LORA BASED CABLE THEFT DETECTION SYSTEM FOR STREET LIGHTING

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honors

Faculty of Electronics and Computer Technology and Engineering
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DEDICATION

I would like to record a million thanks to both of my parents who have given me a lot of encouragement and words of advice throughout my study on this course. After completing this project, a lot of knowledge is gained which is very beneficial and very useful through learning and skills throughout this final year project. The highest appreciation is given to Mr Mazran bin Esro and UTeM for providing an opportunity to undergo this final year project. Despite the many trials we went through, we finally succeeded as well spend our training.

ABSTRACT

Cable theft in Malaysia has caused significant losses and damage for TNB. To address this issue, this project proposes a LoRa-based cable theft detection system for street lighting. The project aims the development of a cable theft detection system for street lighting based on long range wireless network (LoRa), implementing an Internet of Things, IoT and analyzing the accuracy of optocoupler by varying limiting resistor (RD). For this project, PC817 optocoupler was utilized to sense 240Vac. The hardware development includes a transmitter, receiver, and optocoupler module. The transmitter uses LoRa communication for wireless data transmission to the gateway. The receiver uses ESP32 to interact with IoT platform. This project successfully implemented a cable theft detection system for street lighting, generating warning notification using IoT.

ABSTRAK

Kes kecurian kabel yang berlaku di Malaysia telah mengakibatkan kerugian dan kerosakan yang besar kepada TNB. Bagi menangani isu ini, projek ini mencadangkan sistem pengesanan kecurian kabel berasaskan LoRa untuk lampu jalan. Projek ini menyasarkan pembangunan sistem pengesanan kecurian kabel untuk lampu jalan berdasarkan rangkaian tanpa wayar jarak jauh (LoRa), melaksanakan Internet Pelbagai Benda, IoT dan menganalisis ketepatan optocoupler dengan mengubah perintang had (RD). Untuk projek ini, optocoupler PC817 telah digunakan untuk mengesan 240Vac dan mendeteksi kecurian kabel. Pembangunan perkakasan adalah termasuk modul pemancar, modul penerima dan optocoupler untuk mengesan voltan AC. Modul pemancar menggunakan komunikasi LoRa untuk penghantaran data tanpa wayar ke laluan memori. Modul penerima menggunakan ESP32 untuk berinteraksi dengan platform IoT. Papan PCB dibina, dan reka bentuk terlebih dahulu sebelum pematerian dan ujian di makmal fabrikasi. Projek ini telah berjaya melaksanakan sistem pengesanan kecurian kabel untuk lampu jalan dan menjana amaran notifikasi dengan menggunakan IoT.

ACKNOWLEDGEMENTS

The sense of accomplishment that comes from completing a task successfully would be insufficient if it did not include acknowledgement of the individuals who were instrumental in making the accomplishment possible and whose unwavering support and motivation were essential to the accomplishment of all of the endeavors.

My sincere gratitude goes out to my supervisor, Mr. Mazran Bin Esro, who inspired, helped me, and supported me at every step of the way, from the very beginning to the very conclusion of the project, and so made it possible for me to acquire a grasp of the topic.

Finally, but certainly not least, I would like to express my gratitude to En. Imran bin Mohamed Ali, the laboratory technician for the faculty, as well as the friends who assisted me in finishing the project. During the course of the completion of the project, I would want to show my appreciation and bestow my blessing on everyone who assisted me in any way.

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LIST OF SYMBOLS AND ABBREVIATIONS

LoRa	: (From “Long Range”)
IoT	: Internet of Things
TNB	: Tenaga Nasional Berhad
PCB	: Printed Circuit Board
CTMS	: Cable Theft Monitoring System
GSM	: Global System for Mobile Communication
PWM	: Pulse Width Modulation
AC	: Alternating Current
I_F	: Forward Current of The Optocoupler
I_C	: Collector Current
CTR	: Current Transfer Ratio
R_D	: Limiting Resistor
R_L	: Pull-Up Resistor

Cin	:	Input Capacitor
Cout	:	Output Capacitor
LED	:	Light-Emitting Diode
VCC	:	Voltage Common Collector

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The cases of cable theft from street lighting occur rather frequently each year in some locations, particularly in new residential areas. The country’s extensive network of street lighting makes it impractical to monitor or install a sensor at every position. Vast highway regions need surveillance systems that can operate over great distances to detect cable theft when it occurs. Thus, this project proposes a cable theft detection system based on long range wireless network, LoRa. The project will be possible to track current data on an IoT platform and identify cable theft. By using LoRa, the data can be transmitted within a distance of about 1 kilometer. The system will be developed to monitor and generate feedback for sensor detection. Two sets of LoRa will be implemented as Transmitter and Transceiver. The transmitter will sense the AC voltage at the location of the street lighting and report its findings to the receiver.

Transceiver will receive the data input and determine whether or not there has been a cable theft. The project will deal with the integrated monitoring system, which gives authorities accessibility at all times.

1.2 Problem Statement

Tenaga Nasional Berhad, TNB is the biggest listed electricity firm in Southeast Asia with assets at MYR 182.60 billion and one of Malaysia’s major street light providers. In some locations, cable theft from street lighting happens rather frequently every year and costs the government and TNB a lot of money. According to TheStar news in 2012, between 2004 and 2011, cable thefts at TNB’s sub-stations in the peninsula cost the company over MYR 170 million.

On other issue related to the Problem above, Street lighting without surveillance system at the new residential area led to cable theft occur. Because there was no advanced system in that place to monitor the cable serial in real time, the authorities had to wait on reports from the locals before taking action. Based on Mr. Bongani Mandla, director of electrotechnical services for the George Municipality, Damages occur at night, and load shedding is clearly a significant effect because some places that were left on or fixed the day before were reported to be damaged shortly after.

Thus, a LoRa-based cable theft detection system for street lighting will be proposed to address all of the issues mentioned above. The government and authorities can reduce the losses brought on by cable theft by using this approach. Authorities will be able to monitor cable activity via IoT platforms or social media with a focus on new residential areas according tothe development of current sensor technique and the deployment of LoRa.

1.3 Objectives of The Project

In this thesis paper, our goal is to develop a prototype of LoRa based cable theft detection system for street lighting that can be readily installed by the authorities, no matter where they are located. The utilization of this approach has the potential to enhance the monitoring system for cable street lighting in addition to being able to assist the authorities in lowering the likelihood that cable theft would occur. The major justification for this project's development is listed below:

1. To develop a cable theft detection system for street lighting based on long range wireless network, LoRa.
2. To implement an Internet of Things, IoT on the system and display the digital output of the optocoupler data on IoT dashboard.
3. To analyze the accuracy of optocoupler by varying Limiting Resistor, R_D.

1.4 Scope of The Project

This project involves constructing an optocoupler circuit module using the PC817 optocoupler in order to detect the presence of AC power. As part of the hardware development phase, the transmitter and receiver modules are developed. Transmitter and receiver are connected via LoRa to transmit data. The receiver module uses an

ESP32 to interact with the Blynk IoT platform, which enables the Blynk mobile app and email notifications. As part of the research, the limiting resistor (R_D) will be adjusted in order to test the optocoupler's accuracy. It is important to note that this project is limited to the prototype stage an cannot be tested on actual street lighting infrastructure.

CHAPTER 2

BACKGROUND STUDY

2.1 Introduction Literature Review

This chapter provides a concise summary of the research that was conducted in relation to the project an Lora Based Cable Theft Detection System for Street Lighting. The study of Arduino microcontrollers, PC817 optocoupler, Internet of Things, and even the underlying principles and products that have been applied are the subjects of the literature review. It is also necessary to summarize the existing body of literature and locate the evidence that can provide solutions to the study objectives and issues.

2.2 Introduction to Street Lighting System

An essential component of contemporary urban infrastructure is street lighting. Street lighting has been a vital part of urban development ever since the first streetlight was created in the 19th century. During the night, streetlights offer lighting, enhancing visibility and enhancing safety for both automobiles and pedestrians. Streetlights also help lower crime rates by discouraging criminal activities and enhancing residents' sense of security in cities. Additionally, lighting improves the aesthetics of urban settings, making them more appealing and pleasurable for locals and tourists alike. But there are certain difficulties with street illumination. The need for street light ing has substantially grown due to the fast development of urban populations across the world, creating new difficulties for city planners and politicians.

2.2.1 Early History of Street Lighting

A streetlight, light pole, lamp pole, lamppost, streetlamp, light standard, or lamp standard is an elevated source of light on the side of a road or path. A platform for a train may feature lights like these. Lighting for urban streets either followed or occasionally led the way as urban electric power distribution extended throughout industrialized nations in the 20th century.

Early lamps were employed in the cultures of Ancient Greece and Ancient Rome, where light was primarily utilized for security, both to prevent wanderers from stumbling over obstacles and to deter would-be burglars. Oil lamps were widely used at the time because they offered a steady and mild light. A lantern Arius was a slave who was in charge of lighting the oil lights in front of Roman villas.

But as early as 500 B.C., Beijing's inhabitants may have been the first to deploy "fixed position lighting" as opposed to hand-carried torches and lamps, using hollow bamboo as a conduit, and naturally occurring gas vents to build a type of streetlamps.[1]

Cities like Antioch illuminated its streets on the cusp of the Middle Ages, that persisted across the Arab Empire long before Europe.[2] Edwin Heathcote wrote: “The Romans lit the streets with oil lamps, and cities from Baghdad to Cordoba were similarly lit when most of Europe was living in what is now rather unfashionably referred to as the Dark Ages, but which was, from the point of view of street lighting, exactly that.”[3][4]

The first public street lighting was created in the 16th century, and it quickly spread after the development of lanterns with glass panes, which significantly increased the amount of light. The Parisian Parliament mandated the installation and lighting of torches at each crossroads in 1588. In 1594, the police replaced the torches with lanterns.[5] However, in the middle of the 17th century, it was common routine for travelers to hire a lantern-bearer if they had to move through the night along the winding, dark lanes.[6] In 1667, King Louis XIV gave the go-ahead for significant changes in Paris, including the installation and upkeep of lights on streets and at junctions as well as harsh penalties for stealing or vandalizing the fixtures. By the end of the 17th century, Paris had more than 2,700 streetlights, and by 1730, that number had doubled.

In the early 1700s, public street lighting was introduced in London. Lanterns were erected all the way from Hyde Park to the Queen's Palace at Kensington, according to a diarist writing in 1712, lighting the streets during the dark hours. [8]

Figure 2.1: Detail of street lighting from Paris.

2.3 Introduction of Cable Theft Detection System

For the purpose of detecting attempts to tamper with or cut cables, a security system known as a “cable theft detection system” has been developed. Using a combination of sensors and detecting techniques, the system keeps an eye on the cables and searches for any unexpected changes that may be indications of theft or tampering.

Cable theft is a significant problem in several industries, including energy distribution, telecommunications, and railway signaling. Cable theft might cause significant service disruptions, risk to public safety, and monetary losses. As a result, cable theft detection systems are necessary for the security and reliability of the cable network.

There are several types of cable theft detection systems, including GSM modem-based cable theft monitoring systems (CTMS), PWM-based power cable anti-theft and monitoring systems, and IntelliSense-enabled distributed street lighting control systems. The system to use depends on the needs and the specific application. Each system has advantages and restrictions unique to it.

