

The Development of a Microcontroller Based Low-Cost Heart Rate Counter for Health Care Systems

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Abstract— The heart rate is one of the significant physiological parameters of the human cardiovascular system. Heart rate is the number of times the heart beats per minute. Heart rate data reflects various physiological states such as biological workload, stress at work and concentration on tasks, drowsiness 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. Thus, monitoring of heart rate plays a significant role in providing the status of cardiovascular system and clinically correlated information to medical professionals. Heart rate measurement is also regarded as an essential parameter in patient care monitoring system.

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 felt from those areas where the artery is close to the skin. This paper highlights on the design of a microcontroller (PIC series) based heart rate counter that is able to capture the pulse from 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 excited states were measured using the designed device and a standard heart rate measuring device. The outputs of the measured device were satisfactory. Also, the designed device, being noninvasive one, can easily find its place in health care monitoring system.

Keywords— Heart rate measurement, cardiovascular system, patient care monitoring, microcontroller, health care systems

I. INTRODUCTION

The heart rate is a parameter of high significance to medicine, physics, and psychology and many other fields. 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. Lower than normal heart rates are usually an indication of a condition known as bradycardia, while higher than normal heart rates are known as tachycardia. Heart rate is closely related to the function and status of the human heart. It is one of the most important physiological parameters to human body, which reflects the body's health in the aspects of cardiovascular, metabolism and mental. 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, 4]. Therefore, heart rate receives more attention from medical field in recent years [4, 5] and should be monitored properly in any health-care and patient care monitoring systems.

Patient monitoring refers to the continuous observation of repeating events of physiologic function to guide therapy or to monitor the effectiveness of interventions. Historically, these medical instruments are designed to be 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 [6].

However, several methods have already been proposed and implemented regarding the design and development of devices for heart rate monitoring. Development of precision digital instrument for calculation of heart rate [7, 8], a beat-to-beat heart rate meter [9] and heart rate meter based on frequency grading [10] have proposed in between 1975-1985. Nakajima et al. described photo-plethysmographic measurement of heart and respiratory rates using digital filters [11]. Yokoyama et al. and A. Wong et al. stressed on the measurement of heart rate based on musical data [12] and current steering technique [13] respectively. Determination of heart rate using PIC microcontroller and temperature measurement were described by Jayasree et al. [14] and À. Cuadras and Ó. Casas [15] in 2006. Design of a contact less measurement of heart rate in home environment has also been proposed [16]. Heart rate monitoring utilizing acceleration sensor [17] and planter bio-impedance measurement [18] are also studied in the same year. Some recent studies also include

detecting heart rate from electronic weighing scale [19], air pressure sensor [20] non-contact ECG measure [21], body sound [22], ZigBee wireless link [23] and finger tips [24], Kim et al. reported about the noninvasive measurement of heart rate using a flexible sensor array [25]. Kang et al. have proposed an electrocardiogram (ECG) and photoplethysmograph (PPG) monitoring device worn on wrist [26]. 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 [27, 28, 29]. Pursche et al. mentioned about the use of video-based heart rate measurement from human faces [30]. Rotariu et al. proposed the development of a telemedicine system for remote blood pressure and heart rate monitoring [6].

It is true that costly and sophisticated medical instruments provide very satisfactory service to patients regarding the medical diagnosis and treatment point of view. Again, the fact that people from developing countries, sometimes have little access to such costly medical equipments for their proper treatment due to socioeconomic structure of their countries, is also undeniable. 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 device is that no calibration would be required during the measurement of heart rate using it.

II. MATERIALS AND METHODS

A. System Description

The sensing part of this project consists of an IR LED transmitter and an infrared sensor. The LED transmits an IR signal through the fingertip of the subject, a part of which is reflected by the blood cells. Obviously 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 analysis. The microcontroller counts the number of pulses over a fixed time interval and thus 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 counter is shown in figure 1.

