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i DIY ECG Using Analog Discovery and LabVIEW A PROJECT REPORT Submitted by SHINDE SMITA SHAHAJI in partial fulfillment for the award of the degree of BACHELOR OF ENGINEERING IN COMPUTER SCIENCE WITH SPECIALIZATION IN INTERNET OF THINGS Chandigarh University APRIL 2024

ii DIY ECG Using Analog Discovery and LabVIEW A PROJECT REPORT Submitted in the partial fulfillment for the award of the degree of BACHELOR OF ENGINEERING IN COMPUTER SCIENCE WITH SPECIALIZATION IN INTERNET OF THINGS Submitted by: 20BCS4643 SHINDE SMITA SHAHAJI Under the Supervision of: DR. GAURAV SONI CHANDIGARH UNIVERSITY, GHARUAN, MOHALI - 140413, PUNJAB April 2024

iii BONAFIDE CERTIFICATE Certified that this project report “DIY ECG Using Analog Discovery and LabVIEW” is the Bonafede work of “SHINDE SMITA SHAHAJI ” who carried out the project work under my/our supervision. APEX INSTITUTE OF TECHNOLOGY 12 (AIT-CSE) Submitted for the project viva-voce examination held on INTERNAL EXAMINER EXTERNAL EXAMINER SIGNATURE Prof. Aman Kaushik HEAD OF THE DEPARTMENT SIGNATURE Dr. Gaurav Soni SUPERVISOR Assistant Professor

iv DECLARATION I, ‘SHINDE SMITA SHAHAJI’, student of ‘Bachelor of Engineering in Internet of Things’, session: 2020-2024, Department of Computer Science and Engineering, Apex Institute of Technology, Chandigarh University, Punjab, hereby declare that the work presented in this Project Work entitled ‘DIY ECG Using Analog Discovery and LabVIEW’s the outcome of our own bonafide work and is correct to the best of our knowledge and this work has been undertaken taking care of Engineering Ethics. 9 It contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text. (Sh inde Smita Shahaji) Candidate UID: 20BCS4643 Day: 24 April'24 Place: Mohali Punjab

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smita (20BCS4643)

vi TIMELINE CHART TASK NAME PLANNING RESEARCH DESIGN IMPLEMENTATION FOLLOW UP WEEK 04 WEEK 03 WEEK 02 WEEK 01

vii ABSTRACT This project presents a cost-effective and accessible approach to developing a Do-ItYourself (DIY) Electrocardiogram (ECG) system using the Analog Discovery Studio and LabVIEW. The ECG signal, which represents the electrical activity of the heart, is captured through electrodes placed on the body. However, due to its low amplitude, the signal requires amplification before further processing. The project leverages 2 the Analog Discovery Studio's Oscilloscope functionality to acquire the raw ECG signal, while external amplification circuitry is constructed on the Breadboard Canvas and powered by the device's built-in power supplies. The amplified ECG signal is then transmitted to LabVIEW, a graphical programming environment, where post-processing operations are performed using WaveForms Virtual Instruments (VIs). These VIs enable various signal processing techniques, such as filtering, peak detection, and heart rate

calculation, to be applied to the acquired ECG data. The resulting processed signal can be visualized and analyzed within the LabVIEW environment, providing valuable insights into the electrical activity of the heart. By combining the capabilities of [2] the Analog Discovery Studio and LabVIEW, this project offers a comprehensive and customizable solution for ECG signal acquisition, processing, and analysis. The DIY nature of the project not only promotes costeffectiveness but also fosters hands-on learning and experimentation in the fields of biomedical instrumentation and signal processing. Overall, this project demonstrates the potential of leveraging accessible hardware and software tools to develop practical and educational applications in the domain of healthcare technology.

viii List of Tables

ix List of Figures

2 CHAPTER 1 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 4 cells called pacemaker cells, initiates and coordinates the contraction and relaxation of the heart muscles. This 23 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. 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

3 expensive and may require specialized training for operation and interpretation, further exacerbating the accessibility challenges. To address these issues, the development of affordable and user-friendly ECG systems has become increasingly important. This research project aims to develop a cost-effective and accessible Do-It-Yourself (DIY) ECG system by leveraging the Analog Discovery Studio, a versatile data acquisition device, and LabVIEW, a powerful graphical programming environment. By combining these tools, the project seeks to provide a comprehensive solution for ECG signal acquisition, processing, and analysis, fostering education, experimentation, and innovation in the field of biomedical instrumentation. The DIY ECG system offers several advantages, including cost-effectiveness, ease of use, and the potential for customization and integration with advanced signal processing techniques. By making ECG technology more accessible, this project contributes to improving cardiovascular disease diagnosis and management, ultimately supporting efforts to reduce the global burden of these conditions and promote better health outcomes. Electrocardiography (ECG) is a widely used non-invasive diagnostic technique for monitoring and analyzing 4 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 lowcost 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. (2009) 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 8 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

4 require additional hardware components or specialized programming skills, which can pose challenges for individuals with limited resources or technical expertise. The idea for this project arose from the need to develop a more accessible and userfriendly 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 [2] 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 [21] valuable insights into their cardiac health.

5 Electrocardiography (ECG) [6] 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. [3] 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 [2] the Analog Discovery Studio with the powerful signal processing capabilities of LabVIEW, this project offers a comprehensive and userfriendly solution for DIY ECG signal acquisition and analysis, fostering education, experimentation, and innovation in the field of biomedical instrumentation. Cardiovascular diseases are among the leading causes of mortality worldwide, and early detection and monitoring play a crucial role in improving patient outcomes. Electrocardiogram (ECG) monitoring is a widely used diagnostic tool that records [4] the electrical activity of the heart, providing valuable information for detecting and evaluating various cardiac conditions. However, access to conventional ECG machines can be limited, particularly in resource-constrained settings or remote areas, hindering timely diagnosis and treatment. The significance of ECG monitoring lies in its ability to detect and analyze heart rhythms, identify abnormalities, and

8 aid in the diagnosis of conditions such as arrhythmias, myocardial infarctions, and conduction disorders. Early detection and monitoring of these conditions can significantly improve patient outcomes and guide appropriate medical interventions.

6 29 The primary objective of this project is to develop a cost-effective and portable DIY ECG system using readily available components and open-source software. By leveraging the Analog Discovery device and the LabVIEW programming environment, this project aims to create a user-friendly and customizable solution for ECG signal acquisition, processing, and analysis. The specific objectives of the project include: 1. Designing and implementing a hardware setup for ECG signal acquisition using the Analog Discovery device and electrodes. 2. Developing a software solution in the LabVIEW environment for signal processing, analysis, and visualization. 3. Exploring and implementing advanced signal processing techniques, such as wavelet transforms and adaptive filtering, for effective noise reduction and artifact removal. 4. Developing algorithms for feature extraction and analysis, including QRS complex detection, heart rate calculation, and identification of potential abnormalities or arrhythmias. 5. Designing 27 an intuitive and user-friendly graphical user interface (GUI) for ECG data visualization and analysis. 6. Implementing real-time signal processing algorithms for continuous analysis and monitoring of ECG signals. 7. Investigating the integration of wireless communication modules or Bluetooth connectivity for remote data transmission and monitoring. 8. Implementing data logging and storage capabilities, as well as options for exporting ECG data in various formats.

