

PORTABLE DEFIBRILLATOR WITH ECG MONITORING SYSTEM

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Technology degree in Biomedical Engineering

By

DANNY ROY (40240007)

DANIEL. R (40240006)



**DEPARTMENT OF BIOMEDICAL ENGINEERING
SCHOOL OF BIO AND CHEMICAL ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade "A++" by NAAC

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI-600119

APRIL 2024



SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited "A++" Grade by NAAC | 12B Status by UGC | Approved by AICTE

www.sathyabama.ac.in

DEPARTMENT OF BIOMEDICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **DANNY ROY (40240007)**, **DANIEL.R (40240006)** who have done the project work as a team and carried out the project entitled "**PORTABLE DEFIBRILLATOR WITH ECG MONITORING SYSTEM**" under our supervision from June 2023 to April 2024.

Ms. Sindu Divakaren
Internal Guide

Dr. T Sudhakar

Head of the Department
Department of Biomedical Engineering
Sathyabama Institute of Science & Technology
(Deemed to be University)
Category I University by UGC
Jyoti Nagar, Rajiv Gandhi Salai,
Chennai - 600 119

Submitted for Vivavoce Examination held on 05 April 2024

Internal Examiner

External Examiner

DECLARATION

We **DANNY ROY (40240007)**, **DANIEL. R (40240006)** hereby declare that the Project Report entitled **PORTABLE DEFIBRILLATOR WITH ECG MONITORING SYSTEM** done by us under the guidance of **Ms. SINDU DIVAKAREN** is submitted in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Biomedical Engineering.

DATE: 05.04.2024

PLACE: CHENNAI



1. DANNY ROY



2. DANIEL. R

SIGNATURE OF THE CANDIDATES

ACKNOWLEDGEMENT

We are pleased to acknowledge our sincere thanks to **The Board of Management of Sathyabama Institute of Science and Technology** for their kind encouragement in doing this project and for completing it successfully. We are grateful to them.

We convey our thanks to **Dr. T Sudhakar**, Head of the Department, Dept. of Biomedical Engineering for providing us necessary support and details at the right time during the progressive reviews.

We would like to express our sincere and deep sense of gratitude to our Project Guide **Ms. Sindu Divakaran** for her valuable guidance, suggestions and constant encouragement paved way for the successful completion of our project work.

We wish to express our thanks to all Teaching and Non-teaching staff members of the Department of Biomedical Engineering who were helpful in many ways for the completion of the project.

We would like to express our thanks to our parents for their unwavering support to us during these years.

ABSTRACT

Portable Defibrillators are Automated External Defibrillators (AED) that are designed for minimally trained or untrained non-medical personnel. A defibrillator is a device that analyzes the heart rhythm and, if necessary, shocks the heart of the individual experiencing cardiac arrest with electricity (defibrillation). While performing CPR, it can keep an eye on the heartbeat and provide a regulated shock to the victim of cardiac arrest. This prototype features patient-attachable pads and an electrocardiogram monitoring system for keeping tabs on the patient's heartbeat. The defibrillator's internal microprocessor analyzes the patient's heartbeat automatically to determine whether a shock is necessary. The user will be led through the procedure by a combination of audio and visual prompts. AED would advise a shock only to ventricular fibrillation. This device meant for quick and simple treatment of sudden cardiac arrest and critical device that helps during CPR. They can be widely used in community locations, such as sports facilities and shopping centers and often operated by members of the public. In this paper, we will present a framework of AED system. There are two crucial components should be elaborately designed, the hardware system and the algorithm of detecting ventricular fibrillation. Also, we will present the design of hardware system and a new algorithm which could discriminate ventricular fibrillation (VF).

Keywords –Cardiac arrest, CPR, Defibrillation, Electrocardiogram, Ventricular Fibrillation

TABLE OF CONTENT

CHAPTER No.	CONTENT	PG.NO
	ABSTRACT	i
	LIST OF ABBREVIATIONS	iv
	LIST OF FIGURES	vi
1	INTRODUCTION	1
2	LITERATURE SURVEY	5
3	AIM AND SCOPE OF THE PRESENT INVESTIGATION	10
	3.1 Scope	10
4	MATERIALS AND METHOD	12
	4.1 Hardware Requirements	12
	4.1.1 Arduino Microcontroller	12
	4.1.2 ECG Electrodes and Sensor	12
	4.1.3 Defibrillation Electrode Pads	14
	4.1.4 Audio Output	15
	4.1.5 Power supply	15
	4.2 Block Diagram	16
	4.3 Calculating Heart Rate Variability (HRV)	16
	4.4 ECG Waveform	17
	4.5 Shock Delivery System	19
	4.5.1 Components for a Shock Delivery Unit	20
	4.6 Schematic of Power Supply Circuit	21

CHAPTER No.	CONTENT	PG.NO
	4.7 HW131 Power Supply Board	22
	4.7.1 Function of HW131 power supply circuit	23
	4.8 DFPlayer Mini mp3 Module	24
	4.8.1 Voice Prompts	24
	4.8.2 Alarms and Alerts	24
	4.8.3 Feedback on Device Status	24
	4.8.4 Procedure Assistance	25
	4.8.5 Multi-Language Support	25
	4.9 Circuit Diagram of AED	26
	4.9.1 Circuit Description	27
5	RESULTS AND DISCUSSION, PERFORMANCE ANALYSIS	28
	5.1 Prototype	28
	5.2 Performance Analysis	30
	5.3 Output and Discussion	35
6	SUMMARY AND CONCLUSION REFERENCES	36 37

LIST OF ABBREVIATIONS

ABBREVIATIONS	DEFINITIONS
AC	Alternating current
ACA	Anterior Cerebral Artery
AED	Automated External Defibrillator
BTE	Biphasic Truncated Exponential
CIED	Cardiovascular Implantable Electronic Devices
DC	Direct current
DFT	Defibrillation Threshold
ECG	ElectroCardioGram
EMS	Emergency Medical Systems
FSR	Fractional Synthesis Rate
GPS	Gray Platelet Syndrome
HVT	Hepatic Vein Thrombosis
HRV	Heart Rate Variability
IOT	Internet Of Things
IGBT	Image-Guided Bipolar Transistor
IEC	Intra-Epidermal Carcinoma
ICD	International Classification of Diseases
OHCA	Out-of-hospital cardiac arrest
SCA	Sudden Cardiac Arrest
VF	Ventricular Fibrillation

VTA	Ventral Tegmental Area
VFTA	Ventricular Fibrillation and Tachycardia Analysis
VT	Ventricular Tachycardia
WCD	Wearable Cardioverter Defibrillator

LIST OF FIGURES

FIGURE.NO	TITLE	PG.NO
1.1	Electrical defibrillation	1
1.2	Automated External Defibrillator	3
4.1	AD8232 sensor interfaced with Arduino	13
4.2	AD8232 sensor (ECG sensor)	13
4.3	Adhesive electrode pads	14
4.4	Block Diagram for ECG Monitor interfaced with defibrillator	16
4.5	Heart Rate Variability	17
4.6	Serial Plotter	18
4.7	Serial Monitor	18
4.8	Power supply unit	19
4.9	Schematic of power supply circuit	21
4.10	Hw131 Power supply board	23
4.11	DfPlayer mini mp3 module	25
4.12	Circuit Diagram of AED	26
5.1	Overall view of the Prototype	28
5.2	System Booting up	30
5.3	Second stage initiated	30
5.4	Indicator light begin to blink to apply pads	31
5.5	IR Remote	32
5.6	Shock delivery and Hazard Indication	33
5.7	CPR Simulation	34
5.8	Prototype Output and Shock Voltage	35

CHAPTER 1

INTRODUCTION

Electrical defibrillation stands as the most effective recourse for addressing cardiac arrest stemming from ventricular fibrillation (VF) or ventricular tachycardia (VT), offering a potential route to restoring the victim's cardiac rhythm to normalcy. Extensive research underscores the critical role of timing in defibrillation, with studies consistently highlighting the paramount importance of prompt intervention from collapse to the delivery of the initial shock (Ball et.al, 2022) Each passing minute significantly impacts the success rate of defibrillation, with a 7-10% decrease in efficacy observed for every minute of delay. Consequently, the development of rescue tools shown in Figure 1.1 during defibrillation procedures is imperative, ensuring swift and effective to maximize chances of survival.

The inception of the defibrillator dates back to 1946, initially employing the alternating current (AC) method. However, the advent of ZOLL's direct current (DC) defibrillation method in the 1950s revolutionized the landscape, swiftly supplanting the antiquated AC method. This transition marked a significant milestone in defibrillation technology, laying the groundwork for subsequent advancements. Notably, the introduction of Automated External Defibrillators (AEDs) emerged as a groundbreaking innovation, democratizing access to defibrillation technology and empowering individuals with life-saving capabilities.



Figure 1.1 Electrical defibrillation

Throughout the history of sudden cardiac arrest (SCA) treatment, single-phase waveform defibrillation stood as the primary method, serving as the cornerstone of resuscitation protocols. This approach involved delivering a unidirectional electrical pulse to the heart in an attempt to restore normal rhythm. While effective to some extent, single-phase waveform defibrillation had limitations, including higher power requirements and variable success rates (Jacob et. al 2019). However, the defibrillator technology underwent a significant transformation with the emergence of biphasic waveform defibrillation. This marked a paradigm shift in SCA treatment, characterized by the delivery of electrical pulses in two phases – first in one direction and then in the opposite direction. This innovative approach offered several key advantages over its predecessor.

One of the primary benefits of biphasic waveform defibrillation is its superior performance in achieving successful defibrillation outcomes. Studies have demonstrated that biphasic waveforms are more effective at terminating ventricular fibrillation and restoring normal heart rhythm compared to single-phase waveforms. This enhanced efficacy translates to higher survival rates and improved patient outcomes.

Furthermore, biphasic waveform defibrillation requires lower energy levels to achieve the same therapeutic effect, leading to reduced power requirements. This not only minimizes the risk of tissue damage and adverse effects but also allows for the development of more compact and portable defibrillator devices (Nath et.al 2023). The increased portability and accessibility of biphasic defibrillators have democratized access to life-saving interventions, enabling prompt treatment in diverse settings, including homes, workplaces, and public spaces.

