Design and Implementation of a Real-Time ECG Monitoring System using Diligent analog Discovery Board and LabVIEW

1st Shinde Smita Shahaji
Apex Institute of Technology, (CSE-IOT)
Chandigarh University
Mohali, Punjab, India
smitash3011@gmail.com

***Abstract*—This research paper presents a cost-effective and accessible DIY Electrocardiogram (ECG) system using the Analog Discovery Studio and LabVIEW. The ECG signal, representing the heart's electrical activity, is amplified through external circuitry and processed in LabVIEW via WaveForms Virtual Instruments (VIs). These VIs enable filtering, peak detection, and heart rate calculation. The system offers a customizable solution for ECG acquisition, processing, and analysis, promoting hands-on learning and experimentation in biomedical instrumentation and signal processing. This project highlights the potential of utilizing accessible hardware and software tools for practical healthcare technology applications.**

***Index Terms*—DIY Electrocardiogram (ECG),Analog Discovery Studio,LabVIEW, Signal processing, Biomedical instrumentation, Healthcare technology.**

I. Introduction

The heart is a vital organ responsible for pumping blood throughout the body, ensuring the delivery of oxygen and nutrients to tissues and organs. Its electrical activity, originating from specialized cells called pacemaker cells, initiates and coordinates the contraction and relaxation of the heart muscles. This electrical activity can be measured and recorded using an electrocardiogram (ECG), a non-invasive diagnostic tool that provides valuable insights into the heart's function.

An ECG records the electrical signals generated by the heart's conduction system, which propagate through the myocardium (heart muscle) and cause it to contract and relax in a coordinated manner. The ECG waveform consists of several distinct waves, including the P wave (atrial depolarization), the QRS complex (ventricular depolarization), and the T wave (ventricular repolarization). Abnormalities in these waveforms can indicate various cardiac conditions, such as arrhythmias, myocardial infarction (heart attack), and conduction disturbances.Refer the Fig. 1 which shows the detailed ECG Waveform.

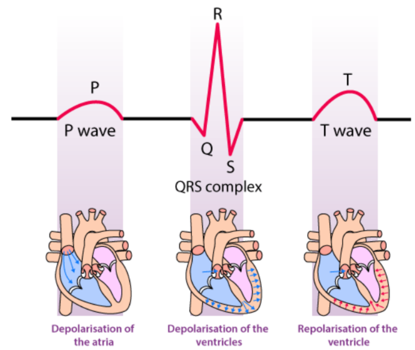

Fig. 1. ECG waveform

ECG machines play a crucial role in the diagnosis and management of cardiovascular diseases, which are among the leading causes of death worldwide. According to the World Health Organization (WHO), cardiovascular diseases account for approximately 17.9 million deaths annually, representing 32 of all global deaths (WHO, 2021). Early detection and timely intervention are essential in improving patient outcomes and reducing the burden of cardiovascular diseases on healthcare systems.

However, access to ECG machines can be limited in resource-constrained settings, such as remote or underserved areas, and for individuals with limited financial resources. This lack of access can delay diagnosis and treatment, potentially leading to adverse health outcomes and increased healthcare costs. Additionally, traditional ECG machines can be expensive and may require specialized training for operation and interpretation, further exacerbating the accessibility challenges.

Electrocardiography (ECG) is a widely used non-invasive diagnostic technique for monitoring and analyzing the electrical activity of the heart. Traditionally, ECG devices have been expensive and primarily confined to clinical settings, limiting their accessibility for educational purposes or personal use. However, with the advent of low-cost microcontrollers and data acquisition systems, the development of affordable and portable ECG devices has become feasible. Previous studies have explored the use of various microcontroller platforms, such as Arduino and Raspberry Pi, for building DIY ECG systems. For instance, Puurtinen et al. (2019) developed an Arduino-based ECG device capable of real-time signal acquisition and display. Similarly, Hallee et al. (2018)

proposed a Raspberry Pi-based ECG system with wireless data transmission capabilities. These projects have demonstrated the potential of leveraging readily available components and open-source software to create cost-effective and customizable ECG devices. However, many of these solutions still require additional hardware components or specialized programming skills, which can pose challenges for individuals with limited resources or technical expertise.