2.3.1 Types of Cable Theft Detection System

2.3.1.1 Cable Theft Monitoring System (CTMS) Using GSM Modem

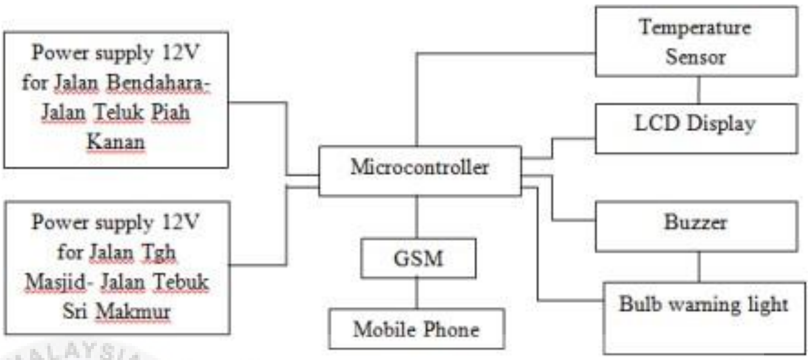

Figure 2.2: Overview of the project.

A cable theft monitoring system (CTMS) uses sensors and a GSM modem to detect any instances of cutting or tampering with cables. This system monitors the power, voltage, and current consumption of the cable network in order to function. It closely monitors any unusual changes that would indicate that a cable has been stolen or manipulated.

The system's components include sensors, a GSM modem, and a data collection system. The sensors are positioned throughout the whole length of the cable and are used to evaluate the electrical properties of the network. The data collecting system transports information from the sensors to the GSM modem, which then sends it via the cellular network to a centralized monitoring system.

The central monitoring system analyses the data and uses it to look for any odd network changes. The system may be set up to notify the appropriate authorities when a suspected theft or tampering incident is discovered.

The advantages of a CTMS and GSM modem-based cable theft detection system are its high accuracy, dependability, and ability to identify a range of cable tampering methods. It is also less prone to false alarms when compared to other types of cable theft detection systems.

However, there are considerable disadvantages to the approach. It could need significant hardware and software expenditures, as well as professional installation and maintenance skills. Network coverage issues could potentially affect it in areas with poor cellular network service. [7]

2.3.1.2 Distributed Street Lighting Control System with IntelliSense

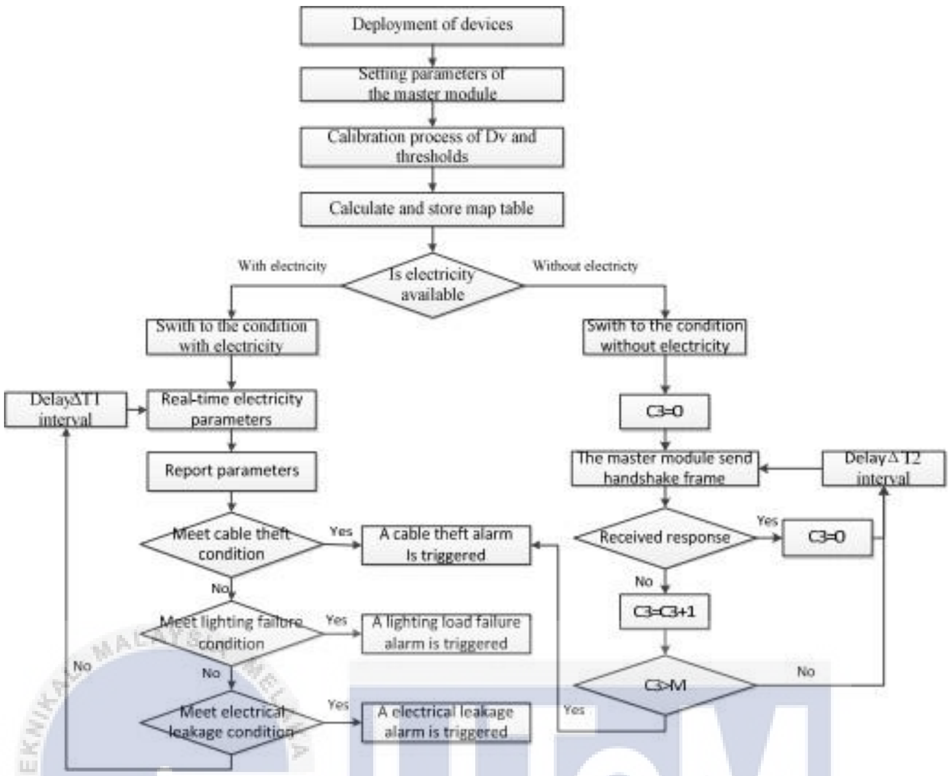

Figure 2.3: Process of cable theft detection.

A cable theft detection system for a distributed street lighting control system with IntelliSense employs sensors and advanced technology to detect any attempts to cut or tamper with street lighting cables. The system works by monitoring the street lighting network's voltage, current, and power usage and searching for any unexpected deviations that would indicate cable theft or manipulation.

The system's components include sensors, a data collection system, and a centralized control system. The sensors are used to assess the electrical properties of the network and are distributed throughout the length of the street lighting wires. The data that the data collecting system collects from the sensors is analyzed and used by the centrally controlled system to look for any anomalous changes in the network. [9]

Using intelligent technologies like artificial intelligence and machine learning algorithms, the system evaluates the data and looks for any trends or irregularities that may indicate cable theft or tampering. When it notices a possible theft or tampering activity, the system may also be set up to alert the relevant authorities.

One advantage of a cable theft detection system for a distributed street lighting control system with intelligence is its high accuracy and reliability as well as its capacity to recognize various cable tampering approaches. It is also less prone to false alarms when compared to other types of cable theft detection systems.

However, there are considerable disadvantages to the approach. It could need significant hardware and software expenditures, as well as professional installation and maintenance skills.

2.3.1.3 Development of a Power Cable Anti-Theft and Monitoring System Based on PWM.

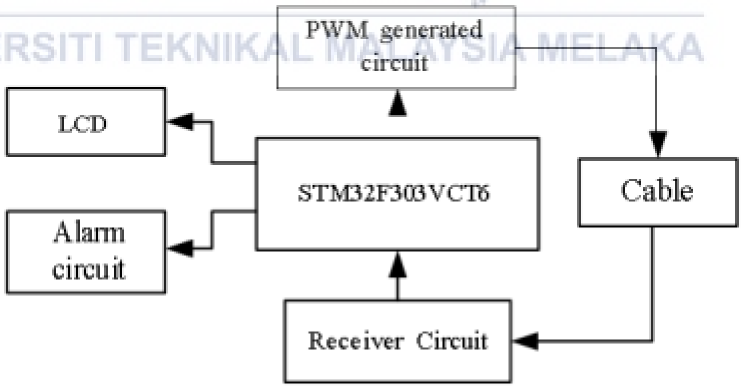

Figure 2.4: Architecture diagram of system.

As part of the creation of a power cable anti-theft and monitoring system, PWM technology is utilized to detect any attempts to cut or tamper with the power line. To run the system, a high-frequency signal is transmitted across the cable, and the reflected signal is then measured. When the cable is cut or tampered with, the signal that is reflected changes, and the system detects the change and activates an alert or warning.

The system's components include a PWM generator, a signal amplifier, a transmission line, and a signal receiver. The PWM generator produces a high-frequency signal, which the signal amplifier then amplifies and sends across the transmission line. The signal receiver receives the reflected signal and processes it to check for any signal changes. The system, which is designed to be put down the length of the power cord, has a PWM generator, signal amplifier, and signal receiver all at one end. The system can be powered by a battery or by the power line itself.

The advantages of a PWM-based power cable anti-theft and monitoring system are affordability, ease of installation, and the ability to detect various cable tampering methods. It is also less prone to false alarms when compared to other types of cable theft detection systems.

However, there are considerable disadvantages to the approach. It might not work well in settings with a lot of background noise or interference, and it might not be able to pick up on really subtle cuts or tampering attempts.

CHAPTER 3

METHODOLOGY

3.1 Project Methodology

In this chapter, the format of the proposal will be covered. The research project's approach is explained in this chapter. Figure 3.1 illustrates the approach flowchart, which has been divided down into three primary operations in order to accomplish the three goals of this research study. The optocoupler module circuit was first intended to detect the presence of AC power. Secondly, the optocoupler will be connected to the transmitter in order to construct the transmitter circuit. Figure 3.2 provides a detailed explanation of the whole process used to create the optocoupler and transmitter circuit's hardware and software.

Next, the Internet of Things (IoT) will be implemented by building the receiver circuit utilizing an ESP32 microcontroller. Additionally, the receiver circuit was designed to trigger an alert when cable theft happens or when the AC electricity is switched off. Figure 3.3 depicted more receiver circuit design operations. Figure 3.4 shows the analysis of the optocoupler component parameters' accuracy and the impact of limiting resistor (R_D) on forward current (I_F) and current transfer ratio (CTR%). Further information on the components that were utilized in the project and covering them in detail. The conceptual features of the software component, the hardware component, and the project implementation components are all covered in this chapter.

3.2 Project Flow Chart

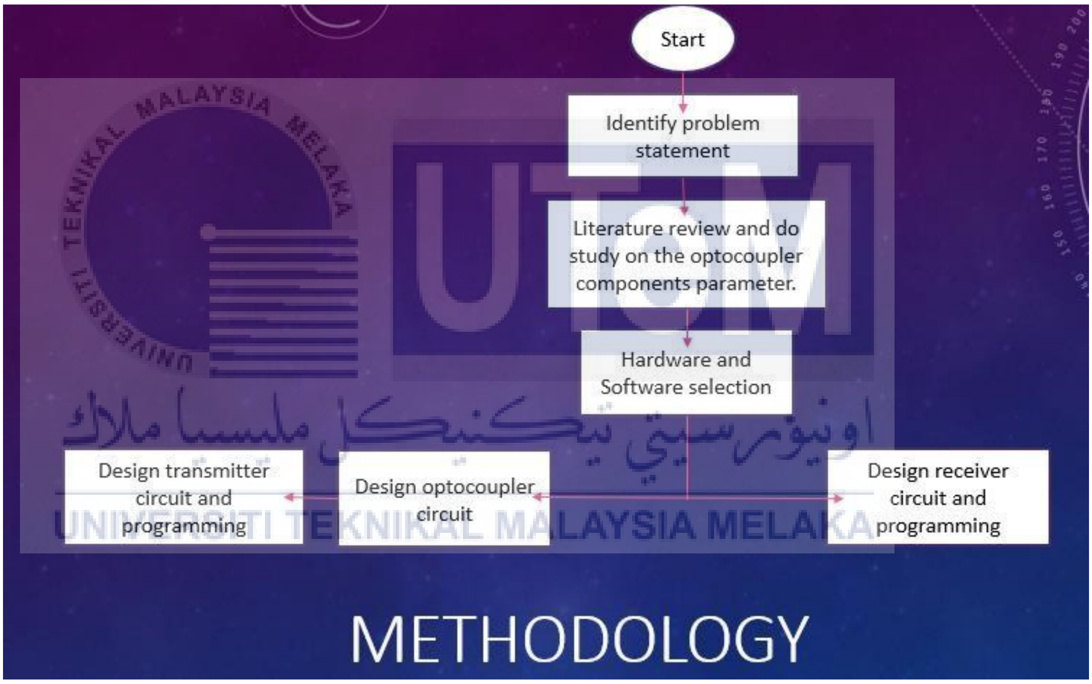

Figure 3.1: Project flowchart.