Moreover, biphasic waveform defibrillation offers heightened reliability and versatility in adapting to individual patient characteristics and varying cardiac conditions (Li et.al 2021). The bidirectional nature of biphasic waveforms allows for greater flexibility in tailoring treatment parameters to suit the specific needs of each patient, thereby

optimizing therapeutic efficacy and minimizing the risk of complications.

Overall, the ascension of biphasic waveform defibrillation represents a testament to the relentless pursuit of innovation and excellence within the field of emergency medicine. This evolutionary leap underscores a steadfast commitment to enhancing patient outcomes, advancing treatment modalities, and ultimately saving lives in the fight against sudden cardiac arrest.

In summary, the defibrillation has undergone significant transformation over the decades, propelled by advancements in technology and a deepening understanding of cardiac arrest management. From the rudimentary beginnings of AC defibrillation to the sophisticated biphasic waveform technologies of today (Emad Mayss et.al 2021), the journey of defibrillation exemplifies the relentless pursuit of excellence in emergency medicine, with each milestone marking a step forward in the quest to save lives and combat sudden cardiac arrest.

Traditional Automated External Defibrillators (AEDs) shown in Figure 1.2 have long been plagued by various shortcomings, ranging from bulkiness to slow charge velocity and poor sensitivity in detecting ventricular fibrillation (VF). Addressing these limitations necessitates the development of a highly robust and efficient AED system.



Figure 1.2 Automated External Defibrillator

In this report, we unveil the comprehensive hardware and algorithmic framework of our innovative AED system. Central to our design is the development of a sophisticated system for collecting electrocardiogram (ECG) signals. Here, our focus lies on the meticulous design of the hardware system's amplifier and acquisition circuit, recognizing its pivotal role as a fundamental component of the defibrillation system as a whole. Subsequently, we delve into the intricacies of the charging circuit and energy selection circuit, meticulously engineered to accumulate and store suitable power within two energy-storing capacitors. This strategic approach ensures the availability of sufficient energy reserves essential for effective defibrillation interventions. Lastly, we unveil the discharge circuit, meticulously crafted to precisely release the stored voltage waveform to the patient, facilitating the delivery of timely and targeted electrical shocks. Through this comprehensive approach, our AED system aims to revolutionize the landscape of defibrillation technology, offering heightened stability, efficiency, and efficacy in the treatment of sudden cardiac arrest.

CHAPTER 2

LITERATURE SURVEY

Numerous research was worked under the topic of portable defibrillators with ECG monitoring system with diverse factors:

Rahul Gopinathan Nath et.al. (2023) designed a user-friendly, portable, and compact defibrillation technology has been developed that is unique in the industry. It allows for both adult and pediatric shock selection with ECG monitoring, making it easy for an unskilled individual to handle the situation. The device further preserves shock safety by capping the number of shock levels at six. The switch modes selection can be activated to control how much energy is released. The results also match the shock energy, timing of release, and waveform characteristics of widely used products. It is also possible to make the system wireless and Internet of Things (IOTs) based to boost operational viability. The Clinical Engineering Department of SCTIMST examined the proposed diagnosing system for hardware design using safety analyser and defibrillator analysers, and the accuracy was 98.03%.

Mahesh K K and Sudheesh P (2020) designed an evaluation of the defibrillator, compared to monophasic waveform defibrillators, biphasic waveform defibrillators are more common today and function much better. Wireless charging will make external defibrillators more user-friendly in the future. The device is portable since it may be divided into two paddles of equal size. To create a capacitor with a smaller size and a higher capacitance value, more research must be conducted in the field of capacitors.

Mohammad Monirujjaman Khan et.al. (2022) in their research paper, a low-cost automated CPR device is suggested for both newborns and the elderly. This proposed CPR device is legitimately constructed to narrow the gap with recent pricey equipment in western markets since their goal is to produce a CPR device that will help save the lives of not only rich individuals but also of middle-class and lower-class people. Perinatal asphyxia, which still accounts for roughly 28% of infant mortality, is also helped by the device for newborns. Special attention has been paid to the accuracy of the applied pressure and compression rate. On the other hand, the more of our

suggested design that clients have access to, the more lives we can save.

In 2021, Johanna B. Tonko and Christopher A. Rinaldi explored that even in the most complicated of cardiac patients, for patients at risk of sudden cardiac death from ventricular tachyarrhythmias, non-traditional ICD designs offer useful alternatives, and the growing range of options enables more specialized treatment methods. The majority of these systems have limited clinical experience, and there are few long-term safety- and device performance-data for the majority of these systems. It is essential to pick patients wisely and collaborate with them to make decisions. Close follow-up in a facility with experience for unconventional systems is recommended in order to guarantee proper device function and early issue discovery

Rik Stoevelaar et.al (2018) researched the first comprehensive analysis that examines all the research that is currently available on the frequency and effects of ICD shocks in the latter stage of life. Shocks were shown to be a regular occurrence in both patients dying slowly and individuals dying abruptly. Shocks hurt and bother patients, and they're often upsetting for loved ones and trained caregivers to see. The study's informational summary should warn healthcare professionals about the risks of having an active ICD near the end of life. Our study emphasizes the value of discussing ICD deactivation with patients at an early illness stage.

Mayss Emad et.al (2020) designed an auto dc-shock prototype as a medical device is appropriate for treating VF, VT, and easy, thus this appropriate diagnosis system was suggested for unskilled persons and may be handled by the physician. Two studies that were applied to the diagnostic system were based on an original trial with a group of patients at Ibn Al-Nafees Hospital. The results of the diagnostic system using the patient's body as the monitor were virtually the same as those detailed in section 3.1. By using hardware design, it was possible to achieve detection sensitivity of 88.88%, specificity of 97.8%, and accuracy of 97.03. By using hardware design, it was determined that the detection error rate is 3.09%, accuracy is 97.03, specificity is 97.8, and sensitivity is 88.88%. Comparable to other commercial varieties, low cost. A number of factors, including transthoracic impedance, cellular response, defibrillation threshold, electrode size, quality of the electrode surface, electrode paddle force, and electrodeposition, affect how much of the myocardium receives the shock during a

successful defibrillation.

Khanista Namee et.al (2019) had developed the EMS services platform to assist those who require ambulances. One frequent issue is that the ambulance doesn't know exactly where the victim is. The researcher has thus mentioned the development of information technology in order to construct a system that can convey the location of the AED and allow people to open and close it using an app. The AED's condition may also be checked by users via the app. By using the GPS system, this may also pinpoint the precise position of the accident site. When the entire system is tested, it is discovered that the AED's position has a 95% accuracy rate and that the average response time through the app is 658 milliseconds, making the EMS service even more efficient.

Norbert Adam et.al (2023) have developed a method for collecting ECG from humans in this study. The hardware itself is reasonably priced, generally accurate, and simple to build. A single-lead ECG can be used to diagnose the majority of typical daily kinds of arrhythmias. According to Einthoven's triangle hypothesis, for their experiment, lead II has been acquired. We have also shown the appropriate methods for eliminating ECG noise so that we may subsequently prepare ECG for diagnosis or categorization.

Wenguang Han et.al (2010) has introduced an innovative ECG-based automated external defibrillator system with a robust hardware design. A key focus was on optimizing the circuit design for capturing faint and widely variable ECG signals. They achieved high-quality, accurate ECG data through active band-pass and trap filters, along with preamplifiers. Real-world testing confirmed the system's efficacy, while simulation modeling of the chest impedance detection circuit yielded excellent results. The study pointed to the need for further research, particularly in scaling the bi-phase waveform using SCR or IGBT discharge circuits. Additionally, they noted the sensitivity of entropy values in ventricular fibrillation (VF) detection, highlighting the importance of studying a broader range of signals to establish more reliable thresholds, given the dynamic nature of VF signals and the limitations of small sample sizes.

Naveed Zaidi et.al (2021) developed ECG data can quickly identify shockable or non-shockable rhythms. The caregivers can evaluate if an electric shock is required to reestablish a normal cardiac rhythm using methods for analyzing ECG data. A

shockable rhythm may be located fast, frequently in less than a second, by searching for conditions in an extensive patient database with strong predictive value. This technique eliminates the need for intensive ECG data processing, enabling faster heart diagnosis as well as therapy.

Graham Nichol et.al (2017) researched to restrict sudden cardiac death (SCD) hereafter to cardiac arrest caused by ventricular fibrillation, includes rhythms that can be shocked by a wearable cardioverter-defibrillator (WCD), implantable cardioverter-defibrillator (ICD), or automatic external defibrillator (AED). In their paper, they provided an overview of the current state of defibrillation in the treatment of SCD. This includes a brief history of the development of defibrillation, technical features of contemporary AEDs, tactics to improve AED accessibility and raise survival rates, supplementary treatments, and the usage of ICDs or WCDs.

In 2022, Grace Brown et.al narrated a review on the role of artificial intelligence in defibrillators and studied the ability to recognize rhythms during CPR is one of the most interesting upcoming developments in machine learning applications in AEDs. This technology has moved from adaptive filters to remove CPR artifacts to the development of end-to-end SAAs. Although the AHA-required sensitivities and specificities have not yet been met, this may happen soon with further algorithm improvement. A critical first step will be to compile a big collection of genuine AED traces during CPR. Jekova et al. were able to utilize a huge database; nevertheless, since, for example, the proportions of VF did not meet criteria, more research would be required for further optimization. Because current models frequently still require reconfirmation of the rhythm in the absence of chest compressions, they have not been able to totally shorten "hands-off" time. Further optimization of these algorithms remains an exciting area of research.

Fahimeh Nasimi and Mohammadreza Yazdchi in 2022 focused on the development of the applied algorithm used in this work was able to automatically identify shockable arrhythmias in a 1.4-second ECG data and distinguish them from non-shockable signals. The advantage of the suggested method is its simple, feature extraction and classifier-integrated end-to-end learning process. The suggested algorithm complies with IEC 60601-2-4 specifications. With 99.64% specificity for other

non-shockable rhythms and 96.13% sensitivity for other shockable rhythms, the gadget reached a shock or no shock decision with high accuracy. Another interesting project of this work is the implementation of the suggested classification algorithm on the Raspberry Pi minicomputer as a component of an AED.