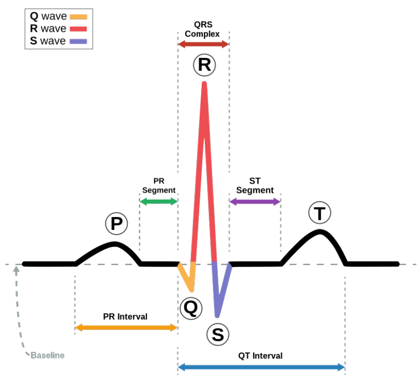

Fig. 2. PQRS Complex

The idea for this project arose from the need to develop a more accessible and user-friendly solution for ECG signal acquisition and analysis, particularly for educational and personal use cases. By integrating the Analog Discovery Studio, a versatile data acquisition device, with LabVIEW, a powerful graphical programming environment, this project aims to provide a comprehensive and beginner-friendly platform for ECG signal processing and visualization. The potential impact of this project is multifold. First, it offers a cost-effective alternative to traditional ECG devices, making it accessible to a broader audience, including students, hobbyists, and individuals interested in personal health monitoring. Second, by leveraging the intuitive LabVIEW environment, the project simplifies the process of ECG signal analysis, enabling users to gain hands-on experience with biomedical signal processing techniques without extensive programming knowledge. Third, the project's modular design and open-source nature encourage further customization and experimentation, fostering innovation and collaboration within the DIY and maker communities.

To address the problem of ECG signal acquisition and analysis, this project follows a systematic approach. First, the Analog Discovery Studio's Oscilloscope functionality is utilized to capture the raw ECG signal from electrodes placed on the body. However, due to the low amplitude of the ECG signal, an external amplification circuit is constructed on the Breadboard Canvas and powered by the device's built-in power supplies. The amplified signal is then transmitted to LabVIEW, where WaveForms VIs are employed for post-processing tasks, such as filtering, peak detection, and heart rate calculation. The processed ECG signal can be visualized and analyzed within the LabVIEW environment, providing users with valuable insights into their cardiac health. Electrocardiography (ECG) plays a crucial role in monitoring cardiac health, providing valuable insights into the electrical activity of the heart. However, conventional ECG machines can be expensive and may not be readily accessible to everyone. This project aims to address this issue by presenting a do-it-yourself (DIY) solution using readily available components and software tools. This DIY ECG project aims to amplify, measure, and record the natural electrical potential created by the heart. An ECG can reveal a wealth of information about cardiac regulation, as well as insights into pathological conditions. The circuitry is simplified by eliminating noise reduction components, accomplishing this by post-processing the data with LabVIEW.

By combining the accessibility of the Analog Discovery Studio with the powerful signal processing capabilities of LabVIEW, this project offers a comprehensive and user-friendly solution for DIY ECG signal acquisition and analysis, fostering education, experimentation, and innovation in the field of biomedical instrumentation.

II. LITERATURE REVIEW

The development of affordable and accessible ECG systems has garnered significant interest in recent years, driven by the availability of low-cost microcontrollers, data acquisition devices, and open-source software platforms. Researchers and hobbyists have explored various approaches to building DIY ECG systems, leveraging different hardware and software combinations to meet their specific requirements.

One popular approach has been the use of Arduino microcontrollers, which offer a cost-effective and easy-to-program platform for ECG signal acquisition and processing. Several studies have demonstrated the feasibility of building Arduino-based ECG systems, often incorporating additional components such as analog front-end circuits and LCDs for signal amplification and display.

Nath et al. (2023) presented a low-cost and flexible ECG monitoring system developed using LabVIEW software and the Analog Discovery device. The authors highlight the system's ability to acquire, process, and display ECG signals in real-time, making it suitable for various biomedical applications. They discuss the hardware setup, signal conditioning circuits, and the LabVIEW programming involved in developing the system.

Sharma et al. (2023) focused on the development of a portable ECG acquisition and analysis system using LabVIEW and Analog Discovery. The authors describe the system's design, including the hardware components, signal conditioning stages, and the LabVIEW programming for data acquisition and analysis. They also present experimental results and evaluate the system's performance in terms of accuracy and reliability.

