Designing of Heartbeat Measurement System in Arduino microcontroller with Noise Reduction

Aesha Akram [1], Anvita Pandit [1]

[1] Electronics and Communications Department

National Institute of Technology, Warangal, India

an21ecb0f03@student.nitw.ac.in , ap21ecb0f08@student.nitw.ac.in

***Abstract*— Regular monitoring of heart rate is essential for the early detection of potential heart diseases. This project focuses on the development of a heart rate measurement and monitoring system using an Arduino microcontroller and incorporating an Infinite Impulse Response (IIR) Low Pass Filter (LPF) to enhance signal denoising. The proposed system utilizes a pulse sensor, like any other optical heart-rate sensor and as blood circulation alters blood volume, these changes are detected by the transmitter and reflected back to the receiver. The received signals are processed within the Arduino microcontroller using software written in python which is tailored to Arduino's syntax. The system calculates the heart rate in beats per minute (bpm) and displays a real-time graph of the bpm and this real-time monitoring system provides users with immediate insights into their cardiovascular health. A notable feature of this project is the incorporation of an IIR LPF, designed to filter out unwanted noise from the signal, ensuring the accuracy and reliability of the heart rate measurements. This innovative approach offers a cost-effective and efficient solution for heart rate monitoring and improvement of healthcare management.**

***Index Terms*—Heart rate measurement, design, simulation, IIR LPF filter, Arduino Uno microcontroller.**

I. Introduction

THIS The application of engineering and technology knowledge in medical science has significantly facilitated the tasks of medical professionals in various fields. Among the plethora of medical data available, heart rate (HR) and body temperature are particularly common. Medical professionals leverage this data to diagnose issues related to cardiovascular diseases, thereby playing a crucial role in timely intervention and treatment.

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Detecting cardiovascular problems is essential, considering that approximately 17.65 million individuals worldwide are at high risk of experiencing Cardiovascular Diseases (CVDs). CVDs encompass a range of ailments affecting the heart and blood vessels, including coronary heart disease, cerebrovascular disease, and rheumatic heart disease [6]. Sadly, CVDs have emerged as the leading cause of global mortality, making them a significant public health concern.

Heart disease not only ranks as the primary cause of premature death in many countries but also contributes significantly to early disability. Disturbingly, statistics reveal that 37% of reported deaths are attributable to CVDs. The integration of technology-driven diagnostic tools, particularly those monitoring heart rate and body temperature, has become indispensable for medical professionals. Without these tools, the ability to detect and address cardiovascular issues promptly would be severely compromised [1]. Therefore, the synergy between engineering, technology, and medical science has become instrumental in advancing healthcare outcomes and addressing the challenges posed by cardiovascular diseases on a global scale.

Monitoring heart rate (HR) is a crucial factor for assessing the cardiovascular system's health. The normal HR range for a healthy adult at rest is between 72 and 120 beats per minute (bpm), with athletes often having a lower resting HR. Various factors influence HR, such as activity level, age, and the presence of underlying medical conditions.

The dynamic nature of HR, rising during activity and gradually returning to rest values afterward, provides insights into an individual's health status. Deviations from the standard values may indicate conditions like bradycardia (lower than normal HR) or tachycardia (higher than normal HR). Early detection of irregularities in HR can be crucial in identifying potential heart diseases and preventing adverse outcomes.
In the field of biomedical engineering, numerous diagnostic tools exist for assessing heart-related conditions, including electrocardiogram (ECG), echocardiogram, cardiac magnetic

resonance imaging (MRI), cardiac computed tomography (CT) scan, positron emission tomography (PET) scan, and angiogram. Among these, HR measurement stands out as a common and widely applicable diagnostic method, enabling healthcare professionals to assess heart function efficiently.

Efforts have been devoted to enhancing healthcare services affordably, leveraging advancements in engineering and technology. This progress has led to the design of more efficient, reliable, and affordable biomedical machines and technology can contribute to the early detection of heart-related issues, potentially reducing mortality rates and improving the overall well-being of individuals with cardiovascular diseases. Our system also aims to filter the acquired heartbeat signal using a suitable IIR real time filter. Filtering the heartbeat signal is a critical step, aimed at enhancing the accuracy and reliability of physiological data.

equipment with additional features. Notably, smart mobile phones and wearable devices now enable the monitoring of cardiovascular signs and symptoms.

In this context, the primary goal of this work is to develop an automated and cost-effective heart rate measurement system. This system aims to assist doctors in monitoring their patients' conditions more efficiently.