Hooman Samani and Rongbo Zhu (2016) built a machine robot ambulance for smart cities offers the assistance of an ambulance and an AED to someone experiencing a cardiac arrest. When the heart has ceased beating properly as a result of an electrical problem with the heart, it experiences sudden cardiac arrest. This happens right away or soon after symptoms start to show. Quick access to an AED in a cardiac arrest situation may save a person's life

S. Ball et.al conducted a comprehensive analysis in 2022 and in Perth, Western Australia, a high number of companies were identified as possible AED host sites due to their potential to enhance the current AED coverage of out-of-hospital cardiac arrests. There are many businesses who received good marks for their improved coverage of arrests in both public and private settings. Even if all 115 business brands had AEDs available around-the-clock in every facility, 92% of arrests in private homes and 57% of arrests in public places would still be unreachable by 100 meters. This emphasizes how crucial it is to take into account alternative AED delivery methods in urban settings.

In 2019, Jerry Jacob et.al This research suggests creating a miniature CPR feedback device to help treat cardiac arrest patients. The proposed method measures compression rate and pressure applied to the FSR. Additionally, anyone may use the equipment because of how convenient it is. Numerous graphical plots are discovered and examined. Using the accepted standards, it is determined that the results are trustworthy. By utilizing a mannequin and FSR with higher specifications, this prototype might be further improved.

CHAPTER 3

AIM AND SCOPE OF THE PRESENT INVESTIGATION

The objective of this project is to determine the heart waveform and deliver the required defibrillation accordingly. The prototype can be used in an emergency situation to diagnose the patient's condition and restore the heart's normal function. Additionally, it can monitor the heart beat during CPR to the person experiencing cardiac arrest. The primary objectives are to create a portable, user-friendly, and cost-effective device that combines automated external defibrillation with real-time ECG monitoring capabilities, enhancing the quality of emergency medical care and potentially saving lives.

3.1 SCOPE

The scope of the present investigation for the project development encompasses a comprehensive exploration of various facets of the proposed device, with a focus on the following key areas:

- **Design and Development:** This will include the detailed design and development of the portable defibrillator with ECG monitoring system. This involves the selection of suitable components, circuitry, and software, ensuring the integration of defibrillation technology with a reliable ECG monitoring system.
- **Functional Performance Evaluation:** The project aims to assess the device's functional performance, including its defibrillation efficacy, signal processing algorithms, and real-time monitoring capabilities.
- **User Interface and Usability:** The investigation will focus on designing an intuitive user interface for the device to make it accessible to both medical professionals and non-medical personnel. Human factors and usability studies will be conducted to ensure ease of operation during emergency situations.
- **Safety and Regulatory Compliance:** The project will address safety considerations and adherence to relevant medical device regulations and standards. It will encompass thorough testing to ensure the safety of users and patients and compliance with industry-specific guidelines.

- **Cost Analysis and Feasibility:** An assessment of the cost of manufacturing and the feasibility of mass production will be carried out. This includes analyzing the economic aspects of producing the device on a larger scale, as well as a cost-benefit analysis.
- **Future Enhancements and Research Opportunities:** The investigation will identify potential areas for future enhancements and research opportunities in the field of portable defibrillation and ECG monitoring, such as advanced diagnostic features, wireless communication, and integration with telemedicine systems (Gajendiran M, 2017).

CHAPTER 4

MATERIALS AND METHODS

4.1 HARDWARE REQUIREMENTS:

- Arduino Microcontroller
- ECG Electrodes and Sensors
- Defibrillation Electrode Pads
- Voltage Generator Circuit
- Audio Output
- Power Supply

4.1.1 Arduino Microcontroller:

The Arduino serves as the brains of your portable defibrillator, responsible for processing and managing the data, user interaction, and ensuring the device's safe and effective operation. It plays a crucial role in the seamless integration of ECG monitoring and defibrillation capabilities, ultimately contributing to the device's overall functionality and user-friendliness.

4.1.2 ECG Electrodes and Sensor:

The AD8232 ECG sensor which is seen in Figure 4.1 can be a valuable component in the portable defibrillator project, serving as the module responsible for capturing and monitoring the patient's electrocardiogram (ECG) signals. The ECG sensor is designed to acquire ECG signals from the patient's body through ECG electrodes. These electrodes should be placed on the patient's skin at the specified locations (limb leads, chest leads) to capture the heart's electrical activity. The Figure 4.2 provides a visual representation of AD8232 includes an integrated ECG amplifier and filter circuitry. It amplifies the weak ECG signals and filters out noise and interference. This ensures that the recorded ECG signal is clear and suitable for analysis (Norbert et.al, 2023) the AD8232 ECG sensor is a key component for ECG signal acquisition and monitoring in

our portable defibrillator project.

It enables real-time ECG waveform visualization, arrhythmia detection, and integration with the defibrillation process, contributing to the overall functionality and safety of our device. Proper calibration and adherence to medical device regulations are essential to ensure accurate ECG monitoring and patient safety.

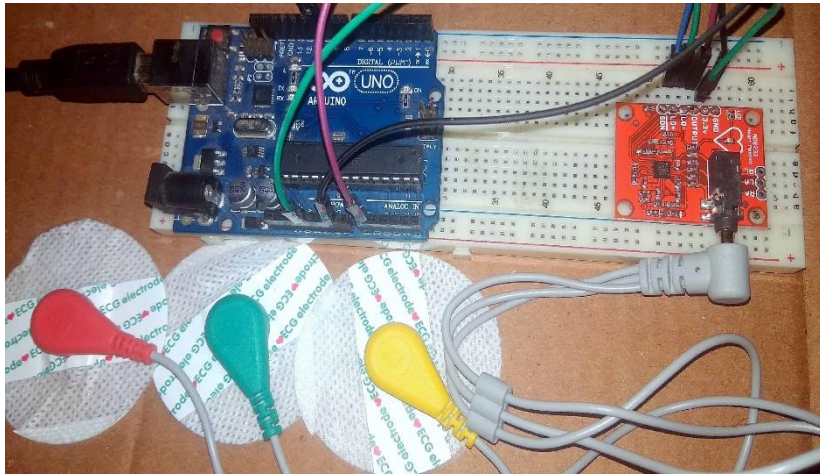


Figure 4.1 AD8232 sensor interfaced with Arduino

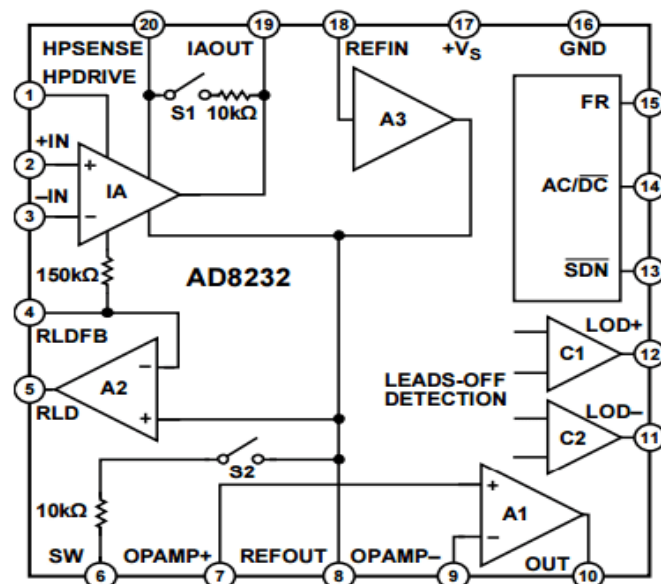


Figure 4.2 AD8232 sensor (ECG sensor)

4.1.3 Defibrillation Electrode Pads:

In the Figure 4.3, these pads serve as the interface between the defibrillator and the patient's body during a cardiac emergency. Defibrillation electrode pads are designed to deliver an electric shock to the patient's heart in order to restore a normal cardiac rhythm during life-threatening conditions like ventricular fibrillation or ventricular tachycardia (Tonko et.al, 2022). Two pads are typically used, one placed on the right side of the patient's chest and the other on the left side below the pectoral muscle.



Figure 4.3 Adhesive electrode pads

4.1.4 Audio Output:

The audio output can provide feedback on the device's status and the progress of the defibrillation procedure. It can announce when the device is ready for use, when it's analyzing the patient's heart rhythm, and when it's charging to deliver a shock. It's necessary that the audio output is clear, easily understandable, and designed to effectively guide users through the defibrillation process.

4.1.5 Power Supply:

The use of a battery as a power supply in a portable defibrillator using Arduino offers several key advantages, making it a suitable choice. Batteries are known for their energy density, which allows for a compact and lightweight power source.

4.2 BLOCK DIAGRAM:

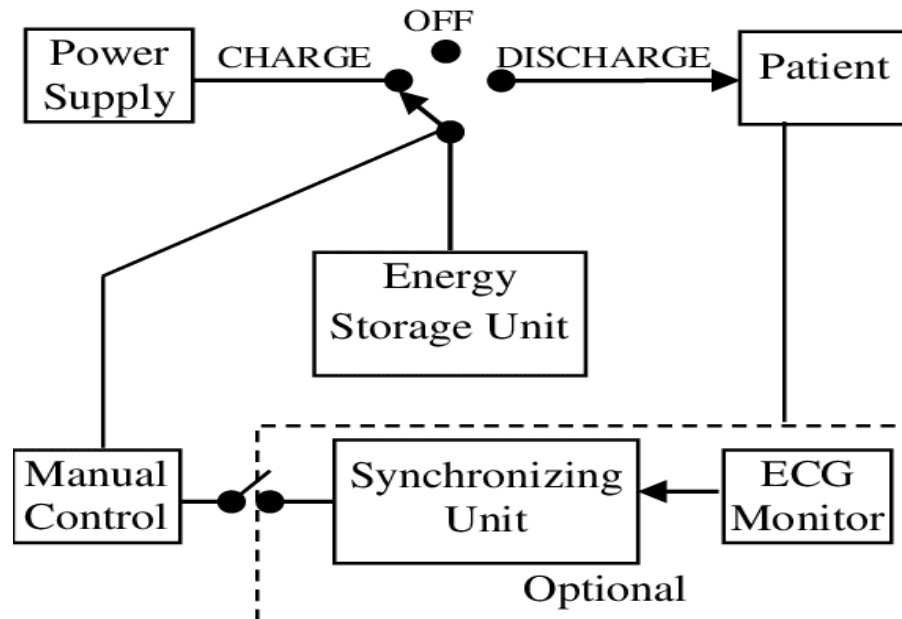


Figure 4.4 Block Diagram for ECG Monitor interfaced with defibrillator

The Block Diagram referring to Figure 4.4, it is evident that it illustrates the seamless integration of an ECG Monitor and Defibrillator, forming a sophisticated system for diagnosing and treating cardiac emergencies. The ECG Monitor detects and analyzes the patient's cardiac activity, transmitting data to the processing unit. Sophisticated algorithms interpret the ECG waveform, identifying life-threatening abnormalities. When detected, the processing unit triggers the Defibrillator to deliver a precise electrical shock, restoring normal heart rhythm. The Defibrillator, with its specialized electrodes and auxiliary features, guides users through the intervention process. This integrated system streamlines diagnostic and treatment procedures, maximizing chances of successful outcomes and ultimately saving lives.

