optical transducer. The transducer can be constructed to sense the heart beat at the tip of a finger, by sensing the change in the optical transmission properties of blood [1].

Electrocardiography (ECG, EKG)

The heart is a muscular pump made up of four chambers. The two upper chambers are called atria, and the two lower chambers are called ventricles [1]. The purpose of the atria is to act as filling chambers for the ventricles; the right side of the heart is the pulmonary pump, that is it pumps blood between the heart and the lungs, and the left side of the heart is the systemic pump, i.e., it pumps blood between the heart and the entire body. The cardiac cycle begins at the Sino-Atria node, located in the right atrium at the superior cava. The beginning of the cycle corresponds to the contraction of the atria. Following this is a 100ms delay until the activation of the Atria Ventricular node. The delay is important because it allows time for the ventricles to fill, increasing the efficiency of the heart.

The signal is then propagated down the ventricular septum resulting in ventricular contraction [2]. The signal generated over one cycle is shown in Figure 1.

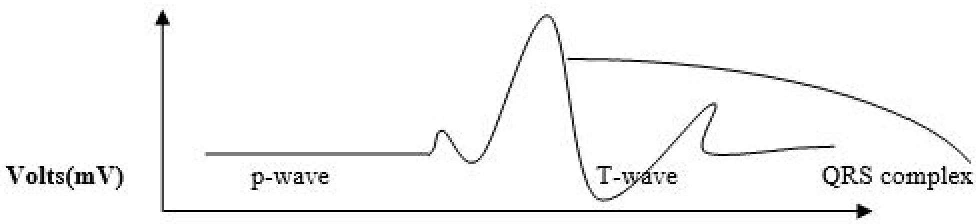

Figure 1: One period of the cardiac cycle **Time(ms)**

(P-wave: Atria Depolarization, QRS- complex: Ventricular depolarization, T-wave: Ventricular re-polarization)

The heart's strong pumping action is driven by powerful waves of electrical activity in which the muscle fibers contract and relax in a conducted sequence. These waves cause weak currents to flow in the body changing the relative electric potential between different parts on the skin. A bio-transducer will then detect the electrical activity of the heart and converts the signal from its form in the body (ionic) into electrical signal [2].

The PIC16F84 Microcontroller

The PIC16F84A is a high performing and affordable complementary metal oxide semi-conductor (CMOS). It is an 8-bits microcontroller with reduced instruction set computer (RISC) architecture. It addresses up to 64 bytes of data EEPROM and 68 bytes of Data RAM. It is a fully static design with high speed and low power consumption. The 18-pin device has 13 I/O (bidirectional) pins, 2 power supply pins (V_{cc} and Ground), a master reset pin and 2 pins for the oscillator. Each of the 13 I/O pins can sink or source 25mA of current. The microcontroller has a flash program memory which can store 1024 words (1K words) of 14 bit long. It also has EEPROM Data retention of at least 40 Years. Fig. 2.1 shows the pin configuration of PIC16f84A microcontroller. [3]

The motivation of this study comes from the interest in applying technologies to solving health related challenges. In a very busy world where most people find it time consuming or unaffordable to undergo frequent medical check-up, this device will assist in sampling the activities of the heart for more frequent monitoring by individuals.

METHODOLOGY

Many approaches can be applied electronically when sensing the human heartbeat among which are acoustic, optical and mechanical methods. In this proposition, the optical technique will be employed to exploits the fact that tiny subcutaneous blood vessels (capillaries) in any patch of skin (fingertip, ear lobe etc.) equipped with a good blood supply, alternately expand and relax in response to the heart beat. The system will be implemented as shown in the block diagram in Figure 2.