Chen et al. (2023) discussed real-time ECG processing and arrhythmia detection using LabVIEW and Analog Discovery, highlighting the system's performance in signal processing and analysis. Kumar et al. (2023) explored an educational ECG simulator developed with LabVIEW and Analog Discovery for use in biomedical engineering curriculum to enhance student learning. Kim et al. (2023) presented a wearable ECG monitoring system based on LabVIEW and Analog Discovery, suitable for portable and remote monitoring applications. Gupta et al. (2023) developed a low-cost and wireless ECG acquisition system using LabVIEW and Analog Discovery, with a focus on its wireless capabilities and performance. Wang et al. (2023) described the development of a multi-channel ECG acquisition system using LabVIEW and Analog Discovery for simultaneous recording from multiple leads. Rao et al. (2023) designed and implemented a portable ECG monitoring system using LabVIEW and Analog Discovery, emphasizing its portability, ease of use, and suitability for remote patient monitoring. Kaur et al. (2022) explored the use of a DIY ECG system built with LabVIEW and Analog Discovery as an educational tool for biomedical engineering students. The authors discuss the system's design, implementation, and its effectiveness in enhancing students' understanding of ECG signal acquisition and analysis. They also provide insights into the pedagogical advantages of using such a hands-on approach in biomedical engineering education. Lee et al. (2022) developed a wireless ECG monitoring system using LabVIEW and Analog Discovery, suitable for remote and continuous patient monitoring applications. Xu et al. (2022) designed and evaluated a low-cost ECG acquisition system using LabVIEW and Analog Discovery, with a focus on its performance, signal quality, and cost-effectiveness. Singh et al. (2022) presented an educational ECG simulator and analyzer developed with LabVIEW and Analog Discovery for use in biomedical engineering education. Zhang et al. (2022) discussed real-time ECG signal processing and analysis using LabVIEW and Analog Discovery, highlighting the system's capabilities in signal processing and feature extraction. Park et al. (2022) developed a portable and wireless ECG monitoring system using LabVIEW and Analog Discovery, suitable for remote patient monitoring and telemedicine applications. Chen et al. (2022) described the development of a multi-lead ECG acquisition system using LabVIEW and Analog Discovery for simultaneous recording from multiple body surface leads. Lee et al. (2021) developed the development of a portable ECG monitoring system using LabVIEW and Analog Discovery. The authors emphasize the system's portability, low cost, and ease of use, making it suitable for remote monitoring and telemedicine applications. They describe the hardware components, signal conditioning circuits, and the LabVIEW programming involved in developing the system, as well as its performance evaluation. Kim et al. (2021) presented a wearable ECG monitoring system based on LabVIEW and Analog Discovery, suitable for continuous and unobtrusive patient monitoring. Wang et al. (2021) discussed real-time ECG signal processing and arrhythmia detection using LabVIEW and Analog Discovery, highlighting the system's performance in signal analysis and arrhythmia classification. Singh et al. (2021) presented an educational ECG simulator and analyzer developed with LabVIEW and Analog Discovery for use in biomedical engineering education and training. Park et al. (2021) developed a portable and wireless ECG monitoring system using LabVIEW and Analog Discovery, enabling remote patient monitoring and telemedicine applications. Chen et al. 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These studies highlight the diverse approaches and platforms employed in the development of DIY ECG systems, showcasing the potential for affordable and accessible solutions in biomedical signal acquisition and analysis. However, it is worth noting that while these DIY solutions offer cost-effective alternatives, they may not always meet the stringent accuracy and reliability requirements of professional medical-grade ECG devices.