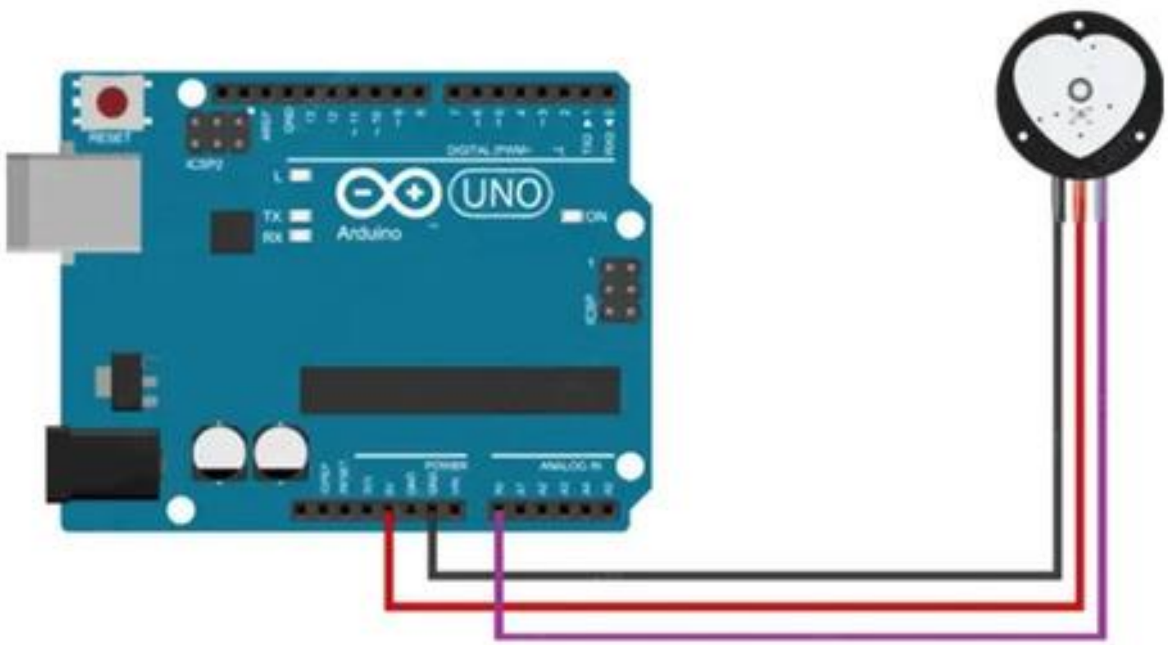

Fig. 1 Block diagram of the HR measurement machine

Heartbeat signals often encounter interference from various sources, such as muscle movements, motion artefacts, and environmental noise. The application of filtering techniques helps to mitigate these interferences, resulting in a cleaner and more accurate representation of the actual heartbeat. By reducing noise, filtering contributes to the precise measurement of heart rate, facilitates the identification of key features in the signal, and enables more effective analysis of heart rate variability. The improved quality of the filtered heartbeat signal not only aids in clinical diagnosis by healthcare professionals but also enhances the reliability of data used in wearable health monitoring devices for continuous and accurate assessment of cardiac activity during various

However, this machine is not still so cheap to the people of the underdeveloped or developing countries. Moreover, doctor and medical staff are not physically available to all required places throughout the country. Therefore, it would be supportive if it is possible to design and then implement a system for the people of these countries to observe their heart conditions at an affordable cost from remote places. The biomedical engineers are trying to find a way to address these problems and a suitable solution for it. This will certainly decrease their on-site visiting time. Moreover, the Arduino microcontroller is very cheap and readily available in the market and requires fewer efforts for its programming to automate the system. Also, these are used in various biomedical and other similar applications due to its compactness, portability, less power consumption, enhanced battery life, high operating speed etc. This Arduino microcontroller with analog interfacing circuits, sensors, electrodes, amplifier, sampler and filter can acquire the very weak signal from the chest and send it to the microcontroller's output port in appropriate format. Then a set of programming instructions inside the microcontroller can determine the HR of the patients being monitored. Further, using a low pass IIR filter, the input signal will be de-noised.