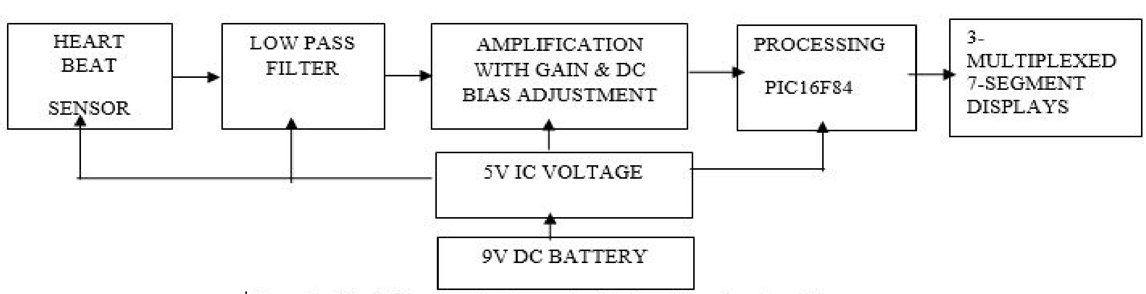

Figure 2: Block diagram of microcontroller-based heartbeat monitor

There are a lot of other methods that can be employed for electronically sensing the human heartbeat. Among which are the acoustic (using stethoscope), mechanical and optical methods [4]. In this project the optical technique will be employed which exploits the fact that tiny subcutaneous blood vessels (capillaries) in any patch of skin (fingertip, ear lobe, etc.) furnished with a good blood supply, alternately expand and contract in time with the heartbeat. An ordinary high intensity LED/Light Dependent Resistor pair can sense this rhythmic change as small but detectable variations in skin contrast.

Low Pass Filter

It is advantageous to ECG signals that contain minimum amount of contamination from noise and high percentages of usable information. Therefore, it gives a very high signal-noise ratio when examined. In an ideal situation of the system, the ratio is expected to be infinite. To ensure this, filtering is circuit is introduced. Basically, a noticeable source of noise is due to the relative movement of the finger between the sensor unit which induces a 5Hz frequency [5], as such a high pass filter with a cut-off frequency any frequency above 7Hz as shown:

$$f_c = [1/2\pi RC] \qquad (1)$$

For a good filtering capacitor value should range between 100pF ≤C≥10μF and the resistor should be in KΩ to draw less current to avoid damage to the circuit [7]. Choosing a capacitor of value: 470nF

$$R= [1/2\pi FcC] = [1/(2\pi\times7\times470\times10E\text{-}9)] =48355.89\Omega \qquad (2)$$

R=48.36Ω R=47KΩ is chosen in

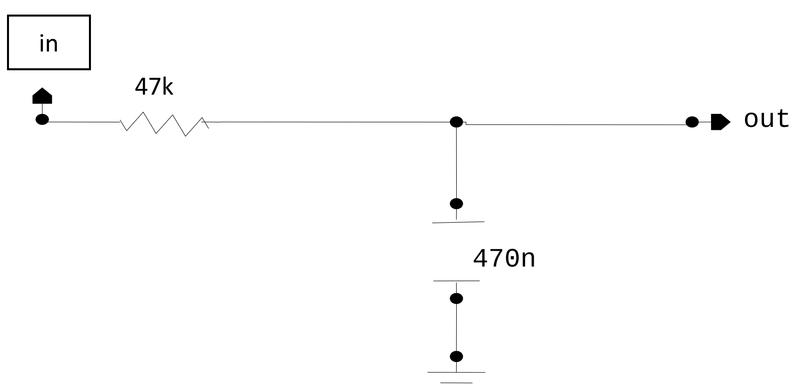

Figure 1: low Pass Filter circuit with cut-off at 7Hz

Heart Rate Sensor

The heart rate sensor serves as the collection point for essential bio-signals. It was designed in such a way that the required signal will be optically acquired using fingertip [5]. The circuit is made up of a photo resistor (LRD) and a high intensity red light emitting diode (LED). The LED reflects through the finger which detects varying pulses due to rhythmic beat of the heart. The circuit is as shown in Figure 2:

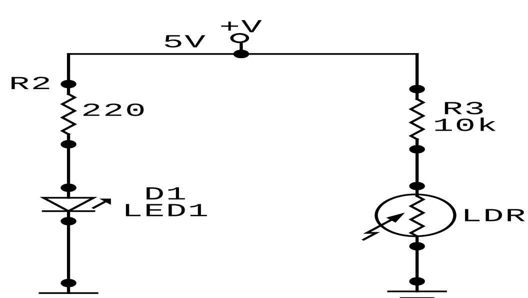

Figure 2: Heart rate sensor

Using resistor R2 to drive the LED (D2) with a nominal current of 15mA and also that the voltage drops across D2 is1.6V. Electrical characteristics per channel at 25^0C ambient Gallium Arsenide LED