4.3 CALCULATING HEART RATE VARIABILITY (HRV):

- We will try to measure heartbeat and heart rate variability (HRV) using AD8232 ECG sensor. As discussed earlier, $HR = \text{No. of R peaks in 1 minute}$.

- Hence, many people tend to measure the time interval between two consecutive R peaks and estimate HR using the following formula

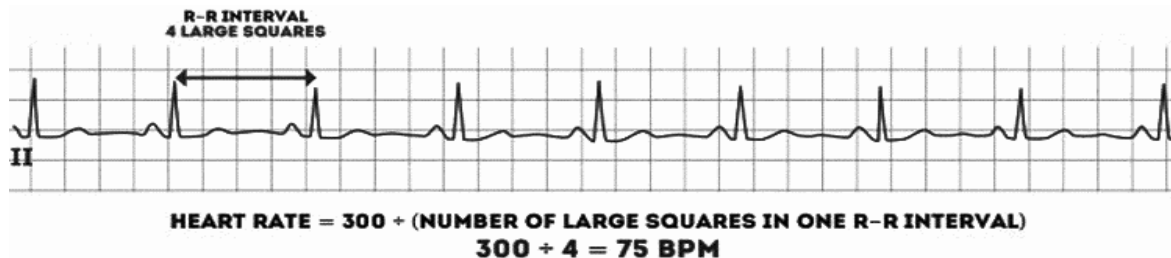


Figure 4.5 Heart Rate Variability

Heart rate variability or HRV is calculated as follows-

➤ $HRV = HR/60 - RR \text{ interval}$

So, for calculating HRV, we need HR first. But 1 minute is too long. Hence, we use a window of 10 seconds to calculate both parameters as shown in Figure 4.5.

➤ $HR = (RR \text{ peaks in 10 seconds}) * 6$

➤ $HRV = HRV = HR/60 - RR \text{ interval}$

We can easily identify the R peak by thresholding. Then we can use interrupts or simple micros () to measure the interval between the two beats (Lucas et.al 2022).

4.4 ECG WAVEFORM:

The output of heart rhythm analysis generated from the heart monitoring system, displayed on the serial plotter as seen in Figure 4.6 and serial monitor as seen in Figure 4.7, serves as a crucial indicator of the patient's cardiac activity. Through real-time monitoring and analysis of electrocardiogram (ECG) signals (Adam et.al, 2023), the

system can detect various cardiac arrhythmias, including ventricular fibrillation (VF) or ventricular tachycardia (VT), which may necessitate defibrillation intervention.

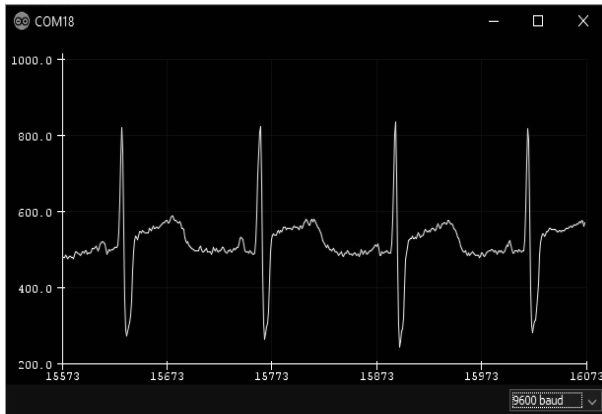


Figure 4.6 Serial Plotter

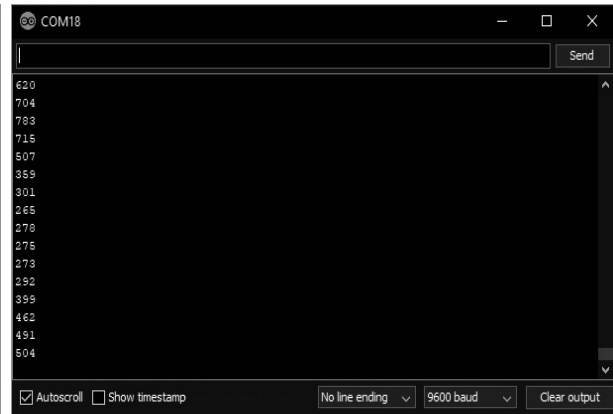


Figure 4.7 Serial Monitor

Once a definitive diagnosis is made, and if indicated, the system proceeds to deliver a therapeutic shock to the patient's heart. The shock is administered through the defibrillation electrodes (Nichol et.al 2017), strategically placed on the patient's chest, in accordance with established protocols and guidelines.

The shock delivered aims to interrupt the chaotic electrical activity of the heart, effectively resetting the cardiac rhythm and restoring normal sinus rhythm. This intervention is critical in cases of VF or VT (Brignoli Marcello et.al 2023), where the heart's electrical signals become disorganized, leading to ineffective pumping and potential cardiac arrest.

Through precise analysis of heart rhythm data and timely delivery of therapeutic shocks, the heart monitoring system plays a pivotal role in managing cardiac emergencies and improving patient outcomes (Zaidi et.al, 2021). By leveraging advanced technology and algorithmic algorithms, the system ensures swift and effective intervention, ultimately contributing to the preservation of life in critical cardiac situations.

4.5 SHOCK DELIVERY SYSTEM:

Designing a shock delivery system for an Automated External Defibrillator (AED) is a complex task that involves ensuring patient safety, meeting regulatory standards, and addressing the specific requirements (Olalera et.al, 2023) of a medical device. Accompanying charging circuits, energy-storage parts (such capacitors), and a way to release the electric shock are common components of AED shock delivery systems.

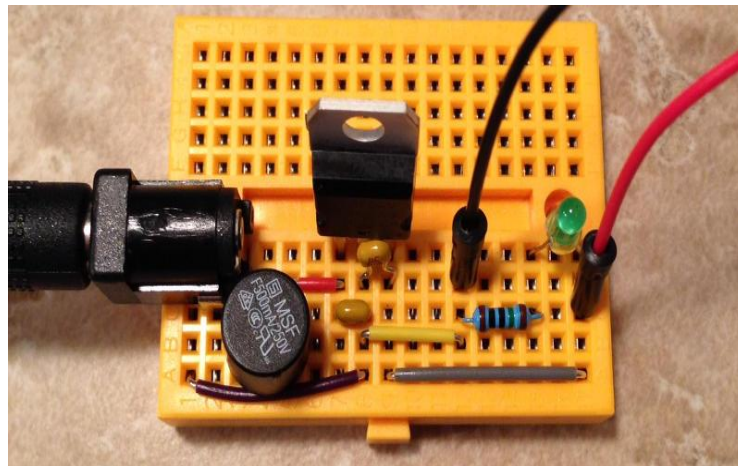


Figure 4.8 Power supply unit

Moreover, during the designed phase shown in the Figure 4.8, strict adherence to regulatory criteria established by governing organizations and health authorities is required (Gianni et.al 2023). These standards cover the shock delivery system's technical requirements as well as more general factors like usability, dependability, and compatibility with the current medical infrastructure.

Overall, the AED's shock delivery system is a painstakingly designed collection of parts that work together to provide a regulated electrical pulse that can, in an emergency, restore normal heart function (Snow et.al, 2023). AED manufacturers guarantee that their devices are capable of providing prompt, accurate, and possibly life-saving actions during cardiac emergencies (Samani et.al 2016) by integrating charging circuits, capacitors, and discharge mechanisms in a seamless manner.

4.5.1 Components for a Shock Delivery Unit:

- *Charging Circuit:*

Implement a charging circuit responsible for gradually charging the high-voltage capacitors to the required energy level.

- *Energy Storage (Capacitors):*

Select high-voltage capacitors with sufficient energy storage capacity to deliver an effective electric shock. Ensure the capacitors meet safety and regulatory standards.

- *Discharge Mechanism:*

Implement a controlled discharge mechanism to release the stored energy from the capacitors. This may involve a solid-state switch (e.g., MOSFET) or a relay can be used.

- *Monitoring Circuitry:*

Include monitoring circuitry to assess the patient's heart rhythm and determine the necessity of a shock. This could involve a monitoring system or other appropriate sensors.

- *LEDs:*

Light Emitting Diodes (LEDs) for indicating the status of the AED. This could include power LEDs, shock LEDs, and pads LEDs.

- *Resistors:*

Resistors may be used in various parts of the circuit for current limiting, voltage division, or other purposes.

