# Cardiovascular System Monitoring Using Photoplethysmography


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***Abstract*— The optical method known as photoplethysmography (PPG) is frequently used due to its low cost and ability to identify variations in blood volume inside tissue microvascular channels. It is widely used in commercial medical equipment to measure blood pressure, blood flow, oxygen saturation and diagnose peripheral artery disease. As a result of the growing need for affordable, portable, and harmless technology, PPG has been incorporated into a variety of devices. Particularly, smart wearables like fitness bands and smartwatches are becoming more sophisticated, offering features that can detect potential cardiovascular diseases (CVD). This paper discusses the development of a system called Cardiosync wristband, primarily focusing on cost-effective early detection of cardiovascular diseases. It is specifically engineered to identify various types of respiratory rate abnormalities while primarily concentrating on estimating heart rate, respiratory rate, and pulse rate variability. Its functionality revolves around the precise acquisition of PPG signals, which are then processed to make a variety of parameter estimation. The paper outlines the fundamental aspects of the Cardiosync wearable device, its capabilities, and its potential significance in the principles of light operation and its interaction within the tissue for PPG measurements. Furthermore, it covers technological advancements such as the analog front end for PPG signal measurement, sensor configurations with multiple light emitters and receivers, minimum sampling rate requirements for low-power systems, and the utilization of PPG signals for measuring stress, sleep, blood pressure, blood glucose levels, and activity.**



***Keywords*— *Photoplethysmography (PPG),cardiovascular diseases (CVD), Cardiosync, Labview, Heart rate variability***


## I. INTRODUCTION

Globally, cardiovascular diseases (CVDs) account for 17.9 million deaths annually, making them the leading cause of death. In individuals under 70 years old, premature deaths account for one-third of all deaths. Therefore, continuous monitoring is essential to identify CVD abnormalities such as tachycardia and bradycardia. This continuous assessment can be achieved through the use of smart wearables for early detection. One of the most widely used techniques for assessing variations in blood volume is photoplethysmography. It is frequently utilized in modern clinical practice and is based on the optical absorption of arterial blood. [1], [2]. It is a non-invasive optical technique extensively utilized in clinical practice for monitoring blood volume changes in the microvascular bed of tissue. By measuring the variations in light absorption by arterial blood, PPG provides valuable insights into cardiovascular health and blood flow dynamics. The principle behind PPG is based on the differential absorption of light by blood at different wavelengths, allowing for the detection of blood volume changes that correspond to the cardiac cycle [3]

In addition to heart rate estimation and pulse oximetry data, several researchers worldwide have recently shown a great deal of interest in deriving additional useful information from the PPG signal. Due in large part to its affordability, ease of use, and simplicity of operation, PPG technology has become more and more popular as a substitute for traditional heart rate monitoring methods [4]. Nonetheless, a significant challenge associated with PPG-based monitoring approaches is their imprecision in recording PPG signals throughout ordinary everyday activities and mild physical activity. This restriction results from the PPG signals' high susceptibility to hand movements-induced Motion Artifacts (MA) [5].

More researchers from all around the world are interested in deriving useful information from the PPG signal than just pulse oximetry and heart rate estimation. Its affordability, convenience of use, and simplicity of operation have all contributed to the PPG technology's recent surge in popularity as an alternate heart rate monitoring method [4]. Yet, tracking PPG signals during regular everyday activities and mild physical activity is a key challenge for PPG-based monitoring systems. Because hand movements can introduce Motion Artifacts (MA) onto PPG signals, this limitation results.

The aim of the study is to create a non-invasive method for tracking blood flow changes to diagnose various diseases related to blood flow disorders. The human pulse signal, or PPG signal, can be captured using optical techniques. An LED-photodetector setup is employed to measure blood flow variations The system is integrated with an Arduino UNO microcontroller and interfaced with LabVIEW software. This integration allows for real-time processing and analysis of the PPG signal. Through this setup, several vital parameters are estimated, including heart rate, respiratory rate, and pulse rate variability. The LED-photodetector assembly works by emitting light into the skin and measuring the amount of light either transmitted or reflected back, which varies with blood volume changes in the microvascular bed of tissue. These variations are captured as the PPG signal, which is then digitized and processed by the Arduino UNO.