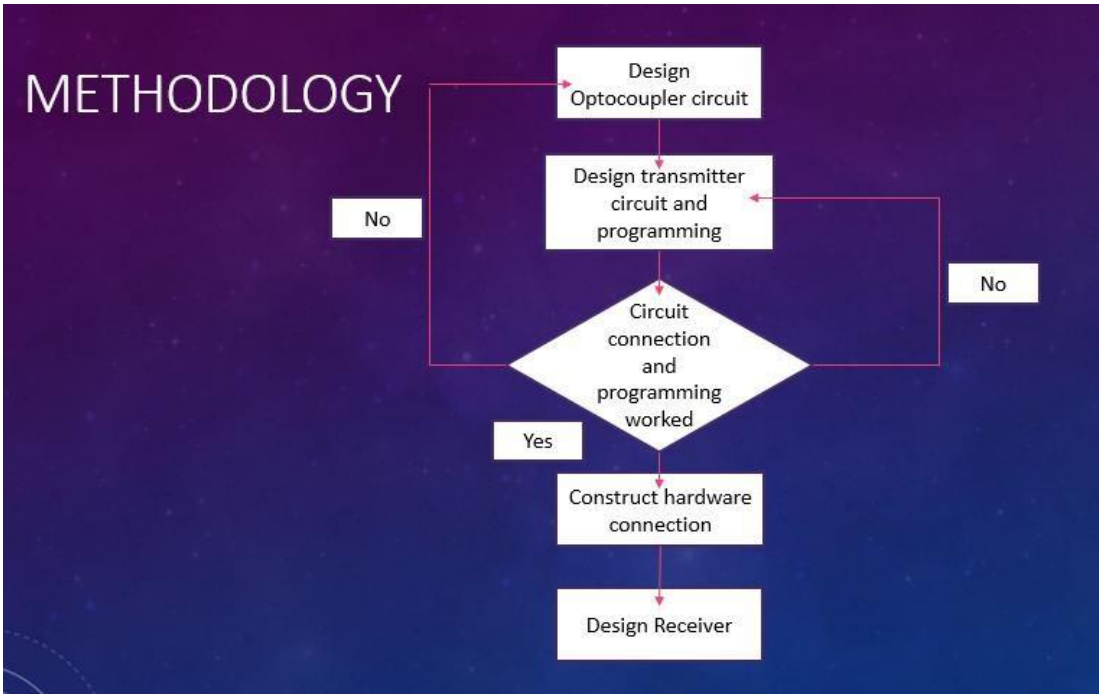

Figure 3.2: Optocoupler and transmitter circuit design flowchart.

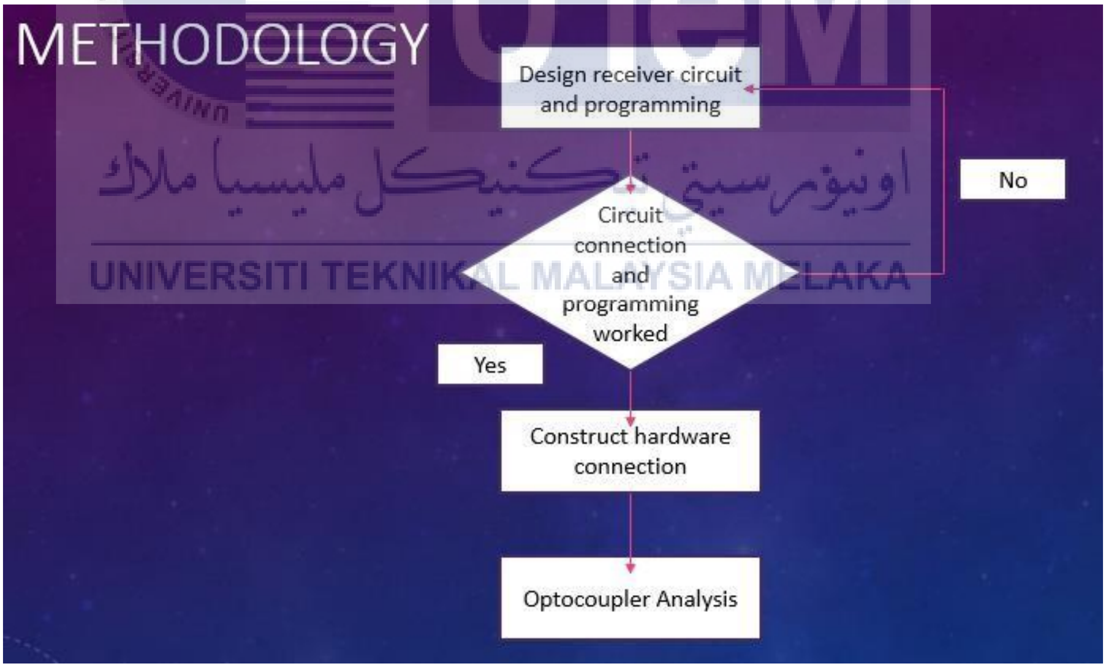

Figure 3.3: Receiver circuit design flowchart.

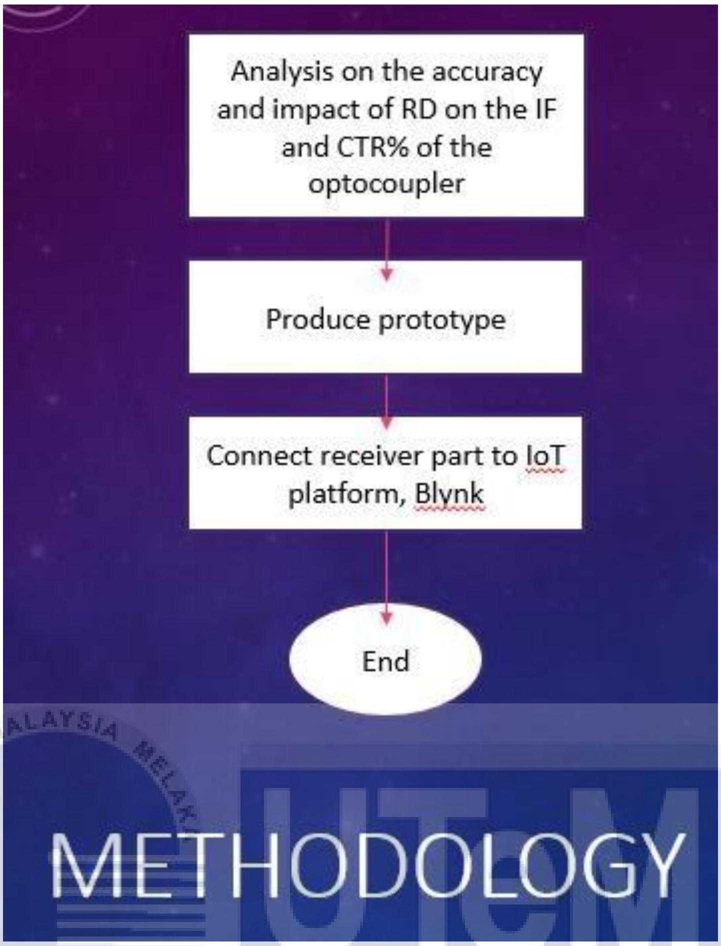

Figure 3.4: Analysis on accuracy and impact RD on IF and CTR% of optocoupler flowchart.

3.3 Software Used

Several different types of software have been utilized in the development of this project. All of this software is installed to provide various functionalities and instructions for the project's development. Proteus, the Blynk mobile application, and the Arduino IDE are the software used in this project.

3.3.1 Arduino IDE

The Arduino IDE software is essential for project development because it offers a straightforward and easy-to-use platform for interacting with and programming Arduino microcontrollers. Developers are able to control and modify different hardware components by writing, compiling, and uploading code to Arduino boards. The Arduino IDE offers a variety of built-in functions, libraries, and examples that simplify the development process. Furthermore, the Arduino IDE comes with a serial monitor that lets programmers interact with their Arduino boards, keep an eye on sensor data, and troubleshoot their code. All things considered, the Arduino IDE software simplifies the project development process by providing a full range of resources and tools for programming and communicating with Arduino microcontrollers. [10]

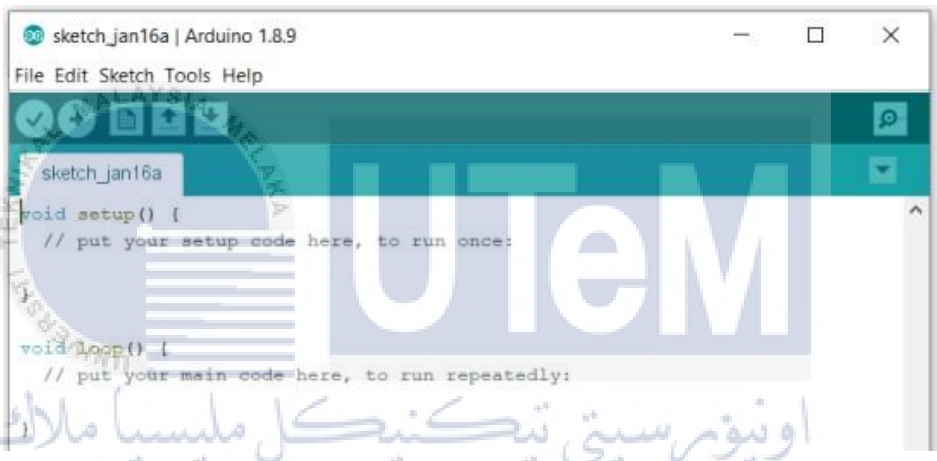

Figure 3.5: Arduino IDE workspace.

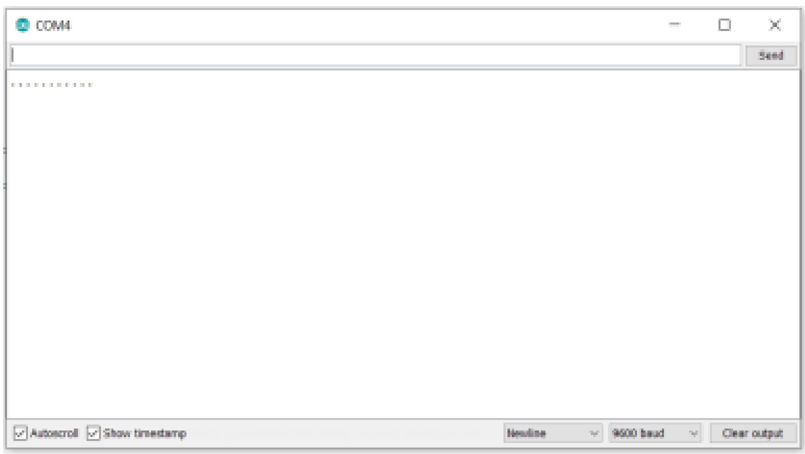

Figure 3.6: Serial monitoring of Arduino IDE.

3.3.2 Proteus

An electronic circuit or system may be designed, simulated, and tested using software called Proteus. Before implementing circuit designs in actual hardware, users can construct and analyze them in a virtual environment. Microcontrollers, sensors, and other electrical devices are just a few of the many components that Proteus offers. These components are readily used in circuit designs. Before moving on with the actual implementation, users may test the circuit's functionality, simulate its behavior, and debug any possible faults using the program. Proteus is a useful tool for engineers, students, and enthusiasts working on electronic projects because of its extensive simulation capabilities.

