NATIONAL INSTITUTE OF TECHNOLOGY

SILCHAR

A PROJECT ON

"OPTICAL HEART RATE MEASURING DEVICE"

PREPARED BY

ARYAN

2114124

2023-2024

DEPARTMENT OF

ELECTRONICS AND COMMUNICATION ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

SILCHAR - 788010

Abstract

In this paper, we have outlined the design and development of an innovative integrated device dedicated to measuring heart rate using the fingertip, with the aim of enhancing the accuracy of heart rate estimation. Given the escalating prevalence of heart-related diseases, there is a growing demand for a heart rate measuring device or monitor that is both precise and affordable to safeguard overall health quality. Many existing heart rate measurement tools and setups tend to be costly and lack ergonomic considerations. Our proposed Heart Rate Measuring (HRM) device stands out for its cost-effectiveness, user-friendly interface, and reliance on optical technology for detecting blood flow through the index finger.

The device incorporates three key phases in its operation: pulse detection, signal extraction, and pulse amplification. Through both qualitative and quantitative assessments using real signals, our HRM device demonstrates remarkable accuracy in heart rate estimation, even in the midst of intense physical activity. To validate its performance, we conducted a comparative analysis with Electrocardiogram reports and manual pulse measurements for 90 human subjects across different age groups. The results unequivocally indicate a negligible error rate for the device, showcasing its reliability and effectiveness.

Keywords

Biomedical; Microcontrollers; Heart Rate Measurement; Pulse Detection; Pulse Amplification; Signal Extraction.

(I) Introduction

The heart rate serves as a crucial indicator of the robustness of our cardiovascular system, providing insights into its overall health. While clinical environments traditionally measure heart rate under controlled conditions such as blood measurement, heart voice measurement, and Electrocardiogram (ECG), advancements have enabled its measurement in home environments as well. Our heart's rhythm intensifies to propel oxygen-rich blood to muscles and transport cell waste products away from them. The level of muscle usage dictates the workload on the heart - the more active the muscles, the faster the heart must beat to fulfil these functions. A heart rate monitor is a device designed to capture a sample of heartbeats and calculate the Beats per Minute (bpm), offering valuable data for tracking heart conditions. Two primary methods are employed in the development of heart monitors: electrical and optical. The electrical method boasts an average error rate of 1 percent and an average cost of $150.00. In contrast, the optical method, with an accuracy rating of 15 percent, presents a more cost-effective option with an average cost of $20.

The average resting heart rate for adult males is approximately 70 beats per minute (bpm), while for adult females, it is around 75 bpm. However, heart rate can vary significantly among individuals, influenced by factors such as fitness level, age, and genetics. Endurance athletes often exhibit very low resting heart rates as a result of their rigorous training. One common method to measure heart rate is by assessing one's pulse. This can be done using specialized medical devices or simply by pressing fingers against an artery, typically on the wrist or neck. While pulse measurement provides a basic indication, it's widely acknowledged that a more accurate assessment can be achieved through auscultation, and listening to heartbeats using a stethoscope.

Several clinical methods exist for measuring heart rates, including Phonocardiogram (PCG), Electrocardiogram (ECG), blood pressure waveforms, and pulse meters. However, these methods are clinical and often come with a higher cost. Some cost-effective alternatives using sensors have been proposed, but they may be susceptible to noise and subject and artery movement.

This paper introduces the design and creation of a low-powered Heart Rate Monitoring (HRM) device that employs optical technology to deliver precise heart rate readings. The device stands out for its ergonomic design, portability, durability, and cost-effectiveness. Optical technology, featuring a standard Light Emitting Diode (LED) and photo-sensor, is seamlessly integrated to swiftly measure the heart rate by utilizing the index finger.

The device's functionality is orchestrated by a microcontroller programmed to accurately count pulses. Subsequently, the microcontroller controls the digital display of the heart rate on an LCD, providing real-time feedback within seconds. This innovative combination of components ensures an efficient and user-friendly HRM device that meets the criteria of accuracy, efficiency, and affordability.

(II) System Overview

In this section, we discuss the system overview like pulse detection, signal extraction, pulse amplification, and physical properties of our propose HRM device.