LabVIEW software serves as the platform for processing the digitized signal. It enables the extraction and visualization of key physiological parameters. Heart rate is determined by identifying the peaks of the PPG signal, while respiratory rate is derived from the low-frequency components of the signal. Pulse rate variability, an important indicator of autonomic nervous system activity, is calculated by analyzing the time intervals between successive heartbeats.

This system's non-invasive nature and integration with readily available technology make it a promising tool for continuous health monitoring and early diagnosis of cardiovascular and respiratory disorders. By providing accurate and timely data, it has the potential to improve patient outcomes through early detection and intervention.

## II. MONITORING DEVICES BASED ON PPG

A light source and a photodetector are components of a conventional PPG gadget. The photodetector detects the light that is reflected from the tissue after it has been exposed to light from the light source [9]. Variations in blood volume are correlated with the reflected light. Because PPG waves consistently show cardiac and respiratory activity, they are useful in the diagnosis of cardiac arrhythmias, or abnormal heartbeats, just like ECGs are. The primary light source of the majority of PPG sensors is either a green LED or an infrared light emitting diode (IR-LED). While green light is usually used to calculate the absorption of oxygen in oxyhemoglobin (oxygenated blood) and deoxyhemoglobin (blood without oxygen present), IR-LEDs are most commonly used for measuring the flow of blood that is more deeply concentrated in certain parts of the body, such as the muscles [10]. Green LED is said to be the most widely used hue for hemoglobin measurement, while there are other LED sensors available as well. This is merely due to the fact that it can produce measurements that are more exact because it can pierce tissue more deeply.

It is necessary to select the emitter based on frequency. Some credentials that could be used are:

- **Red (600-750nm)**
- **Green (600-750nm)**
- **IR(800-1000nm)**

Since the blood looks red, this means it absorbs all the other colors except red and scatters red the most. This makes it a good color to select. Also the emitter is selected based on the sensitivity of the detector and the placement of sensing. The emitter and detector in PPG are crucial components that emit and receive light, respectively, to capture these variations[11]. The interspace distance between the emitter and detector in PPG setups plays a significant role in determining the accuracy and reliability of the measurements. This distance refers to the separation between the light source (emitter) and the light sensor (detector) on the surface of the skin or tissue being monitored.

The optimal interspace distance depends on various factors including the specific application, anatomical site of measurement, and the desired depth of penetration for light into the tissue. Generally, a shorter interspace distance may provide better sensitivity to detect subtle changes in blood volume [12], especially in superficial tissues. However, it may also increase the risk of signal saturation or interference due to direct light transmission from the emitter to the detector without adequate tissue interaction.

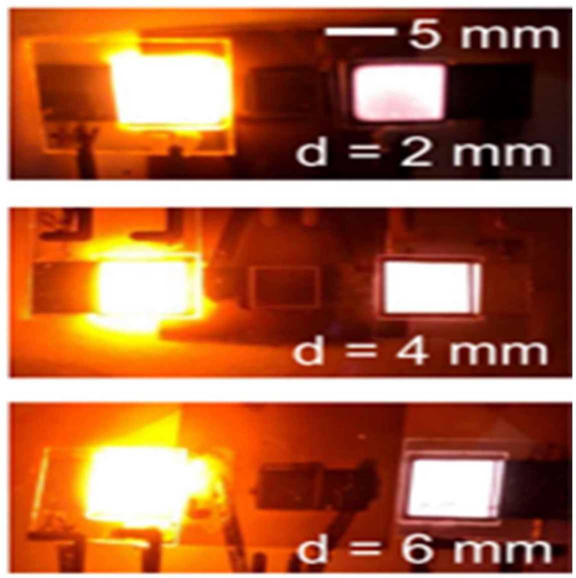


*Figure.1.*

Figure 1 illustrates the interface distance between the emitter and the detector where longer interspace distance may offer deeper penetration into tissues, allowing for measurements from deeper blood vessels. However, this may reduce the sensitivity to changes in superficial blood flow and increase susceptibility to motion artifacts or ambient light interference [13].

Therefore, the interspace distance should be carefully chosen based on the specific requirements of the application, balancing sensitivity, depth of measurement, and against potential sources of error. Additionally, considerations such as the wavelength of light used, tissue properties, and signal processing techniques should also be taken into account when determining the optimal interspace distance for photoplethysmography measurements.