4.6 SCHEMATIC OF POWER SUPPLY CIRCUIT:

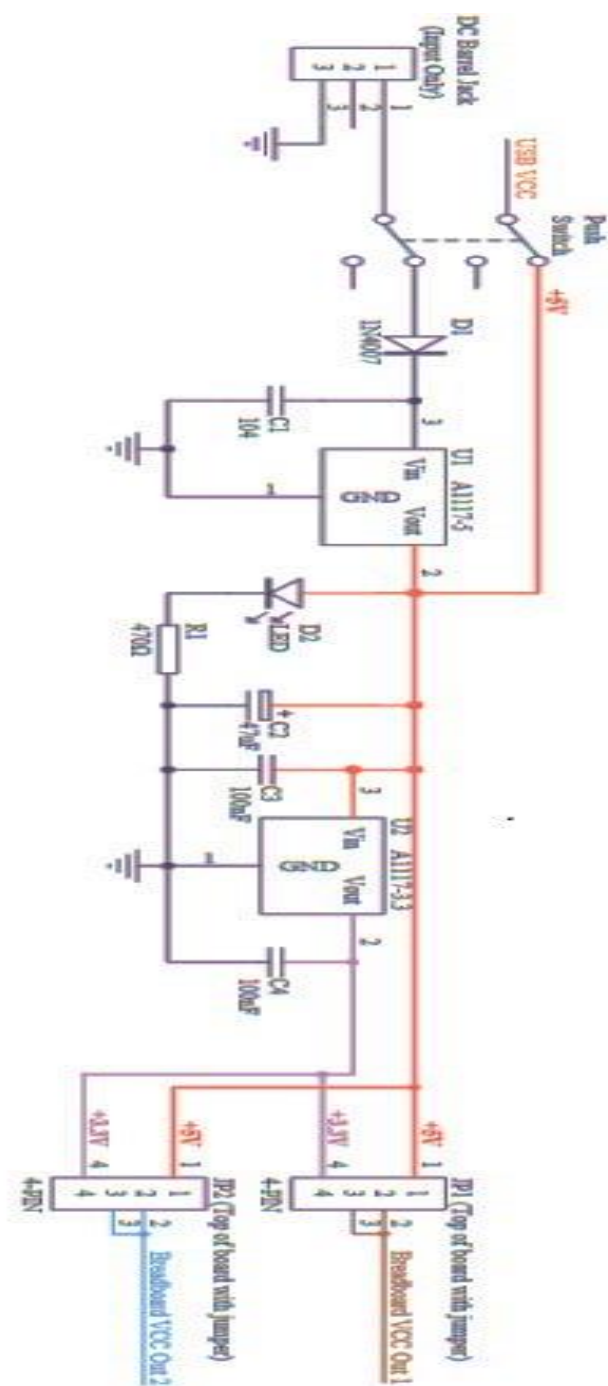


Figure 4.9 Schematic of Power Supply circuit

4.7 HW131 POWER SUPPLY BOARD:

The HW131 power supply circuit shown in Figure 4.9 plays a crucial role in the operation of the portable defibrillator with ECG monitoring system, facilitating both the charging and discharging phases of the capacitor used in the defibrillation process.

During the charging phase simulation, when the circuit is powered on, the capacitor begins to charge. This process is essential for accumulating the necessary electrical energy required for a potential defibrillation shock (Haque et.al 2022). To provide feedback to the user and indicate the progression of the charging phase, the circuit incorporates charging sound or indicator lights. These auditory and visual cues inform the user that the capacitor is actively charging and nearing readiness for potential use presented in Figure 4.10.

Upon reaching a predetermined voltage threshold, the circuit triggers the board timer to initiate the discharge phase simulation. This phase mimics the discharge process without actually delivering a shock to the patient (Mahesh et.al 2020). Instead, it simulates the discharge cycle to replicate the behavior of the defibrillator during a real-world scenario. This simulated discharge phase is crucial for training purposes, allowing healthcare professionals to practice the sequence of events and procedures involved in defibrillation without posing any risk to patients.

In summary, the HW131 power supply circuit in the portable defibrillator with ECG monitoring system effectively manages the charging and discharging phases of the capacitor, providing essential feedback and simulations to ensure the device's functionality and user training capabilities. By accurately replicating these critical phases of the defibrillation process, the circuit contributes to the overall effectiveness and safety of the portable defibrillator system (Stoevelaar et.al 2018).

4.7.1 Function of HW131 Power Supply Circuit:

- *Charging Phase Simulation:*
 1. When the circuit is turned on, the capacitor starts charging.
 2. Charging sound or indicator lights to represent the capacitor charging.
- *Discharging Phase Simulation:*
 1. Once the capacitor reaches a certain voltage, trigger the board timer to initiate the discharge phase.
 2. Simulate the discharge process without delivering a shock.

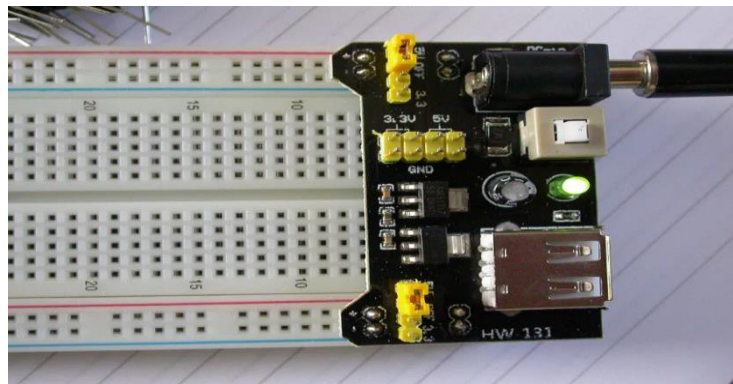


Figure 4.10 Hw131 Power supply

4.8 DFPLAYER MINI MP3 MODULE:

The DFPlayer Mini module shown in the Figure 4.11 is integrated into a portable defibrillator, assumes a crucial role as an audio playback component, primarily tasked with delivering voice prompts, alarms, feedback, and guidance to users throughout defibrillation procedures. Its core function revolves around providing clear and concise auditory instructions to aid users in performing the necessary steps accurately and efficiently during critical moments of defibrillator operation (Nielsen et.al,2015). Additionally, the module features an SD card slot, enhancing its versatility by enabling the storage and playback of a diverse range of audio files, further augmenting its capacity to deliver essential guidance and information during emergency situations.

4.8.1 Voice Prompts:

The DFPlayer Mini can store and play pre-recorded voice prompts that guide the user through various stages of using the defibrillator. These prompts may include instructions on how to apply electrode pads, when to press the shock button, and other relevant information.

4.8.2 Alarms and Alerts:

The module can generate alarms or alerts to grab the user's attention during critical moments or when specific actions are required. For example, it could sound an alarm to signal the need for immediate defibrillation or provide an alert if electrode pads are not properly connected.

4.8.3 Feedback on Device Status:

Voice prompts or audio cues can be used to provide feedback on the status of the defibrillator. This might include confirming that the device is powered on, indicating when it's ready for use, and notifying the user of any errors or issues that need attention.

4.8.4 Procedure Assistance:

The DFPlayer Mini can assist the user by providing step-by-step guidance on performing defibrillation procedures. It can help ensure that the user follows the correct sequence of actions, such as applying pads, pressing the shock button, and initiating CPR if necessary.

4.8.5 Multi-Language Support:

If your DFPlayer Mini supports it, you can implement multi-language support for voice prompts, allowing the defibrillator to communicate with users in different languages.