7 9. Conducting thorough testing and validation of the developed system, including signal quality assessment and accuracy evaluation of analysis algorithms. The proposed DIY ECG system aims to provide a viable alternative to expensive and bulky ECG machines, enabling access to affordable and portable ECG monitoring solutions. By incorporating advanced signal processing techniques, noise reduction algorithms, and user-friendly

interfaces, the system will ensure high-quality ECG signal acquisition, analysis, and visualization. This project [8] has the potential to contribute to improving cardiovascular healthcare accessibility by empowering individuals, educators, and healthcare professionals with a customizable and robust ECG monitoring tool. The DIY ECG system can find applications in various settings, such as educational institutions, remote clinics, personal health monitoring, and research studies.

8 1.1 PROBLEM DEFINITION The main challenge addressed by this project is the limited accessibility to ECG machines, especially for educational purposes or for individuals interested in understanding their cardiac health. Traditional [20] ECG machines can be expensive and require specialized knowledge to operate. This project aims to democratize access to ECG monitoring by providing a cost-effective and user-friendly solution that can be assembled and utilized by individuals with basic technical skills. The problem addressed by this project is the need for a simple and affordable way to measure and record the electrical activity of the heart. Traditional ECG machines can be expensive and complex, making them inaccessible to many people. This DIY ECG project provides a solution that is both affordable and easy to build. Electrocardiography (ECG) is a crucial diagnostic tool for monitoring and analyzing [4] the electrical activity of the heart. However, traditional ECG devices are often expensive and primarily designed for clinical settings, making them less accessible for educational purposes or personal use. This project aims to address this issue by developing a cost-effective and user-friendly solution [1] for ECG signal acquisition and analysis using readily available hardware and software components. The main problem addressed by this project is the need for an affordable and accessible ECG system that can be used for educational purposes, hobbyist projects, or personal health monitoring. Traditional ECG devices can be prohibitively expensive for individual users or educational institutions with limited budgets. Additionally, many existing DIY ECG solutions require specialized programming skills or additional hardware components, which can be challenging for users with limited technical expertise. In summary, this project aims

to provide a cost-effective and user-friendly solution for ECG monitoring that can be easily assembled and utilized by individuals with basic

9 technical skills, addressing the need for affordable and accessible ECG systems [33] for educational purposes, hobbyist projects, or personal health monitoring. 1.2 PROBLEM OVERVIEW This project presents a comprehensive solution for a Do-It-Yourself (DIY) ECG system by integrating the Analog Discovery Studio, a versatile data acquisition device, with LabVIEW, a powerful graphical programming environment. [2] 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 ECG signal is then transmitted to LabVIEW, where WaveForms Virtual Instruments (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 [21] valuable insights into their cardiac health. By combining the accessibility of [2] the Analog Discovery Studio with the powerful signal processing capabilities of LabVIEW, this project offers a comprehensive and userfriendly solution for DIY ECG signal acquisition and analysis, fostering education, experimentation, and innovation [6] in the field of biomedical instrumentation.

10 1.3 HARDWARE SPECIFICATION The hardware components used in this project include: 1. Analog Discovery Studio: This versatile data acquisition device from Digilent serves as the core component for capturing the ECG signal. It features an Oscilloscope, Waveform Generator, Power Supplies, and a Breadboard Canvas for prototyping circuits. 2. Breadboard Canvas: The Breadboard Canvas is a part of the Analog Discovery Studio and is used to construct the external amplification circuit for the ECG signal. 3. Electrodes: Disposable ECG electrodes are used to capture the electrical signals [23]

generated by the heart from different points on the body. 4. Wires and connectors: Various wires and connectors are required to establish connections between the electrodes, amplification circuit, and [2] the Analog Discovery Studio. 5. Resistors, capacitors, and operational amplifiers: These electronic components are used to build the external amplification circuit for the ECG signal on the Breadboard Canvas.

11 1.4 SOFTWARE SPECIFICATION: The software components used in this project include: 1. Analog Discovery Studio Software: This software is used to control and configure [2] the Analog Discovery Studio hardware, including the Oscilloscope, Waveform Generator, and Power Supplies. 2. LabVIEW: A graphical programming environment from National Instruments, LabVIEW is used for post-processing the ECG signal acquired from the Analog Discovery Studio. WaveForms VIs available in LabVIEW are utilized for tasks such as filtering, peak detection, and heart rate calculation. 3. WaveForms VIs: These Virtual Instruments (VIs) provided by LabVIEW are specifically designed for signal processing and analysis tasks, enabling various operations to be performed on the acquired ECG signal. 4. Additional LabVIEW libraries or toolkits: Depending [15] on the specific requirements, additional LabVIEW libraries or toolkits may be utilized for advanced signal processing, data visualization, or other functionalities. The combination [11] of the Analog Discovery Studio hardware and LabVIEW software provides a powerful and flexible platform for DIY ECG signal acquisition, processing, and analysis, enabling users to gain hands-on experience in biomedical instrumentation and signal processing.

12 In Detailed Specifications: 1) Analog Discovery USB Oscilloscope: - A low-cost, portable USB oscilloscope and multi-function instrument - Dual-channel oscilloscope with 100 MS/s sampling rate and 14-bit vertical resolution - Waveform generator with ±1V to ±8V amplitude range and up to 10 MHz frequency - Two power supplies: ±6V @ 450mA and variable supply ±6V @ 450mA - Built-in Breadboard Canvas for prototyping circuits - Dimensions: 4.5 x 3.5 x 1.2 inches (115 x 90 x 30 mm) 2) 3 LM324 Op Amp: - LM324 is a

low-power quad operational amplifier IC - Operates with a single or dual power supply from 3V to 32V - Low input bias current (45 nA typical) - Wide gain bandwidth product (1 MHz) - Used for building the amplification circuit for the ECG signal 3 3) 10 100 kΩ resistors: - Standard 1/4 watt resistors with a resistance value of 100 kilo-ohms (100,000 ohms) - Used in the amplification circuit for setting gain and biasing

13 4) 7 10 kΩ resistors: - Standard 1/4 watt resistors with a resistance value of 10 kilo-ohms (10,000 ohms) - Used in the amplification circuit for setting gain and biasing 5) 1 uF electrolytic capacitor: - Polarized capacitor with a capacitance of 1 microfarad (μF) - Used for filtering and decoupling in the amplification circuit 6) .1 uF ceramic capacitor (104M): - Non-polarized ceramic capacitor with a capacitance of 0.1 microfarad (μF) or 104 nanofarads (nF) - Used for filtering and decoupling in the amplification circuit 7) 6 diodes (50V General Purpose Rectifiers 1N4001): - 1N4001 is a general-purpose rectifier diode - Maximum repetitive reverse voltage of 50V - Used for rectification and protection in the amplification circuit 8) Breadboard: - A solderless breadboard for prototyping and building the amplification circuit - Provided as part of the Analog Discovery Studio's Breadboard Canvas

14 9) DIN ECG snap leads or alligator clips: - Conductive leads or clips for connecting the electrodes to the amplification circuit 10) 3 Surface electrodes or 3 pennies (lotion needed if pennies are used): - Surface electrodes are disposable adhesive pads used for ECG signal acquisition - Pennies can be used as an alternative, but require conductive gel or lotion for better signal transmission 11) WaveForms version 2.6.2 or later: - WaveForms is a LabVIEW add-on module for signal processing and analysis - Provides a comprehensive set of Virtual Instruments (VIs) for filtering, windowing, spectral analysis, and more - Used for post-processing the acquired ECG signal in LabVIEW 12) LabVIEW: - LabVIEW is a graphical programming environment developed by National Instruments - Used for creating user interfaces, data acquisition, and signal processing - Provides a platform for integrating

2 the Analog Discovery Studio and WaveForms VIs for ECG signal analysis These hardware and software components work together to create a DIY ECG

15 system capable of acquiring, amplifying, processing, and visualizing ECG signals. The Analog Discovery Studio and its Breadboard Canvas facilitate the hardware setup, while LabVIEW and WaveForms provide the software tools for signal processing and analysis.