Therefore, our objectives of this work are to

i. Design a low-cost HR monitoring scheme that can measure heart beat
ii. Use the microcontroller for signal processing and other computation to make it faster responding
iii. De-noise acquired signal using a low pass IIR filter
iv. Analyze HR signals

II. Methodology

The methodology employed in the development of the heartbeat sensor using Arduino [4], aimed at providing a real-time graph of heart beats per minute (bpm) with the integration of an Infinite Impulse Response (IIR) Low Pass Filter (LPF) for signal denoising, adheres to rigorous engineering principles to ensure accuracy and reliability, see Fig 1. The Arduino platform plays a pivotal role in seamlessly interfacing with various sensor components, processing incoming data, and executing the necessary computations to derive meaningful heart rate information. Arduino's versatility and user-friendly interface make it an ideal choice for integrating diverse sensors, such as pulse sensors or photoplethysmography (PPG) modules, which are commonly employed in heartbeat measurement systems. These sensors capture physiological signals, typically in the form of light variations associated with blood flow and convert them into electrical signals that Arduino can readily process. Arduino's open-source nature and extensive community support facilitate the development and sharing of custom algorithms and code for signal processing tasks, enabling researchers and developers to implement sophisticated filtering techniques to enhance the accuracy of heartbeat measurements.

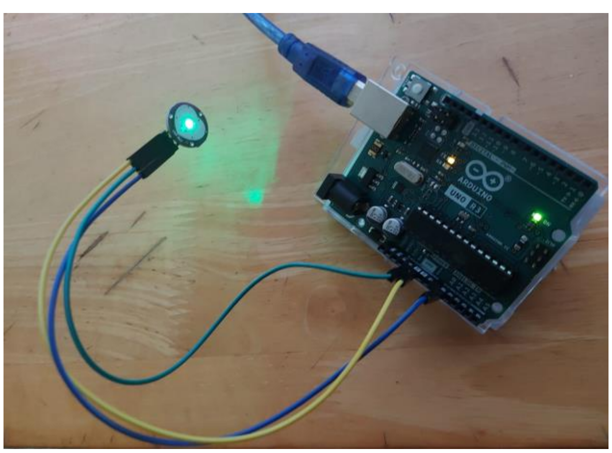

Fig. 2 Proposed application

Moreover, Arduino's real-time processing capabilities are crucial for applications like heartbeat measurement, where prompt and precise data analysis is imperative. The microcontroller's ability to handle analog and digital signals, coupled with its efficient computational performance, enables it to swiftly process incoming physiological data and generate real-time heart rate estimates. Additionally, Arduino's compatibility with various communication protocols allows for seamless integration with display interfaces or wireless communication modules, enabling users to monitor heart rate readings remotely or display them in real-time. Furthermore, Arduino's low cost and accessibility contribute to the democratization of healthcare technology, allowing for the creation of affordable and portable heartbeat measurement devices that can be utilized in diverse settings, from clinical environments to personal health monitoring systems.

The foundation of this approach involves the utilization of a pulse sensor, a crucial component for capturing heart rate information. Reflection-type pulse sensors, (seen in Fig 3) such as Optical Sensors for Heart Rate Monitors, emit light in the infrared, red, or green spectrum (around 550nm) directed toward the body. These sensors gauge the reflected light using a photodiode or phototransistor [3]. The oxygenated haemoglobin in arterial blood has the property of absorbing incident light. By detecting changes in blood vessel volume, corresponding to heart contractions over time, the pulse wave signal can be measured.

Fig. 3 Pulse sensor pin diagram

Unlike transmission-type pulse sensors, which have limitations on suitable areas, reflection-type sensors, by measuring reflected light, are not constrained in terms of application areas. However, when using red or infrared light for pulse wave measurement, interference from infrared rays in sunlight can impact stability, making indoor or semi-indoor usage preferable. For outdoor pulse wave measurement, as seen in smartwatches, green light is favoured. Green light demonstrates a high absorption rate in haemoglobin and is less affected by ambient light. ROHM, therefore, employs green

LEDs as transmission light sources for more reliable operation in outdoor settings.

This optical pulse detection technique is known as a Photoplethysmogram. The oxygenated haemoglobin in arterial blood has the property of absorbing green light. The redder the blood (the higher the haemoglobin), the greater the absorption of green light. With each heartbeat, blood is pumped through the finger, causing a change in the amount of reflected light, which in turn produces a waveform at the photosensor's output. As you keep shining light and taking photosensor readings, you quickly begin to obtain a heart-beat pulse reading as seen in Fig 4.

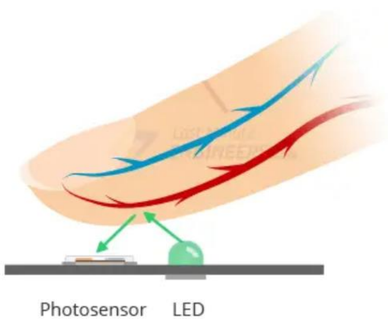

Fig. 4 Working of Pulse sensor

This signal from the photosensor is typically small and noisy therefore, it is passed through an IIR LPF filter network to create a signal that is significantly cleaner, and easier to detect. The utilization of an Infinite Impulse Response (IIR) Low-Pass Filter (LPF) in heartbeat measurement with Arduino is grounded in the necessity to extract and emphasize the fundamental components of the pulse signal while mitigating the impact of high-frequency noise. The IIR LPF is preferred in this context due to its capability to efficiently filter out unwanted high-frequency components, allowing for a smoother and more accurate representation of the underlying heart rate signal.