# III. METHODOLOGY

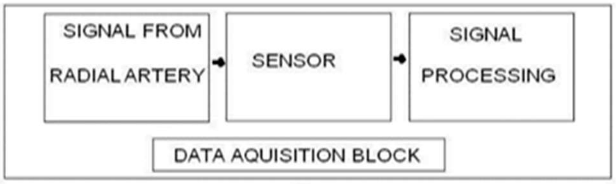


*Figure.2 Data Acquisition block*

The proposed photoplethysmography (PPG) system detects signals from the radial artery using an infrared (IR) sensor, with a microcontroller, specifically the Arduino Uno, integrated into the system for data acquisition as shown in Fig.2. Initially, the IR sensor, positioned on the skin above the radial artery, emits light that penetrates the skin and reflects off the blood vessels. The sensor's detector captures the reflected light, which varies with blood volume changes corresponding to cardiac cycles.

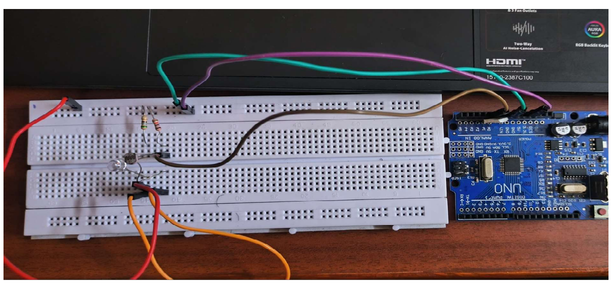

*Figure 3 Hardware setup*

The Figure 3 illustrates the hardware setup, where the Arduino Uno reads these analog signals from the IR sensor, sampling them at a predefined rate to ensure accurate representation. These sampled signals are then transmitted to a connected computer and stored in a CSV file.

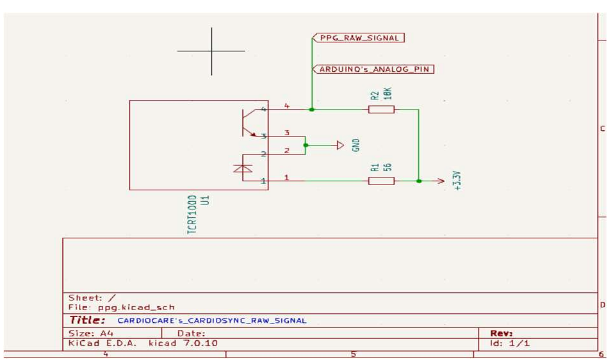


*Figure 4. Raw signal circuit*

The circuit designed for raw signal acquisition in our photoplethysmography (PPG) system utilizes the Arduino Uno microcontroller and the TCRT1000 sensor, an integrated reflective optical sensor that combines an infrared emitter and phototransistor in a single package. Positioned on the skin above the radial artery, the TCRT1000 emits infrared light that penetrates the skin and reflects off blood vessels. The reflected light, which varies with blood volume changes due to the cardiac cycle, is detected by the phototransistor. In this setup, the IR emitter is connected to a digital output pin of the Arduino Uno to control light emission, while the phototransistor's output is connected to an analog input pin, allowing the Arduino to read the varying voltage corresponding to the reflected IR light intensity. The Arduino Uno samples this raw signal at a predefined rate, converting the analog voltage into digital values without any intermediate amplification or filtering stages. The simplicity of this circuit allows for effective raw signal acquisition, enabling detailed examination and extraction of meaningful physiological parameters.

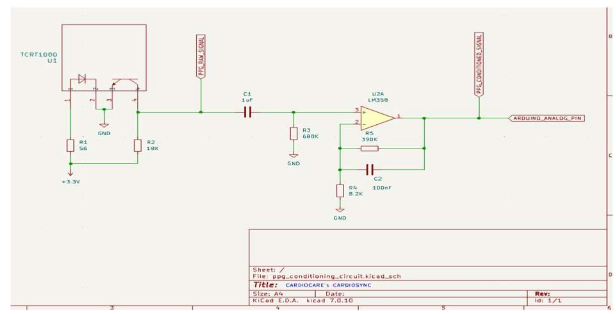

*Figure.5. Amplified and filtered circuit*

Figure.5. shows the circuit for amplified and filtered signal acquisition in photoplethysmography (PPG) system to enhances the raw signals from the TCRT1000 sensor using the LM358 operational amplifier. Initially, the TCRT1000 sensor, which combines an infrared emitter and phototransistor, detects blood volume changes in the radial artery by measuring reflected IR light. This raw signal is then fed into the LM358 for amplification and filtering.

