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Simple and Cost-effective Heart Rate Meter Using PIC Microcontroller

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Abstract

One of the major and significant physiological parameters of human cardiovascular system is the heart rate. Heart rate is represented by the number of times the heart beats per minute. The heart rate data can reflect various physiological states such as stress at work, concentration on tasks, drowsiness, biological workload, and the active state of the autonomic nervous system. Human cardiac dynamics are driven by the complex nonlinear interactions of two competing forces: sympathetic regulation increases and parasympathetic regulation decreases the heart rate. Monitoring of heart rate plays an important role in conveying the status of cardiovascular system and clinically correlated information to medical professionals. Therefore, heart rate measurement is regarded as an essential parameter in patient care monitoring system. Human heart rate can be measured either by the ECG waveform or by sensing the pulse, the rhythmic expansion and contraction of an artery as blood is forced through it by the regular contractions of the heart. The pulse can be sensed from those areas where the artery is close to the skin. This research paper highlights on the design of a microcontroller (PIC series) based simple and cost-effective heart rate meter that is able to capture the pulse from human finger tip by sensing the change in blood volume. The heart rates of fifteen healthy normal subjects (students of age 21-22 yrs.) both in relaxed and exercised (stressed) states were measured using the designed system. The heart data, measured from the designed system showed satisfactory result while compared to a standard heart rate meter. The Also, the designed meter, being non-invasive one, can easily find its place in health care monitoring system.

Keywords: Hear rate meter, Heart rate measurement, cardiovascular system, patient care monitoring, PIC microcontroller, health care systems.

Introduction

It is undeniable that the application of microcontroller is contributing a great deal to the development and improvement of modern health care systems. The use of modern microcontrollers has speeded up the process of measuring various significant human physiological parameters. The heart rate is a parameter of high significance to medicine, physics, and psychology and many other fields. In general, the heart rate of a healthy adult [1, 2] at rest is around 72 beats per minute (bpm). Athletes normally have lower heart rates than less active people. Babies have a much higher heart rate at around 120 bpm, while older children have heart rates at around 90 bpm. The heart rate rises gradually during exercises [2] and returns slowly to the rest value after exercise. The rate when the pulse returns to normal is an indication of the fitness of the person. Heart rates, lower than normal, are usually an indication of a condition known as bradycardia, while higher than normal heart rates are known as tachycardia. The function and status of the human heart is also closely related with Heart rate. It is one of the major physiological parameters to human body that reflects status of cardiovascular system, mental condition and metabolism of human body. As people's living standards improve, the cardiovascular disease is increasing year by year, and has become the second cause of death among the urban and rural residents [3]. Therefore, measurement of heart rate has received a great attention from medical field in recent years [3, 4] and should be monitored properly in any health-care and patient care monitoring systems. It is well known that patient monitoring aims to the continuous observation of repeating events of physiologic function to guide therapy or to monitor the effectiveness of interventions. Historically, medical instruments designed for patient monitoring are majorly used by highly trained personnel, in the intensive care units and operating rooms of hospitals. Successful trauma management requires accurate monitoring of several important physiological parameters, so that proper action can be taken to help maintain critical functionality [5]

Several methods have already been proposed and implemented regarding the design and development of systems for heart rate monitoring. Development of precision digital instrument for calculation of heart rate [6, 7], a beat-to-beat heart rate meter [8] and heat rate meter based on frequency grading [9] have proposed in between 1975-1985. Nakajima *et al.* described photo-plethysmographic measurement of heart and respiratory rates using digital filters [10]. Yokoyama *et al.* and A. Wong *et al.* emphasised on the measurement of heart rate based on musical data [11] and current steering technique [12] respectively. Determination of heart rate using microcontroller and temperature measurement were described by Jayasree *et al.* [13] and À. Cuadras and Ó. Casas [14] in 2006. Design of a contact less measurement of heart rate in home environment has also been proposed [15]. Heart rate monitoring utilizing acceleration sensor [16] and planter bio-impedance measurement [17] are also studied in the same year. Some recent studies also include detecting heart rate from electronic weighing scale [18], air pressure sensor [19] non-contact ECG measure [20], body sound [21], ZigBee wireless link [22] and finger tips [23], Kim *et al.* reported about the nonintrusive measurement of heart rate using a flexible sensor array [24]. Kang *et al.* have proposed an electrocardiogram (ECG) and photoplethysmograph (PPG) monitoring device worn on wrist [25]. The idea of using the human face for physiological measurements was first introduced by Pavlidis and associates in 2007 and later demonstrated by analyzing thermal videos of the front face [26-28]. Pursche *et al.* mentioned about the use of video-based heart rate measurement from human faces [29]. Rotariu *et al.* proposed the development of a telemedicine system for remote blood pressure and heart rate monitoring [5].

