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**The Development of a Microcontroller Based LowCost 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-tobeat heart rate meter [9] and heat 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 nonintrusive 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.

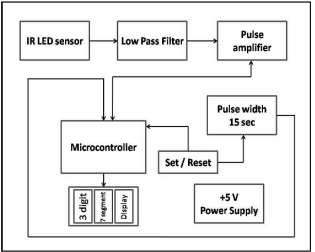


Fig 1: Block diagram of the heart rate counter

**B. Circuit Description**

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

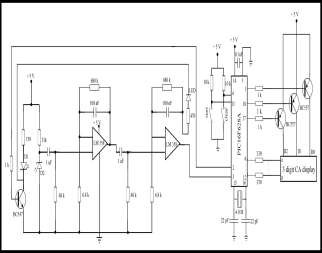


Fig 2: Circuit diagram of the heart rate counter

**C. Data Processing and Analysis**

In the circuit, 1 μF 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 T0CKI input that is the pin no. 3 of the microcontroller PIC16F628A (figure 3).

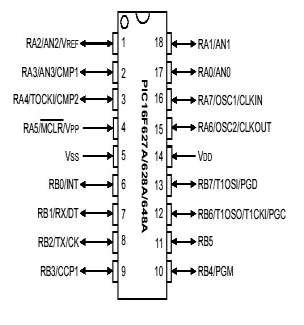


Fig 3: Pin configuration of PIC16F628A microcontroller

**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/m2)** |
| 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.

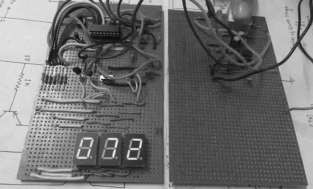


Fig 4: Result for individual in the designed heart rate counter

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.

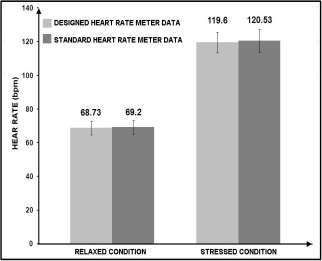


Fig 5: Graphical comparison between the mean heart rates

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) x 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) 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 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 nonmedical 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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基于单片机的医疗保健系统低成本心率计数器的研制

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摘要 - 心率是人类心血管系统的重要生理参数之一。心率是心跳每分钟的次数。心率数据反映了各种生理状态，如生物工作负荷，工作压力和任务集中，睡意和自主神经系统的活动状态。人类心脏动力学受两种竞争力的复杂非线性相互作用驱动：交感神经调节增加，副交感神经调节降低心率。因此，监测心率在向心血管系统状态和临床相关信息提供给医疗专业人员方面起着重要作用。心率测量也被视为患者监护系统中的一个重要参数。

心率可以通过心电图波形或通过感测脉搏来测量 - 血液通过心脏的正常收缩被迫通过它时，动脉的节奏性扩张和收缩。脉搏可以从动脉靠近皮肤的那些区域感觉到。本文重点介绍了基于微控制器（PIC系列）的心率计数器的设计，该计数器能够通过感测血量的变化来捕捉指尖脉搏。使用所设计的装置和标准心率测量装置测量15名健康正常受试者（21-22岁的学生）在心率和兴奋状态下的心率。被测设备的输出令人满意。而且，所设计的设备是非侵入性设备，可以很容易地在医疗监护系统中找到它的位置。

关键词 - 心率测量，心血管系统，病人监护，微控制器，医疗保健系统

**一、导言**

心率是医学，物理学和心理学等许多领域的重要参数。休息时健康成人[1,2]的心率约为每分钟72次（bpm）。运动员的心率通常低于不太活跃的人。婴儿的心率在120 bpm左右，而年龄较大的孩子的心率在90 bpm左右。锻炼期间心率逐渐升高[2]，并在运动后缓慢恢复到休息状态。脉搏恢复正常时的速率表示该人的适应性。低于正常心率通常表示称为心动过缓的情况，而高于正常心率则称为心动过速。心率与人类心脏的功能和状态密切相关。它是人体最重要的生理参数之一，它反映了人体在心血管，代谢和精神方面的健康状况。随着人们生活水平的提高，心血管疾病逐年增加，成为城乡居民的第二大死因[3,4]。因此，近年来心率受到医学界的重视[4,5]，应在任何医疗和病人监护系统中进行适当的监测。

患者监测指持续观察生理功能重复事件以指导治疗或监测干预措施的有效性。从历史上看，这些医疗器械被设计成由训练有素的人员在医院的重症监护室和手术室中使用。成功的创伤管理需要准确监测几个重要的生理参数，以便采取适当的行动来帮助维持关键功能[6]。