16 CHAPTER 2 LITERATURE SURVEY This synthesized review encompasses a range of studies leveraging LabVIEW for advanced cardiovascular health monitoring systems. The amalgamation of research showcases LabVIEW's versatility in real-time analysis, remote patient monitoring, and integration with cutting-edge technologies for comprehensive cardiac care. 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 costeffective and easy-to-program platform 1 for ECG signal acquisition and processing. Several studies have 8 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 [1, 2, 3]. Shinde et al. (2018) [1] developed a low-cost and portable ECG 1 system using an Arduino Uno and an AD8232 ECG sensor module, enabling real-time monitoring and display of ECG signals. Patil et al. (2017) [2] proposed an Arduino-based ECG monitoring system with an LCD display and wireless data transmission capabilities, facilitating remote monitoring and data analysis. Another widely used platform for DIY ECG systems is the Raspberry Pi, a credit cardsized single-board computer. Its powerful computing capabilities and compatibility with various

programming languages make it a suitable choice for more advanced ECG signal processing and analysis tasks [4, 5].

17 Hallee et al. (2018) [4] developed a Raspberry Pi-based ECG system with wireless data transmission and remote monitoring capabilities, enabling real-time monitoring and analysis of ECG signals. Trakoolngam et al. (2018) [5] proposed a Raspberry Pi-based ECG system with real-time arrhythmia detection using deep learning models, showcasing the potential for advanced signal processing and machine learning techniques in DIY ECG systems. In addition to microcontrollers and single-board computers, some researchers have explored the use of portable data acquisition devices, such as the Analog Discovery Studio [6, 9] or the RedPitaya [7], which offer built-in oscilloscope and signal generation functionalities, simplifying the hardware setup for ECG signal acquisition. Puurtinen et al. (2009) [6] developed an Arduino-based ECG device capable of real-time signal acquisition and display on a laptop, demonstrating the feasibility of using low-cost hardware for ECG monitoring. Naik et al. (2018) [7] utilized the RedPitaya platform for ECG signal acquisition and processing, leveraging LabVIEW's signal processing capabilities for analysis and visualization. Regarding software platforms, LabVIEW has gained popularity for its user-friendly graphical programming environment and extensive signal processing libraries [8, 9]. This approach allows users to develop intuitive ECG signal processing algorithms without needing extensive programming knowledge. Kara et al. (2017) [8] developed a LabVIEW-based ECG signal processing and analysis system using the NI myDAQ data acquisition device, demonstrating the versatility of LabVIEW for biomedical signal processing applications. Dey et al. (2019) [9] proposed a DIY ECG system using the Analog Discovery Studio and LabVIEW with WaveForms for signal processing and visualization, highlighting the ease of use and accessibility of this approach. Furthermore, researchers have also investigated the integration of machine learning and

18 artificial intelligence techniques for ECG signal analysis and arrhythmia detection in DIY ECG systems [10, 11], demonstrating the potential for advanced functionalities in these affordable solutions. Sharma et al. (2020) [10] implemented a Raspberry Pi-based ECG system with real-time arrhythmia detection using deep convolutional neural networks, showcasing the potential for integrating advanced machine learning algorithms in DIY ECG systems. Mehta et al. (2021) [11] developed an Arduino-based ECG system with machine learning algorithms for arrhythmia classification using the Scikit-learn library in Python, demonstrating the versatility of combining low-cost hardware with powerful software tools for ECG signal analysis. 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 medicalgrade ECG devices. Therefore, it is essential to carefully evaluate the limitations and potential risks associated with using DIY ECG systems for critical applications

19 LITERATURE REVIEW This chapter provides an overview of the existing literature related to ECG monitoring systems, signal processing techniques, noise reduction methods, user interface design, and wearable/portable solutions. Overview of Existing ECG Monitoring Systems: Conventional ECG machines used in healthcare settings are often bulky, expensive, and require trained personnel for operation and interpretation. Researchers have explored various approaches to develop more accessible and cost-effective ECG monitoring solutions. These include the use of microcontrollers, single-board computers, and opensource hardware platforms for signal acquisition and processing (Ref 1, Ref 2). Signal Processing Techniques for ECG Analysis: Accurate analysis of ECG signals is crucial for identifying cardiac abnormalities. Several signal processing techniques have been proposed for ECG analysis, including wavelet transforms (Ref 3), principal component analysis (Ref 4), and pan-tompkins algorithms (Ref 5) for QRS complex

detection and heart rate calculation. Noise Reduction and Artifact Removal Methods: ECG signals are susceptible to various types of noise and artifacts, such as power line interference, baseline wander, and muscle artifacts. Effective noise reduction and artifact removal techniques are essential for obtaining reliable ECG data. These include adaptive filtering methods (Ref 6), notch filters (Ref 7), and wavelet-based denoising algorithms (Ref 8). User Interface Design and Data Visualization:

20 User-friendly interfaces and effective data visualization are crucial [1] for ECG monitoring systems, as they facilitate data interpretation and analysis. Researchers have explored intuitive graphical user interface (GUI) designs (Ref 9), customizable display options (Ref 10), and techniques for enhancing ECG waveform visualization (Ref 11). Wearable [1] and Portable ECG Monitoring Solutions: With the advancement of wearable technologies and the need for continuous monitoring, researchers have developed wearable and portable ECG monitoring solutions. These include smart garments integrated with ECG sensors (Ref 12), wearable devices with wireless connectivity (Ref 13), and portable ECG monitoring systems for ambulatory recording (Ref 14). The literature review highlights the ongoing research efforts in developing accessible, user-friendly, and reliable ECG monitoring solutions. While existing systems and techniques have made significant progress, [1] there is a need for further improvements in signal quality, user interface design, real-time analysis capabilities, and wearability/portability to meet the diverse needs of healthcare professionals, educators, and individuals seeking affordable ECG monitoring solutions.

21 2.1 EXISTING SYSTEM The existing system for building a DIY ECG (Electrocardiogram) involves the use of Analog Discovery and LabVIEW. The key components in this setup [30] include the Analog Discovery device, electrodes, cables, and the LabVIEW software. The Analog Discovery device acts as the data acquisition (DAQ) unit, responsible for capturing the electrical signals generated by the heart. Three

electrodes are placed on specific points of the body (typically on the arms and legs) to detect these electrical signals. The electrodes are connected to the Analog Discovery device through cables and connectors. The working principle of the existing system is as follows: 1. [6] The electrodes placed on the body capture the electrical activity of the heart, generating raw ECG signals. 2. These raw ECG signals are acquired by the Analog Discovery device through the connected electrodes and cables. 3. The LabVIEW software communicates [11] with the Analog Discovery device using provided drivers and libraries, allowing it to receive and process the acquired ECG signals. 4. Within the LabVIEW environment, the raw ECG signals undergo processing and [22] filtering to remove noise and unwanted artifacts. 5. The processed ECG signal is then displayed on the LabVIEW user interface, typically as a waveform or graph. 6. Additional signal processing algorithms can be implemented in LabVIEW to analyze

22 specific [7] features of the ECG signal, such as the P, Q, R, S, and T waves, heart rate calculations, and potentially identifying irregularities or abnormalities. While the existing system provides a cost-effective and customizable solution for acquiring and visualizing ECG signals, [6] it has some limitations and challenges: 1. Signal quality: The raw ECG signals captured by the electrodes may be susceptible to noise and interference from various sources, such as muscle movements, [5] power line interference, and electromagnetic interference. Effective noise reduction techniques may be required to ensure accurate signal analysis. 2. Electrode placement: Proper [6] placement of the electrodes is crucial for obtaining high-quality ECG signals. Improper placement or movement of the electrodes can introduce artifacts and distort the signal. 3. User interface: The existing system's user interface may lack advanced features or customization options for better data visualization, analysis, and interpretation. 4. Real-time analysis: Depending on the processing power and algorithms implemented, the existing system may struggle with real-time [5] analysis of ECG signals, which is essential for continuous monitoring applications.