It is true that costly and sophisticated medical instruments provide very satisfactory service to patients regarding the medical diagnosis and treatment point of view. But, people from developing countries have a little access to such costly medical equipments for their proper treatment due to socioeconomic structure of their countries. Hence, design and development of low-cost instruments using modern technology should be given a great concern to facilitate the access of every patient to have satisfactory medical service. In this concern, an attempt has been made in this paper to design a microcontroller based low-cost heart rate meter, which is one of the important physiological parameters to interpret the status of human cardiovascular activities. Another advantage of this meter is that no calibration would be required during the measurement of heart rate using it.

Materials and Methods

A. *System Description*

The sensing part of the heart rate meter includes of an IR LED transmitter and an infrared sensor. The LED transmits an IR signal through the fingertip of the subject. A part of the transmitted signal is reflected by the blood cells. As a result, a less amount of light is reached to the detector and also the value of detector signal varies with each signal. This signal, which is in the form of pulses is then amplified and filtered suitably by op-amp LM358 before feeding to a low-cost microcontroller PIC16F628A for further processing. The microcontroller that counts the number of pulses over a fixed time interval obtains the heart rate of the subject. Several such readings are obtained over a known period of time and the results are averaged to give a more accurate reading of the heart rate. The block diagram of the designed heart rate meter is shown in figure 1.

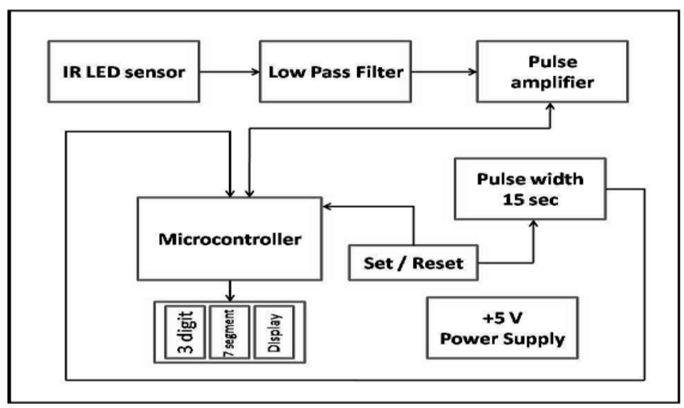

Fig 1: Block diagram of the heart rate meter

B. *Circuit Description*

The whole circuit diagram of the designed digital heart rate meter is shown in figure 2.

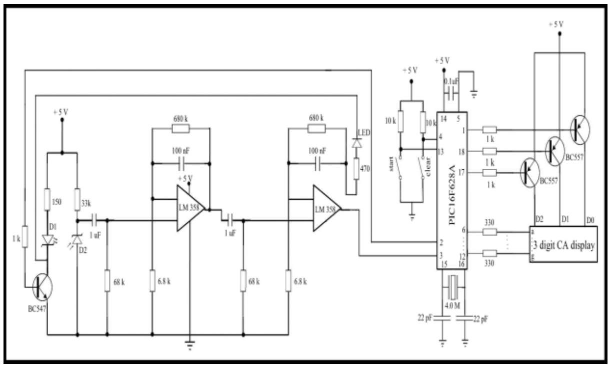

Fig 2: Circuit diagram of the heart rate meter

C. *Data Processing and Analysis*

In this circuit, 1 μF capacitors are used at the input of each stage for blocking the dc component in the signal. The two stage amplification provides sufficient gain for a weak signal to be converted into a pulse. An LED is connected in the circuit that blinks every time a heart beat is detected. The output from the second LM358 IC goes to the T0CKI input (pin no. 3) of PIC16F628A microcontroller (figure 3).