In this setup, the signal undergoes a two-stage filtering process. First, a passive high-pass filter is applied to remove low-frequency noise, followed by an active low-pass filter to eliminate high-frequency components. Together, these filters form an equivalent band-pass filter with a lower cut-off frequency of 0.2 Hz and an upper cut-off frequency of 4.1 Hz, ensuring that the system effectively isolates the relevant physiological signals within the useful bandwidth of 0.2 Hz to 6 Hz.

The LM358 amplifies the filtered signal, providing a gain of approximately 33.73 dB, which significantly enhances the signal strength for accurate analysis. This amplification is crucial for capturing the subtle variations in the PPG signal, allowing for more precise and reliable measurements. By processing the signal in this manner, the circuit ensures that only the most pertinent information is retained, facilitating effective analysis and extraction of physiological parameters.

The processed signal, now amplified and filtered, is then read by the Arduino Uno's analog input pin, sampled at a predefined rate, and transmitted to a connected computer. The data is saved in a CSV file for further analysis and interpretation. This methodology allows the PPG system to provide signals for accurate monitoring and diagnosis of cardiovascular health parameters.

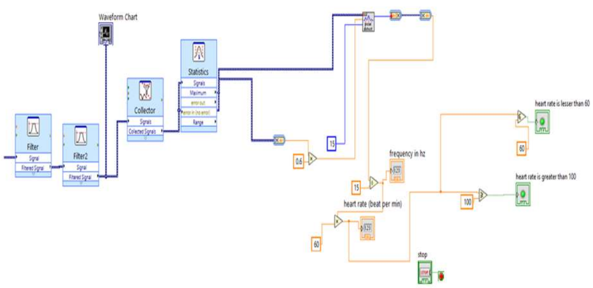


*Figure.4. PPG signal simulation using Labview*

After data acquisition, the CSV file is imported into LabVIEW for feature extraction. The diagram is shown in the figure 4.
In LabVIEW, three key parameters are estimated: (a) Heart rate (b) Respiratory rate (c) Heart rate variability. The extracted features are analyzed to identify patterns and anomalies associated with cardiovascular diseases (CVD).

**(A) Heart rate:**
It is determined by analyzing the periodic peaks of the PPG signal, the heart rate provides essential information about the cardiovascular system's performance. Abnormal heart rates can indicate conditions such as tachycardia, bradycardia, and arrhythmias, which are significant markers of CVD.

**(B) Respiratory rate:**
Estimated by identifying the variations in the PPG signal due to the respiratory cycle, this parameter is valuable for monitoring breathing patterns.

**(C) Heart rate variability:**
Calculated by examining the time intervals between consecutive heartbeats, HRV is an important indicator of autonomic nervous system activity and overall heart health. Reduced HRV is associated with a higher risk of cardiovascular events and can signal conditions such as coronary artery disease and myocardial infarction.

By utilizing LabVIEW for these estimations, the process becomes more efficient and accurate, Here LabVIEW applies algorithms and models to these features to determine the presence of CVD conditions, with the analysis results indicating potential cardiovascular issues based on the PPG signal characteristics. This methodology offers a systematic approach to developing and implementing a PPG system for detecting cardiovascular conditions, effectively combining hardware and software components.

## IV. RESULT AND DISCUSSION

The proposed photoplethysmography (PPG) system is designed to output raw data signals using a specified configuration that includes a RED LED with a wavelength of 640 nm and a diameter of 5 mm, paired with a photodetector ADS:90086, chosen for its high sensitivity. The system integrates these components with a microcontroller to effectively capture and process the PPG signals.

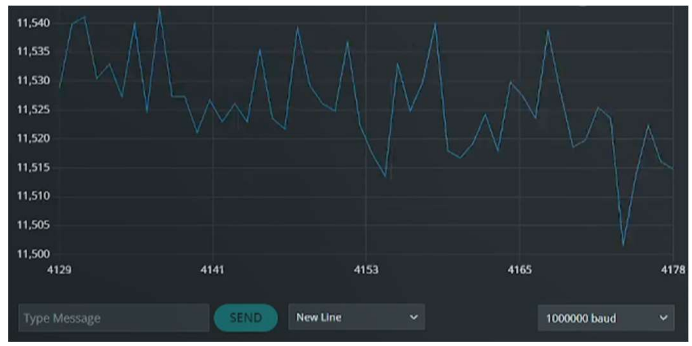


*Figure 5. Raw PPG output signal*

In this setup, the RED LED emits light at 640 nm, which penetrates the skin and reflects off the underlying blood vessels. The photodetector ADS:90086, positioned to receive the reflected light, detects the variations in light intensity caused by changes in blood volume with each cardiac cycle. The sensitivity of the ADS:90086 ensures that even minute changes in the reflected light are accurately detected, making it an ideal choice for this application. The output raw PPG signal is shown in Figure 5.

