ISSN:0975-9646

Deepak Verma et al, / (IJCSIT) International Journal of Computer Science and Information Technologies, Vol. 5 (6) , 2014, 7265-7269

Real Time Optical Heart Rate Monitor

Deepak Verma[#], Mahika Bhasin[#]

[#] *Instrumentation and Control Department,*
Bharati Vidyapeeth's College of Engineering, GGSIPU
New Delhi, India

***Abstract*—Persistent aberration of heart rate may be an indication of serious health complications such as Tachycardia, Coronary Artery Disease, and Hypertension. Hence, heart rate monitoring is extremely essential in order to keep track of one's health. Unlike traditional methods like Electro-cardiogram (ECG), which are complicated and non-portable, there is a need for a simple and affordable heart rate measuring device. This paper expounds the design and working of a device based on the principle of Photoplethysmography. It is an economical, user friendly, and low power consuming device. The performance of the device was evaluated and its results were compared with the reports of conventional heart rate monitors, and the deviation was observed to be minimal.**

Keywords-Photoplethysmography, Microcontroller, Pulse Detection, Signal Filtration and Amplification

I. INTRODUCTION

Heart rate is an important parameter of a person's cardiovascular health [4]. The conventional method to measure heartbeat is to sense the arterial pulse by manually placing fingers or thumb over the wrist. Thereafter, the sensed pulse is counted and beats per minute (bpm) is estimated. However, this method is highly inaccurate and unreliable. When the pulse rate is high or irregular, it becomes more susceptible to error. Clinically, more advanced methods like Electro-cardiogram (ECG) are employed for measurement of heart beat. Although accurate results are obtained, these methods are uneconomical and complex in nature. This calls for a device that is economical and dependable.

There are two ways in which heart monitors can be developed: Electrical and Optical. Optical method is advantageous over the electrical method. Firstly, there is no electrical contact in optical systems making it safer. Secondly, unlike electrical method, there is less electromagnetic interference in the detected signal. The optical method makes use of the concept of Photoplesthysmography (PPG). It measures the relative changes in blood volume from body tissues [2]. These changes in volume cause the amount of incident light to modulate.

In this paper we describe a heart rate measuring device employing an optical sensor which makes use of an Infrared diode and Photodiode to extract pulse signals. When the heart pumps, a pulse of blood flows through the blood vessels and the finger becomes slightly opaque [7]. Consequently, less Infrared light is received by the Photodiode. Along with the pulse signals, unwanted noise is obtained. A band pass filter is used to remove this interference. The filtered signal is then amplified and converted into a digital signal whose frequency is calculated using a microcontroller.

This low cost device has LCD interfaced with the microcontroller that displays the pulse rate. If the microcontroller is programmed and connected to PC software accordingly, an added advantage is that user will be able to see average, maximum or minimum rates of the pulse. Moreover, the waveforms obtained can also be saved for future references in the software. Patients can now measure and analyze their heart rate in home environment as well.

II. METHODOLOGY

The block diagram [Fig. 1] explains the procedure used to develop the Heart Rate Monitor.

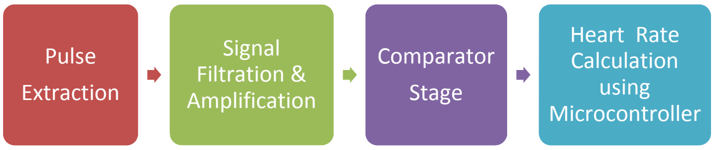


Fig. 1. Block Diagram.

A. Pulse Extraction

An optical sensor which makes use of Infrared diode and Photodiode is used for pulse detection. Generally, the light in infrared spectrum is used as transmitter because the wavelength in this zone can penetrate through hemoglobin of blood and provide a strong modulating signal.

When the heart expands, the volume of the blood in the fingertip increases, and when the heart contracts the volume decreases. A PPG sensor can be used either in reflection mode or in transmission mode [1]. In the reflection mode [Fig. 3], when the heart beats, the volume of blood increases and hence more light is reflected onto the photodiode. In this mode, both IR Diode and Photodiode are placed on the same side. In transmission mode [Fig. 4], The LED and photodiode are placed opposite to each other and the finger is placed between the two. When the heart beats, less light is transmitted through the fingertip. During no beat, more light is transmitted. This pulsating transmission, received by the photodiode, is converted into voltage signal. The transmission mode is preferred over reflection mode because reflection mode has poor Signal-to-Noise Ratio [1]. Additionally, in reflection mode extra care must be taken that the finger doesn't move with respect to sensor, as slightest variation tends to affect the accuracy of the result. Transmission mode, however, is more immune to relative movement of finger.