然而，已经提出并实施了几种关于心率监测设备的设计和开发的方法。 1975 - 1985年期间提出了用于计算心率的精密数字仪器[7,8]，节拍心率表[9]和基于频率分级的热率表[10]。中岛等人。使用数字滤波器描述心脏和呼吸频率的光电容积描记测量[11]。 Yokoyama等。和A.Wong等人强调基于音乐数据[12]和当前转向技术[13]的心率测量。 Jayasree等人描述了使用PIC微控制器和温度测量来确定心率。 [14]和À。 Cuadras和Ó。 Casas [15]。2006年，还提出了设计一种较少接触的家庭环境心率测量[16]。同年还研究了利用加速度传感器[17]和播种机生物阻抗测量[18]进行心率监测。最近的一些研究还包括从电子秤[19]，气压传感器[20]非接触式心电测量[21]，体音[22]，ZigBee无线链路[23]和指尖[24]检测心率， Kim等人报道了使用灵活的传感器阵列进行非侵入性测量心率的方法[25]。 Kang等人提出了佩戴在手腕上的心电图（ECG）和光电容积描记器（PPG）监测装置[26]。 Pavlidis及其同事在2007年首次提出了使用人脸进行生理测量的想法，后来通过分析正面热敏视频证明了这一点[27,28,29]。 Pursche等人提到使用基于视频的人脸测量心率[30]。 Rotariu等人提出了开发远程血压和心率监测远程医疗系统[6]。

确实，昂贵而复杂的医疗器械为患者提供了有关医疗诊断和治疗观点的非常满意的服务。再次，由于其国家的社会经济结构，来自发展中国家的人有时几乎无法获得如此昂贵的医疗设备以获得适当治疗，这一事实也是不可否认的。因此，设计和开发使用现代技术的低成本仪器应该受到极大关注，以方便每个病人获得满意的医疗服务。在这个问题上，本文尝试设计一种基于微控制器的低成本心率计，这是解释人类心血管活动状态的重要生理参数之一。该设备的另一个优点是在使用它的心率测量过程中不需要校准。

**二、材料和方法**

**A.系统描述**

该项目的传感部分包括一个红外LED发射器和一个红外传感器。 LED通过对象的指尖发送IR信号，其中一部分被血细胞反射。 显然，检测器到达的光量较少，而且检测器信号的值随每个信号而变化。 该信号采用脉冲形式，然后在输入低成本微控制器PIC16F628A进行分析之前，通过运算放大器LM358进行适当放大和滤波。 微控制器在固定的时间间隔内对脉冲数进行计数，从而获得对象的心率。 几个这样的读数是在一段已知的时间内获得的，并且结果被平均以给出更准确的心率读数。 设计的心率计数器的框图如图1所示。

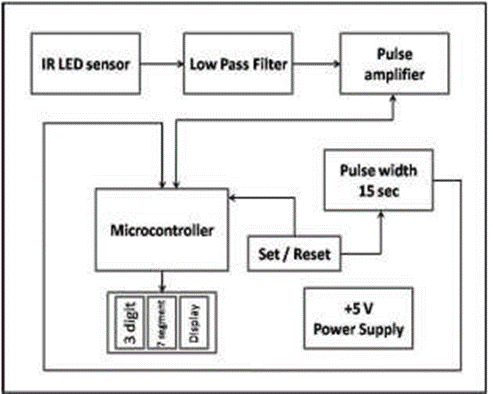


图1：心率计数器的框图

**B.电路描述**

所设计的数字心率计的整个电路图如图2所示。

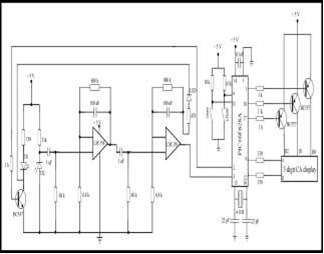


图2：心率计数器的电路图

**C.数据处理和分析**

在电路中，每级输入端使用1μF电容来阻断信号中的直流分量。 两级放大为弱信号转换为脉冲提供了足够的增益。 每次检测到心脏跳动时，电路中都会连接一个LED闪烁。 信号调节器的输出转到T0CKI输入，即引脚号。 3的单片机PIC16F628A（图3）。

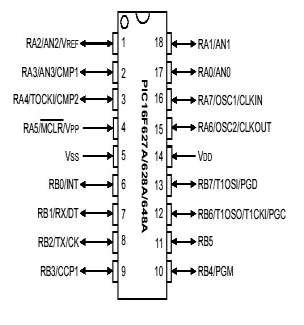


图3：PIC16F628A微控制器的引脚配置

**D.显示**

显示单元由一个3位共阳极，由多路复用技术驱动的七段显示器组成。段a-g通过引脚号与微控制器连接。 6至12或RB0-RB6。该单元的十位和百位数字与RA2，RA1和RA0端口引脚复用。连接轻触开关输入以开始心率测量。按下此开关后，微控制器激活红外LED发射15秒。在此间隔内，计数到达T0CKI输入的脉冲数。然后在显示单元中显示计数值的4倍结果。微控制器使用外部晶振运行在4.0 MHz，整个电路通过USB端口提供的+ 5V电源供电。 LED的预期输出是心率“XXX”，其中XXX是介于0和999之间的数字，这将成为受试者的BPM。在软件部分，已经为微控制器研究了许多算法，最适合的编程是用MikroC编译器编写的。