Vf=typical 1.7v, max 2.0v; If(max)=30mA

Dropper resistor(R) = [Supply voltage (Vs)-Voltage across LED (V_f)]/ Current through LED (If)

$$R= (Vs-V_f)/ I_f \quad (3)$$

$$= (5-1.6)/15x10E-3=226.67\ \Omega$$

Resistor selected: 220Ω, also resistor **R3 =10KΩ** is used to drive the LDR

Amplifier with Adjustable Gain

The amplifier uses an internally compensated op-amps of LM358 operational amplifier with a potentiometer on the feedback circuit to create a variable gain to the amplifier [8]. The potentiometer on the other side increases the value of the fixed gain thereafter making it more sensitive. The circuit is shown in Figure 3 with adjustable gain and the gain is calculated as:

$$GAIN = 1+ [(R6+R7) / R5 \quad (4)$$

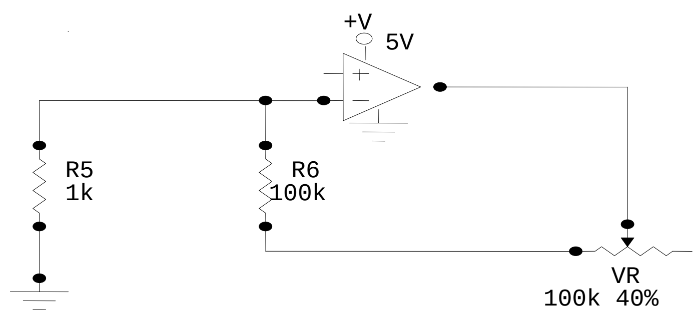

Figure 3: Amplifier with adjustable gain

With VR (potentiometer) = 0, Gain=1+[(R6+R7)/R5]

Gain=1+ [(100k+0)/1k] =101

With VR (potentiometer) = 50K, = 1+ [(R6+R7)/R5] = 1+[(100k+50k)/1k] = 151

With VR (potentiometer) =100K

Gain=1+[(R6+R7)/R5] = 1+[(100k+100k)/1k] = 201

This implies that as the potentiometer is increased, the gain increases hence the sensitivity of the system to the signal.

DC Bias Adjustment

The bias adjustment stage (using the 2^{nd} internally compensated amplifier of the op-amp) allows the user to vary the DC offset of the output signal from 0v to +5v DC with the aid of the variable resistor. The extremes of the potentiometer at the inverting terminal of the op-amp are used to cancel out this dc offset as shown in Figure 4.

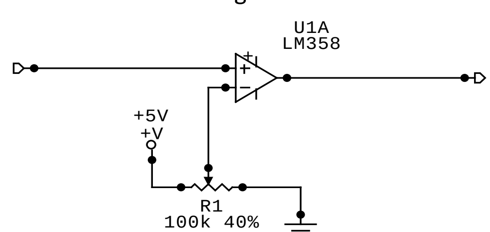

Figure 4: DC bias adjustment

The PIC16F84 Microcontroller Unit

The PIC16F84 microcontroller is used to calculate the heartbeat acquired from the amplification stage. The circuit configuration is as shown in Figure 5.

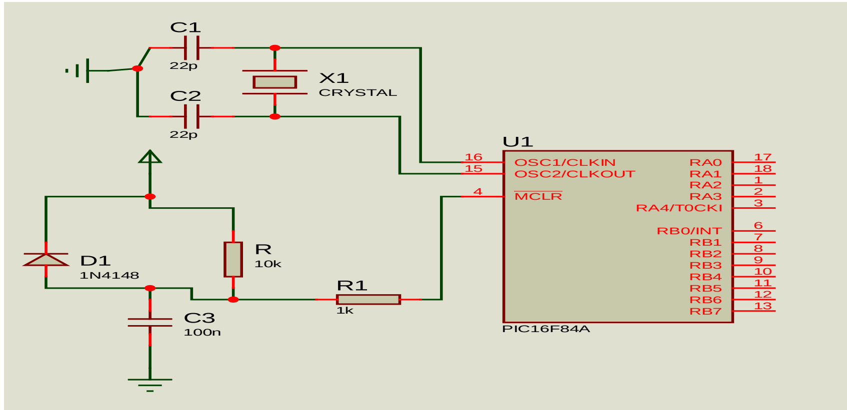

Figure 5: Configuration of the PIC16F84 microcontroller for heartbeat measurement