In this paper, transmission mode has been used. The fingertip sensor is shown in [Fig. 2]. In order to minimize the occurrence of ambient light, the black colored photodiode is chosen. Two holes are drilled on each side of the clip respectively. In one hole the infrared diode is placed and in the other machine screw is inserted. Photodiode is horizontally attached and the band is wound on it. Before inserting the diodes in the clip, the wire strips should be soldered onto their cathode and anode. The clip helps the fingertip to be in a stable position thereby increasing the accuracy of the system.

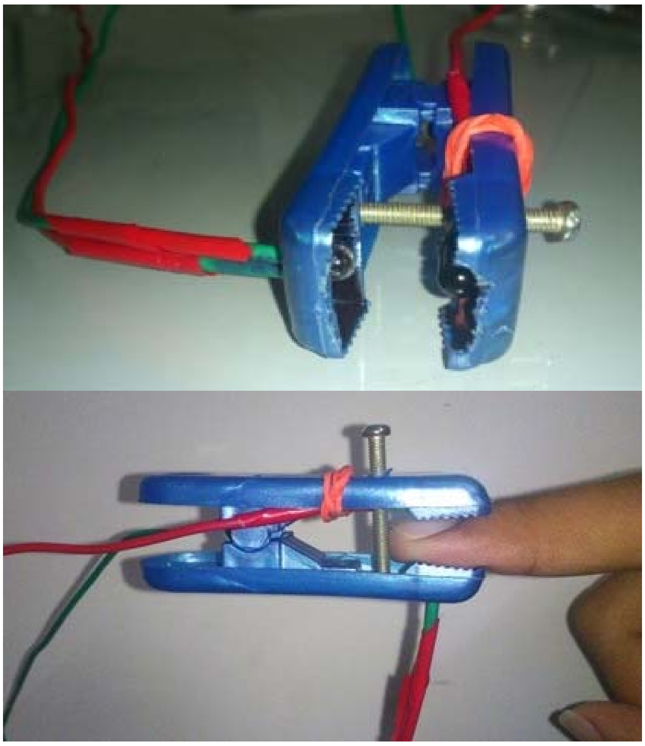


Fig. 2. Fingertip Sensor.

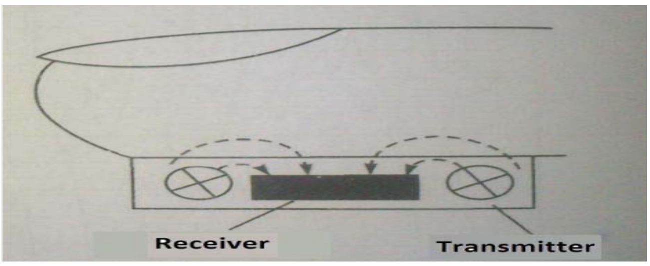


Fig. 3. Reflection Mode [1].

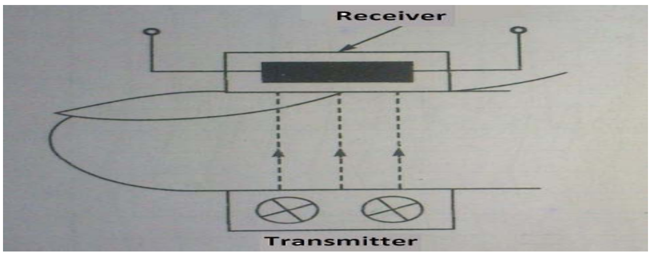


Fig. 4. Transmission mode [1].

B. Signal Filtration And Amplification

The signal detected through the optical sensor has to be filtered and amplified before feeding into the microcontroller. The high frequency noise due to ambient light and other disturbances is reduced by allowing only a controlled band of frequencies into the amplification circuit. For this purpose, we have designed a band pass filter using a passive high pass filter in series with an active low pass filter. Active low pass filter facilitates amplification along with filtration. The band pass filter thus obtained is repeated in order to get better response of the filter.

The lower and upper cut-off frequencies provided by the High Pass filter and the Low Pass filter are given by the following equations [Fig. 6]:

$(2\pi R_3C_1)^{-1}$ and $(2\pi R_4C_2)^{-1}$ [5]

A pass band of 1.06 – 15.92 Hz is chosen to reject any unwanted noise and allow only the pulse signal for amplification.