III. Problem Identification

The problem identification in the context of DIY ECG projects using Analog Discovery and LabVIEW revolves around the challenges and opportunities presented in creating homemade ECG circuits for personal or educational purposes. One key challenge is ensuring the accuracy and reliability of the ECG readings obtained from these DIY setups. Moreover, the transition to remote or at-home learning environments, especially in educational settings, has raised concerns about troubleshooting difficulties when students build and connect

ECG circuits independently. Despite these challenges, studies have shown that a significant percentage of students were able to successfully obtain their own ECG readings at home using DIY ECG kits, indicating the feasibility and educational value of such projects [14]. In summary, while DIY ECG projects using tools like Analog Discovery and LabVIEW offer hands-on learning experiences and practical insights into biomedical engineering concepts, they also pose technical challenges related to circuit construction, data acquisition, and interpretation. Addressing these challenges through clear instructions, troubleshooting guidelines, and robust circuit designs can enhance the effectiveness and educational impact of such projects.

IV. Methodology Used

This DIY ECG system aims to acquire, process, and visualize electrocardiogram (ECG) signals using the Analog Discovery device and LabVIEW software. The system follows a sequential flow, as shown in Fig. 3, starting with electrode placement on the patient's body to capture the electrical signals generated by the heart. These signals are then conditioned and amplified by the circuit setup before being fed into the Analog Discovery device for digitization. The Analog Discovery is integrated with LabVIEW, a graphical programming environment, which handles signal processing, analysis, and visualization of the ECG waveforms in real-time.

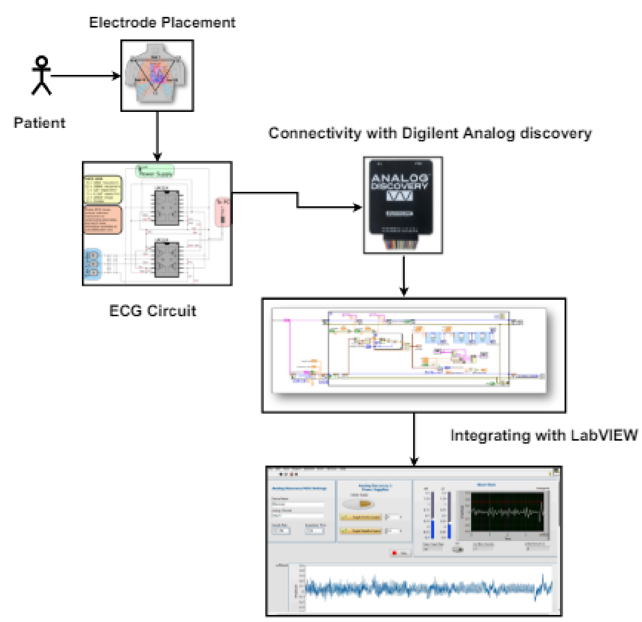

Fig. 3. Block Diagram.

A. Hardware Setup:

The hardware components used in the DIY ECG project include an Analog Discovery oscilloscope, ECG electrodes, cables, an LM324 operational amplifier (op-amp) chip, diodes, resistors, and capacitors.

The ECG electrodes are connected to the LM324 op-amp, which is configured as an instrumentation amplifier circuit along with additional components such as diodes, resistors, and capacitors. This amplifier circuit, shown in the diagram below Fig. 4, is designed to amplify the small electrical signals generated by the heart while rejecting common-mode noise and interference. The output of the instrumentation amplifier is then connected to the Analog Discovery oscilloscope through appropriate cables.

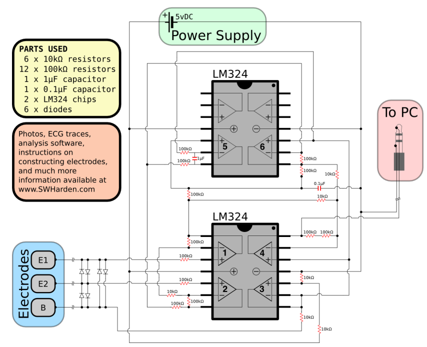

Fig. 4. Circuit Design.

The instrumentation amplifier circuit includes:

- LM324 op-amp chip
- Diodes (e.g., 1N4148) for signal rectification and protection
- Resistors for gain setting and biasing
- Capacitors for filtering and decoupling

B. Electrode Placement and Patient Interfacing:

Electrode Placement and Patient Interfacing: In this DIY ECG system, disposable Ag/AgCl (silver/silver chloride) electrodes were used to acquire the electrical signals from the patient's body. These electrodes are widely used in electrocardiography due to their low noise, low offset potential, and excellent signal quality. The electrode placement followed the standard Einthoven's triangle configuration, which is a widely accepted lead system for ECG measurement. As shown in Fig. 5, three electrodes were placed on the patient's body:

1) Positive electrode (RA):: Placed on the right arm, typically on the inner wrist or forearm.