There are many sections in the library of ISIS. Sources, signal generators, switches, displays, loads like motors and lamps, discrete components like resistors, capacitors, inductors, and transformers, semi-conductor switches, relays, microcontrollers, processors, sensors, and more are all included. Probes for real-time monitoring of circuit parameters are also included.

ARES offers through-hole and surface mount PCB designs with a maximum of 14 inner layers. It has the imprints of several discrete component types, including headers, connectors, transistors, ICs, and others. The routing methods available to the PCB Designer are both automated and manual. The ISIS design may be directly translated to ARES, which includes microcontrollers, microcontrollers, sensors, and other components.

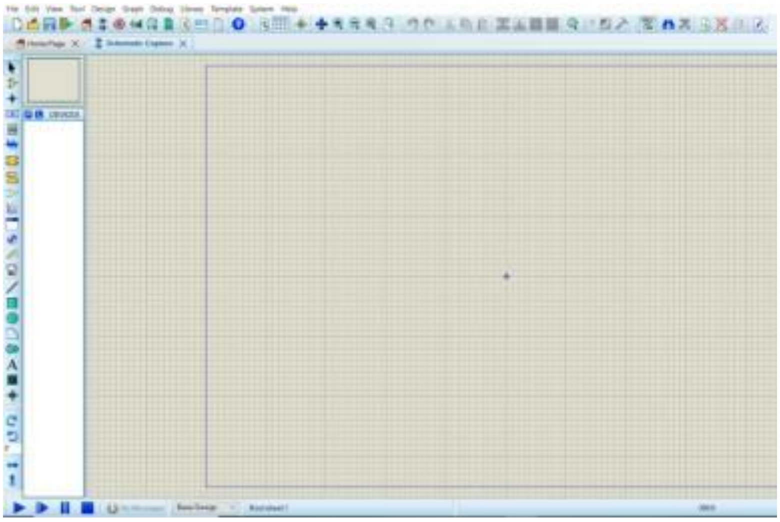

Figure 3.7: ISIS schematic interface.

Figure 3.8: ARES schematic interface.

3.3.3 Blynk Application

Arduino, Raspberry Pi, and NodeMCU devices may be controlled online with the Blynk app, an Internet of Things platform for iOS and Android smartphones. By gathering and providing the appropriate widget address, this program generates a graphical user interface (GUI) or human machine interaction (HMI). The program may be used to do a variety of tasks, including storing and visualizing data, presenting sensor data, and remotely managing devices. The three primary parts of this platform are Blynk App, Blynk Server, and Blynk Libraries. This makes it possible to create excellent project interfaces by employing a variety of available application widget kinds. Every kind of communication between devices, from smartphones to hardware connectivity, is managed by the Blynk Server function. It works well with many different devices and is a free source. Lastly, libraries handle all incoming and outgoing instructions and provide server communication for all popular hardware platforms.

Figure 3.9: Blynk dashboard on PC.

3.4 Electrical Hardware Design

In this subsection, the design of electronics is explained. In order to detect cable theft, the optocoupler PC817 requires an electronic system that can detect the presence of AC voltage. Three primary blocks will be used in this project: the optocoupler module, the transmitter block, and the receiver block.

3.4.1 Optocoupler Module Design Illustration

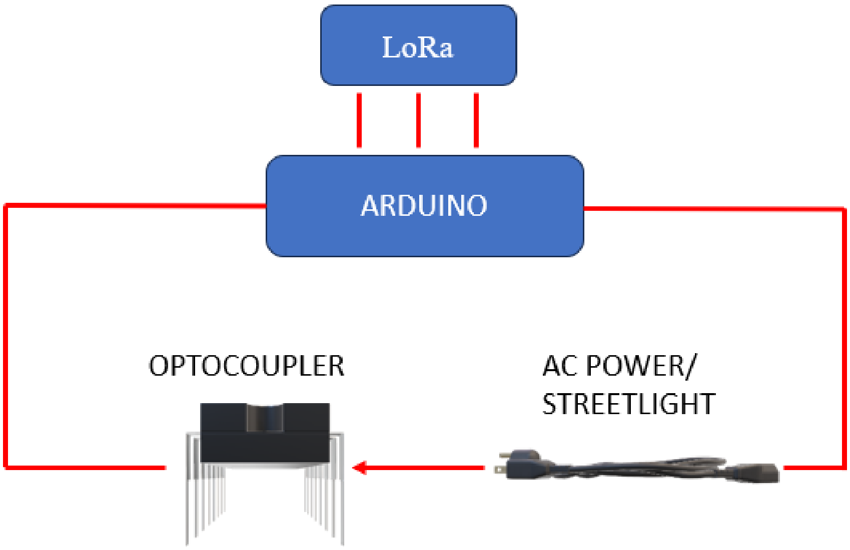

Figure 3.10: Optocoupler block diagram illustration.

In this project, optocoupler circuit will act as the AC voltage sensor. To develop the optocoupler circuit, PC 817 SHARP has been used. One popular optocoupler that may be used to detect 240 VAC (alternating current) is the PC817. A phototransistor and light emitting diode are optically connected in the PC817. Its lowest CTR is 50% at an input current of 5 mA, and its input-output isolation voltage is 5000Vrms. Two 1N4007 diodes, which provide the rectifier configuration for converting the AC power into DC voltage, were located on the LED side of the optocoupler module. To smooth the signal, the input capacitor (Cin) was employed at 470uF. 33k ohm was used as the limiting resistor (R_D) to generate 7.24mA for the forward current (I_F). In contrast, the transistor side of the optocoupler was composed of a 10k pull-up resistor (R_L) and an output capacitor (Cout) of 10uF. To get the collector current (I_C) to be 0.33 mA, the R_L value was selected. For the PC817 optocoupler, the R_D and R_L were methodically constructed to achieve a current transfer ratio (CTR%) of around 50%.

3.4.2 Optocoupler Circuit Design Using Proteus

After the circuit has been finalized in the form of block diagram, the circuit is continued to be redrawn in the Proteus software accordingly to all specifications require for every component so that the circuit could work and give the expected output later. The circuit must be rectified by two diodes, preferably 1N4007, in order to convert the AC voltage into DC voltage because the optocoupler must perceive the 240 AC voltage. The optocoupler's LED side was equipped with a 33k ohm resistor in order to supply 7.24mA for the forward current (IF), or the current passing through the LED. The collector current (I_C) was set to 0.33mA by setting the pull-up resistor (R_L) to 10k ohm. Since the PC817 is able to operate at the minimum 50% CTR value at 5mA, the forward current (I_F) and collector current (I_C) values will then be used to construct the current transfer ratio (CTR%) approximation by 50%. The CTR value in this circuit is 46%. The components list and circuit design are shown in Table 3.1 and Figure 3.11.

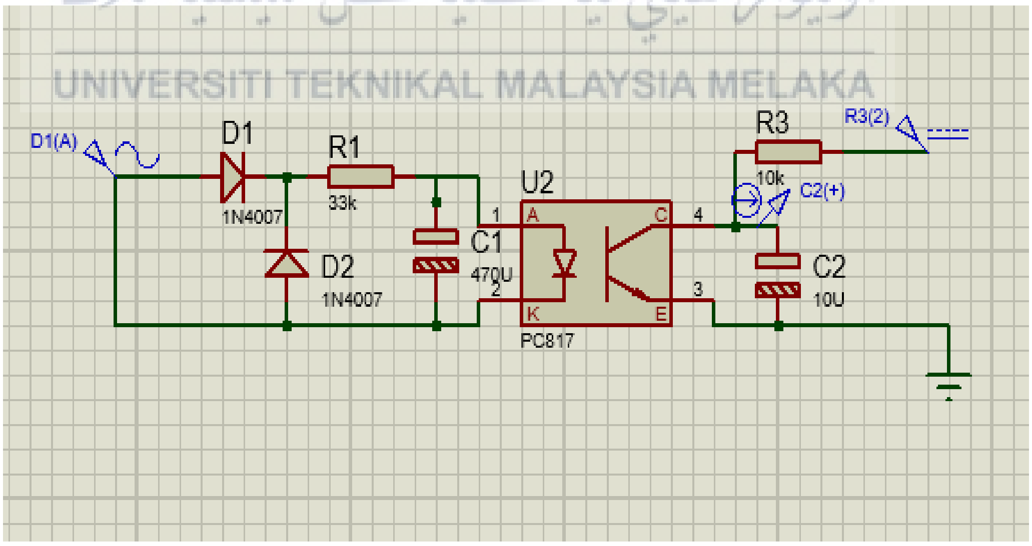

Figure 3.11: Optocoupler circuit module design using Proteus.

Table 3.1: List of components for optocoupler module.

No	Components	Quantity
1	Optocoupler PC817	1
2	1N4007 Diode	2
3	33k ohm (R_D), R1	1
4	10k ohm (R_L), R2	1
5	10uF Cout, C2	1
6	470uF Cin, C1	1

3.4.3 Optocoupler Circuit Design and Fabrication

There were two types of drawing that needed to be done in the Proteus software. First was the standard configuration of the circuit while the other one was layout of the circuit that will be printed on the UV board. Component connections between these two circuits are intertwined in a manner so critical that a single mistake might cause the entire circuit to malfunction, or worse, stop working altogether. So, every connection was configured carefully to each end before developing the PCB layout afterwards. The circuit layout design in Proteus is shown in Figure 3.12 and Figure 3.13 below with their respective labels.

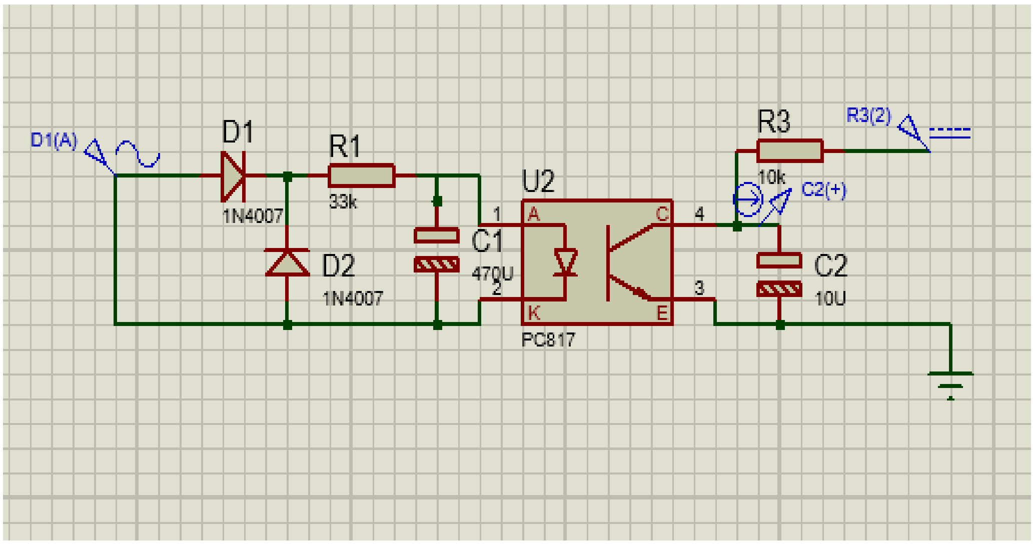

Figure 3.12: Schematic diagram for the optocoupler module.