C. Comparator Stage

The filtered and amplified signal, thus obtained, is a sinusoidal wave which corresponds to the blood pulses. Before feeding this to the microcontroller for estimation of beats per minute (bpm), the signal has to be converted into a digital pulse whose peaks can be counted by the microcontroller. Therefore, a comparator is used in order to get a digital pulse representing the heart rate.

D. Heart Rate Calculation using Microcontroller

Microcontroller is used to calculate the pulses obtained and display the count on LCD. The LCD is interfaced with the microcontroller and displays the digitized result. The microcontroller is programmed in such a way that the timers in it count the number of peaks obtained in 10 seconds. The number is then multiplied by 6 for the estimation of beats per minute (bpm). Beats per minute, a measure of Heart rate, is displayed on the LCD.

III. DESIGN & SELECTION OF COMPONENTS

A. Optical Sensor Design

The optical sensor employed here consists of an Infrared LED as emitter and a Photodiode as receiver. The value of resistor R_1 [Fig. 5] is chosen by using the following equation:

$$R_1 = (V_{cc} - V_f) / I_f$$

Where, V_{cc} = Supply voltage
V_f = Forward Voltage of IR LED
I_f = Forward current of IR LED

I_f is chosen to be 38 mA which is below the maximum allowable current for Infrared LED (65mA).

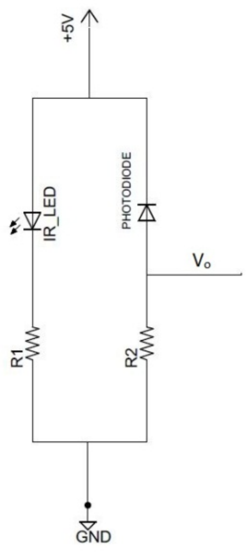


Fig. 5. Optical Sensor circuit.

For a supply voltage of 5V and Forward voltage of 1.2V, the value of R_1 is calculated as:

$$R_1 = (5V - 1.2V) / 38mA = 100\ \Omega$$

A Photodiode is connected in Reverse Bias mode as receiver to detect the incident Infrared variations due to blood pulses. When more Infrared rays are incident on the photodiode, current through it increases. This current is passed through a resistor R_2 which causes change in voltage across R_2. Hence, the current variation through the photodiode is converted to a voltage signal. This varying voltage signal is tapped across the resistor R_2. Value of R_2 is chosen to be 27kΩ.

$$V_0 = I * R_2$$

Where, V_0 = Output Voltage

I = Current through photodiode

B. Filter Circuit Design

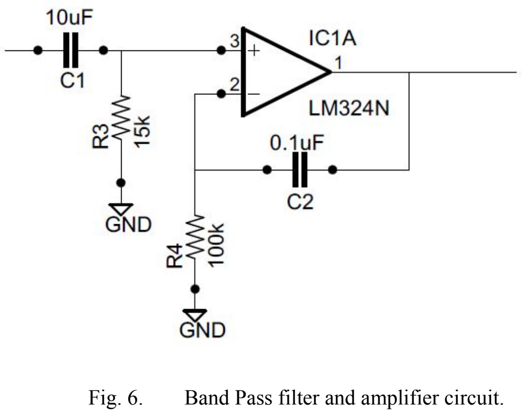


Fig. 6. Band Pass filter and amplifier circuit.

In Fig. 6, R_3 and C_1 constitute the passive High Pass filter with the cut- off frequency (F_1) given by the following equation:

$$F_1 = (2\pi R_3 C_1)^{-1}$$
$$= (2\pi * 15k * 10uF)^{-1}$$
$$= 1.06 \text{ Hz}$$

R_4 and C_2 constitute the active Low Pass filter with the cut-off frequency (F_h) given by the following equation:

$$F_h = (2\pi R_3 C_1)^{-1}$$
$$= (2\pi * 100k * 0.1uF)^{-1}$$
$$= 15.92 \text{ Hz}$$

C. Comparator

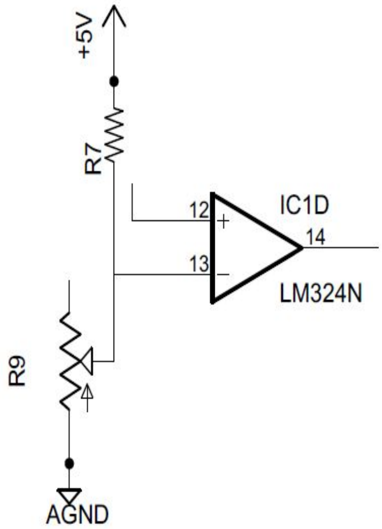


Fig. 7. Comparator circuit.