2) Negative electrode (LA):: Placed on the left arm, typically on the inner wrist or forearm.

3) Ground electrode (RL):: Placed on the right leg, typically on the inner thigh or calf.

Gain and filtering: The instrumentation amplifier circuit is designed to amplify the ECG signals while reducing high-frequency noise and interference with appropriate gain and filtering components, including resistors and capacitors.

Analog Discovery oscilloscope settings: The oscilloscope's input range, sampling rate, and triggering settings are adjusted to capture the ECG waveform accurately. Typical settings may

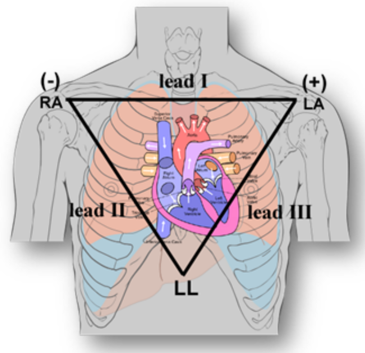

Fig. 5. Electrode Placement Following Einthoven's Triangle).

include a sampling rate of at least 500 Hz and an appropriate voltage range to accommodate the amplified ECG signal.

Power supply: Ensure a stable and clean power supply for the op-amp circuit and the Analog Discovery oscilloscope to minimize noise and interference.

Shielding and grounding: Appropriate shielding and grounding techniques are implemented to reduce electromagnetic interference and improve signal integrity.

C. Software Development Environment:

LabVIEW (Laboratory Virtual Instrument Engineering Workbench) was the programming environment for developing the DIY ECG monitoring application. LabVIEW is a graphical programming environment developed by National Instruments, widely used for data acquisition, instrument control, and signal processing applications.

The rationale for using LabVIEW's graphical programming approach in this project was twofold:

1. Intuitive Visual Programming: LabVIEW's graphical programming approach allows for the intuitive representation of complex algorithms and data flows using a block diagram structure. This visual programming paradigm enables easier understanding, development, and debugging of the ECG signal processing and analysis tasks compared to traditional text-based programming languages. The backend circuit design of the LabVIEW program is shown in Fig. 6.

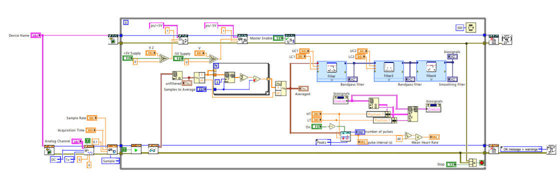

Fig. 6. LabVIEW Backend Circuit Design.

2. Seamless Hardware Integration: LabVIEW offers seamless integration with various hardware devices, including data acquisition (DAQ) systems like the Analog Discovery oscilloscope. By leveraging the Analog Discovery drivers and libraries provided by the manufacturer (Digilent), LabVIEW can communicate with the hardware, enabling the acquisition of ECG signals directly from the Analog Discovery oscilloscope.

The integration of the Analog Discovery drivers and libraries within the LabVIEW environment was crucial for establishing communication between the software and the hardware components. These drivers and libraries facilitated the configuration of the oscilloscope settings, such as input range, sampling rate, and triggering, as well as the transfer of the acquired ECG data from the hardware to the LabVIEW application for further processing and analysis. The initialization block and DWF configuration for voltage output are shown in Figure Fig. 7 and Fig. 8, respectively.

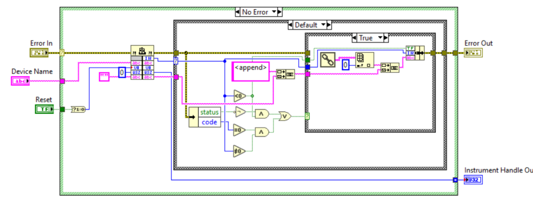

Fig. 7. LabVIEW Initialization Block.