(A) Pulse Detection

The pulse detection mechanism in heart rate monitors comprises two main components: a pulse sensing unit and a heart rate displaying unit. Our device utilizes two red LEDs and a photo-sensor to gauge heart rate by detecting changes in blood reflectivity on the index finger. The power emitted by the LEDs is carefully aligned with the photo sensor, leading to variations in resistance within the sensor's range after passing through the index finger. Given that attenuations differ from person to person, our specifications assume an average attenuation of 80 percent of the transmitted light.

To translate changes in resistance into changes in voltage, a resistance network is employed alongside the sensor. The resulting voltage ranges from 0 to 10 mV with each heartbeat. Fig.(a) illustrates a clip sensor comprising two high-intensity LEDs illuminating the tissue and a Light Detective Resistor (LDR) whose resistance alters based on the amount of light transmitted through the tissue.

The LED and LDR are affixed to a spring-loaded device that can be clipped onto the fingertip. The light emitted by the LED diffusely scatters through the fingertip tissue, and the LDR, or photosensor, positioned on the opposite side of the skin, measures the transmitted light. Blood absorbs light effectively, while tissue absorbs it weakly. Any variations in blood volume are registered, as an increase or decrease in volume leads to more or less absorption. Assuming the subject remains still, the absorption level of the tissue and non-pulsating fluids remains constant.

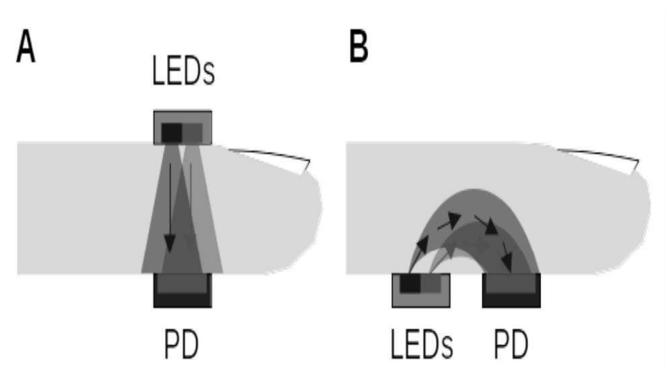

Fig (a). Finger positioning on the HRM device

(B) Signal Extraction

In our system, we implemented a bandpass filter to eliminate interference from ambient light and minimize level detection distortions. The selected filter has a cutoff frequency of 2.5 Hz, enabling the device to accurately measure a maximum heart rate of 125 beats per minute (bpm). This cutoff frequency ensures a roll-off that provides 23.5 dB of attenuation at 60 Hz. Before passing through the filter, the pulse exhibits a Signal to Noise Ratio (SNR) of -14 dB. Within the pass-band frequencies, a small signal amplifier amplifies these signals by a factor of 40 dB. Additionally, we employed DC blocking to mitigate immeasurable pulses resulting from a high DC offset caused by ambient light. This comprehensive filtering and amplification approach enhances the accuracy and reliability of heart rate measurements in the presence of potential noise and interference.

(C) Pulse Amplification

In our design, the extracted signal undergoes analysis by an amplifier, generating a high-amplitude pulse that is then fed into the input of the microcontroller. The amplifier is designed to identify the peak of each pulse, producing a corresponding pulse of substantial amplitude. To ensure the generation of a clean, high-amplitude pulse, this stage of the design necessitates that the amplified and filtered heart pulse signal maintain a Signal to Noise Ratio (SNR) of 20 dB.

The microcontroller interprets the time interval between successive rising edges of the high-amplitude pulse as the period between each heart pulse. For signal amplification, an LM358 is employed, amplifying the heart signal twice after passing through the bandpass filter (see Fig. 2). Ultimately, the amplified output is used by the microcontroller as its input, facilitating the calculation of the heart rate. This integrated approach ensures accurate and reliable heart rate determination by effectively handling signal amplification and interpretation.

(D) Physical Properties

The heart rate, calculated by the microcontroller, is displayed on an LCD in our device. To aid users in identifying when a heart rate is being measured, a flashing segment on the LCD is incorporated. The formatted heart rate result is presented on a character LCD. The accuracy of our device is primarily influenced by the duration spent averaging the pulse rate from the user. A dynamic time approach for pulse gathering is employed, where the pulse is averaged after a set number of pulses, five in our case. This method ensures a more even distribution of accuracy across the range of measurable pulses.