The filtered and amplified signal thus obtained is fed to a comparator [Fig. 7] in order to get a digital pulse corresponding to the heart rate. To design the comparator, the following resistor values are used:

R_7 = 1k Ω

R_9 = 10k Ω (Potentiometer)

IV. Hardware

The circuit was initially implemented on Breadboard as shown in [Fig. 9]. LM324 IC has been used in the circuit for amplification. LM324 is a DIP 14-pin IC consisting of 4 independent, internally frequency-compensated operational amplifiers [Fig. 8], which operate on a single power supply. It has a wide power supply range of 3V to 32V and draws supply current as low as 700 µA.

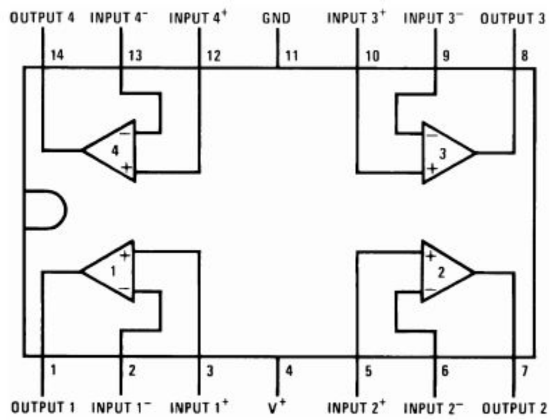


Fig. 8. LM324 Internal Structure [3].

The circuit is designed to operate on 5V power supply. Positive terminal of the supply is connected to Pin 4 and the ground terminal is connected to Pin 11 of the LM324 IC. First operational amplifier is used for Band Pass filter. The fourth operational amplifier is used as a comparator while the second and third operational amplifiers are left unused. The output of pulse sensing clip is connected to a High Pass filter followed by a Low Pass filter obtained by the first operational amplifier. The output of this stage, which is obtained at Pin 1 of LM324, is connected to Pin 12 for the comparator stage. The final output is obtained at Pin 14, which is a digital wave corresponding to the heartbeat. Further, a LED is connected to Pin 14 to show heartbeats according to the waveform obtained. The complete circuit schematic is shown in [Fig. 10]. The circuit is implemented on a Printed Circuit Board for better portability.

a.

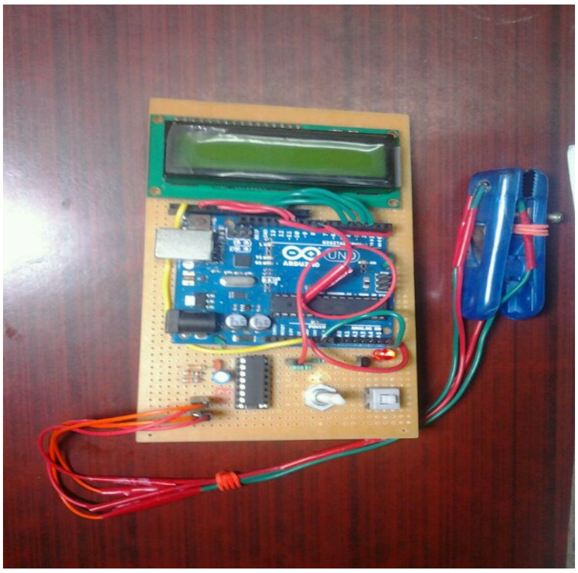
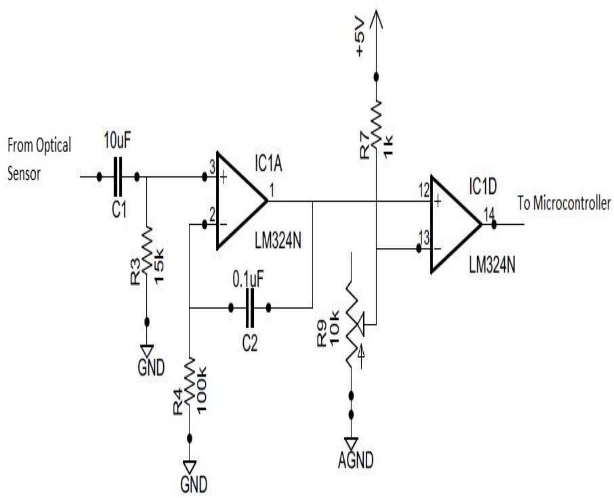


Fig. 8. Overall Hardware.

V. Circuit Diagram



b.

Fig. 9. Circuit Diagram of Heart Rate Monitor.