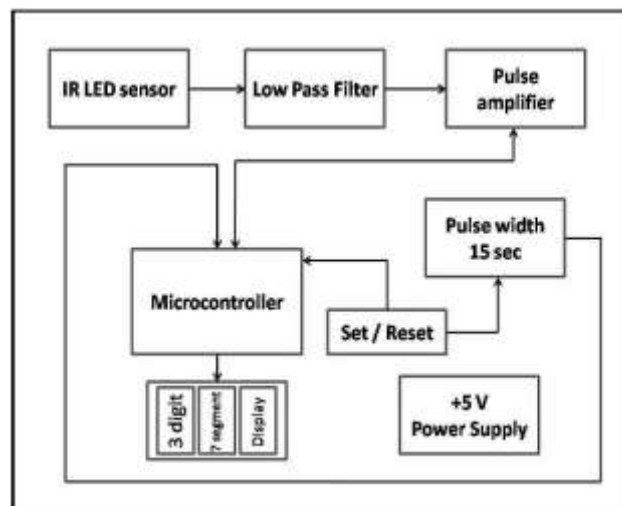


Fig 1: Block diagram of the heart rate counter

B. Circuit Description

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

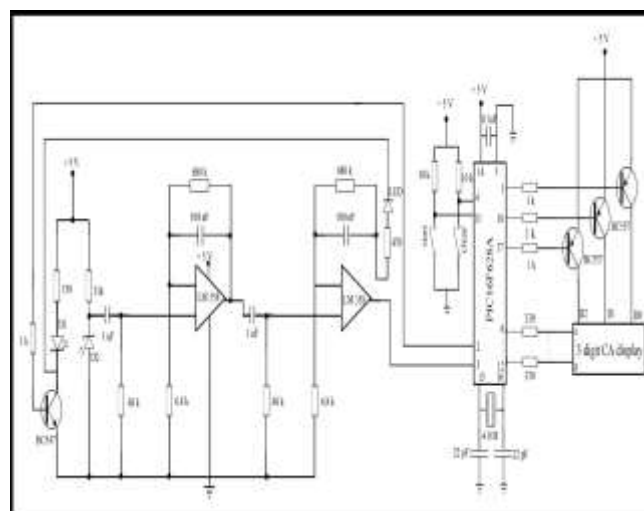


Fig 2: Circuit diagram of the heart rate counter

C. Data Processing and Analysis

In the circuit, 1 μ F capacitors are used at the input of each stage to block 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 which blinks every time a heart beat is detected. The output from the signal conditioner goes to the TOCKI input that is the pin no. 3 of the microcontroller PIC16F628A (figure 3).

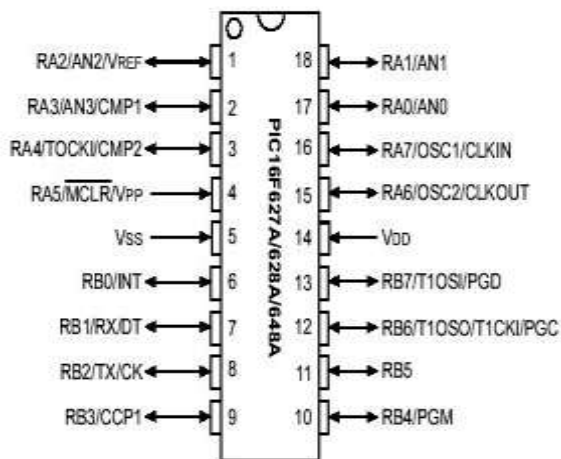


Fig 3: Pin configuration of PIC16F628A microcontroller

D. Display

The display unit consists of a 3-digit, Common Anode, seven segment display which is driven by the multiplexing technique. The segments a-g is connected with microcontroller through pin no. 6 to 12 or 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. After pressing this switch the microcontroller activates the IR LED to transmit for 15 seconds. Within this interval, 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 runs at 4.0 MHz using an external crystal and the total circuit runs with the help of +5V power supply derived from USB port. The expected output of the LED is the heart rate "XXX" with XXX being a number between 0 and 999, which will be the subject's BPM. In the software part many algorithms had been investigated for the microcontroller and the best fit programming is written in MikroC compiler.