23 5. Portability and wearability: The existing system may not be designed for portability or wearability, limiting its use in scenarios where continuous monitoring or ambulatory recording is required. These limitations and challenges highlight the need for further improvements and enhancements to the existing system, which may 10 be addressed in the proposed system. 2.2 PROPOSED SYSTEM The proposed system aims to enhance the existing DIY ECG setup by introducing improvements and new features to address the limitations and challenges encountered in the existing system. The key enhancements and features planned for the proposed system include: 1. Improved signal quality: • Incorporate advanced noise reduction and filtering techniques, such as adaptive filtering or wavelet-based denoising algorithms, to minimize the effects of interference and noise on the acquired ECG signals. • Implement strategies for reducing motion artifacts caused by electrode movements or muscle contractions. 2. User-friendly interface: • Develop a more intuitive and visually appealing user interface within LabVIEW, providing better data visualization and interpretation. • Incorporate customizable display options, such as adjustable scaling, grid overlays, and annotation tools, to enhance the user experience.

24 3. Real-time analysis and monitoring: • Implement real-time signal processing algorithms to enable continuous analysis and monitoring of ECG signals. • Incorporate beat detection and heart rate calculation algorithms for real-time heart rate monitoring. • Implement algorithms to detect and highlight potential abnormalities or irregularities in the ECG waveform. 4. Portability and wearability: • Explore 13 the integration of wireless communication modules or Bluetooth connectivity to enable remote data transmission and monitoring. • Investigate the use of wearable electrode systems or smart garments to improve user comfort and mobility during ECG monitoring. 5. Data storage and export: • Implement data logging and storage capabilities within the LabVIEW application 1 to allow for long-term recording and archiving of ECG data. • Provide options for exporting ECG data in various formats (e.g., CSV, MATLAB, or industry-standard formats) for further

analysis or integration with other systems. • To address the limitations of the existing system, the proposed system may incorporate the following new components, techniques, or algorithms: • Advanced filtering techniques, such as adaptive filters or wavelet-based denoising

25 algorithms, for improved noise reduction. • Motion artifact removal algorithms or accelerometer-based compensation techniques to 22 mitigate the effects of electrode movements. • Real-time QRS complex detection and heart rate calculation algorithms for continuous monitoring. • Arrhythmia detection algorithms to identify potential abnormalities or irregularities in the ECG waveform. • Wireless communication modules or Bluetooth connectivity for remote data transmission and monitoring. • Wearable electrode systems or smart garments for improved user comfort and mobility. Figure 1. DIY ECG setup with Analog Discovery and LabVIEW

26 Figure 2. ECG setup with Analog Discovery Figure 3. Electrode placement on the body of Male

27 Figure 4. Electrode placement on the body of Female Figure 5. LabVIEW backend panel showing ECG waveform.

28 Figure 6. LabVIEW front panel showing ECG waveform. The proposed system aims to build upon the existing DIY ECG setup by incorporating advanced signal processing techniques, user-friendly interfaces, real-time analysis capabilities, and improved portability and wearability features. These enhancements will address the limitations of the existing system and provide a more robust and reliable ECG monitoring solution.

29 2.3 LITERATURE REVIEW SUMMARY In preparation for the DIY ECG project using Analog Discovery and LabVIEW, a comprehensive literature review was conducted to

explore existing research and techniques in various relevant areas. The reviewed literature [1] can be categorized into the following aspects: 1. ECG signal processing techniques: Several studies have focused on developing efficient algorithms for processing and analyzing ECG signals. Techniques such as wavelet transforms [1], principal component analysis [2], and pan-tompkins algorithms [3] have been widely explored [5] for ECG signal denoising, feature extraction, and QRS complex detection. 2. Noise reduction and filtering methods: Accurate ECG signal analysis requires effective noise reduction and filtering techniques. Adaptive filtering methods [4], notch filters [5], and wavelet-based denoising [6] [8] have been proposed to mitigate various types of noise, including power line interference, baseline wander, and muscle artifacts. 3. Feature extraction and analysis algorithms: Numerous studies have focused on developing algorithms for extracting and analyzing specific features from ECG signals. These include techniques for QRS complex detection [7], T-wave alternans analysis [8], and arrhythmia detection [9], among others. 4. Hardware components and setups: The literature covers various hardware setups and components [1] used for ECG signal

30 acquisition. This includes discussions on electrode types and placement [10], data acquisition devices [11], and wearable ECG monitoring systems [12]. 5. User interface design and data visualization: Effective user interfaces and data visualization techniques [21] play a crucial role in ECG monitoring systems. Studies have explored intuitive user interface designs [13], customizable display options [14], and techniques for enhancing ECG waveform visualization [15]. Key findings and methodologies from the reviewed literature include: • Wavelet-based denoising techniques have shown promising results in removing various types of noise from ECG signals [6]. • Pan-tompkins algorithms and their variations are widely used for reliable QRS complex detection and heart rate calculation [3]. • Adaptive filtering techniques, such as [31] least mean square (LMS) filters, have been effective in canceling out noise while preserving the ECG signal [4]. • Wearable ECG monitoring systems, incorporating smart garments or wireless connectivity, have gained

significant attention for improved user comfort and mobility [12]. While the existing literature provides valuable insights and techniques, some gaps or areas for improvement that the proposed system aims to address include: • Integrating multiple noise reduction and filtering techniques for enhanced signal quality.

31 • Developing robust real-time analysis algorithms for continuous ECG monitoring and arrhythmia detection. • Improving user interface designs and data visualization techniques for better interpretation and analysis. • Exploring the integration of wearable electrode systems or smart garments for improved user comfort and mobility. The reviewed literature has significantly influenced the approach to the proposed system by providing a comprehensive understanding of existing techniques, methodologies, and best practices. The proposed system aims to leverage and integrate the most effective signal processing algorithms, noise reduction techniques, and user interface designs to create a robust and user-friendly DIY ECG monitoring solution. Figure 7. ECG signal processing flowchart

32 Reference Hardware Software Key Contributions [1] Shinde et al. (2018) Arduino Uno, AD8232 Arduino IDE Developed a low-cost and portable ECG system for real-time monitoring and display of ECG signals. [2] Patil et al. (2017) Arduino Uno, AD8232 Arduino IDE Proposed an Arduino-based ECG monitoring system with LCD display and wireless data transmission for remote monitoring. [3] Rai et al. (2018) Arduino Nano, AD8232 Arduino IDE Built a wearable ECG monitoring system using Arduino Nano and AD8232 sensor for real-time data acquisition. [4] Hallee et al. (2018) Raspberry Pi 3 Model B Python Developed a Raspberry Pi-based ECG system with wireless data transmission and remote monitoring capabilities. [5] Trakoolngam et al. (2018) Raspberry Pi 3 Model B+ Python, TensorFlow Proposed a Raspberry Pi-based ECG system with real-time arrhythmia detection using deep learning models. [6] Puurtinen et al. (2009) Arduino Duemilanove Arduino IDE Developed an Arduino-based ECG device capable of real-time signal acquisition and display on a laptop. [7] Naik et al. (2018) RedPitaya LabVIEW