VI. Result

The device was tested and the output waveforms corresponding to heart rate were obtained. Processing software is used to view the pulse waveforms of different human subjects. Processing is an open source programming language and integrated development environment (IDE) [6]. Waveforms were obtained before filtration [Fig. 11], after filtration and amplification [Fig. 12] and after the comparator stage [Fig. 13]. The device was tested on five human subjects and the results were verified with the standard machine results. Test results are shown in TABLE. 1. Errors were calculated and found to be minimal.

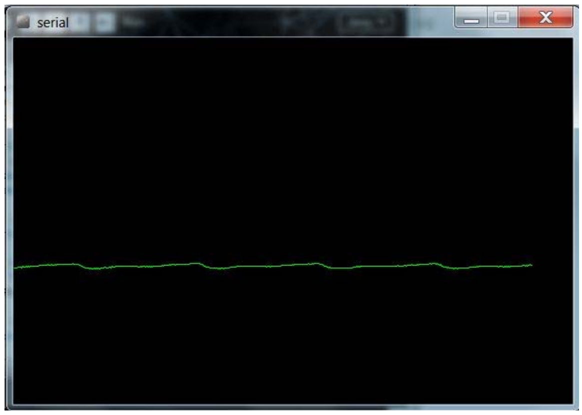


Fig. 10. Signal before filteration and amplification

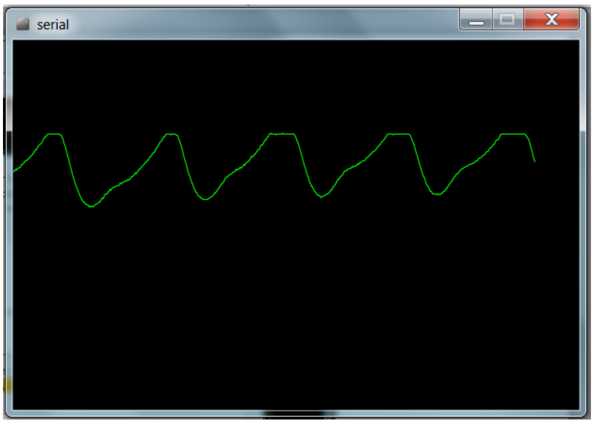


Fig. 11. Filtered and amplified heart pulse signal.

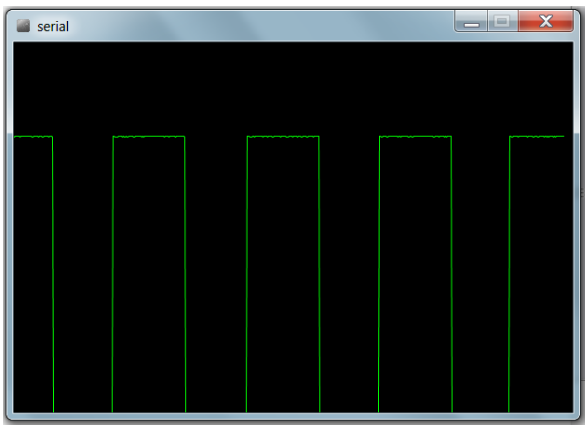


Fig. 12. Signal after Comparator Stage.

TABLE I. TEST RESULTS OF THE DEVICE

S.No.	Heart Rate Measurement		Error %
	Standard Machine	Our Device	
1.	92	90	2.2%
2.	95	93	2.1%
3.	96	94	2.1%
4.	81	85	-4.9%
5.	75	78	-4.0%

REFERENCES

[1] R S Khandpur, Handbook of Biomedical Instrumentation, 2nd ed., McGraw Hill Education (India) Pvt. Ltd., pp.204-208.

[2] Wikipedia, Photoplethysmogram, http://en.wikipedia.org/wiki/Photoplethysmogram.

[3] LM324 Datasheet, http://www.ti.com/lit/ds/symlink/lm124-n.pdf.

[4] Riccardo Barbieri and Emery N. Brown, “Analysis of Heartbeat Dynamics by Point Process Adaptive Filtering”, IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, VOL. 53, NO. 1, JANUARY 2006.

[5] The Basic RC Filters, http://www.experimentalistsanonymous.com/ve3wwg/doku.php?id=rc_simple_filter.

[6] Processing language reference, http://www.processing.org/reference/.

[7] Sharief F. Babiker, Liena Elrayah Abdel-Khair, Samah M. Elbasheer, “Microcontroller Based Heart Rate Monitor using Fingertip Sensors”, UofKEJ Vol. 1 Issue 2 pp. 47-51 (October 2011).