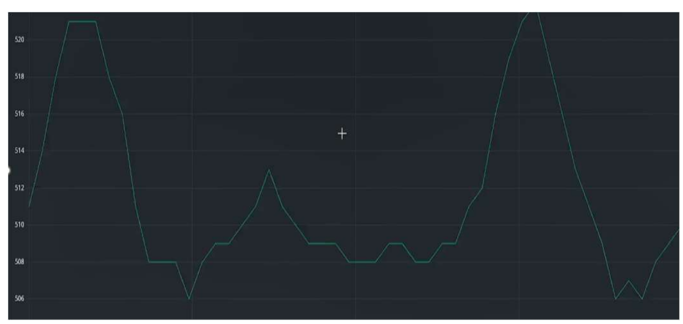

*Figure 6. Filtered amplified signal*

Figure 6 shows the filtered PPG output, which is processed using a passive high-pass filter followed by an active low-pass filter. The filters have a lower cut-off frequency of 0.2 Hz and an upper cut-off frequency of 4.1 Hz. The operational amplifier used is an LM358, and the gain is set to 33.73 dB

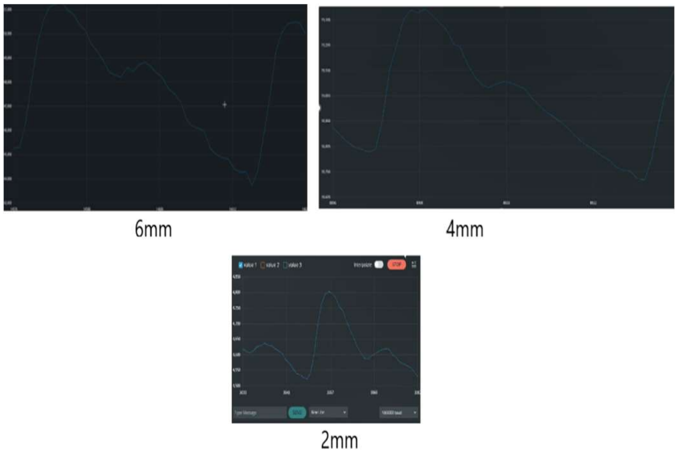


*Figure 7. Filtered signal with different interspacing distance*

Figure.7 illustrates the interspacing distance between the emitter and detector in the PPG system. Signals are acquired at three distinct distances: 6mm, 4mm, and 2mm. This variation in interspacing distance allows for the examination of signal characteristics at different depths within the tissue. By capturing signals at these specific distances, the PPG system can provide insights into the penetration depth of light into the tissue and the corresponding changes in signal quality. This information is crucial for optimizing the performance of the PPG system and improving its accuracy in assessing blood volume changes and vascular dynamics.


*Figure 8. Ambient noise removed signal*

Figure 8 demonstrates the effectiveness of ambient noise removal on the resulting PPG signal. This illustration highlights the PPG signal before and after the noise reduction process, showing a significant improvement in signal clarity. By removing ambient noise, the resulting PPG signal becomes more reliable and easier to analyze, which is crucial for applications requiring precise physiological data interpretation. This process ensures that external noise does not interfere with the primary PPG signal, leading to more accurate and consistent results. Such noise reduction techniques are essential in environments with high levels of background noise, enhancing the performance of various biomedical devices and monitoring systems.