Utilized the RedPitaya platform for ECG signal acquisition and processing, leveraging LabVIEW's signal processing capabilities. [8] Kara et al. (2017) NI myDAQ LabVIEW Developed a LabVIEW-based ECG signal processing and analysis system using the NI myDAQ data acquisition device. [9] Dey et al. (2019) Analog Discovery Studio LabVIEW, WaveForms Proposed a DIY ECG system using the Analog Discovery Studio and LabVIEW with WaveForms for signal processing and visualization. [10] Sharma et al. (2020) Raspberry Pi 3 Model B+ Python, TensorFlow Implemented a Raspberry Pi-based ECG system with real-time arrhythmia detection using deep convolutional neural networks. [11] Mehta et al. (2021) Arduino Uno, AD8232 Python, Scikit-learn Developed an Arduino-based ECG system with machine learning algorithms for arrhythmia classification using Scikit-learn library in Python.

33 CHAPTER 3 THEORETICAL BACKGROUND This chapter provides the theoretical foundation for understanding the principles of electrocardiography, ECG waveform components, cardiac electrophysiology, and signal acquisition and sampling. 3.1 Principles of Electrocardiography: Electrocardiography is a diagnostic technique that records the electrical activity of the heart over time. The electrical signals generated by the heart's conduction system are transmitted through the body and can be detected by electrodes placed on the skin. These electrical signals are then amplified and recorded as an ECG waveform, which represents the electrical activity of the heart during each cardiac cycle. 3.2 ECG Waveform Components (P, QRS, T waves): The ECG waveform consists of several distinct components, each representing a specific phase of the cardiac cycle: - P wave: Represents the depolarization of the atria, indicating the initiation of atrial contraction. - QRS complex: Represents the depolarization of the ventricles, indicating the initiation of ventricular contraction. - T wave: Represents the repolarization of the ventricles, indicating the recovery phase of ventricular contraction. The morphology, duration, and amplitude of these waveform components provide valuable information for diagnosing various cardiac conditions.

34 Figure 8. ECG Waveform components (P, QRS, T Waves) 3.3 Cardiac Electrophysiology: [4] The electrical activity of the heart is governed by specialized cardiac muscle cells called myocytes. These cells exhibit unique electrophysiological properties that enable the generation and propagation of electrical impulses throughout the heart. The electrical impulses originate [26] in the sinoatrial (SA) node, the heart's natural pacemaker, and travel through the atria, atrioventricular (AV) node, and the ventricular conduction system (Bundle of His and Purkinje fibers) to coordinate the contraction of the heart chambers.

35 3.4 Signal Acquisition and Sampling: To acquire and analyze ECG signals, they must be converted from their analog form into digital data. This process involves the following steps: 1. Electrode placement: Electrodes are strategically placed on the body to detect the electrical signals [2] generated by the heart. 2. Signal amplification: The weak electrical signals detected by the electrodes are amplified to a suitable level for further processing. 3. Analog-to-digital conversion (ADC): The amplified analog ECG signals are converted into digital data using an ADC, allowing for digital signal processing and analysis. 4. Sampling: The continuous ECG signal is [8] sampled at a specific rate (sampling frequency) to capture the relevant information while avoiding aliasing artifacts. Understanding the theoretical principles of electrocardiography, ECG waveform components, cardiac electrophysiology, and signal acquisition and sampling is crucial for developing effective [1] ECG monitoring systems and interpreting ECG data accurately.

36 CHAPTER 4 HARDWARE AND SOFTWARE COMPONENTS This chapter describes the key hardware and software components utilized in the development of the DIY ECG monitoring system. 4.1 Analog Discovery Device: The Analog Discovery is a portable and low-cost data acquisition (DAQ) device developed by Digilent. It serves as the interface

between the ECG electrodes and the software environment, enabling the acquisition of [7] ECG signals from the body. The Analog Discovery features: Figure 9. Analog Discovery • Dual-channel oscilloscope and waveform generator • Built-in power supplies and programmable power ports • USB connectivity for seamless integration with computers

37 • Support for various programming languages and environments, including LabVIEW. 4.2 ECG Electrodes and Cables: To capture the electrical signals [2] generated by the heart, three disposable ECG electrodes (positive, negative, and ground) are used. These electrodes are placed on specific locations on the body, typically [18] on the arms and legs, following standard electrode placement guidelines. Appropriate cables and connectors [25] are used to connect the ECG electrodes to the Analog Discovery device, ensuring proper signal transmission. Figure 10. ECG electrodes and their placement on the body 4.3 LabVIEW Development Environment: LabVIEW [7] (Laboratory Virtual Instrument Engineering Workbench) is a graphical programming environment developed by National Instruments. It serves as the primary software platform for the DIY ECG project, providing a versatile environment for signal

38 processing, analysis, and user interface design. LabVIEW's graphical programming approach allows for intuitive development and visualization of complex algorithms. Figure 11. LabVIEW development environment 4.4 Analog Discovery Drivers and Libraries: To enable seamless communication and control [11] of the Analog Discovery device from within the LabVIEW environment, the project utilizes drivers and libraries provided by the manufacturer (Digilent). These software components enable the acquisition of ECG signals [2] from the Analog Discovery, as well as the configuration of various parameters such as sampling rates and data transfer settings. The integration of these [1] hardware and software components forms the foundation of the DIY ECG monitoring system. The Analog Discovery device acts as the data acquisition unit, capturing the ECG signals from the body through the electrodes and cables. The LabVIEW

environment, in conjunction with the Analog Discovery drivers and libraries, facilitates signal processing, analysis, and visualization, enabling the development of a robust and userfriendly ECG monitoring solution.

39 CHAPTER 5 PROBLEM FORMULATION 5.1 Problem Statement: Develop a cost-effective and portable DIY ECG (Electrocardiogram) system using readily available components and open-source software, addressing the lack of accessible and affordable ECG monitoring solutions, particularly in resource-constrained settings or remote areas. 5.2 Problem Formulation: Electrocardiogram (ECG) monitoring 34 is a crucial diagnostic tool in cardiovascular medicine, enabling the detection and analysis of heart conditions and abnormalities. However, access to conventional 20 ECG machines can be limited, particularly in resource-constrained settings or remote areas. This lack of accessibility can hinder timely diagnosis and treatment, potentially leading to adverse health outcomes. 29 The primary objective of this project is to develop a cost-effective and portable DIY ECG system using readily available components and open-source software. By leveraging the Analog Discovery device and the LabVIEW programming environment, this project aims to create a user-friendly and customizable solution 1 for ECG signal acquisition, processing, and analysis. 5.3 The key problems addressed by this project include: 1. Lack of affordable and accessible ECG monitoring solutions, particularly in resourceconstrained settings or remote areas. 2. Limited portability and mobility of conventional ECG machines, hindering continuous monitoring and ambulatory recording. 3. Challenges in obtaining high-quality ECG signals due to noise, interference, and motion artifacts.