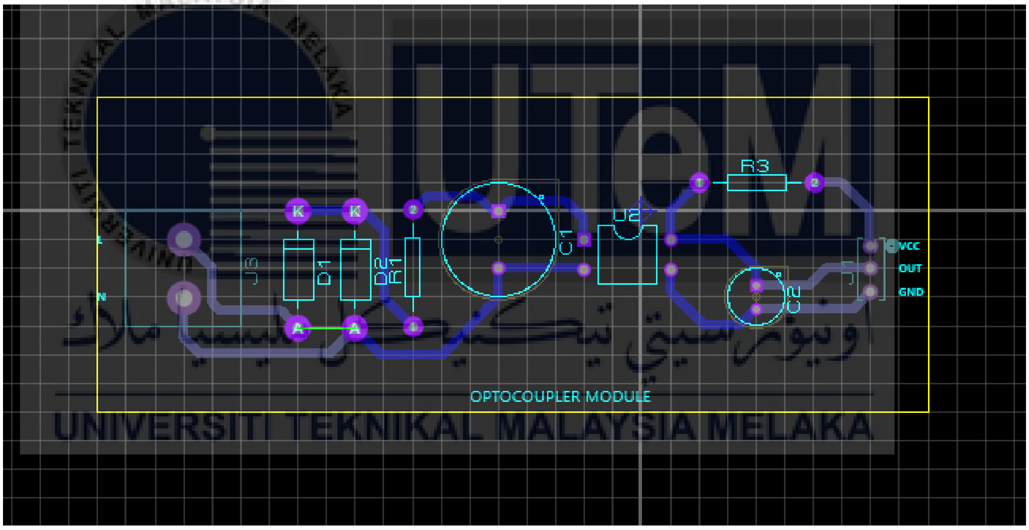

Figure 3.13: PCB layout of the optocoupler module

3.4.4 Transmitter Components Design

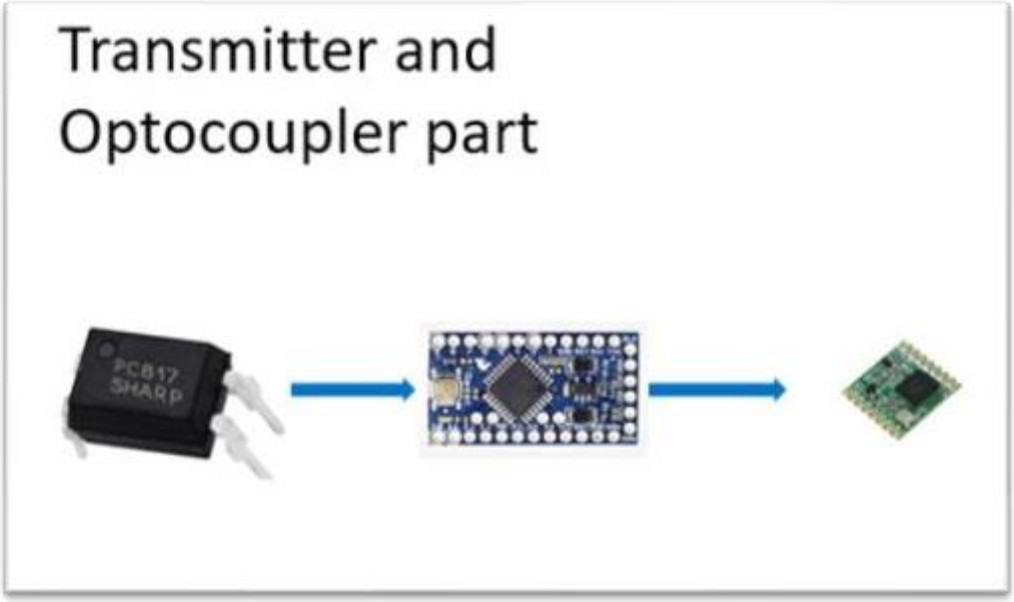

Figure 3.14: Transmitter components.

The transmitter block was composed of an optocoupler module, an Arduino Pro Mini 3.3V, and a LoRa RFM 95. After getting the digital output from the optocoupler module, the transmitter is configured to send the data to the receiver block. The optocoupler and LoRa RFM 95 could be powered by the Arduino Pro Mini's 3.3V VCC supply. This project is a good fit for LoRa RFM 95 as it can send and receive data over long distances.

Table 3.2: Optocoupler I/O pin configuration.

Optocoupler Module	Arduino Pro Mini 3.3V
V+	3.3V
GND	GND
Po	D6

Table 3.3: LoRa RFM 95 I/O configuration.

LoRa RFM 95	**Arduino Pro Mini 3.3V**
3.3V	VCC
GND	GND
DIO 0	D2
MISO	D12
MOSI	D11
SCK	D13
NSS	D10
RESET	D9

3.4.5 Receiver Components Design

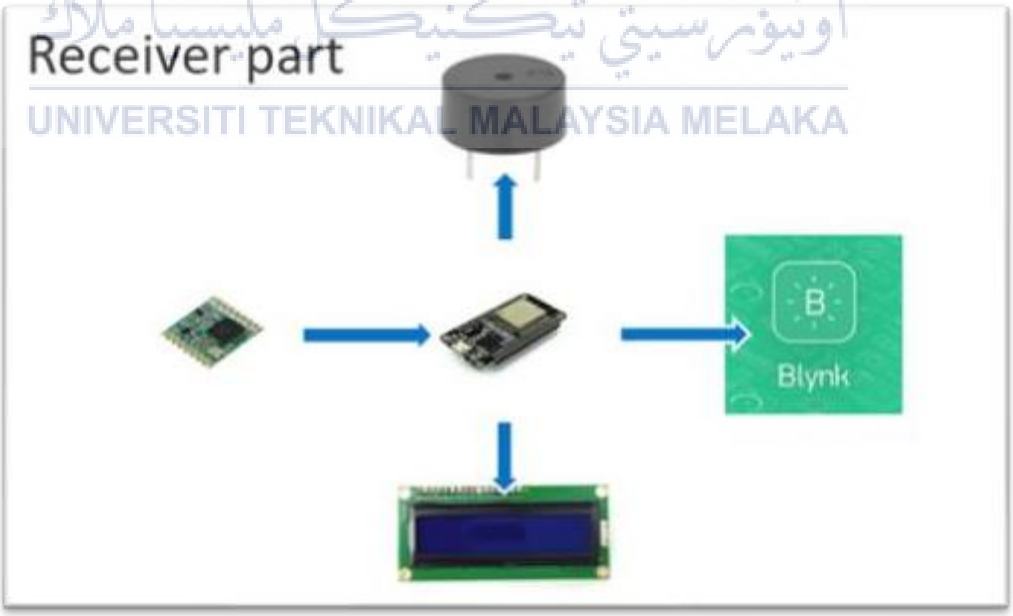

Figure 3.15: Receiver components.

The receiver block is a crucial part of the project as it has to be able to transmit digital data and generate alerts on the Blynk application. The receiver block will consist of the LCD I2C, ESP 32 microcontroller. LoRa RFM 95, and buzzer. After the transmitter transmits data, the receiver receives it and sends it to the Blynk IoT platform. The Wi-Fi module that the ESP 32 provides will enable communication between the receiver and the IoT platform. The buzzer will then sound either when the AC power is switched off or when the digital output is set to "1."

The optocoupler's digital output, which indicates the cable state, will be shown on the LCD. When the digital output is received as "0," the LCD will display "cable is okay," and when the digital output is obtained as "1," it will display "theft detected." When the digital output is set to "1," the Blynk application allows users to monitor their data on the dashboard and send warning notifications via email and mobile Blynk console.

Table 3.4: LCD I2C I/O pin configuration.

LCD I2C	**ESP 32**
VCC	3.3V
GND	GND
SDA	D21
SCL	D22

Table 3.5: Buzzer I/O pin configuration.

Buzzer	**ESP 32**
INPUT	D26
GND	GND

Table 3.6: LoRa RFM 95 I/O configuration on ESP 32.

LoRa RFM 95	**ESP 32**
3.3V	3.3V
GND	GND
DIO 0	D2
MISO	D19
MOSI	D23
SCK	D18
NSS	D5
RESET	D14

3.4.6 LoRa Based Cable Theft Detection System IoT Integration Process

The optocoupler module is used in this project to identify possible cable theft by detecting when the AC power is switched off. The aim is to produce a cautionary message and distribute it using email and an Internet of Things platform. In order to accomplish this, the optocoupler module is connected to the Wi-Fi application Blynk via the ESP32 board. This functionality's necessary coding is created and put into use. The details are in Figure 3.16.

Figure 3.16: Declaration & define line code in Arduino IDE.

After the code had been developed successfully, it was uploaded to the ESP32 microcontroller, which allowed it to connect to the Blynk application. The dashboard involved in the Blynk program is used to show cable status for monitoring purposes. There is a visual depiction in the figure below.

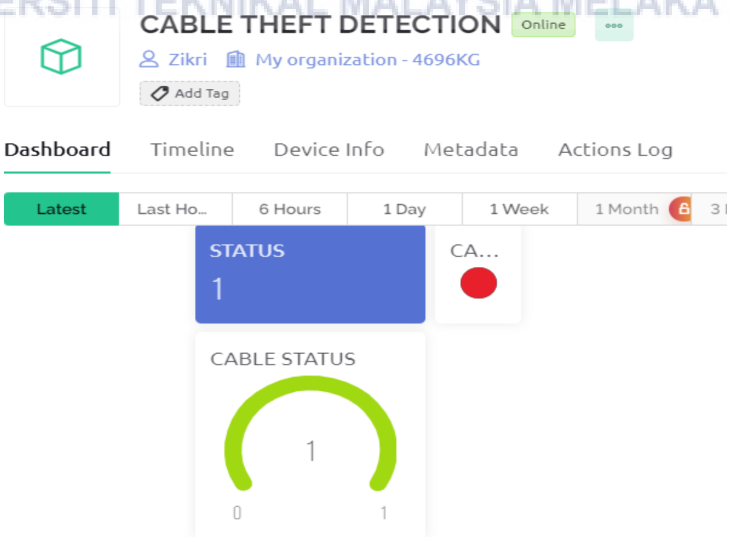

Figure 3.17: Cable theft detection status on Blynk dashboard.

3.5 Lists of Components

The parts utilized in this project, such as the 3.3V Arduino Pro Mini and ESP32 microcontrollers, will be covered in this section. There will also be discussion of other parts, like the LoRa RFM95 module and a buzzer.

3.5.1 Arduino Pro Mini

Figure 3.18: Arduino pro mini.

The Atmega328P chip is used in an Arduino Pro Mini microcontroller board. It is a more compact and scaled-down version of the Arduino Uno board designed for uses where a small form factor and low power consumption are required. The Pro Mini board is like the Arduino Nano in that it lacks USB connectivity and a voltage regulator, making it more appropriate for applications where size and power consumption are crucial factors. The Pro Mini board contains a 16 MHz quartz crystal, 6 analogue inputs, and 14 digital input/output ports. It can be programmed using the Arduino IDE, and serial communication protocols including I2C, SPI, and UART may be used to connect it to other hardware.