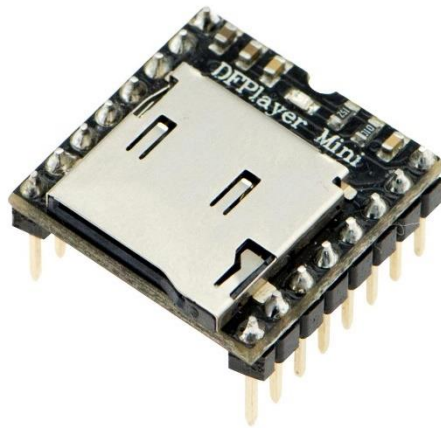


Figure 4.11 DfPlayer mini mp3 module

4.9 CIRCUIT DIAGRAM OF AED:

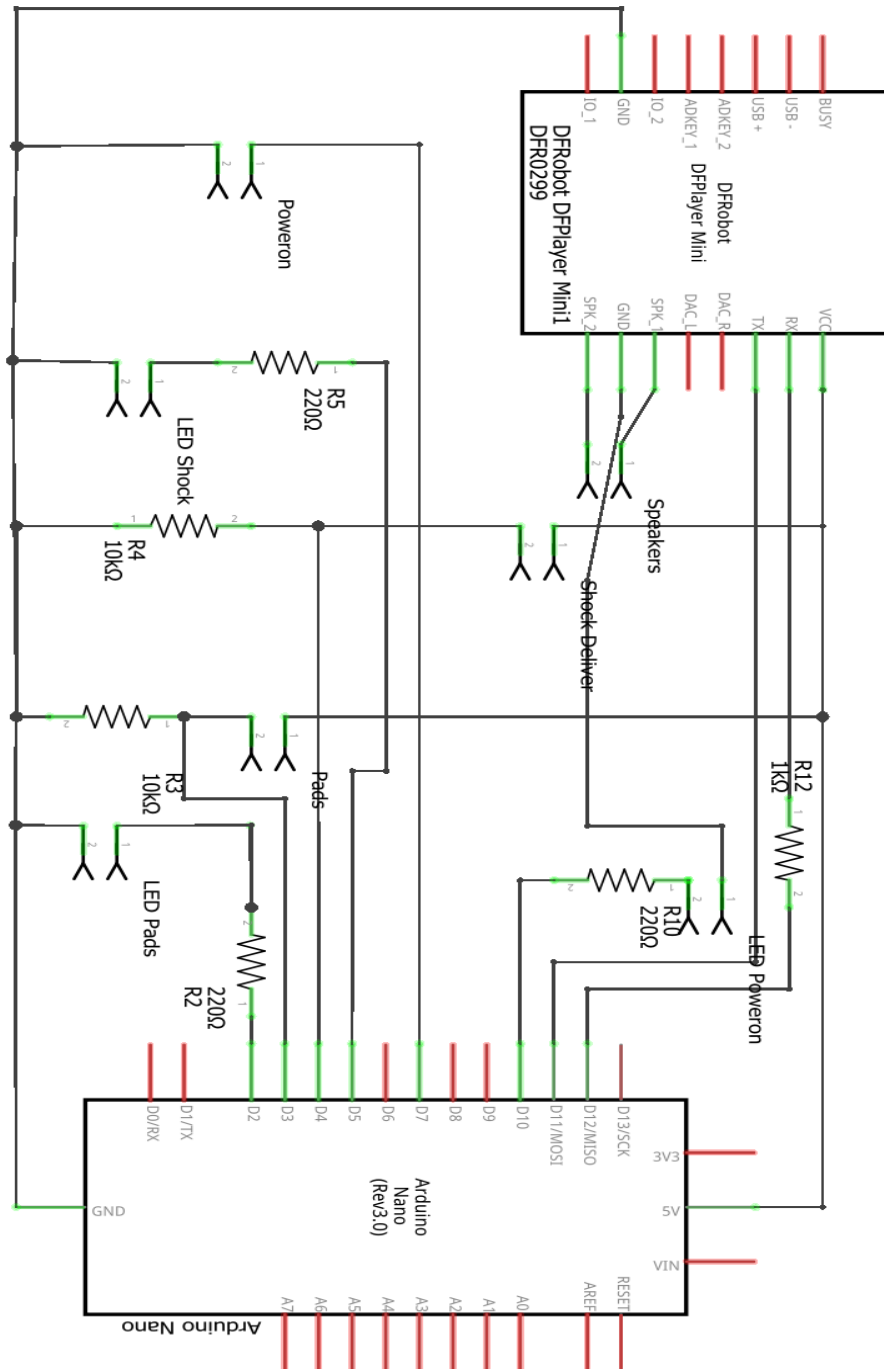


Figure 4.12 Circuit Diagram of AED

4.9.1 Circuit Description:

Referring to Figure 4.12, the circuit diagram portrays the intricate interconnections and components integral to a defibrillator system, with a particular focus on the integration of the DFPlayer Mini module and the Arduino Nano microcontroller. Serving as a pivotal component, the DFPlayer Mini assumes the role of an audio playback module, crucial for delivering essential voice prompts, alarms, and feedback throughout defibrillation procedures. These auditory cues play a pivotal role in guiding users through the intricate steps of defibrillation, ensuring swift and accurate response during critical moments.

Key connections within the circuit include power inputs such as VCC and GND, which provide the necessary electrical supply to the DFPlayer Mini and other components. Communication lines like RX and TX facilitate seamless data exchange between the DFPlayer Mini and Arduino Nano, enabling effective control and synchronization of audio playback functions. Furthermore, control inputs like ADKEY_1 and ADKEY_2 allow for user interaction and input, enhancing the defibrillator's usability and versatility.

The presence of various passive components such as resistors (R2, R3, R4, R5, R10, R12) and LEDs (LED Shock, LED Poweron, LED Pads) underscores the comprehensive functionality and safety considerations inherent in the defibrillator design. These components play crucial roles in regulating electrical signals, indicating operational status, and ensuring safe and effective shock delivery.

Overall, the integration of the DFPlayer Mini augments the defibrillator's functionality by providing clear and concise auditory guidance to users. This enhancement not only streamlines the defibrillation process but also holds the potential to significantly improve response times and patient outcomes during emergency situations. By combining advanced technology with robust safety features, the defibrillator circuit exemplifies a sophisticated yet user-friendly medical device aimed at saving lives in critical scenarios.

CHAPTER 5

RESULTS AND DISCUSSION, PERFORMANCE ANALYSIS

5.1 PROTOTYPE:

Our prototype shown in Figure 5.1, portable defibrillator with an integrated ECG monitoring system, designed to deliver defibrillation shocks based on real-time ECG data. The system incorporates a DFPlayer Mini module responsible for providing audio prompts that guide users through the defibrillation procedure, ensuring accurate execution. Additionally, four LED indicators offer visual cues to assist users in monitoring the device's status and progression of the procedure.

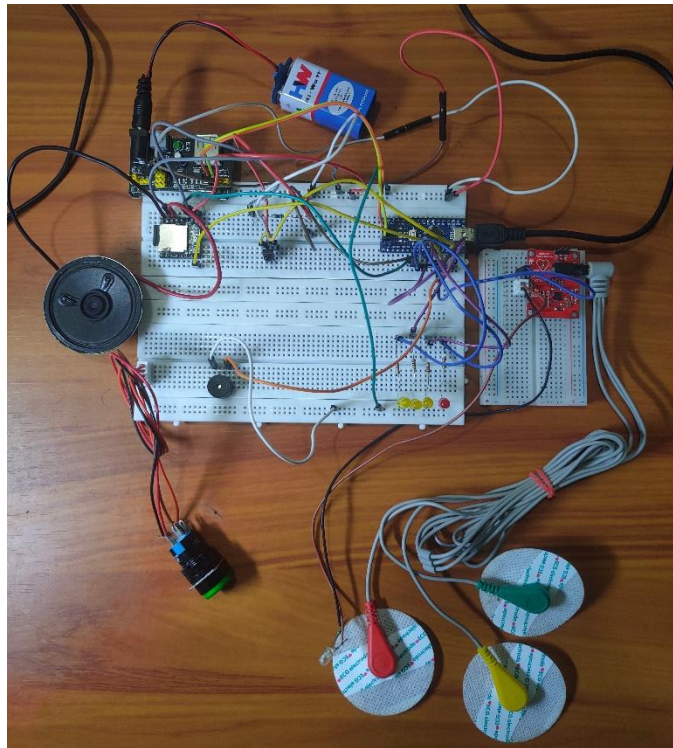


Figure 5.1 Overall view of the Prototype

The ECG monitoring system continuously analyzes the patient's cardiac rhythm, detecting any abnormalities that may indicate a life-threatening arrhythmia requiring defibrillation intervention. Once such an anomaly is identified, the system triggers the DFPlayer Mini module to deliver audio prompts, instructing users on the necessary steps to prepare for defibrillation.

Simultaneously, the LED indicators illuminate to provide visual feedback regarding the device's status. For instance, one LED may indicate that the system is ready for defibrillation, while another may signal the charging phase, informing users that the capacitor is accumulating energy for the shock. Additional LEDs can signify the completion of the charging phase and readiness to deliver the shock.

As the procedure progresses, the DFPlayer Mini continues to provide audio prompts, guiding users through the critical steps of defibrillation, such as ensuring proper electrode placement and verifying that bystanders are clear of the patient. The LED indicators complement these instructions by offering real-time visual feedback.

5.2 PERFORMANCE ANALYSIS:

1. Boot-Up:

When we switch on the system, the "System Booting Up" audio prompt is played, accompanied by the illumination of the corresponding LED connected to pin 4 as shown in Figure 5.2.

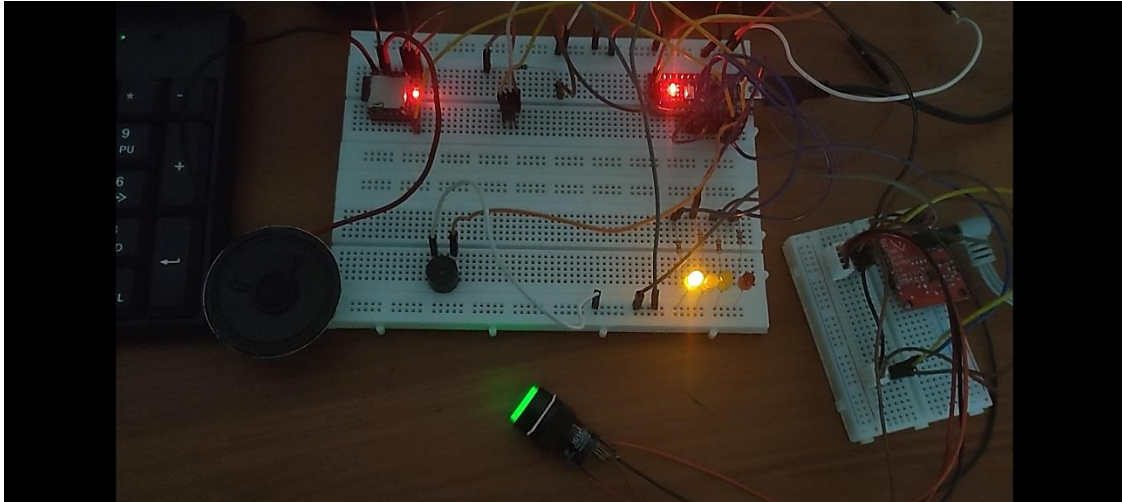


Figure 5.2 System Booting up

2. Calm and Contact Emergencies:

Following the boot-up process, the "Stay Calm and Contact Medical Emergencies " audio prompt is initiated, signaling users to remain calm and seek emergency assistance. Simultaneously, referring to Figure 5.3, the LED linked to pin 5 lights up.

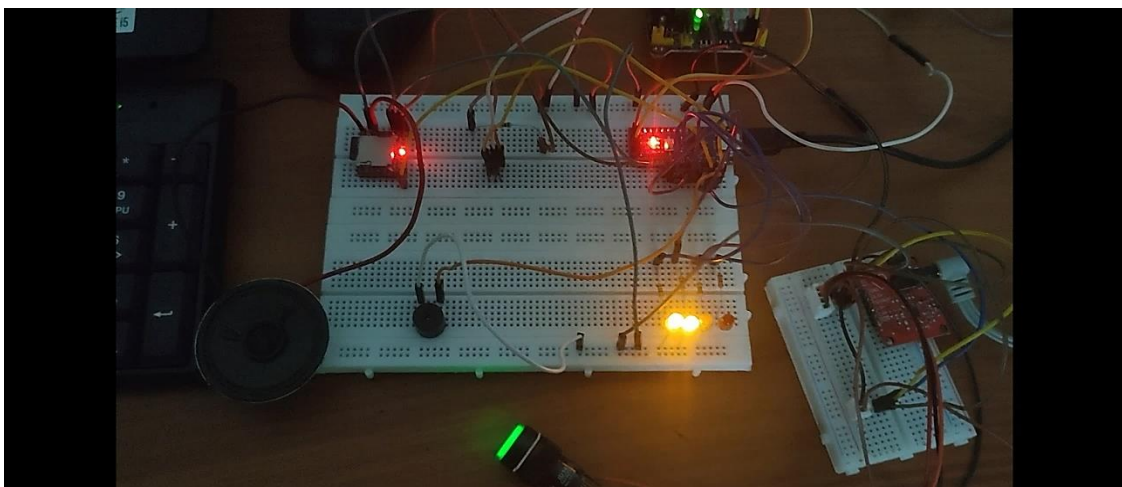


Figure 5.3 Second stage initiated

3. Apply the Pads:

The system enters a continuous loop prompting users to "Plug the electrode and apply the pads to bare skin as instructions." This audio prompt, essential for proper AED usage, is reiterated to ensure user understanding. Meanwhile, referring to Figure 5.4, the Apply the Pads LED, connected to pin 6, either flashes or remains steadily illuminated, providing visual guidance.