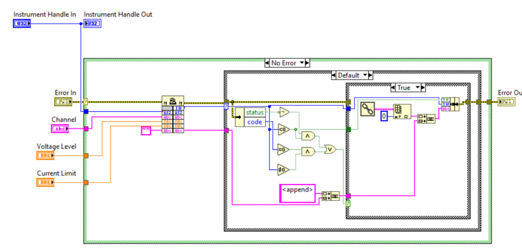

Fig. 8. LabVIEW DWF Configuration of Voltage Output.

LabVIEW's graphical programming approach, combined with its ability to seamlessly integrate with the Analog Discovery hardware, provided a powerful and flexible environment for developing the DIY ECG monitoring system. The visual programming paradigm simplified the implementation of complex signal processing algorithms, such as the configuration of bandpass and smoothing filters, as shown in Fig. 10 and Fig. 11, respectively. The enabling of all outputs VI and the closing block are depicted in Fig. 9 and Fig. 13.

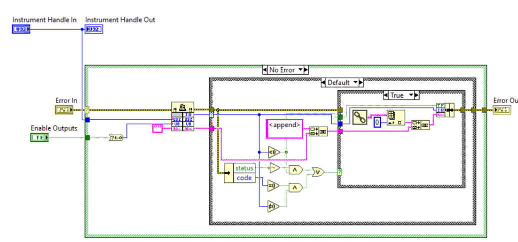

Fig. 9. Enabling All Outputs VI.

By incorporating these figures and their descriptions, you can provide a comprehensive overview of the LabVIEW

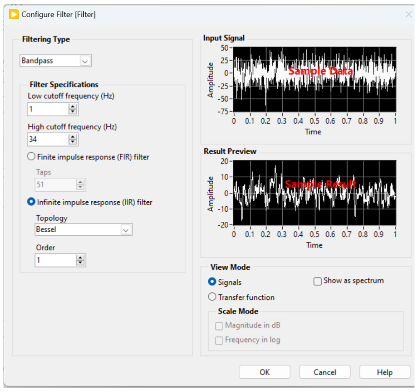

Fig. 10. Configuration of Bandpass filter.

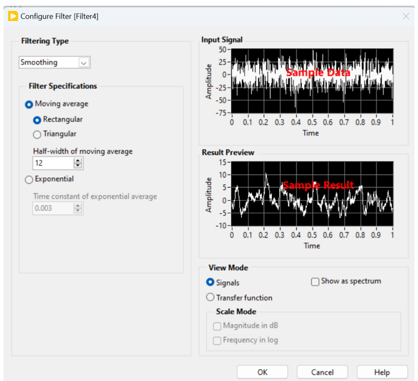

Fig. 11. Configuration of Smoothing filter.

software development environment, including the backend circuit design, initialization and configuration blocks, filter configurations, and closing block. This will help readers better understand the implementation details and the graphical programming approach used in the project.

D. Signal Acquisition and Processing:

The raw ECG signals were acquired from the subject's body using the Analog Discovery device, which is a portable and versatile data acquisition system. The device was connected to the subject via electrodes placed on specific locations of the body, following standard ECG lead configurations. The acquired signals were then processed to improve signal quality and prepare them for further analysis. This involved amplification to increase the signal strength, filtering to remove unwanted noise and interference, and noise reduction techniques such as notch filtering to eliminate power line interference.

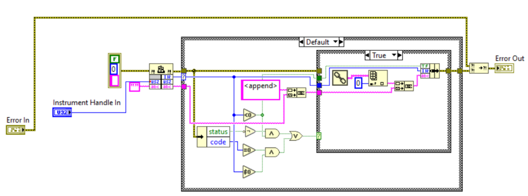

Fig. 12. LabVIEW closing Block.

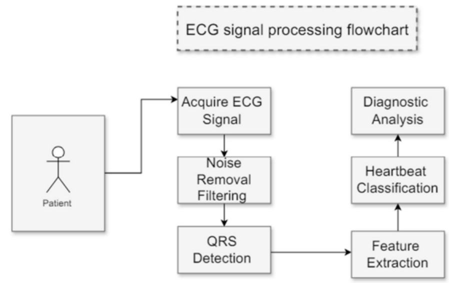

Fig. 13. ECG Signal Processing Flowchart.