One of the Pro Mini board's unique characteristics is its low power consumption, which makes it ideal for battery-powered applications. Due to its broad input voltage range of 3.3V to 12V, it is also compatible with a variety of power sources. The Pro Mini board is often used in robotics, automation, and wireless sensor network projects.

Due to its small size and low power consumption, it is the ideal choice for projects with a limited amount of space and electricity. [11]

3.5.2 ESP32 Module

Figure 3.19: ESP32 module

TSMC's ultra-low-power 40 nm technology was used to develop the ESP32, which is a single chip that combines Wi-Fi and Bluetooth and operates at 2.4 GHz. It is built to produce the greatest possible power and RF performance, demonstrating durability, adaptability, and dependability in a broad variety of applications and power circumstances. Its design aims to fulfil these goals. The ESP32 series of chips comprises the ESP32-D0WD-V3, the ESP32-D0WDR2-V3, the ESP32-U4WDH, the ESP32-S0WD, the ESP32-D0WD (NRND), and the ESP32- D0WDQ6 (NRND). Of these chips, the ESP32-D0WD-V3, the ESP32-D0WDR2-V3, the ESP32-U4WDH.

<u>Some of the main features:</u>

Ultra-Low-Power Solution:

Microcontrollers like the ESP32 are made especially for wearable, mobile, and Internet of Things applications. Because of its advanced features, which include dynamic power scaling, power modes, and fine-grained clock gating, it consumes less power than other devices. In an IoT sensor hub application that requires minimal power, for example, the ESP32 can be configured to wake up on a regular basis only in response to certain events. A low-duty cycle can be used to further reduce power consumption. A balance between power consumption, data rate, and communication range can also be achieved by adjusting the power amplifier output.

Complete Integration Solution:

The ESP32 is a highly integrated solution for Wi-Fi and Bluetooth Internet of Things applications, and it requires around 20 external components. In addition to filters and power management modules, the ESP32 incorporates an antenna switch, RF balun, power amplifier, low noise receive amplifier, and filters. As a consequence of this, the Printed Circuit Board (PCB) area that the solution requires is relatively small. The ESP32 utilizes CMOS for single-chip fully integrated radio and baseband, and it also integrates sophisticated calibration circuitries, which enables the solution to eliminate external circuit defects or respond to changes in external circumstances. As a result, expensive and specialist Wi-Fi testing equipment is not necessary for the mass production of ESP32 products. [12]

3.5.3 Buzzer

Figure 3.20: Buzzer.

The addition of sound characteristics to this project or system may be accomplished with the help of a buzzer, which is a compact yet effective component. Due to the fact that it has a very small and compact 2-pin construction, it can be readily utilized on breadboard, Preboard, and even on PCBs. Because of this, it is a component that is commonly employed in the majority of electronic applications.

There are two main types of buzzers available for purchase. The buzzer that can see here is a basic design that, when used, emits a constant beweeps sound. The second kind, called a preset buzzer, will be bigger than this one and sound a Beep. It emits a beep. It had an oscillating circuit within, which is why sound was emanating from it. However, the one displayed here is the one that is most frequently used since it is simple to modify with the assistance of other circuits to fit into our application.

For this project, a DC power source with a voltage range of 4V to 9V is needed for the buzzer. Instead of using a 9V battery, it is advised to utilize a controlled +5V or +6V DC supply. Usually, the buzzer is wired to a switching circuit so that it can be turned on and off as needed. [13]

3.5.4 RFM95 – Low Power Long Range Transceiver Module

Figure 3.21: LoRa RFM95 module.

The LoRaTM long range modem, which enables long range communication, has great interference immunity, and uses very little current, is included with the RFM95/96/97/98(W) transceivers. Thanks to Hope RF's LoRaTM modulation technology, these transceivers have a high sensitivity of over -148dBm. They are inexpensive because they make use of inexpensive crystals and components. Applications requiring long range or durability can benefit from the industry-leading link budget offered by the integrated power amplifier with +20 dBm. LoRaTM delivers notable gains in blocking and selectivity over traditional modulation systems, doing away with the need to choose between energy usage, interference immunity, and range. High-performance (G)FSK modes for different system architectures are also available with these devices. The RFM95/96/97/98(W) transceivers provide superior performance in terms of phase noise, selectivity, receiver linearity, and IIP3 even with their lower current consumption. [14]

3.6 Experimental Work & Data Analysis

The limiting resistor (R_D) will be changed in this experiment to analyze the optocoupler's accuracy. The resistance values of the limiting resistors (R_D) that will be tested are 33k ohm, 100k ohm, and 220k ohm. Figure 3.22 and table 3.7 illustrate the various values of the pull-up resistor (R_L) and limiting resistor (R_D) that will be analyzed.

Table 3.7: The variation of components and characteristics that will be used for analysis.

R_D Value	**R_L Value**	**CTR %**	**I_F (mA)**
33k Ohm	10k Ohm	46	7.24
100k Ohm	10k Ohm	138.2	2.388
220k Ohm	10k Ohm	304.15	1.085

Figure 3.22: Different values of limiting resistor (R_D) that will be used in analysis.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter explains in detail the analysis process of the proposed LoRa Based Cable Theft Detection System for Street Lighting in order to achieve the three objectives of this research work. First, the long-range wireless network (LoRa), which can function with low power consumption and contribute to the achievement of sustainable environmental goals, served as the base for the design and development of the cable theft detection system. This project's major parameter is the optocoupler value, which indicates whether cable theft is taking place. To determine how well the cable theft system performs overall in terms of time response and accuracy. These parameter data will be gathered, and the results are analyzed.

4.1 Optocoupler Circuit

The PC 817 optocoupler circuit's limiting resistor, diode, and capacitor values were designed and experimented with to determine the proper values at the outset of the project in order to detect the presence of AC voltage as shown in figure 4.1 and actual circuit as shown in figure 4.2. After the circuit had been designed, its functioning was tested by connecting the optocoupler circuit to the housing's AC voltage, which is 240V AC. This project is a prototype only. For safety reasons, this project can only be tested at the same voltage as actual streetlight, not against it.

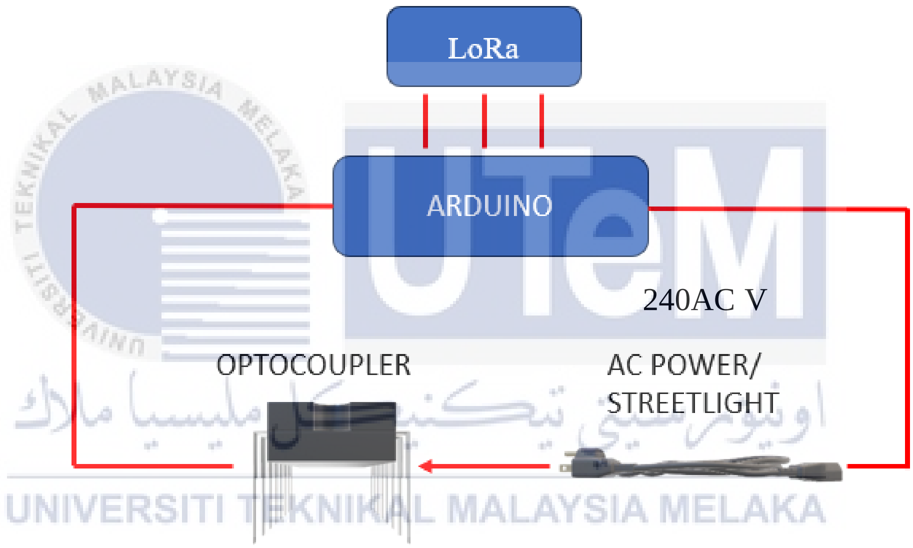

Figure 4.1: Optocoupler block diagram.

Figure 4.2: Optocoupler circuit design.

4.2 Transmitter Circuit

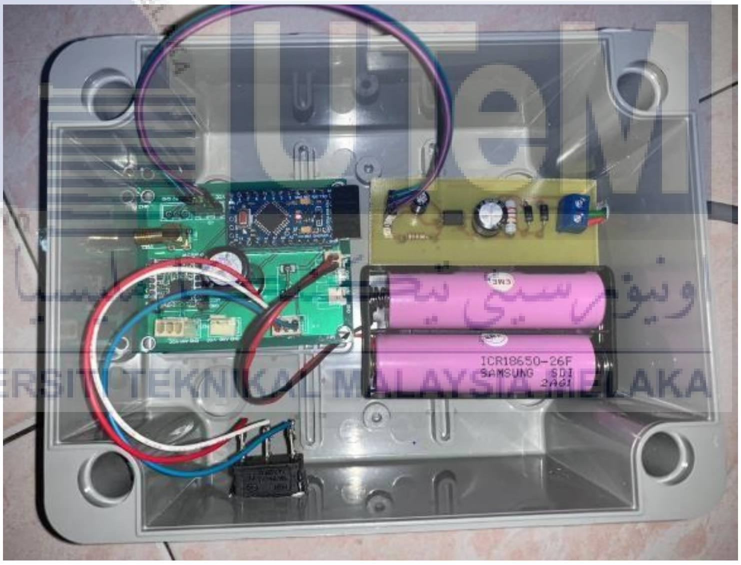

Figure 4.3: Circuit connection for transmitter.

In order to evaluate the optocoupler's accuracy using a range of limiting resistor (R_D) values, certain system quality-related data must be obtained. This is to ensure that the LoRa-based cable theft detection system can accurately produce an alert when the streetlight's cable is cut. The optocoupler's digital output is the parameter that is analyzed for this project. The optocoupler module that has been constructed previously will be connected to the Arduino 3.3V Pro Mini, the primary transmitter microcontroller, in order to determine the optocoupler's digital output. The LoRa RFM95 has also been installed in the transmitter circuit as the digital output needs to be sent to the receiver. The circuit connection for this project is shown in Figure 4.3. Consequently, an optocoupler can only read the digital output. When the AC voltage is switched on, the output is "0," and when it is turned off, it is "1." Using a 33k ohm R_D value and a 10k ohm RL value, the optocoupler module successfully and appropriately recognized the presence of AC during the project's final session. Then, using the LoRa RFM 95, the data was successfully sent from the transmitter to the receiver.

4.3 Receiver Circuit

Figure 4.4: Circuit connection for receiver.

In order to achieve the project's goal of implementing the Internet of Things (IoT) on the system and displaying the digital output of the optocoupler data on an IoT dashboard that the authority can access at any time, the receiver used the ESP32 feature to communicate with the Blynk application. In order to show the cable status based on the digital output of the optocoupler, LCD 2IC has also been placed in the receiver. When cable theft happens, the LCD will also alert the transmitter with a warning display. The data for the digital output that has been received from the optocoupler at the transmitter will subsequently be received by the LoRa RFM95 via communication with the LoRa transmitter. LoRa can send data across several kilometers, which is a great distance. When cable theft is discovered, the buzzer was designed to sound an alert. According to this project, cable theft will occur when the optocoupler's digital output is set to"1," which occurs when the AC power is switched off. The "theft detected" warning on the LCD 2IC was successfully shown by the receiver, as shown in figure 4.4. The warning signal was also successfully sent via mobile device Blynk console app and email.