**E.主题选择和实验设置**

使用设计的心率计数器招募15名年龄在21-22岁（21.53±0.52）和体重指数（BMI）为（21.21±1.72）Kg / m 2的正常健康男性学生用于测量其心率。每个学生都被告知实验的目的，并且每个学生都表示同意自愿参加这项研究。参加研究的学生以前没有任何心血管疾病史，神经系统问题，吸烟习惯和高血压史。这些学生是心率测量研究的主题。表1列出了学生的详细信息。学生姓名保密。

在未施行状态（放松状态）和行使状态（强调状态）下拍摄心跳数据（以bpm为单位）。对于未施行的状态，每个受试者被要求坐在椅子上，在他们的数据被记录之前以放松的心情闭上他们的眼睛5分钟。这些数据提到他们的心率处于放松状态。对于锻炼状态，指导每位受试者进行5分钟的骑自行车，然后再次记录他们的数据。数据由设计的心率计和标准心率计（Mini Heart Rate Monitor，Model：EEC-007，Make：Electronic Engineering Corporation，Chennai，India）记录。

表格一、学生细节

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **学号.** | **学生** | **年龄** | **体重** | **身高** | **BMI (Kg/m2)** |
| 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 |

打开电源时，显示屏首先显示三个零点几秒钟。当零点熄灭时，指尖被放置在传感器组件上。现在，按下开始/设置按钮，拍摄对象将等待15秒，并尽可能保持其手指在该间隔内稳定。 LED闪烁表示正在将心跳输入微控制器，15秒后显示结果。以这种方式也可以获得几个这样的读数。在下次读取之前，应按下重置按钮。图4显示了来自设计系统的单个主题的数据收集。

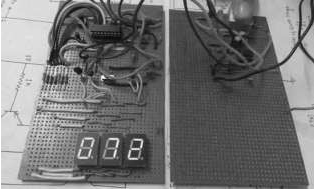


图4：个人在设计心率计数器中的结果

**三、结果和讨论**

记录的数据列在表2中，如下所示：

表2：记录的数据

表格2、数据记录

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **学号** | **学生** | **心率 (bpm)** | | | |
| **自主设计仪器输出值** | | **标准仪器输出值** | |
| **放松态** | **紧张态** | **放松态** | **紧张态** |
| 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 |
| 平均值 | | 68.73 | 119.60 | 69.20 | 120.53 |
| 标准差 | | ±4.06 | ±6.70 | ±4.09 | ±6.89 |

图5中示出了从表2获得的平均值的图形表示，其示出了从设计的心率计数器收集的受试者的平均心率和放松和受压条件下的标准装置的平均心率的比较研究。

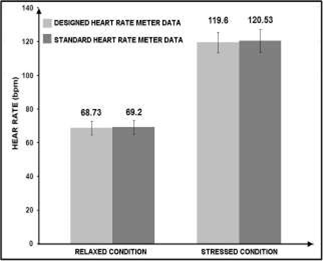


图5：平均心率之间的图形比较

由设计听力计数器和标准心率监视器分别获得的松弛状态下的平均心率之间的百分比误差（E1）

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

由设计听力计数器和标准心率监视器分别获得的应激状态下的平均心率之间的百分比误差（E2）

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

因此，从图4和上述计算可以清楚地看到，从设计的心率表和标准心率表获得的平均值的结果之间的差异分别在未执行状态和已执行状态下均小于1％ 。与标准设备相比，可以声称设计能够令人满意地运行并提供结果。

**四、结论**

从上述研究可以得出结论，设计的低成本心率计（Rs.400，约）可以满意地运作，以及这里使用的标准装置（成本约为1000，约）。由于没有复杂的功能，设计的设备也可以由任何非医疗专业人员进行处理。因此它也可以在家中使用。但是，这里必须指出，在记录数据时，指尖正确放置在传感器组件上是至关重要的一步。否则，系统可能会提供错误的结果。但是，关于设备的有效性测试，必须对大量患者进行测试，并进行统计分析。该设备还可以通过在PCB布局中的进一步实施进行改进。还应该考虑设计和开发低成本的医疗设备，能够在单一系统中记录其他生理参数，以便为任何类别的人提供医疗诊断和治疗。

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