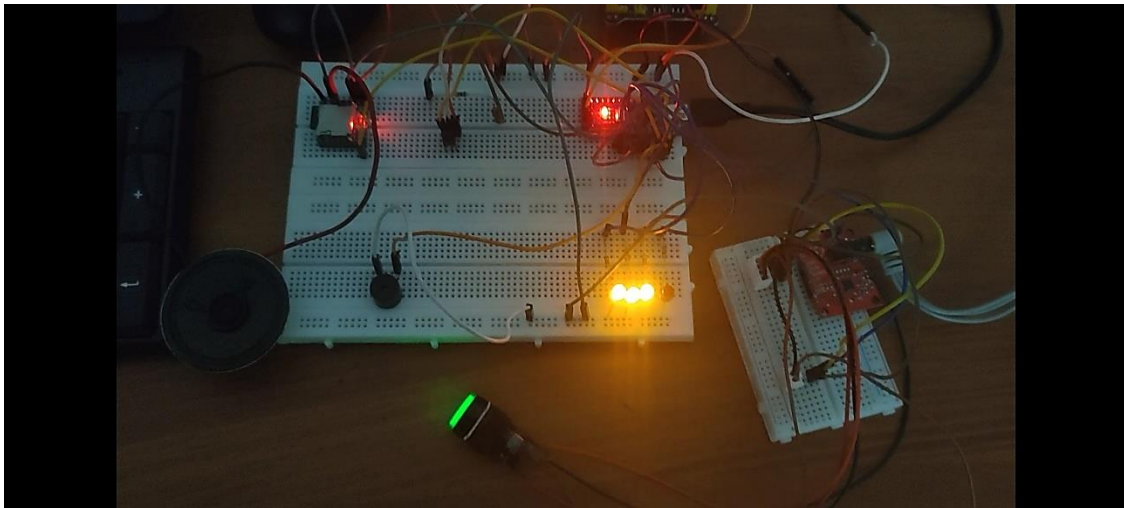


Figure 5.4 Indicator light begin to blink to apply pads

4. Remote Control Operation:

In Figure 5.5, Users can interact with the system using an IR remote control:

Pressing "1" initiates the playback of the "Evaluating heart rhythm, do not touch the patient" audio prompt.

Pressing "2" triggers the "Shock recommended, press the shock button to deliver shocks" audio prompt, indicating the readiness for potential defibrillation.

Pressing "3" prompts the playback of the "No shock advised, please continue" audio prompt, guiding users to proceed without delivering a shock.

"+" and "-" buttons adjust the volume level.

Pressing the "EQ" button resets the system.



Figure 5.5 IR Remote

5. Shock Delivery Simulation:

If shock delivery is recommended (by pressing "2"), the system enters a standby state. The Shock Recommended LED, connected to pin 7, flashes to indicate readiness. Users can simulate shock delivery by pressing the shock button seen in the Figure 5.6 connected to pin 8. Upon activation, the corresponding audio prompt is played to guide users through the process.

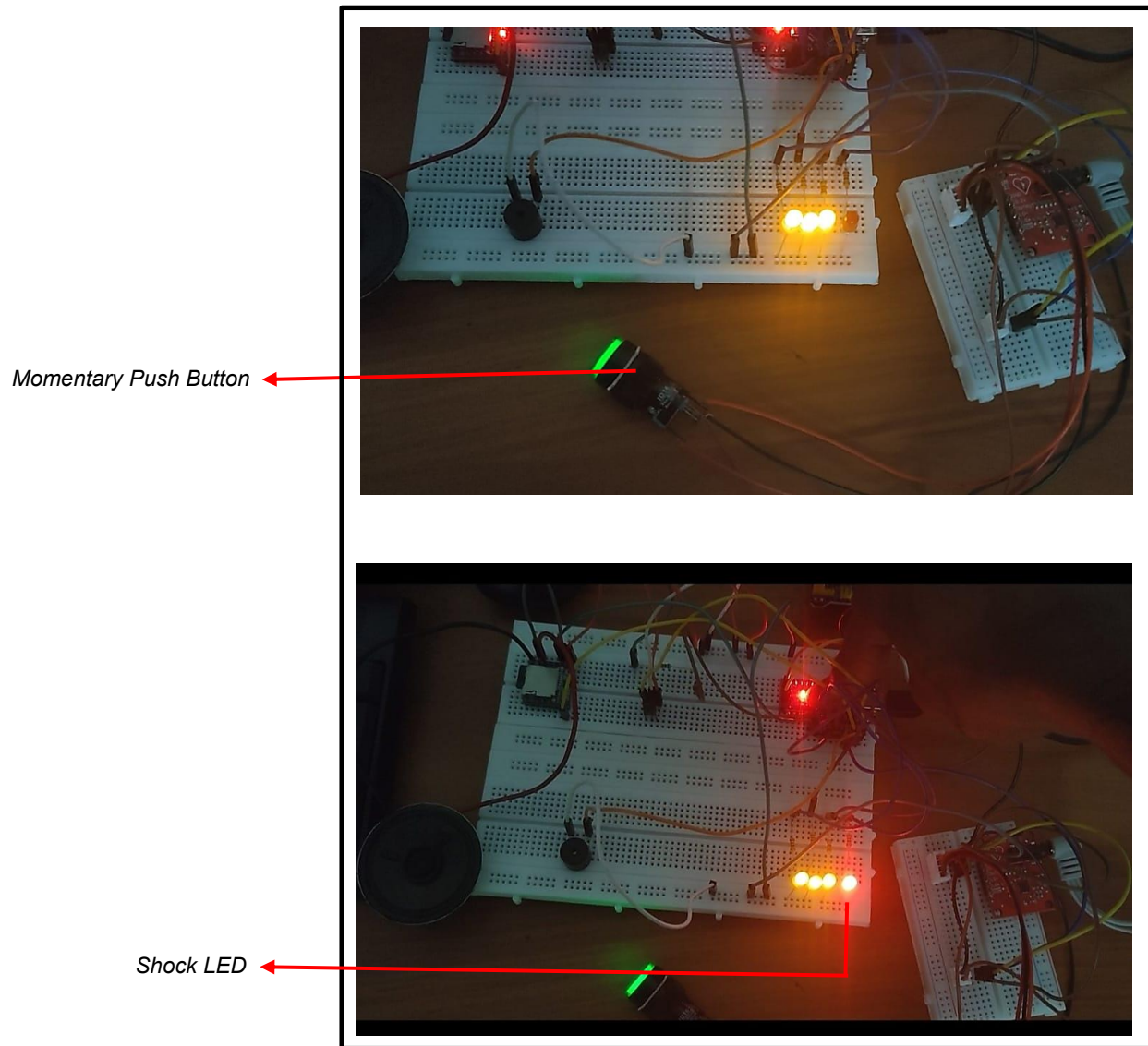


Figure 5.6 Shock delivery and Hazard Indication

6. CPR Simulation:

After shock delivery or when "No shock advised" is selected (by pressing "3"), the system enters a CPR simulation mode. Here, the buzzer connected to pin 10 simulates the compression frequency required during CPR presented in Figure 5.7. This simulation persists for 2 minutes, after which the system returns to the looped "Plug the electrode and apply the pads" audio prompt.

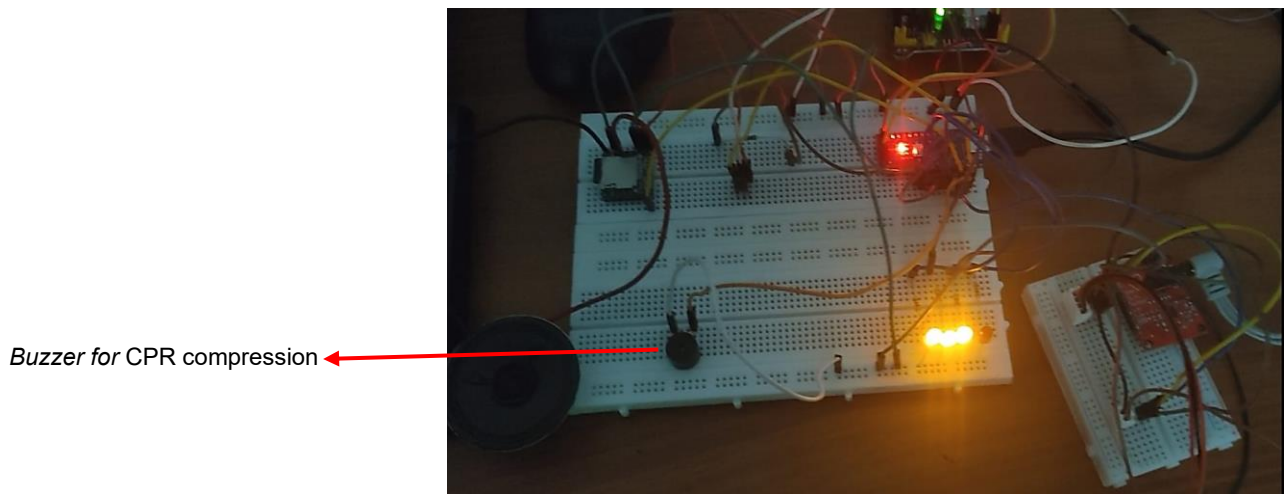


Figure 5.7 CPR Simulation

7. Reset:

To reset the system and return to the initial state, users can press the "EQ" button on the remote control, ensuring a seamless transition for subsequent training sessions.

5.3 OUTPUT AND DISCUSSION:

We have tested the prototype to ensure its effectiveness and safety. Through meticulous experimentation and measurements using a multimeter, we have determined that the shock delivered by the prototype exceeds 4.5V as shown in the Figure 5.8, meeting the requirements for effective defibrillation. This voltage level has been verified through multiple trials, ensuring consistency and reliability in training simulations.