From the circuit in Figure 5, When the power supply to a PIC is switched on, the rise of the voltage on the Vdd pin is detected by internal circuitry which then generates a reset pulse to initialize the device. For the internal power on reset (POR) scheme to work, the rate of rise of the power supply voltage must be sufficiently fast. The operation of the circuit is as follows. When the power is applied, the capacitor C discharges and start to charge up through the resistor R. the diode provides a rapid discharge path for the capacitor when the power is removed and the resistor R1 prevents MCLR input from being damaged. The rise in capacitor voltage obeys the equation:

$$Vc = V_{dd}\,(1-e^{-t/RC}) \qquad (5)$$

$$t = RC \ln [Vdd/ (Vdd-Vcc)] \qquad (6)$$

From equation (6) the capacitor voltage will take 0.693RC seconds to reach a voltage of Vdd/2, so the appropriate values of R and C can be determined from the equation RC=1.44 $t_{0.5}$ with $t_{0.5}$ is the time taken for the capacitor to charge to a voltage 0.5 Vdd. The value of 0.5 V_{dd} is chosen, as this is the voltage in the middle of the linear region and roughly represents the onset of a logical high.

The conditioned signal (measured heartbeat) from pin 7 of the op-amp is fed into the microcontroller through pin RA3. Pins RA0, RA1 and RA2 are used in controlling the signal to on/off the 7-segment modules. While pins RB0-RB6 are used in powering the segments of the modules.

Display Unit

The display unit is implemented using three 7-segment display modules multiplexed so as to provide the combination of the multiple messages simultaneously. Using the dropper resistors to drive the segments with a nominal current of 10mA (If max=30mA) and also that voltage drop across the segment is 1.2V (Vf typical=1.7V).

Dropper Resistor (R) = [Supply voltage (Vs) - Voltage across LED (Vf)]/ Current through LED (If) (7)

R = (V_s-V_f)/ If = (5-1.2)/ 10x10E-3 =380 ohms, Dropper resistor selected: 390 ohms. To calculate the value of the base resistor Rb so that excessive base current Ib would not burn out the E/B junction.

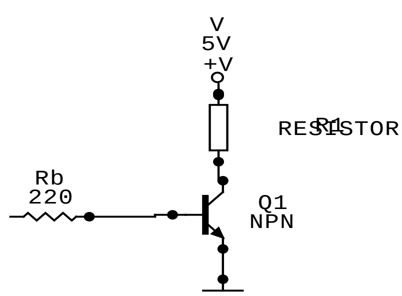

Figure 6: Transistor as a switch

The microcontroller sinks 25mA at 5v, this implies;

$$V_{BB} = 5V(logic1),\ V_{BE} = 0.7(Si),\ I_B = 20mA,$$

$$R_B = (V_{BB} - V_{BE})/I_B \qquad (8)$$

$$R_B = (5-0.7)/25E\text{-}3 = 220$$

R_B selected: 220 Ω, Transistor selected for fast switching [10]: BC548 series

Power Supply Unit

The voltage supply is utmost importance to the proper function of the detecting system, portability of the power supply must be ensured [7]. The heartbeat monitor system is completely isolated from AC power supply as shown in Figure 7. To isolate the system from AC power source, a battery is used. It is also necessary to determine the current consumed by the system to find out how long the battery would last.

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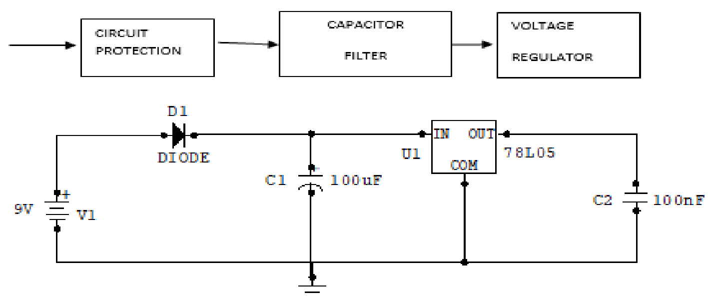


Figure 7: Block diagram and circuit diagram of the power supply

Total current consumed by system with the microcontroller sinks current of 25mA
The 7-segment display LEDs each consume 10mA; the three (3) modules consume:

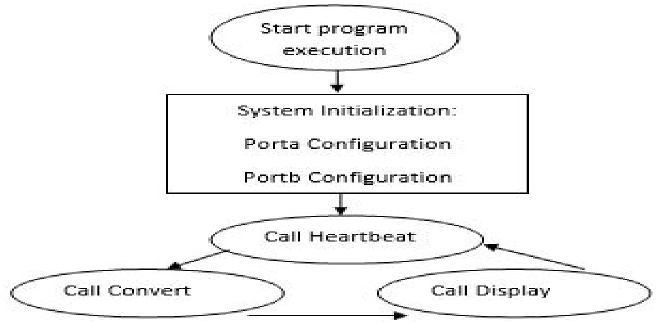
$$10mA \times 7 \times 3 = 210mA$$

Consumption of sensor LED= 15mA

$$\text{Total consumed current} = 25+210+15 = 250mA$$

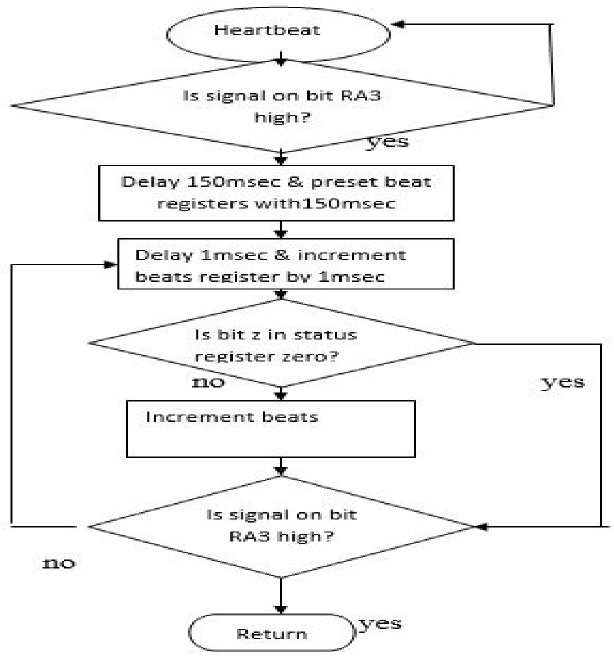
Since a battery would be used and 5v is ideal for operation of components used in the project, the input to the voltage regulator must be at least 2v above the output voltage to maintain regulation. A battery with rating above 7v would do. For ease a 9v battery is selected which based on manufacturer has capacity of 500mAH, 700mAH, 1200mAH or 1500mAH. This means that the battery could last about 2-6Hrs with continuous usage. The complete design functioning **flow chart** is a drawn:

Main loop:



Name of Subroutine: Heartbeat

Description: measure the time between two heartbeat signals



DESIGN VERIFICATION AND DISCUSSION OF RESULT

To verify the proper working of the project and certify that it meets the design requirement, test was carried out on the simulation and mode of operation of the system.

Simulation

The program was simulated with the aid of the MPLAB SIM in the MPLAB IDE. The SIM (Simulator) as the name implies simulates the microcontroller. One of its main features is the ability to view register status (SFR and GPR) within the microcontroller as the program is being executed. The program was debugged, the program flow and execution followed step by step while observing the variables, registers and the status of the port pins in the appropriate watch windows. The SFR shows the contents of the SFR address while the file register shows both the content the SFR and information about variable locations.

The circuit as a whole was simulated with the aid of PROTEUS DESIGN SUITE which is a software with the capability of drawing a complete circuit for a micro-controller-based system and then test it interactively, all from within the same piece of software. Output from each module (PSU, sensor, amplifier etc.) of the circuit was tested and expected results were obtained.

Mode of Operation

The finger was placed in between the sensing unit of high intensity Light Dependent resistor and the Red LED. The transducer senses the heart beat at the tip of a finger by sensing the change in the optical transmission properties of blood flowing through the finger.

The signal is fed into a low pass filter at this stage to attenuate frequency is a low amplitude and noisy signal which unwanted signals: in this case those bellow the range of useful bio-signal from the finger. The filtered signal is then feed into the op-amp for amplification. The amplification stage provides means for adjusting the gain (hence the sensitivity) of the signal.

The converted heartbeat in beat per minute (BPM) is output through the pins RB0-RB6. These outputs are connected to the display unit (3 cascaded 7-segment displays) through limiting resistors. The resistors are connected to corresponding pins of all displays to limit the segment current when on. This is possible because the displays are time multiplexed and only one display is turned on at a time using the transistor connected to the common cathode of each display.

CONCLUSION

The low-cost heartbeat monitor can be described as a journey that brought about the fusion of two fields i.e., medicines (cardiology) and computer technology. It finds extensive use in areas of medicine to assist in various diagnostic applications such as detection of irregular heartbeat pattern. It also finds use in sports-therapy to assist in tracking the heartbeat through various levels of physical activity to assist the patient in attaining desired, optimum heart rate.

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