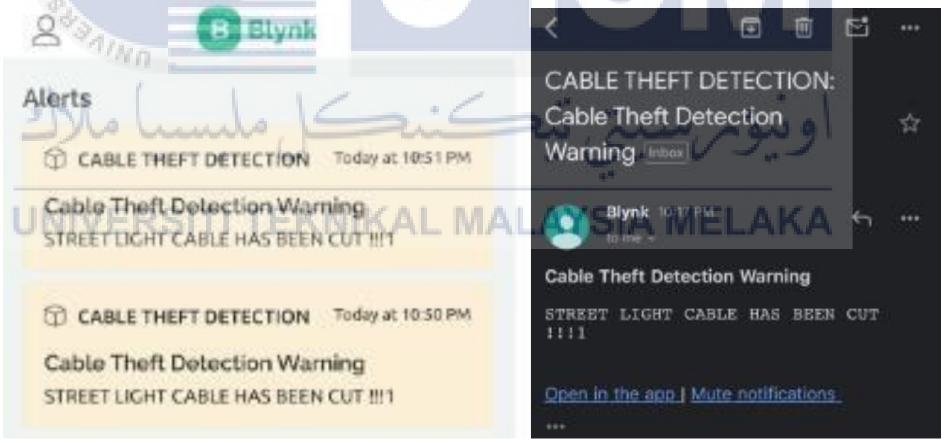

Figure 4.5: Warning notification sent via Blynk console and via email.

Figure 4.5 shows that the user received the warning signal for "cable theft detected" via email and the Blynk interface on mobile devices. Every minute, the notification was sent out.

4.4 Analysis on the Optocoupler Accuracy by Varying the Limiting Resistor (R_D)

It is essential to analyze the accuracy of the optocoupler by adjusting the value of the limiting resistor (R_D) in order to understand the impacts of different resistor values on the optocoupler's capability to sense voltage. The limiting resistor serves to regulate the current that flows through the optocoupler, which affects how sensitive and accurate the device is in detecting changes in AC voltage. By varying the R_D value, the project's objective is to determine the optimal resistor value that provides the optocoupler with the most accurate voltage sensing capabilities. This research ensures that the system will accurately detect cable theft and helps to improve the circuit architecture.

Table 4.1: Perecntage error of the optocoupler

RESISTOR (RD)	ACTUAL OUTPUT	EXPECTED SAMPLES	OBTAINED SAMPLES WHICH EQUAL TO EXPECTED OUTPUT	PERCENTAGE ERROR %
33k Ohm	1	24	24	0
100k Ohm	1	24	20	16.67
220k Ohm	1	24	18	25

In this section, percentage error of the optocoupler can be simply calculated using this formula: $\sigma = |\frac{uA-uE}{uE}|.100\%$ where, σ is the percent error, υA is the actual value observed (the total number of samples with a digital output similar to the expected value) and υE is the expected value. In table 4.1 presents the percentage error (%) for different values of limiting resistor (R_D) where 0% for 33k ohm, 16.67% for 100k ohm, and 25% for 220k ohm. These values indicate the deviation between the observed and expected values.

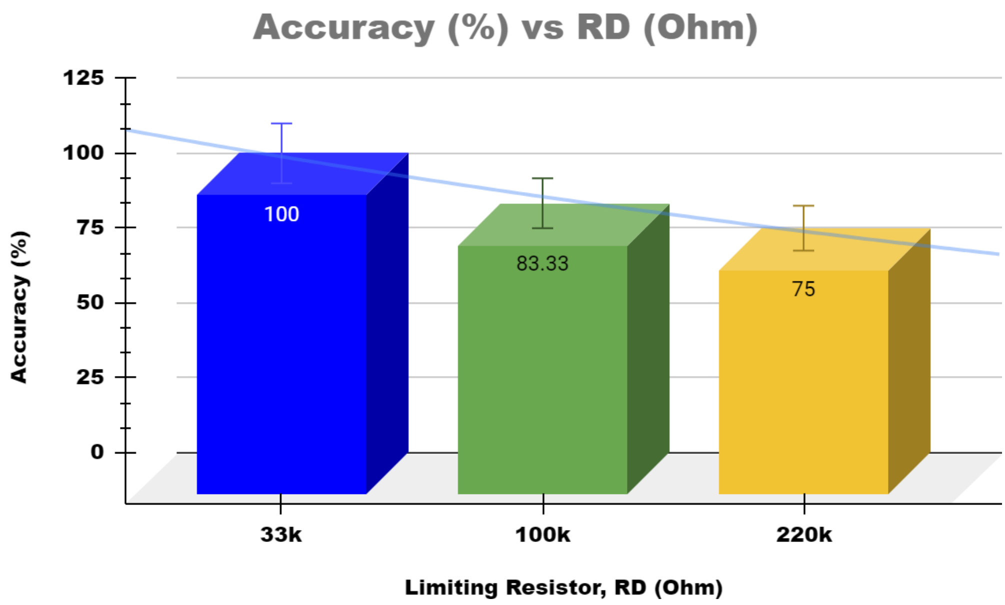

Figure 4.6: The optocoupler's accuracy versus the limiting resistor's (RD).

The accuracy of the PC817 optocoupler is determined by the limiting resistor value used in the circuit. When a limiting resistor of 33k ohm is used, the accuracy is reported as 100% in figure 4.6. This means that all twenty-four samples consistently produced the expected output of "0" when the optocoupler was connected to 240 Vac.

However, when the limiting resistor value is varied to 100k ohm and 220k ohm, the accuracy decreases to 83.33% and 75% respectively. This means that there were instances where the output deviated from the expected "0" value. The decrease in accuracy can be attributed to the change in the forward current (IF) flowing through the optocoupler. The forward current is determined by the limiting resistor value using the formula; $IF = \frac{(VCC-VF)}{RD}$, where VCC is the supply voltage and Vf is the forward voltage drop of the optocoupler's LED. [15]

A limiting resistor of 33k ohm provides a higher forward current input (I_F) compared to 100k ohm and 220k ohm. This higher forward current improves the efficiency and reliability of the optocoupler in detecting the AC voltage, resulting in a more accurate output. Based on these results, the best limiting resistor value that meets the preference of the PC817 optocoupler is 33k ohm. It offers the highest accuracy of 100% and provides a reliable and stable performance in sensing the AC voltage.

4.5 The Optocoupler's Digital Output with Respect to the Twenty-Four Hours

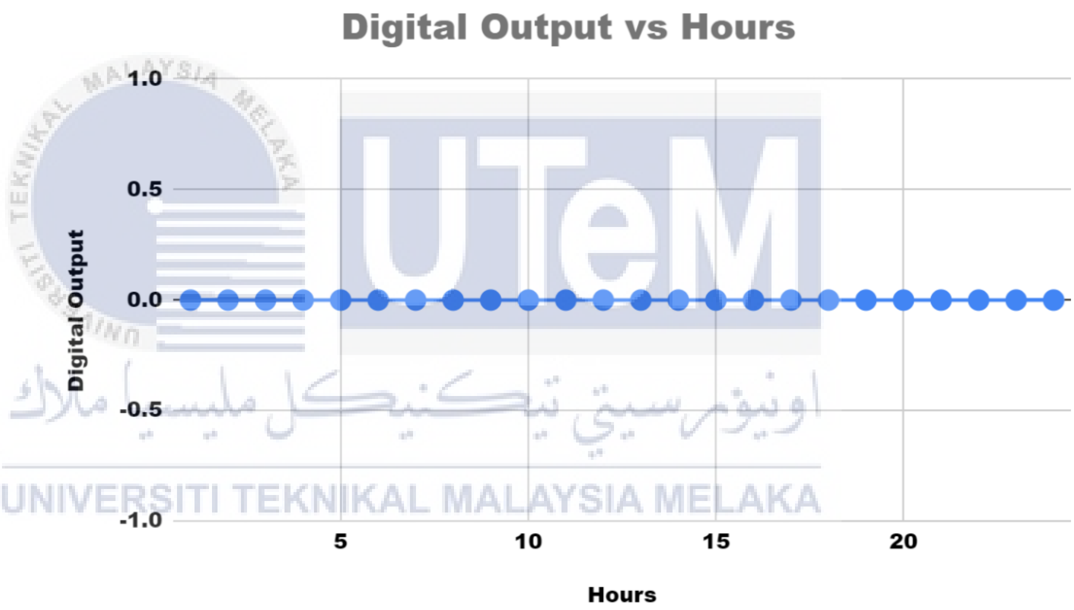

Figure 4.7: Digital output for R_D equal to 33k ohm.

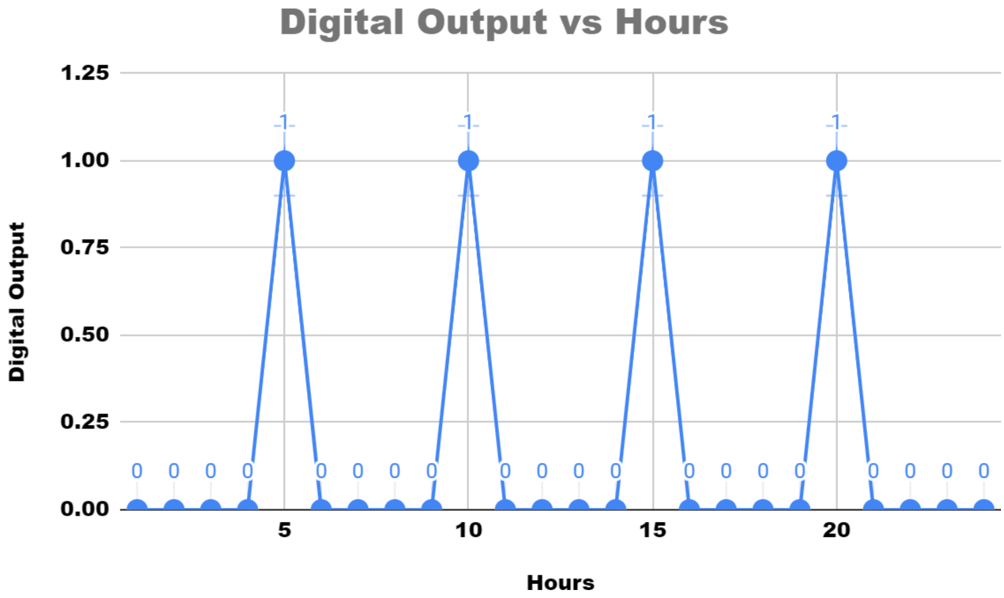

Figure 4.8: Digital output for RD equal to 100k ohm.

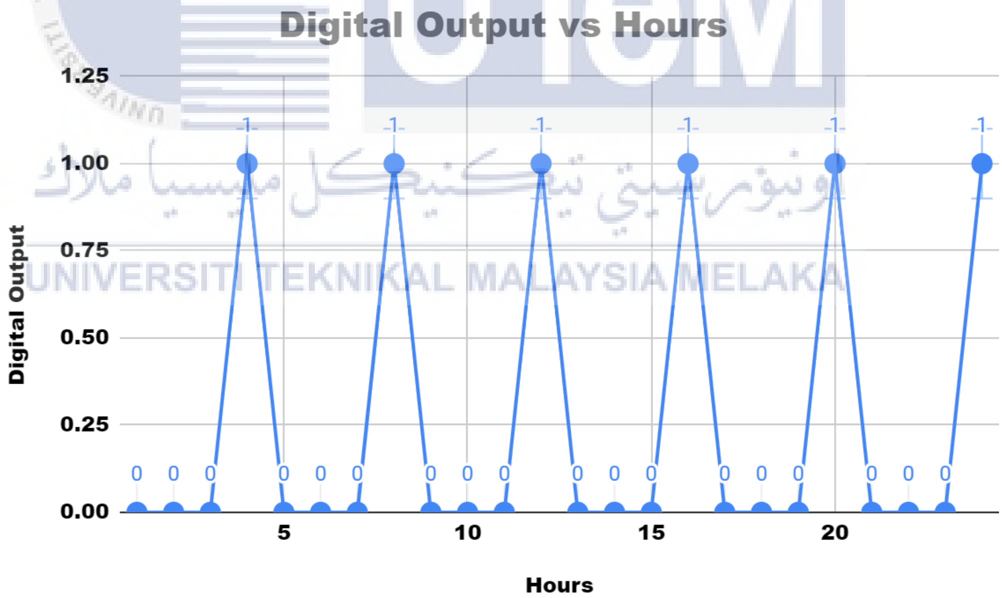

Figure 4.9: Digital output for RD equal to 220k ohm.