The device operates on a 5 Volt battery source for compactness, and under normal use, the battery is expected to last one year, though actual duration may vary based on usage. With typical daily usage of 15 minutes, the device can operate for approximately two months. The design accommodates a standard temperature environment of -30°C to 80°C. The device is designed to be small, lightweight, and portable, with final dimensions not exceeding 3.5” x 2” x 1” (H x W x D). To maintain competitiveness with existing products, the cost of the HRM device is kept to a minimum, with a maximum estimate for components at $20. This cost-effectiveness is achieved through our unique design approach and thoughtful component selection. See Fig. 3 for the physical properties of the HRM device.

(III) Methodology

(A) Optical Transmitter and Receiver Circuit

The Heart Rate Monitor (HRM) operates by measuring the pulse rate through changes in blood flow within an index finger. With each heartbeat, blood is pumped from the heart, increasing the density of blood in the pulsatile tissue of the finger and causing a decrease in the light power received by the photo-sensor. It's important to note that the photo-sensor doesn't capture a purely AC signal due to the presence of DC components from non-pulsatile tissues and ambient light levels.

The varying light levels received are then transformed into a varying resistance in the photo-sensor. This varying resistance is further converted into a varying voltage using a resistance network and power source. To facilitate this process, two red LEDs are employed in conjunction with a photo-sensor to detect and transmit the pulse rate. The choice of red LEDs is based on the fact that human tissue acts as a filter for red light. Using two red LEDs maximizes the amount of light energy that can pass through the index finger, enhancing the efficiency of the system.

The circuit, as depicted in Fig. 4, is specifically designed to achieve this objective, allowing for the successful detection and transmission of the pulse rate through the index finger. This combination of optical technology and circuitry forms the basis of the HRM's functionality.

The circuit depicted in Fig. 4 serves as our pulse-rate to voltage converter and the source of constant red light, purposefully designed and constructed for collecting real-world data. Here's a breakdown of its components and operation:

1. Red LED Configuration: The red LED is forward-biased through a resistor (R2) to facilitate a controlled current flow. The value of resistor R2 is meticulously selected to generate a maximum amount of light output. This choice is crucial for optimal performance.

2. Resistance Network: The calculated value of R2 is approximated to a resistance value that is commonly available in electronic components.

3. Photo-Resistor and Current Reduction: The photo-resistor is placed in series with another resistor to reduce the current drawn by the detection system. This configuration helps prevent shorting of the power supply when no light is detected by the photo-resistor.

In summary, this circuit is tailored to convert the pulse rate, detected through changes in light intensity due to blood flow, into a corresponding voltage signal. The use of a red LED, combined with careful resistor selection and configuration, ensures reliable and efficient operation for real-world data collection in the context of a Heart Rate Monitor.

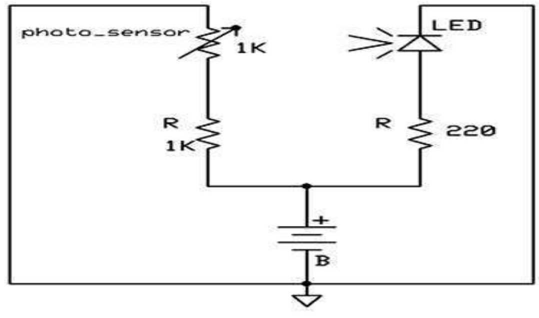

Fig. (b) Optical Transmitter and Receiver Circuit

(B) Amplification of Pulse signal

To enable the microcontroller to count the pulse rate, the signal must undergo amplification. An amplifier is employed to detect the rising edges of the filtered signal received by the photo-sensor. This detection enables one pin of the microcontroller to be utilized as an input. The time interval between successive rising pulse edges is precisely determined by the microcontroller, allowing for the measurement of the heart rate frequency. The designed circuit for this purpose is illustrated in Fig. 5.