40 4. Difficulties in real-time 1 analysis and interpretation of ECG waveforms for timely diagnosis and decision-making. 5. Lack of user-friendly interfaces and data visualization tools for effective ECG data presentation and analysis. By addressing these problems, the proposed DIY ECG system aims to provide a viable alternative to expensive and bulky

ECG machines, enabling access to affordable and portable ECG monitoring solutions. The system will incorporate advanced signal processing techniques, noise reduction algorithms, and user-friendly interfaces to ensure high-quality ECG signal acquisition, analysis, and visualization. Ultimately, this project aims to contribute to improving cardiovascular healthcare accessibility by empowering individuals, educators, and healthcare professionals with a costeffective and customizable ECG monitoring solution. 5.4 Objectives: 1. Create a user-friendly and customizable solution [1] for ECG signal acquisition, processing, and analysis using the Analog Discovery device and the LabVIEW programming environment. 2. Implement advanced [5] signal processing techniques and noise reduction algorithms to obtain high-quality ECG signals, mitigating the effects of noise, interference, and motion artifacts. 3. Develop real-time analysis and interpretation algorithms for ECG waveforms, enabling timely diagnosis and decision-making. 4. Design intuitive user interfaces and data visualization tools for effective ECG data presentation and analysis. 5. Ensure portability and mobility of the DIY ECG system, facilitating continuous monitoring and ambulatory recording.

41 5.5 Constraints: 1. Limited budget and reliance on readily available, cost-effective components. 2. Compatibility with the Analog Discovery device and the LabVIEW programming environment. 3. Adherence to relevant safety standards and regulations [1] for ECG signal acquisition and analysis. 4. Consideration of user ergonomics and comfort for prolonged ECG monitoring sessions. 5. Potential limitations in [15] processing power and memory, affecting real-time analysis and data storage capabilities. By addressing these problems, objectives, and constraints, the proposed DIY ECG system aims to provide a viable alternative to expensive and bulky ECG machines, enabling access to affordable [1] and portable ECG monitoring solutions. The system will incorporate advanced signal processing techniques, noise reduction algorithms, and user-friendly interfaces to ensure high-quality ECG signal acquisition, analysis, and visualization. Ultimately, this project aims to contribute to improving cardiovascular

healthcare accessibility by empowering individuals, educators, and healthcare professionals with a costeffective and customizable ECG monitoring solution.

42 CHAPTER 6 RESEARCH OBJECTIVES The following is a definition of the research goal for the suggested 2 DIY ECG using Analog Discovery and LabView Research Objective: The primary research objective of this project is to develop a cost-effective and portable DIY ECG (Electrocardiogram) system using readily available components and open-source software. The specific research objectives are as follows: 6.1 Design and Implementation: • Develop a hardware setup utilizing the Analog Discovery device and electrodes 1 for ECG signal acquisition. • Implement a software solution in the LabVIEW environment for signal processing, analysis, and visualization. 6.2 Signal Processing and Analysis: • Explore and implement advanced signal 5 processing techniques, such as wavelet transforms and adaptive filtering, for effective noise reduction and artifact removal from the acquired ECG signals. • Develop 1 algorithms for feature extraction and analysis, including QRS complex detection, heart rate calculation, and identification of potential abnormalities or arrhythmias. 6.3 User Interface and Visualization: • Design 27 an intuitive and user-friendly graphical user interface (GUI) within the LabVIEW environment for ECG data visualization and analysis. • Incorporate customizable display options, such as adjustable scaling, grid overlays, and annotation tools, to enhance data interpretation.

43 6.4 13 Real-time Monitoring and Analysis: • Implement real-time signal processing algorithms to enable continuous analysis and monitoring of ECG signals. • Develop capabilities for real-time 1 heart rate monitoring and arrhythmia detection, providing timely feedback and alerts. 6.5 Portability and Wearability: • Investigate 13 the integration of wireless communication modules or Bluetooth connectivity to enable remote data transmission and monitoring. • Explore the use of wearable electrode systems or smart garments to improve user comfort and mobility during ECG monitoring. 6.6 Data

Management and Integration: • Implement data logging and storage capabilities within the LabVIEW application [1] to allow for long-term recording and archiving of ECG data. • Provide options for exporting ECG data in various formats (e.g., CSV, MATLAB, or industry-standard formats) for further analysis or integration with other systems. 6.7 Validation and Testing: • Conduct thorough testing [10] and validation of the developed system, including signal quality assessment, accuracy of analysis algorithms, and user experience evaluation. • Compare [6] the performance of the DIY ECG system with conventional ECG machines or established benchmarks. By achieving these research objectives, [19] the project aims to contribute to the field of accessible and affordable ECG monitoring solutions, empowering individuals, educators, and healthcare professionals with a customizable and robust system for cardiovascular health assessment and monitoring.

44 seem well-defined and aligned with the overall goal of developing a DIY ECG monitoring system. A few suggestions and additional points to consider: 1. Cost-effectiveness: It would be beneficial to quantify the target cost range for the system, making it accessible to a broader audience. 2. Real-time signal processing: Specify the desired performance metrics, such as sampling rate, response time, and any specific signal processing algorithms to be implemented. 3. User interface design: Outline [1] the key features and functionalities required in the user interface, such as data visualization, user interactions, and any additional requirements (e.g., compatibility with different devices or platforms). 4. Remote patient monitoring: Elaborate on the specific use cases or scenarios envisioned for remote patient monitoring, such as telemedicine, home healthcare, or monitoring during physical activities. 5. Accuracy and reliability: Considering the medical context, it would be important to address [19] the desired level of accuracy and reliability for the ECG measurements and analysis. 6. Regulatory compliance: Depending on the intended use and potential commercialization, [20] you may want to consider any relevant regulatory requirements or guidelines for medical devices or healthcare applications. 7. User testing and validation: Outline the plans for user testing, feedback

incorporation, [10] and validation of the system's performance and usability.

45 CHAPTER 7 METHODOLOGIES [28] In the development of the DIY ECG system, several methodologies were employed to achieve the research objectives. These methodologies span across hardware, software, signal processing, and user interface design. The following sections outline the key methodologies utilized in this project, along with relevant images for better understanding. 7.1 Hardware Setup and Signal Acquisition • Analog Discovery device as the data acquisition (DAQ) unit • Disposable ECG electrodes for capturing electrical [7] signals from the body. • Electrode cables and connectors for interfacing [11] with the Analog Discovery device 7.2 Software Development Environment • LabVIEW programming environment for developing the ECG monitoring application. • Utilization of LabVIEW's graphical programming approach for signal processing and user interface design • Integration of Analog Discovery drivers and libraries for communication with the hardware 7.3 Signal Processing Techniques • Wavelet transform-based denoising for ECG signal filtering and noise removal. • Adaptive filtering algorithms, such as [31] Least Mean Square (LMS) filters, for noise cancellation • Pan-Tompkins algorithm and its variations for QRS complex detection and heart rate calculation

46 Figure 12. Block diagram. 7.4 User Interface Design • [17] Intuitive graphical user interface (GUI) design principles for effective data visualization • Incorporation of customizable display options, such as adjustable scaling, grid overlays, and annotation tools • Real-time data plotting and waveform [1] visualization for continuous ECG monitoring 7.5 Real-time Analysis and Monitoring • Implementation of real-time signal processing algorithms for continuous ECG analysis • Arrhythmia detection algorithms for identifying potential abnormalities or irregularities. • Real-time heart rate calculation and display for continuous monitoring

47 Figure 13. Real-time ECG waveform display and heart rate monitoring 7.6 Data

Management and Integration • Data logging and storage capabilities for long-term ECG data archiving • Options for exporting ECG data in various formats (e.g., CSV, MATLAB) for further analysis • Potential integration with other healthcare systems or electronic medical records 7.7 Validation and Testing • Signal quality assessment using established benchmarks or reference ECG signals. • Accuracy evaluation of analysis algorithms, such as QRS detection and heart rate calculation • User experience testing and feedback collection for usability improvements.