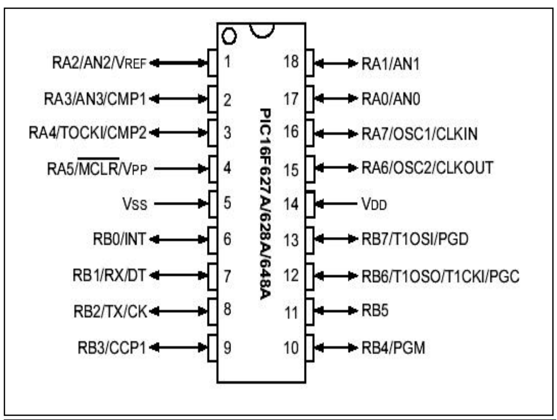

Fig 3: Pin diagram of PIC16F628A microcontroller
Fig 4: Intelligent Universal Programmer

D. *Display*

The display unit includes a 3-digit, Common Anode, 7-segment display, driven by the multiplexing technique. The segments a-g is connected with microcontroller through pin no. 6 to 12 (RB0-RB6), respectively. The unit's, ten's and hundred's digits are multiplexed with RA2, RA1, and RA0 port pins. A tact switch input is connected to start the heart rate measurement. When this switch is pressed, the microcontroller enables the IR LED to transmit for 15 seconds. During this period, the numbers of pulses arriving at the T0CKI input are counted. Then, a result 4 times of the count value is shown in the display unit. The microcontroller is operated at 4.0 MHz using an external crystal. The total circuit runs with the help of +5V power supply. The counted numbers displayed on LED display indicates the heart rate the subject. Figure 4 represents the Intelligent Universal Programmer (Model: ESA IUP-UXP, Sl. No. 431011087, and Make: Electro Systems Associates Pvt. Ltd, Bangalore, India), used to write the program onto the PIC microcontroller.

E. *Subject selection and Experimental setup*

Fifteen normal healthy male students of age range 21-22 years (21.53±0.52) and body mass index (BMI) of (21.21±1.72) Kg/m^2 were recruited for measurement of their heart rates using the designed heart rate meter. Each student was informed about the purpose of the experiment and each of them gave their consents to take part in the study voluntarily. Students, participated in the study, had no previous history of any cardiovascular disorders, neurological problems, smoking habit and hypertension. These students were the subjects for the study of heart rate measurement. The student details are enlisted in Table 1. Name of the students are kept confidential.

TABLE 1: Subject Details

Serial No.	Subjects	Age (Years)	Weight (Kg.)	Height (cm.)	BMI (Kg/m2)
1	Student 1	21	62.83	170.1	21.71
2	Student 2	21	57.33	161.5	21.98
3	Student 3	21	58.40	172.5	19.63
4	Student 4	22	53.23	156.8	21.65
5	Student 5	22	56.77	156.0	23.33
6	Student 6	21	55.50	172.0	18.76

7	Student 7	22	64.80	173.0	21.65
8	Student 8	22	44.60	155.5	18.44
9	Student 9	22	58.85	164.5	21.75
10	Student 10	22	49.42	161.9	18.85
11	Student 11	21	61.00	159.0	24.13
12	Student 12	22	57.00	165.0	20.94
13	Student 13	21	63.42	167.8	22.52
14	Student 14	22	50.45	149	22.72
15	Student 15	21	53.00	162.3	20.12
Mean		21.53	56.44	163.13	21.21
Standard Deviation		±0.52	±5.41	±7.12	±1.72

Heart beat data (in bpm) were taken under unexercised state (relaxed condition) and exercised state (stressed condition). For the unexercised state each subject was asked to sit on a chair closing their eyes for 5 minutes in relaxed mood before their data were recorded. These data referred to their heart rates in relaxed condition. For the exercised state, each subject was instructed to perform 5-minute bicycling and thereafter, their data were again recorded. The data were recorded both by the designed heart rate meter and a standard heart rate meter (Mini Heart Rate Monitor, Model: EEC-007, Make: Electronic Engineering Corporation, Chennai, India).

While the power is turned on, the display at first shows three zeroes for few seconds. When the zeroes go off, the finger tip is placed on the sensor assembly. Now, the start / set button is pressed and the subject would wait for 15 seconds and should keep his/her finger stabilized in that interval as much as possible. The LED blinking indicates the heart beat is being fed to the microcontroller, and after 15 sec, the result will be displayed. Several such readings can be also obtained in this manner. The reset button should be pressed before the next reading is taken. Figure 5 shows the data collection from an individual subject from the designed system.