With heartbeat measurement, the pulse signal typically contains both the desired low-frequency information associated with the rhythmic heart contractions and higher-frequency noise, often originating from various physiological and environmental factors. The IIR LPF achieves this by exploiting the recursive nature of its filtering mechanism, where the current output is influenced not only by the present input but also by past outputs [5]. This recursive nature allows to effectively attenuate high-frequency noise while preserving the essential characteristics of the pulse waveform.

Additionally, the implementation of it on Arduino is favoured due to the computational efficiency and relatively lower hardware requirements compared to alternative filtering methods. This makes it well-suited for real-time applications such as heartbeat measurement, where processing speed and resource efficiency are critical for accurate and timely results. Overall, the use of an IIR LPF in conjunction with Arduino in heartbeat measurement reflects a strategic choice to enhance the signal quality by isolating the pertinent physiological information from unwanted noise, ultimately contributing to more reliable and precise heart rate monitoring.

From the waveform of heart signal (amplitude vs. time), the HR in bpm can be calculated by (1):

$$\text{HR} = \frac{1}{\text{Time to complete one cylce in sec}} \times 60 \qquad (1)$$

III. Results and Discussions

In conclusion, we have successfully designed and simulated a straightforward and cost-effective heart rate measurement machine based on a microcontroller. As seen in Fig 5 and 6, our system successfully removed unnecessary noise hence giving cleaner signals for further analysis. This system, with its nominal implementation cost, offers a portable solution that eliminates the need for on-site medical personnel, enabling the monitoring of patients' heart rates at any time and location. The ability for patients to transmit their heart rate data to physicians, regardless of geographical distance, enhances accessibility to healthcare services [7].

While the current system represents a significant step forward, there are opportunities for further development and improvement. Future plans for enhancement include implementing the complete circuit with an LCD screen, designing a rechargeable battery for increased portability, developing a program for smartphone connectivity, creating a real-time analysis application for smartphones, housing the system in a secure box with a printed circuit board (PCB), and optimizing components and circuits for increased cost-effectiveness, efficiency, and reliability.

Throughout this project, our primary objective was to provide a simple, portable, and affordable solution for ECG signal monitoring and heart rate computation, particularly targeting individuals in low- and middle-income groups. By addressing these specific needs, we aim to contribute to improving healthcare accessibility and empowering individuals to monitor their cardiovascular health more effectively. This work represents a valuable step toward bridging gaps in healthcare services and promoting overall well-being.