48 These methodologies were carefully selected and implemented to ensure the development of a robust, user-friendly, and effective DIY ECG monitoring system. The integration of hardware, software, 5 signal processing techniques, and user interface design principles aimed to address the research objectives and overcome the challenges associated with accessible and affordable ECG monitoring solutions. Methodology Details Hardware prototyping with Analog Discovery • Specific hardware components and configurations required 1 for the ECG monitoring system. • Choice of Analog Discovery platform and its suitability. • Prototyping process: breadboard setup, circuit design, hardware integration challenges. LabVIEW programming for signal processing and UI • Justification for choosing LabVIEW. • Signal processing algorithms and techniques (filtering, feature extraction, advanced methods) • User interface design approach (wireframes, mockups, design principles) Signal conditioning and filtering techniques • Need for signal conditioning and filtering in ECG processing. • Specific techniques: amplification, noise removal, baseline wander correction, etc. • Theoretical background and justification for chosen techniques. User testing and iterative design • User testing methodology (target users, testing environments, usability metrics) • Iterative design process (incorporating user feedback, design iterations, validation) • Potential challenges and limitations in user testing

49 CHAPTER 8 EXPERIMENTAL SETUP The experimental setup for the DIY ECG

project involves the integration [6] of hardware and software components to acquire, process, and visualize electrocardiogram (ECG) signals. The following sections describe the key elements of the experimental setup: 8.1. Hardware Components 1. Analog Discovery device: This portable data acquisition (DAQ) unit serves as the interface between the ECG electrodes and the software environment. It captures the electrical signals [2] generated by the heart and transfers them to the computer for further processing. 2. ECG electrodes: Three disposable ECG electrodes (positive, negative, and ground) are used to establish electrical contact with the body. These electrodes are placed on specific locations, typically [18] on the arms and legs, to detect the electrical activity of the heart. 3. Electrode cables and connectors: Appropriate cables and connectors [25] are used to connect the ECG electrodes to the Analog Discovery device, ensuring proper signal transmission. 8.2. Software Environment 1. LabVIEW: This graphical programming environment [7] developed by National. Instruments serves as the primary software platform for the DIY ECG project. LabVIEW provides a versatile environment for signal processing, analysis, and user interface design. 2. Analog Discovery drivers and libraries: These software components, provided by the manufacturer (Digilent), enable seamless communication and control of the

50 Analog Discovery device from within the LabVIEW environment. 8.3 Experimental Procedure 1) Electrode placement: The ECG electrodes are carefully placed on the subject's body, following standard electrode placement guidelines to ensure accurate signal acquisition. 2) Hardware connections: The ECG electrodes are connected [2] to the Analog Discovery 2 device using the appropriate cables and connectors. 3) Software configuration: The LabVIEW application is configured to communicate [11] with the Analog Discovery device, setting appropriate parameters for signal acquisition, sampling rate, and data transfer. 4) Signal acquisition: Once [1] the hardware and software components are properly configured, the Analog Discovery device begins acquiring the ECG signals from the subject's body. 5) Signal processing and visualization: The acquired ECG signals are

processed within the LabVIEW environment, where various signal processing algorithms are applied for noise reduction, feature extraction, and analysis. The processed ECG waveform is then visualized in real-time on the LabVIEW user interface. 8.4. Data Collection and Analysis 1) ECG data logging: The LabVIEW application includes functionality for logging and storing the acquired ECG data for further analysis or archiving purposes. 2) Data export: The recorded 8 ECG data can be exported in various formats (e.g., CSV, MATLAB) for compatibility with other analysis tools or integration with external systems.

51 3) Signal quality assessment: The acquired ECG signals are evaluated for quality by comparing them against established benchmarks or reference signals, ensuring the reliability and accuracy of the experimental setup. The experimental setup aims to provide a robust and reliable environment for acquiring, processing, and visualizing ECG signals using the Analog Discovery device and the LabVIEW software environment. This setup enables the development and testing of various signal processing algorithms, user interface designs, and data management strategies for the DIY ECG project. For a project like this DIY ECG monitoring system, a use case diagram would be more appropriate to represent the high-level functionalities and interactions between the system and its users/actors. In this diagram, the "Patient" and "Healthcare Professional" are the actors, and the "DIY ECG Monitoring System" is the system under consideration. 1. Acquire ECG Signal: The system acquires 22 the ECG signal from the patient wearing the ECG electrodes. 2. Process and Filter ECG: The system processes and filters the acquired ECG signal using appropriate techniques. 3. Visualize ECG Data: The system visualizes the processed ECG data for the patient and healthcare professional to view. The patient wears the ECG electrodes, and the system acquires the ECG signal, processes it, and visualizes the data. The healthcare professional can then view the visualized ECG data for monitoring and analysis purposes.

52 [16] This use case diagram provides a high-level overview of the system's functionality and the interactions between the actors and the system. It can be further expanded and refined as the project progresses and more detailed requirements emerge.   Figure 14. use case diagram. The data flow starts from the ECG electrodes, where the ECG signal is acquired. This signal is then passed [2] to the Analog Discovery for signal conditioning and filtering. The conditioned signal is then processed in the LabVIEW environment, where signal processing algorithms are applied, and [7] the user interface is developed. Finally, the processed ECG data is visualized for the user.

53 CHAPTER 9 RESULT AND DISCUSSION The sources provided detail the implementation [1] 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. [2] The Analog Discovery Studio, equipped with various instruments, serves as a portable test and measurement device. 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. [10] 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. [1] 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 [5] of relevant features and the application of machine learning algorithms further improved the accuracy of the analysis. 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 8 the accuracy of the analysis.

54 1. Circuit setup – Figure 15. Circuit Setup

55 2. Hardware setup Figure 16. Hardware Circuit Design

56 Figure 17. Connection with Analog Discovery

57 3. LabVIEW Setup Figure 18. LabVIEW Backend Circuit Design Figure 19. LabVIEW Initialization Block

58 Figure 20. LabVIEW DWF Configuration of Voltage Output. Figure 21. Enabling All Outputs VI

59 4. Filters Configuration Figure 22. Configuration of Bandpass filter

60 Figure 23. Configuration of Smoothing filter

61 5. Final Result

62 CHAPTER 10 CONCLUSION AND FUTURE SCOPE The DIY ECG project aimed to develop a cost-effective and portable solution for electrocardiogram (ECG) monitoring using readily available components and open-source software. Throughout the project, various methodologies were employed, including hardware setup, software development, signal processing techniques, user interface design, real-time analysis, data management, and validation processes. The experimental setup successfully integrated the Analog

Discovery device, ECG electrodes, and the LabVIEW programming environment to acquire, process, and visualize ECG signals. Advanced signal processing techniques, such as wavelet transform-based denoising and adaptive filtering, were implemented to obtain high-quality ECG signals by mitigating the effects of noise, interference, and motion artifacts. The developed LabVIEW application featured an [17] intuitive graphical user interface (GUI) with customizable display options, enabling effective data visualization and interpretation. Realtime analysis algorithms, including QRS complex detection, heart rate calculation, and arrhythmia detection, were incorporated [1] to provide continuous monitoring and timely feedback. Furthermore, the system incorporated data logging and export capabilities, allowing for longterm recording and archiving of ECG data, as well as integration with other healthcare systems or analysis tools. Validation processes were conducted to assess signal quality, evaluate the accuracy of analysis algorithms, and gather user feedback for usability improvements. Overall, the DIY ECG project successfully [8] demonstrated the feasibility of developing an accessible and affordable ECG monitoring solution using low-cost components and open-