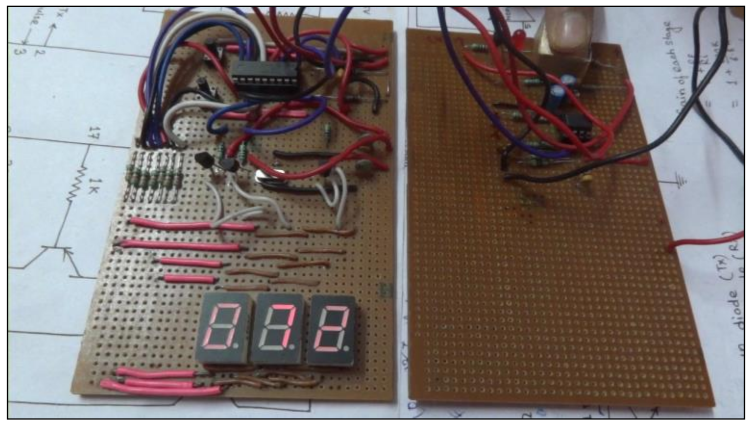

Fig 5: The designed heart rate meter showing the heart rate

Results & Discussions

The recorded data are tabulated in table 2 as shown below:

TABLE 2: Recorded Data

Serial No.	Subjects	Heart Rate (bpm)			
		Designed Heart Rate Meter Output		Standard Heart Rate Meter Output	
		Relaxed Condition	Stressed Condition	Relaxed Condition	Stressed Condition
1	Student1	67	112	66	114
2	Student2	62	112	63	112
3	Student3	70	120	70	121
4	Student4	71	123	71	122
5	Student5	73	125	74	125
6	Student6	69	118	70	119
7	Student7	62	109	62	108
8	Student8	72	124	73	125
9	Student9	74	130	74	132
10	Student10	64	112	65	114

11	Student11	71	122	72	123
12	Student12	63	110	64	112
13	Student13	68	125	70	126
14	Student14	73	124	72	125
15	Student15	72	128	72	130
Mean		68.73	119.60	69.20	120.53
Standard Deviation		±4.06	±6.70	±4.09	±6.89

A graphical representation of the average value obtained from the table 2 is illustrated in figure 6 which shows a comparative study of the mean heart rates of the subjects collected from the designed heart rate meter and that of the standard heart rate meter under the relaxed and stressed conditions, respectively.

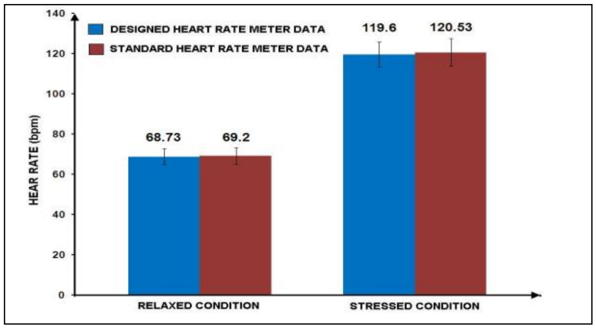

Fig 6: Graphical comparison between the mean heart rates

Percentage error (E1) between mean heart rates in relaxed condition obtained from the designed hear rate meter and the standard heart rate monitor respectively is given by,

E1 = [(69.20 -68.73) x 100]/69.20 = 0.68 % < 1%

Percentage error (E2) between mean heart rates in stressed condition obtained from the designed hear rate meter and the standard heart rate monitor respectively is given by,

E2 = [(120.53 -119.60) x 100]/120.53 = 0.77 % < 1%

Thus, it can clear from figure 4 and the above calculations that the difference between the results of the mean values obtained from the designed heart rate meter and that of standard heart rate meter is less than 1% for both in the unexercised and exercised states respectively. Compared to the standard meter, it can be claimed that the designed heart rate meter is able to function and provide results satisfactorily.

Conclusions

From the above study, it can be concluded that the designed low-cost heart rate meter (Rs.400, approx.) can function satisfactorily as well as that of a standard heart rate meter, used here (Costs Rs. 1000, approx.). Due to absence of complex features, the designed meter can also be handled by any non-medical professionals. Thus, it can also be used in home. But, it must be noted here that the proper placement of finger tip over the sensor assembly is a crucial step while recording data. Otherwise, system may provide erroneous outcome. However, regarding the validity testing of the meter, it must be tested on a large number of patients and statistical analysis should also be performed. The meter can be improved by further implementation in PCB layout also. Concern should also be given to design and develop low cost medical device, able to record other physiological parameters in a single system that would facilitate the medical diagnosis and treatment for any class of people.

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