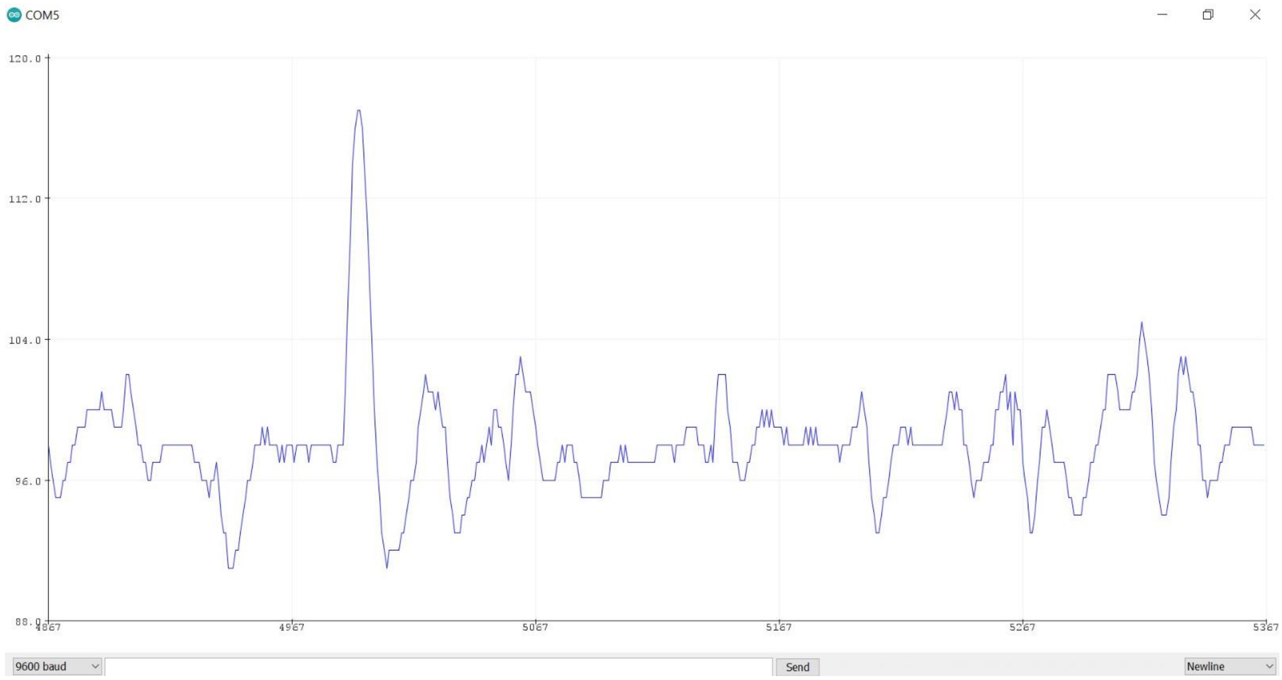

Fig. 5 Unfiltered Heart Rate

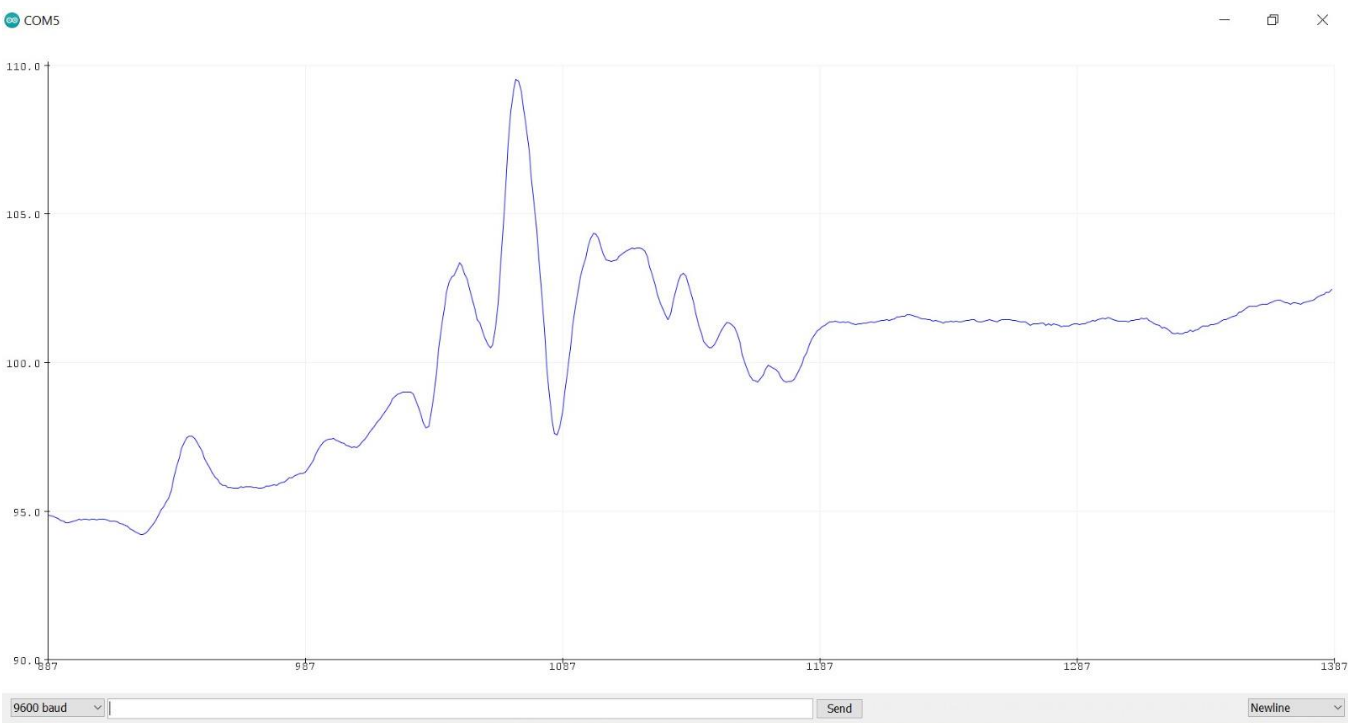

Fig. 6 Filtered Heart Rate