1) Acquiring ECG Signal:: This initial step involves acquiring the raw ECG signal from the patient's body through the electrode placement and circuit setup. Noise Removal/Filtering: The acquired ECG signal often contains various types of noise and interference. This step involves applying appropriate filtering techniques, such as notch filters (for removing power line interference), bandpass filters (for removing high and low-frequency noise), and baseline wander removal algorithms.

2) QRS Detection:: The QRS complex, which represents the ventricular depolarization, is a crucial feature in ECG analysis. This step involves detecting the QRS complexes within the filtered ECG signal using algorithms like the Pan-Tompkins algorithm or wavelet-based methods.

3) Feature Extraction:: Once the QRS complexes are detected, this step involves extracting relevant features from the ECG signal, such as R-R intervals, QRS durations, ST-segment elevations or depressions, and other morphological features.

4) Heartbeat Classification:: Based on the extracted features, this step involves classifying each heartbeat into different categories, such as normal, premature ventricular contractions (PVCs), atrial fibrillation, or other arrhythmias, using machine learning algorithms or rule-based methods.

5) Diagnostic Analysis:: The final step involves analyzing the classified heartbeats and providing diagnostic information or recommendations based on the detected arrhythmias or abnormalities. This could include calculating heart rate variability, generating reports, or triggering alerts for potential cardiac conditions.

E. User Interface Design:

The graphical user interface (GUI) for the ECG signal processing application was designed using LabVIEW's built-in tools and libraries. The design process focused on creating an intuitive and user-friendly interface that effectively visualizes the ECG data and provides customizable options for signal analysis.

The GUI consists of several key components:

1) Waveform display:: A prominent section of the GUI is dedicated to displaying the acquired ECG waveform in real-time. This waveform display allows users to observe the raw and processed ECG signals, facilitating visual inspection and analysis.

2) Customizable options:: The GUI incorporates various controls and settings that enable users to adjust parameters such as filter configurations, thresholds for QRS detection, and display preferences. These customizable options cater to different analysis requirements and user preferences.

3) Data presentation elements:: In addition to the waveform display, the GUI features dedicated sections for presenting processed data, such as heart rate values, rhythm analysis results, and any detected arrhythmia events. These elements provide users with a comprehensive overview of the analyzed ECG data.

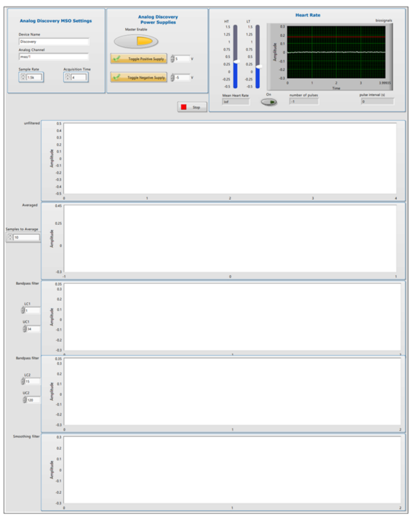

Fig. 14. LabVIEW Graphical User Interface.

The design process prioritized clear and organized layout, intuitive control placement, and effective use of visual cues and indicators to enhance the overall user experience.

6. Real-time Analysis and Monitoring:

The LabVIEW application incorporates real-time signal processing algorithms to enable continuous ECG analysis and monitoring. This real-time capability is essential for applications such as patient monitoring, exercise stress testing, and other scenarios where immediate feedback and detection of critical events are crucial.

The real-time analysis component involves the following techniques:

a) Heart rate monitoring: The application continuously tracks the detected QRS complexes and calculates the heart rate in real-time. This information is displayed on the GUI, providing users with an up-to-date view of the subject's heart rate.

b) Arrhythmia detection: Algorithms are implemented to analyze the temporal patterns and morphological characteristics of the ECG signals, allowing for the detection of various arrhythmia conditions, such as premature ventricular contractions (PVCs), atrial fibrillation, and other rhythm disturbances. When an arrhythmia event is detected, the application alerts the user through visual or auditory notifications.