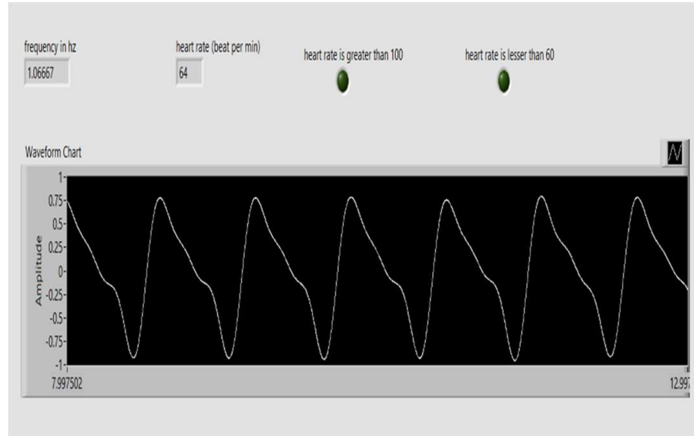


*Figure.9 Estimated parameters output*

Here the readings were taken for about 7 minutes, and the estimated parameters were observed and noted. The frequency was set to 1.00667 Hz. Among the parameters measured, the heart rate was found to be 82 beats per minute as shown in Figure 9. This heart rate is within the normal range, indicating that the person is not suffering from any cardiovascular disease (CVD) at the moment.

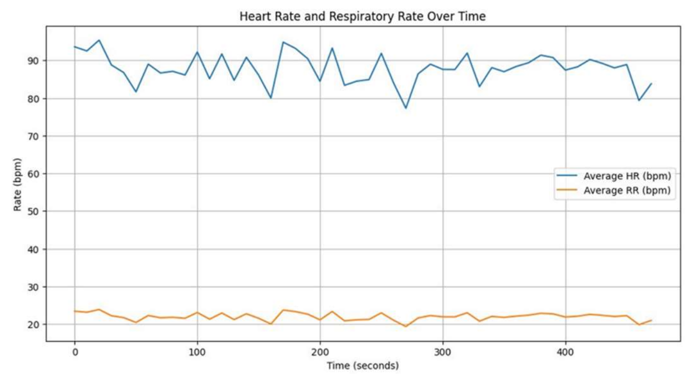


*Figure. 10 Heart Rate and Respiratory rate over Time*

Figure 10 illustrates the heart rate and respiratory rate over time. This graph provides a comprehensive visual representation of both parameters, showcasing how they fluctuate during the monitoring period.

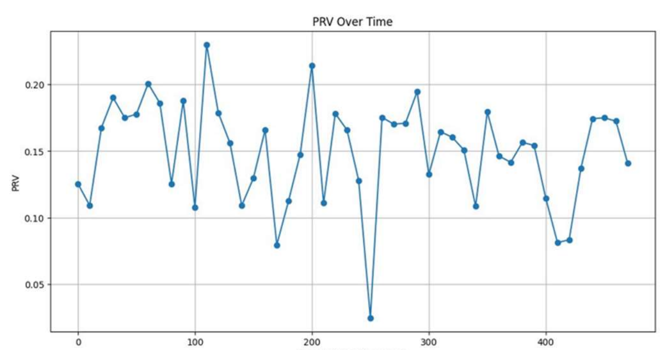


*Figure.11 Estimation of pulse rate variability.*

The pulse rate is estimated over a period of time, and the resulting graph is shown in Figure 11. This graph illustrates the variations in pulse rate, providing a visual representation of the heart rate trend throughout the monitoring period. By analyzing this graph, one can observe patterns and fluctuations in the pulse rate, which can be indicative of the individual's cardiovascular health.

Thus, the designed circuit provides an effective solution for cardiovascular system monitoring using photoplethysmography (PPG). It accurately estimates vital parameters such as heart rate, respiratory rate, and heart rate variability. These measurements are crucial for the early detection and management of cardiovascular diseases (CVD).

## V. CONCLUSION

The cardiovascular system monitoring using photoplethysmography (PPG) is designed, and the vital parameters are estimated. Here the proposed photoplethysmography (PPG) system successfully recorded signals from the radial artery over a period of approximately 7-8 minutes, which were then saved in a CSV file for further analysis. This recorded data was subsequently fed into LabVIEW, where critical parameters such as heart rate, respiratory rate, and pulse rate variability were accurately estimated. The methodology demonstrated here effectively integrates hardware and software components to achieve reliable PPG signal acquisition and analysis.

In future work, this system has the potential to be developed into a comprehensive diagnostic tool within a single wristband device. This advanced wristband could not only monitor heart rate and respiratory rate but also diagnose and estimate conditions such as atrial fibrillation, blood pressure, obstructive sleep apnea, mental stress, and preeclampsia. The versatility and compactness of such a device would represent a significant advancement in continuous health monitoring and early detection of various health conditions, providing a valuable tool for both patients and healthcare providers.

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