This circuit configuration ensures that the microcontroller can accurately interpret the amplified signal, identify the rising edges, and subsequently calculate the frequency of the heart rate. The coordination between the amplifier and the microcontroller is critical in achieving reliable and precise pulse rate measurements in the Heart Rate Monitor system.

The amplifier in the circuit utilizes an LM358 dual operational amplifier (op amp) to create two identical broadly-tuned bandpass stages with gains of 100. The specific type of op amp is not crucial, as long as it operates at 5V and can drive the output rail to rail. The choice of signal frequencies is constrained by movement artifacts at the low end (generated by the peg moving and distorting the underlying tissues) and mains-hum interference at the top end.

Key features of the amplifier circuit include:

1. Power Source: The circuit is powered by a single 5 Volt battery.

2. Output Offset: The output zero is offset by approximately 1 Volt by referencing everything to an internal common line at a voltage set by a pair of forward-biased silicon diodes. This facilitates compatibility with a 0-5 Volt input interface.

3. Gain Adjustment: A potentiometer is included to allow adjustment of the overall gain. This feature prevents clipping on large signals.

4. Component Considerations: Components in general are not highly critical. The two 2.2 μF capacitors must be able to withstand some reverse bias, so non-polarized or tantalum capacitors are recommended.

5. Construction: The circuit can be easily assembled on a small piece of stripboard. This amplifier configuration is designed to effectively process the signal from the photo-sensor, providing the necessary amplification for accurate pulse rate measurement while addressing potential sources of interference and distortion.

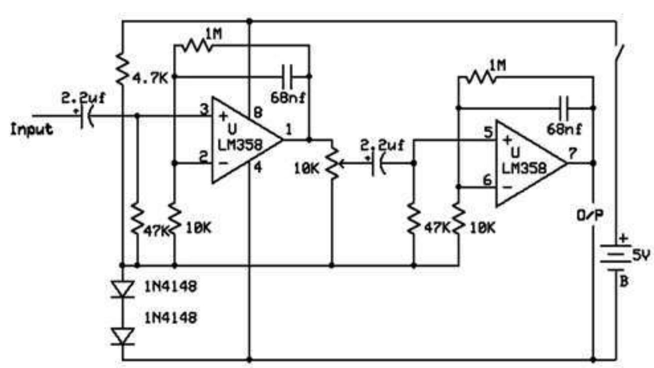

Fig. (c) Amplifier circuit use in device

(C) Displaying Unit

A microcontroller proves to be a cost-effective solution for counting the pulse rate and controlling a LED display. The method outlined below eliminates the need for a display driver by setting and refreshing the displays through multiplexing the segment lines to the same I/O pins on the microcontroller.

Programming the microcontroller involves the development of a calculation algorithm to count the pulse rate. This calculation algorithm, implemented in firmware, simplifies the process of signal, the algorithm initiates, following the flow chart depicted in Fig. 6. The flow of the algorithm likely involves steps such as signal detection, pulse counting, and updating the LED display to reflect the current pulse rate. This approach ensures an efficient and streamlined process for monitoring and displaying the pulse rate using the microcontroller.

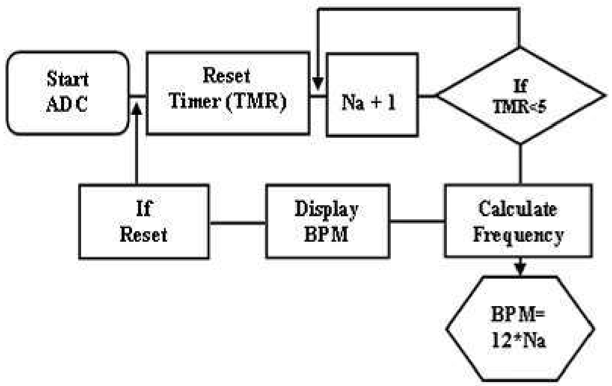

Fig. (d) Flowchart for Heart Rate Measurement device working

After simulating each stage of the design to validate its unit efficiency, the components are integrated. In Fig. (e), the working principle is illustrated to showcase how the different elements come together to form a cohesive and functional system. This integration phase is crucial to ensure that the individual units, previously validated through simulation, operate harmoniously when combined. The illustration in Fig. (e) likely provides an overview of how signals flow through the integrated system, demonstrating the culmination of the design efforts in a comprehensive and operational Heart Rate Measuring (HRM) device.