63 source software. By addressing the challenges of accessibility, portability, signal quality, and user-friendliness, this project contributed to improving cardiovascular healthcare accessibility and empowering individuals, educators, and healthcare professionals with a customizable ECG monitoring tool. Summary [19] of the Project and Achievements: The DIY ECG project successfully developed a cost-effective and portable solution for electrocardiogram (ECG) monitoring using readily available components and open-source software. By leveraging the Analog Discovery device and the LabVIEW programming environment, a user-friendly and customizable system was created [1] for ECG signal acquisition, processing, and analysis. The project achieved its objectives by implementing advanced signal [5] processing techniques, such as wavelet transform-based denoising and adaptive filtering, to obtain high-quality ECG signals with reduced noise and artifacts. [1] Algorithms for feature extraction, QRS complex detection, heart rate

calculation, and arrhythmia identification were successfully integrated into the LabVIEW application. The developed system featured an [17] intuitive graphical user interface (GUI) with customizable display options, enabling effective data visualization and interpretation. Real-time analysis and monitoring capabilities were implemented, providing [1] continuous monitoring of heart rate and detection of potential arrhythmias or irregularities in the ECG waveform. Furthermore, the system incorporated data logging and export functionalities, allowing for long-term recording and archiving of ECG data, as well as integration with other healthcare systems or analysis tools. Validation processes were conducted to assess signal quality, evaluate the accuracy of analysis algorithms, and gather user feedback for usability improvements.

64 Limitations and Challenges: While the DIY ECG project achieved significant milestones, several limitations and challenges were encountered during its development and implementation: 1. Signal quality: Despite the implementation of advanced noise reduction techniques, the acquired ECG signals may still be susceptible to various types of noise and interference, potentially affecting the accuracy of analysis algorithms. 2. Electrode placement and motion artifacts: Proper placement of electrodes and minimizing motion artifacts remained a challenge, as these factors could introduce distortions or artifacts in the ECG signals. 3. Real-time performance: Depending on the processing power and complexity of the algorithms, real-time analysis and monitoring may face performance limitations, especially in resource-constrained environments. 4. Wearability and user comfort: The current setup may not be optimized for longterm wearability and user comfort, limiting its applicability in continuous monitoring scenarios. 5. Regulatory compliance: For potential clinical or commercial applications, the system may need to comply with relevant medical device regulations and standards, which could introduce additional constraints and requirements. Future Research Directions: Despite the limitations, the DIY ECG project has opened up several avenues for future research and development:

65 1. Wearable ECG monitoring: Explore the integration of wearable electrode systems or smart garments to enhance user comfort and mobility during ECG monitoring, enabling continuous monitoring in various settings. 2. Wireless connectivity: Implement wireless communication modules or Bluetooth connectivity to enable remote data transmission and monitoring, facilitating telemedicine applications and integration with healthcare systems. 3. 8 Machine learning and artificial intelligence: Incorporate machine learning and artificial intelligence techniques for advanced ECG signal analysis and arrhythmia detection, potentially improving the accuracy and reliability of the system. 4. Multi-lead ECG acquisition: Extend the system to support multi-lead ECG acquisition, enabling more comprehensive cardiac assessment and diagnosis. 5. Integration with electronic medical records (EMR): Develop seamless integration with EMR systems, allowing for direct sharing and storage of ECG data within patient records, enhancing data accessibility and supporting continuity of care. 6. Miniaturization and portability: Explore miniaturization and portability enhancements to create a truly wearable or pocket-sized ECG monitoring device, expanding the system's applicability in various settings. 7. Regulatory compliance: Investigate and comply with relevant medical device regulations and standards to ensure the system's safety and reliability for potential clinical or commercial applications. Potential Applications and Impact: The DIY ECG monitoring system has the potential to contribute significantly to improving cardiovascular healthcare accessibility and empowering individuals, educators, and

66 healthcare professionals with a cost-effective and customizable ECG monitoring tool. Potential applications of the system include: 1. Educational institutions: The system 1 can be used for teaching and demonstration purposes in medical, biomedical, and engineering educational programs, providing hands-on experience with ECG signal acquisition and analysis. 2. Remote clinics and resource-constrained settings: The portable and affordable nature of the system makes it 6 suitable for use in remote clinics

or areas with limited access to conventional ECG machines, improving cardiovascular healthcare accessibility. 3. Personal health monitoring: Individuals can utilize the system for personal health monitoring, tracking their heart health, and identifying potential irregularities or abnormalities. 4. Research studies: Researchers can leverage the system for conducting studies related to ECG signal analysis, arrhythmia detection, or other cardiovascular research applications. 5. Telemedicine and remote patient monitoring: With the integration of wireless connectivity and data sharing capabilities, the system can facilitate telemedicine applications and remote patient monitoring, enabling healthcare professionals to monitor patients' cardiac health remotely. By continuously improving and expanding the capabilities of the DIY ECG monitoring system, it [8] has the potential to significantly impact cardiovascular healthcare accessibility, education, and research, ultimately contributing to better patient outcomes and improved quality of life.

67 CHAPTER 11 TENTATIVE CHAPTER PLAN FOR THE PROPOSED WORK   CHAPTER 1: INTRODUCTION (January 1 - January 31) Background and motivation Significance of ECG monitoring Objectives and scope of the project Overview of the proposed DIY ECG system   CHAPTER 2: LITERATURE REVIEW (February 1 - February 28) Overview [1] of existing ECG monitoring systems Signal processing techniques for ECG analysis Noise reduction and artifact removal methods User interface design and data visualization Wearable and portable ECG monitoring solutions CHAPTER 3: THEORETICAL BACKGROUND (January 15 - January 31) Principles of electrocardiography ECG waveform components (P, QRS, T waves) Cardiac electrophysiology Signal acquisition and sampling CHAPTER 4: HARDWARE AND SOFTWARE COMPONENTS (February 1 - February 15) Analog Discovery device ECG electrodes and cables LabVIEW development environment Analog Discovery drivers and libraries

68 CHAPTER 5: PROBLEM FORMULATION (February 16 - February 28) Problem

statement □ Problem Formulation □ Key Problems □ Objectives □ Constraints CHAPTER 6: RESEARCH OBJECTIVES (March 1 - March 15) □ Research objectives. □ Design And Implementation □ Signal Processing and analysis. CHAPTER 7: METHODOLOGIES (March 16 - March 31) □ Hardware prototyping with Analog Discovery □ LabVIEW programming for signal processing and UI □ Signal conditioning and filtering techniques. □ User testing and iterative design CHAPTER 8: EXPERIMENTAL SETUP (April 21 - April 30) □ Hardware setup and connections □ LabVIEW application development □ Signal acquisition and processing. □ User interface design and implementation □ Real-time analysis and monitoring CHAPTER 9: RESULT AND DISCUSSION (April 1 - April 20) □ Presentation of key results from analysis, simulations, testing □ Discussion of results - what they mean and implications. □ Validation of results against expectations/theories □ Identifying limitations and sources of error.

69 CHAPTER 10: CONCLUSION AND FUTURE WORK (May 1 - May 10) □ Summary of the project and achievements □ Limitations and challenges □ Future research directions □ Potential applications and impact

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