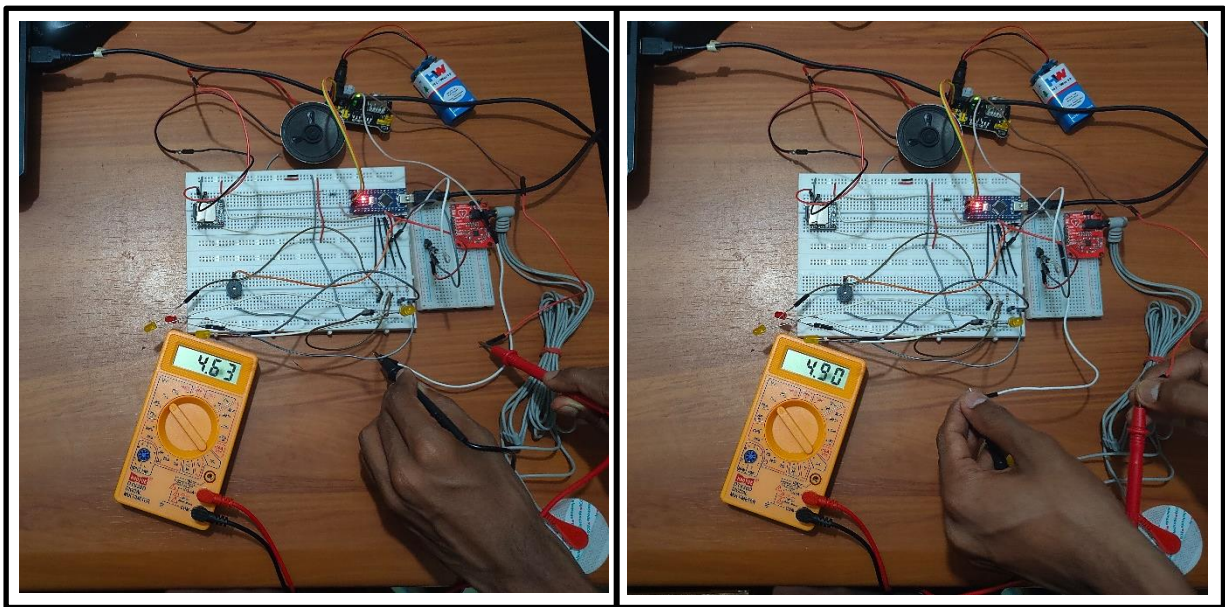


Figure 5.8 Prototype Output and Shock Voltage

By delivering a shock voltage exceeding 4.5V, our prototype accurately replicates the conditions encountered during actual defibrillation procedures. This ensures that users receive a realistic training experience, preparing them to confidently respond to cardiac emergencies in real-life scenarios.

CHAPTER 6

SUMMARY AND CONCLUSION

The Portable Defibrillator with ECG Monitoring System represents a significant advancement in training technology for automated external defibrillator (AED) usage. Designed to provide users with an easy-to-use and realistic training experience, the prototype incorporates intuitive features such as audio prompts, visual feedback, and remote-control operation. By simulating real-life emergency scenarios, users can effectively practice AED usage protocols, enhancing their preparedness to respond to cardiac emergencies. The ability to deliver a defibrillation shock in response to detected abnormalities can significantly improve patient outcomes, increasing the likelihood of survival during cardiac emergencies.

In conclusion, the Portable Defibrillator prototype offers a comprehensive solution for training individuals in the application of AEDs. By combining technology with user-friendly design, the prototype enables users to gain practical experience in administering defibrillation and monitoring cardiac rhythms. With its simple interface and realistic simulation capabilities, the prototype empowers users to confidently respond to cardiac emergencies. With its successful delivery of defibrillation shocks and emphasis on realistic training experiences, this prototype represents a significant step forward in the field of emergency medical training. As we continue to refine and optimize this technology, we aim to further enhance user preparedness and ultimately contribute to improved outcomes for cardiac arrest victims worldwide. ultimately contributing to improved outcomes for victims of sudden cardiac arrest. As technology continues to evolve, innovations like the Portable Defibrillator prototype play a vital role in enhancing emergency response capabilities and saving lives.

REFERENCES:

- [1] Ádám, Norbert, Dávid Vaľko, and Branislav Madoš. "Acquiring favorable ECG signal from low-cost devices." In 2023 IEEE 21st World Symposium on Applied Machine Intelligence and Informatics (SAMI), pp. 000191-000194. IEEE, 2023.
- [2] Ball, Morgan, Simmonds, Bray, Bailey, & Finn (2022). Strategic placement of automated external defibrillators (AEDs) for cardiac arrests in public locations and private residences. *Resuscitation Plus*, 10, 100237.
- [3] Brignoli Marcello, Agostino Mattera, Raffaele Chianese, Angelo Simonetti, Domenico Vittoria, and Miguel Viscusi. "Real world use of a novel ventricular tachyarrhythmia detection algorithm: a case report." *HeartRhythm Case Reports* 2023
- [4] Brown, Grace, Samuel Conway, Mahmood Ahmad, Divine Adegbe, Nishil Patel, Vidushi Myneni, Mohammad Alradhawi et al. "Role of artificial intelligence in defibrillators: A narrative review." *Open Heart* 9, no. 2: e001976, 2022.
- [5] Emad Mayss, Ahmed Rashid, and Amjad J. Humaidi. "Design and Implementation of Portable Auto Defibrillator." In *IOP Conference Series: Materials Science and Engineering*, vol. 1105, no. 1, p. 012069. IOP Publishing, 2021.
- [6] Gajendiran M. "An Automated External Defibrillator in Robotic Ambulance (Ambubot) ." (IRJAET) Vol 3 issue 2, pp 2095 – 2106, 2017.
- [7] Gianni, Alessandro, Marco Botteri, Giuseppe Stirparo, Giulia Mattesi, Alessandro Zorzi, and Guido Francesco Villa. "The Impact of the Italian Law Mandating an Automatic External Defibrillator in All Sports Venues on Sudden Cardiac Arrest Resuscitation Rates." *European Journal of Preventive Cardiology*, 2023.

- [8] Haque, Md Fahim Inzamam Ul, Sadia Sabina, Mohammad Monirujjaman Khan, and Ipseeta Nanda. "Arduino based Smart Design of a Cheaper and Portable Automated Cardiopulmonary Resuscitation (CPR) Device." In 2022 6th International Conference on Computing Methodologies and Communication (ICCMC), pp. 1098-1105. IEEE, 2022.
- [9] Han, Wenguang, Yongjun Li, Rui Zhang, Chao Hu, and Max Q-H. Meng. "A new ECG-based automated external defibrillator system." In 2010 8th World Congress on Intelligent Control and Automation, pp. 2204-2209. IEEE, 2010.
- [10] Jacob, Jerry, Adarsh S. R, Ashis C. K and Resmi R.. "Miniaturized CPR feedback device using Arduino and ardlab." In 2019 IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT), pp. 1-4. IEEE, 2019.
- [11] Li, Weiming, Jingru Li, Liang Wei, Jianjie Wang, Li Peng, Juan Wang, Changlin Yin, and Yongqin Li. "A framework of current based defibrillation improves defibrillation efficacy of biphasic truncated exponential waveform in rabbits." Scientific Reports 11, no. 1: 1586, 2021.
- [12] Lucas, Brendan, Aditya Mahamuni, Vinyas Kulal, Abhi Gupta, and Kalpana Deorukhkar. "Affordable Real-Time Heart Rate, ECG & SpO2 Monitoring System Using Internet of Things (IoT)." 2022.
- [13] Mahesh and Sudheesh . P. "Design Anaysis of Defibrillator and Implementing Wireless Charging System." In 2020 5th International Conference on Communication and Electronics Systems (ICCES), pp. 295-299. IEEE, 2020.
- [14] Nath, Rahul Gopinathan, Manikandan .S, and Manoj G. S. "Development of Low-Cost Portable Defibrillator for Sudden Cardiac Arrest Management." Biomedical Materials & Devices pp. 1-7, 2023.

- [15] Namee, Khanista, Nuttapat Panong, and Jantima Polpinij. "Integration of IoT, edge computing and cloud computing for monitoring and controlling automated external defibrillator cabinets in emergency medical service." In 2019 5th International Conference on Information Management (ICIM), pp. 237-241. IEEE, 2019.
- [16] Nasimi, Fahimeh, and Mohammadreza Yazdchi. "LDIAED: a lightweight deep learning algorithm implementable on automated external defibrillators." Plos one 17, no. 2 e0264405, 2022.
- [17] Nichol, Graham, Michael R. Sayre, Federico Guerra, and Jeanne Poole. "Defibrillation for ventricular fibrillation: a shocking update." Journal of the American College of Cardiology 70, no. 12: 1496-1509, 2017.
- [18] Nielsen, Jens Cosedis, Jens Christian Gerdes, and Niraj Varma. "Infected cardiac-implantable electronic devices: prevention, diagnosis, and treatment." European heart journal 36, no. 37: 2484-2490, 2015
- [19] Olalere, Saidi Olayinka. "Analysis of Vibration and Thermal of a Modeled Circuit Board of Automated External Defibrillator (AED) Medical Device." arXiv preprint arXiv:2309.14747, 2023.
- [20] Samani. H and Zhu .R. Robotic automated external defibrillator ambulance for emergency medical service in smart cities. IEEE Access, 4, pp.268-283, 2016.
- [21] Snow, Lucas, James Whiting and Christopher Smith. "PP51 Dispatcher assisted AED use: a scoping review." Emergency Medicine Journal 40, no. Suppl 1 : A21-A21, 2023.
- [22] Stoevelaar.R, Brinkman-Stoppelenburg.A, Bhagwandien. R.E, van Bruchem Visser R.L., Theuns D.A, van der Heide A. and Rietjens J.A. The incidence and impact of implantable cardioverter defibrillator shocks in the last phase of life: an integrated

review. *European Journal of Cardiovascular Nursing*, 17(6), pp.477-485, 2018.

[23] Tonko J.B and Rinaldi, Non-traditional implantable cardioverter-defibrillator configurations and insertion techniques: a review of contemporary options. *EP Europace*, 24(2), pp.181-192, 2022.

[24] Zaidi, Naveed, Frederick J. Geheb, Qing Tan, and Gary A. Freeman. "Fast identification of shockable or non-shockable rhythms in ECG data." U.S. Patent 10,960,222, issued March 30, 2021.