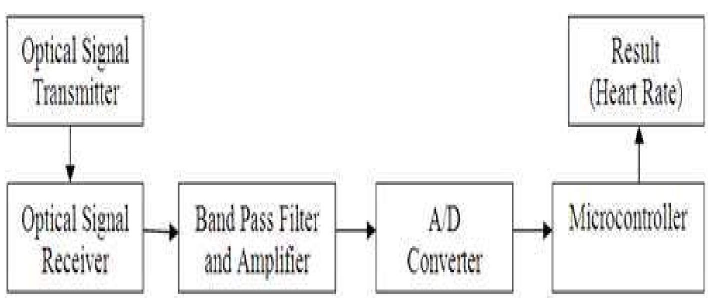

Fig. (e) Block Diagram of HRM device

(IV) Experimental Results

The initial phase of the device, involving the construction and testing of the optical receiver and transmitter, has been successfully completed. The output from the receiver is connected to an oscilloscope (O-scope) to capture the heartbeat signal. A bandpass filter is employed to effectively eliminate noise from the heartbeat signal. Fig. (g) presents the output achieved after the application of the bandpass filter, showcasing the signal with reduced noise. This step is crucial in enhancing the signal quality and ensuring accurate and reliable monitoring of the heartbeat. The filtering process contributes to a clearer representation of the desired physiological signal by attenuating unwanted frequencies.

Comparing Fig. (f) and Fig. (g), it's evident that the high-frequency noise at 120 Hz from ambient lights has been successfully filtered out, aligning with expectations. The filtered signal is crucially required to maintain a Signal to Noise Ratio (SNR) of 20 dB or greater. This ensures that the amplifier can accurately convert the continuous signal into a higher amplitude form without triggering false signals due to noise. The filtered signal, in this case, exhibits a Signal to Noise Ratio of approximately 24 dB. This level of SNR is crucial as it allows the amplifier to effectively amplify the heartbeat signal without introducing errors or misinterpretations caused by noise. This successful test indicates that the filter is indeed capable of removing high-frequency noise from the heartbeat signal, contributing to the accuracy and reliability of the monitoring system.

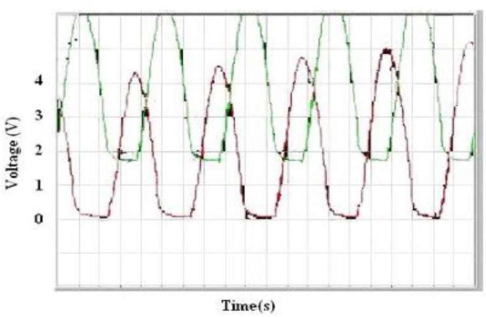

Fig. (f) Amplified Output Signal

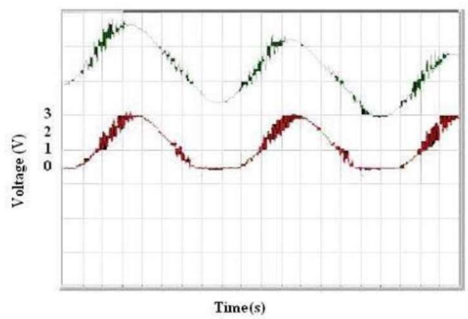

Fig. (g) Filtered Output Signal

The microcontroller is programmed to count the number of peaks in the input signal over a duration of 5 or 10 seconds. The resulting count is then multiplied by 12 or 6, corresponding to the chosen time duration, to obtain the total number of peaks per minute. An LCD is connected to the microcontroller, and a known frequency pulse signal is fed into it. The correct number of peaks per minute value is displayed on the LCD. Once the microcontroller is integrated into the entire circuitry, it can effectively count the number of heart beats per minute and drive the LCD to display the calculated value.

The performance of the HRM device is assessed by testing it with the output of Electrocardiogram (ECG) data for 15 patients. The error rate e is calculated using method denoted by equation (1).

$$e = \frac{100*|A-M|}{A} \% \qquad \dots (1)$$

Here,

A is Actual heart rate, M is Measured heart rate and e is Error rate.