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/m² were recruited for measurement of their heart rates using the designed heart rate counter. 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

Sl. No.	Subjects	Age (Years)	Weight (Kg.)	Height (cm.)	BMI (Kg/m ²)
1	Student1	21	62.83	170.1	21.71
2	Student2	21	57.33	161.5	21.98
3	Student3	21	58.40	172.5	19.63
4	Student4	22	53.23	156.8	21.65
5	Student5	22	56.77	156.0	23.33
6	Student6	21	55.50	172.0	18.76
7	Student7	22	64.80	173.0	21.65
8	Student8	22	44.60	155.5	18.44
9	Student9	22	58.85	164.5	21.75
10	Student10	22	49.42	161.9	18.85
11	Student11	21	61.00	159.0	24.13
12	Student12	22	57.00	165.0	20.94
13	Student13	21	63.42	167.8	22.52
14	Student14	22	50.45	149	22.72
15	Student15	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 counter 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 4 shows the data collection from an individual subject from the designed system.

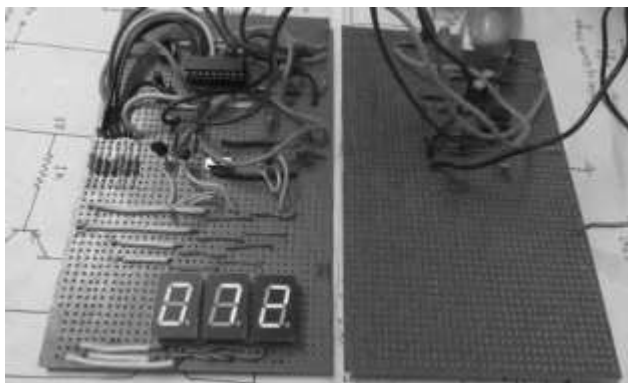


Fig 4: Result for individual in the designed heart rate counter

III. RESULTS & DISCUSSIONS

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

TABLE 2: Recorded Data

Sl No.	Subjects	Heart Rate (bpm)			
		Designed Device Output		Standard Device Output	
		Relaxed State	Stressed State	Relaxed State	Stressed State
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 5 which shows a comparative study of the mean heart rates of the subjects collected from the designed heart rate counter and that of the standard device under the relaxed and stressed conditions.

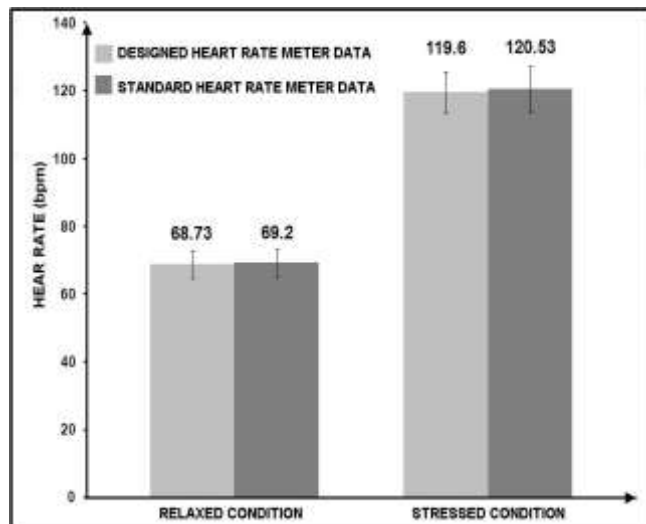


Fig 5: Graphical comparison between the mean heart rates

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

$$E1 = [(69.20 - 68.73) \times 100] / 69.20 = 0.68 \% < 1\%$$

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

$$E2 = [(120.53 - 119.60) \times 100] / 120.53 = 0.77 \% < 1\%$$

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 device, it can be claimed that the designed is able to function and provide results satisfactorily.

IV. CONCLUSIONS

From the above study, it can be concluded that the designed low-cost heart rate counter (Rs.400, approx.) can function satisfactorily as well as that of a standard device, used here (Costs Rs. 1000, approx.). Due to absence of complex features, the designed device can also be handled by any non-medical professionals also. 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 device, it must be tested on a large number of patients and statistical analysis should also be performed. The device 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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