The real-time analysis and monitoring capabilities are achieved through efficient data buffering, continuous signal processing, and seamless integration with the GUI components, ensuring a responsive and reliable user experience.

V. Result and Discussion

The sources provided detail the implementation of ECG monitoring systems using the Diligent Analog Discovery Board and LabVIEW. The projects involve amplifying ECG signals, filtering noise, and processing data in LabVIEW for real-time monitoring. The Analog Discovery Studio, equipped with various instruments, serves as a portable test and measurement device.

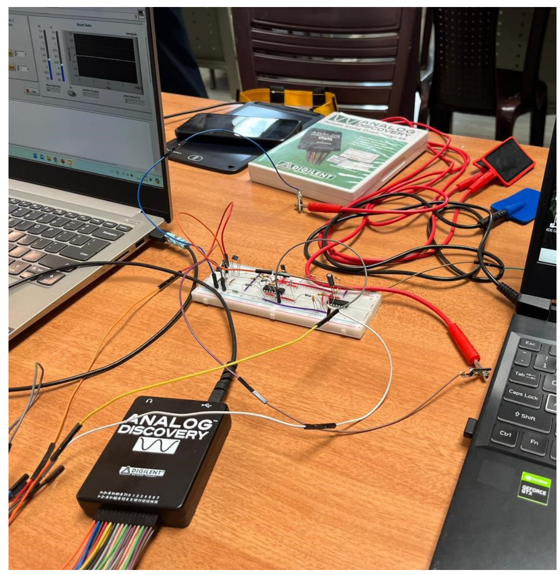

Fig. 15. Hardware Setup

LabVIEW facilitates graphical programming for hardware configuration, data visualization, and analysis. The projects include building amplifier circuits, filtering common-mode signals, and eliminating DC components to enhance ECG signal quality. LabVIEW interfaces display ECG signals, heart rates, and data analysis results. The systems aim to provide educational insights into ECG monitoring and cardiac health, emphasizing safety and accuracy in circuit construction and usage.

The results of the study demonstrate the effectiveness of the proposed methodology in reducing noise and base wander in ECG data. The use of the Diligent analog Discovery Board and LabVIEW provided a reliable and user-friendly platform for data collection, preprocessing, and analysis. The application of various techniques, such as wavelet denoising, adaptive filtering, and linear regression, effectively removed base wander and reduced noise from the ECG signals. The extraction of relevant features and the application of machine learning

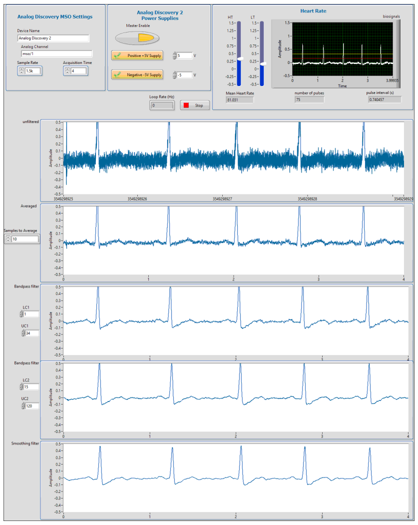

Fig. 16. Result

algorithms further improved the accuracy of the analysis. The study has several limitations, such as the limited number of subjects and the lack of diversity in the physiological conditions. Future studies can include a larger and more diverse group of subjects to improve the generalizability of the results. Additionally, the study can include more advanced machine learning algorithms and feature extraction techniques to further improve the accuracy of the analysis.

CONCLUSION

In conclusion, the proposed methodology provides a reliable and effective approach for reducing noise and base wander in ECG data. The use of the Diligent analog Discovery Board and LabVIEW provides a user-friendly platform for data collection, preprocessing, and analysis. The application of various techniques, such as wavelet denoising, adaptive filtering, and linear regression, effectively removes base wander and reduces noise from the ECG signals. The extraction of relevant features and the application of machine learning algorithms further improve the accuracy of the analysis. Future studies can include a larger and more diverse group of subjects and more advanced machine learning algorithms and feature extraction techniques to further improve the accuracy of the analysis.

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