This error rate measurement serves as a quantitative assessment of the HRM device's accuracy and reliability in comparison to the ECG data, which is a standard and precise method for monitoring heart activity. The comparison shows that the HRM device has accuracy with a mean of 5.29% error.

Table (I) : Accuracy Comparison with ECG

Electrocardiogram ECG (bpm)	HRM device (bpm)	Error rate (%)
76	80	5.26
78	74	5.12
81	83	2.46
82	88	7.32
77	73	5.19
74	78	5.40
73	79	8.21
77	74	3.89
86	93	8.13
85	89	4.70
79	73	7.59
81	84	3.70
70	75	7.15
71	72	1.41
77	80	3.89

The accuracy of the HRM device may vary depending on the circumference size of the user's finger. An assessment of the error rate was conducted, considering different finger sizes, revealing that the HRM performs well with medium-sized fingers. The specific results of this analysis are presented in Table II. This information provides valuable insights into the device's performance across various finger sizes, contributing to a more comprehensive understanding of its effectiveness and limitations.

Table (II) : Error rate in different finger size

Finger Circumference Size	Error rate (%)
Small (2.125 ”)	7.23
Medium (2.5 ”)	3.41
Big (3.0 ”)	14.56

The accuracy of the heart monitor is further tested manually, involving the selection of 90 human subjects spanning different age ranges from 3 years to 65 years. Their heartbeats were measured manually by assessing the pulse and simultaneously with the HRM device. Fig. (f) illustrates that the variance between the actual heart rate and the measured heart rate is minimal, indicating a low error rate. This comparison serves as a validation of the HRM device's accuracy across a diverse range of age groups, reinforcing its reliability in providing accurate heart rate measurements. Fig. (f) demonstrates that the HRM device boasts an average error rate of only 4.56 percent. This result highlights the efficiency of the device in measuring heartbeats in a cost-effective and ergonomic manner. The low error rate signifies the accuracy and reliability of the

HRM device, reinforcing its effectiveness as a practical and dependable tool for heart rate monitoring across various age groups and finger sizes.

(V) Conclusions

In this paper, we present the design and development of a Heart Rate Measuring (HRM) device that efficiently measures heart rate in a short time and with reduced expenses, avoiding the use of time-consuming and expensive clinical pulse detection systems. The device utilizes a combination of analog and digital signal processing techniques to maintain simplicity while effectively suppressing signal disturbances. Simulations indicate that heart rate can be discerned from changes in blood flow through an index finger. Experimental results demonstrate that the heart rate can be successfully filtered and digitized, allowing for accurate pulse rate calculation.The device encompasses the ability to detect, filter, digitize, and display the user's heartbeat in an ergonomic manner. This innovative approach combines efficiency and affordability, making it a practical solution for heart rate monitoring without the need for complex and costly clinical setups.

References

[1] R.G. Landaeta, O. Casas, and R.P. Areny, "Heart rate detection from plantar bioimpedance measurements", 28th IEEE EMBS Annual International Conference, USA, 2006, pp. 5113-5116.

[2] P. F. Binkley, "Predicting the potential of wearable technology", IEEE Eng. Med. Biol. Mag., Vol. 22,2003, pp.23-27.

[3] Wikipedia, "Heart rate", Available at: http://en.wikipedia.org/wiki/Heart_rate [December 27, 2009]

[4] Y. Chen, "Wireless heart rate monitor with infrared detecting module," US2005075577-A1, 2005.

[5] Pico Technology, "Calculating the heart rate with a pulse plethysmograph", Available at: http://www.picotech.com/experiments/calculating_heart_rate/index.html [December 27, 2009]

[6] S. Rhee, B.-H. Yang, and H. H. Asada, "Modelling of finger photoplethysmography for wearable sensors," 21st Annual Conference and the 1999 Annual Fall Meeting of the Biomedical Engineering Soc. BMES/EMBS Conference, 1999.

[7] C. C. Tai and J.R.C. Chien, "An improved peak quantification algorithm for automatic heart rate measurements", IEEE 27th Annual Conference on Engineering in Medicine and Biology, China, 2005, pp. 6623-6626.