For the twenty-four samples, the result should obtained as "0". This occurs when the LED is connected to 240 VAC and forward current (I_F) is passing through it. The light-sensitive component, a phototransistor or photodiode on the optocoupler's output side, detects the light that the LED emits as a result. The light-sensitive component conducts current or changes its electrical characteristics in response to the light it receives. When a phototransistor is exposed to light, it may become conductive and let current to pass through it. When it comes to a photodiode, the light that is received can directly produce a current. Consequently, the light-sensitive component on the output side conducts current or produces a voltage drop in response to the AC voltage being applied to the LED side when the LED emits light. As a result, the optocoupler detects the presence of the AC voltage on the input side, as indicated by the logic low, or "0," output.

In figure 4.7, the digital output for the R_D value of 33k ohm consistently generated a "0" output for all twenty-four samples, indicating accurate detection of the AC voltage. However, the results for the R_D values of 100k ohm and 220k ohm in figures 4.8 and 4.9 showed slight differences. Every five hours, the digital output displayed a value of "1" for the R_D value of 100k ohm, while the R_D value of 220k ohm generated the digital output "1" more frequently.

The difference in the digital output can be attributed to the optocoupler's sensitivity and stability, which vary with different R_D values. In this case, the optocoupler's efficiency and stability are lower at the R_D values of 100k ohm and 220k ohm compared to the R_D value of 33k ohm. This results in a more frequent occurrence of a digital output of "1", indicating that the optocoupler may not accurately detect the AC voltage at these R_D values.

4.6 The Optocoupler's Forward Current, I_F (mA) with Respect to Limiting Resistor, R_D (K Ohm)

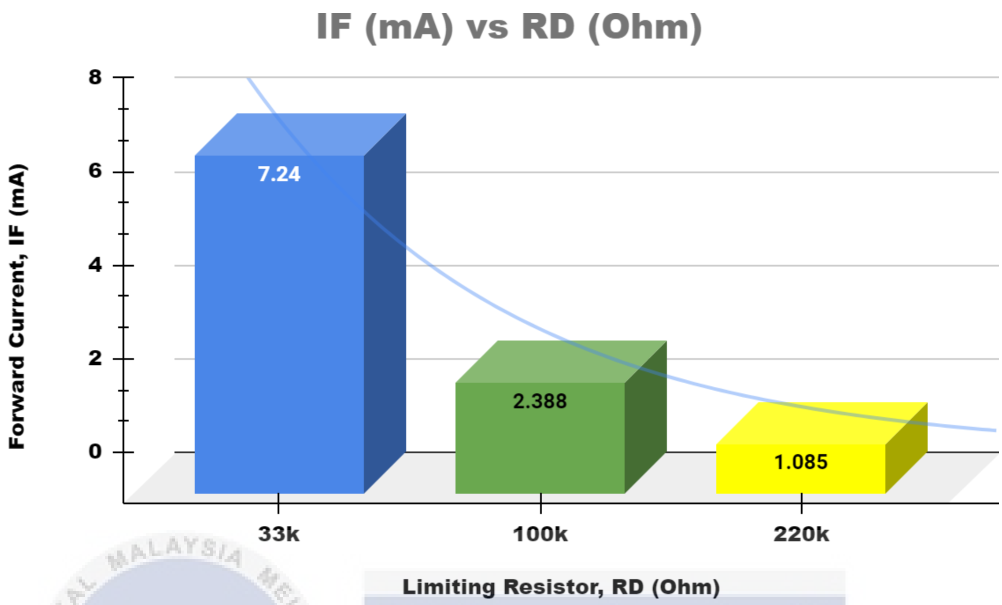

Figure 4.10: The optocoupler's forward current (I_F) versus the limiting resistor's (R_D).

The forward current (I_F) of the optocoupler decreases proportionally with the increasing value of the limiting resistor (R_D). From the provided information in figure 4.10, it can be observed that the R_D value of 33k ohm provides the highest forward current of 7.24mA, while the R_D values of 100k ohm and 220k ohm provide lower forward currents of 2.388mA and 1.085mA, respectively.

In general, a higher forward current can provide better signal transmission capabilities and improved performance. It ensures that the LED is adequately driven and can emit sufficient light to activate the phototransistor or photodetector in the optocoupler.

Since as a result, the signal transmission is stronger and more dependable when the RD value of 33 k ohm is used since it has the greatest IF value. Therefore, the forward current of 7.24mA obtained with the RD value of 33k ohm is considered the best choice for the PC817 optocoupler as it provides a higher forward current, better signal transmission capabilities, and improved overall performance.

4.7 The Optocoupler's Current Transfer Ratio (%) with Respect to Limiting Resistor, RD (K Ohm)

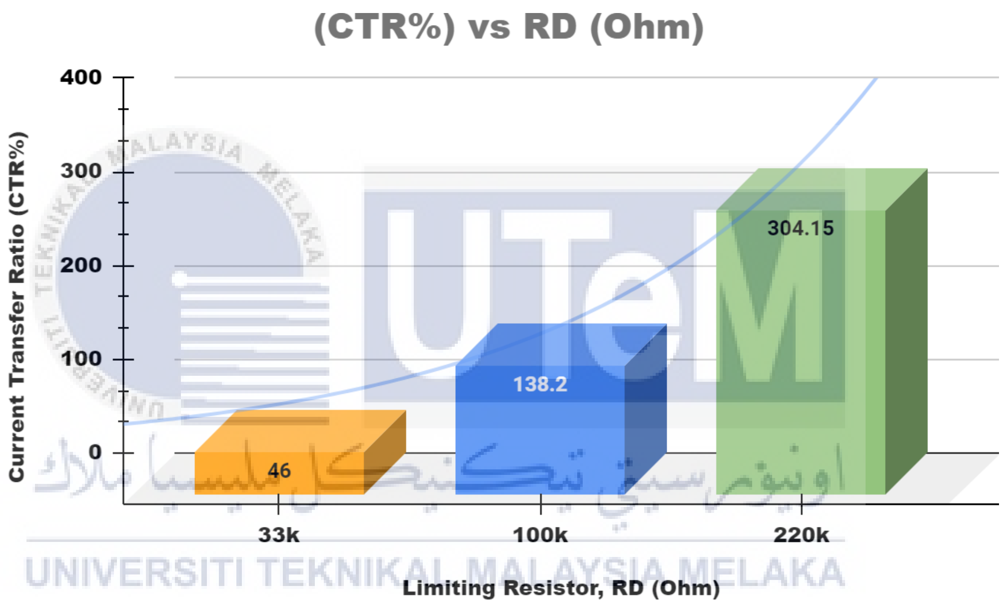

Figure 4.11: The optocoupler's current transfer ratio (CTR%) versus the limiting resistor's (RD).

From the graph obtained in figure 4.11, it was observed that the current transfer ratio, CTR increased proportionally with the limiting resistor (RD). The CTR values obtained for different RD values are as follows: 46% for RD = 33k ohm, 138.2% for RD = 100k ohm, and 304.15% for RD = 220k ohm. The CTR represents the ratio of output current (collector current, IC) to the forward current (IF) of the optocoupler.

The PC817's CTR value normally falls between 50% and 600%. [15] The CTR calculation can be simply calculated by using this formula: $CTR = (\frac{IC}{IF})\ x\ 100$. Where IF is the forward current (current passing through the optocoupler's LED), and I_C is the collector current of the phototransistor in the optocoupler.[11]

In this analysis, the R_D value of 220k ohm is found to provide the highest CTR value of 304.15%, which is significantly higher than the CTR values obtained with the R_D values of 100k ohm and 33k ohm. According to theoretical considerations, a higher CTR value is generally considered desirable as it indicates a better transfer of the input signal to the output.

However, when selecting the optimal configuration for the PC817 optocoupler, it is essential to consider both the CTR value and the forward current. Analyzing the provided graphical information, we can observe that the R_D value of 33k ohm yields a CTR of 46% and a forward current of 7.24mA. While this CTR value is significantly lower than that obtained with the R_D value of 220k ohm, it falls within the preferred CTR range for the PC817 optocoupler. Additionally, the forward current of 7.24mA is notably higher than the forward currents obtained with the R_D values of 100k ohm and 220k ohm.

It is worth noting that the CTR values for the R_D values of 100k ohm and 220k ohm exceed 100%. This suggests that the optocoupler may not be operating within its optimal range for these R_D values, potentially leading to inaccuracies or distortions in the output signal. Furthermore, the forward current values obtained with these R_D values (2.388mA and 1.085mA) are considerably lower than the forward current of 7.24mA obtained with the R_D value of 33k ohm.

Considering both the CTR and forward current values, the optimal configuration for the PC817 optocoupler would be an R_D value of 33k ohm. This configuration ensures that the optocoupler operates within its preferred CTR range while also providing a higher forward current. By selecting this configuration, the optocoupler can effectively transfer the input signal current to the output with an acceptable CTR value and sufficient forward current, meeting the preferences for optimal performance.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Introduction

This chapter discusses the conclusion and future work for a LoRa Based Cable Theft Detection System for Street Lighting.

5.2 Conclusion

In conclusion, this thesis project focused on the development of the LoRa Based Cable Theft Detection System using Optocoupler and IoT Platform. The goal was to offer real-time detection and monitoring to guarantee ideal conditions and to aid in preventing street lighting cable theft.

This technology offers a comprehensive and reliable respond to the challenges faced by authorities and utility companies in ensuring the uninterrupted operation of the infrastructure supporting street lighting. The system makes use of the long-range and low-power features of LoRa technology to monitor and identify cable theft in an efficient manner. It is made feasible for this preemptive strategy to prevent theft and minimize disruptions to street lighting systems.

This method is even more successful since optocoupler technology has been included in it. By serving as an isolator, the optocoupler maintains the integrity and dependability of the detecting system. The optocoupler increases the system's capacity to detect cable theft correctly and guards against any interference by separating the electrical impulses between the detection circuit and the main system. With this connection, any illegal efforts to theft the street lighting cables are certain to be quickly discovered and dealt with.

The cable theft detection system is made more convenient and accessible by the use of Blynk, an intuitive smartphone application. Authorities and utility companies may use Blynk to remotely monitor the condition of the street lighting infrastructure and get real-time notifications in the case that there is any manipulation of the cables. This makes it possible to respond and intervene quickly, cutting down on the amount of time needed to handle theft occurrences and lowering the risk to public safety. Blynk’s user-friendly interface facilitates efficient navigation and feature utilization by streamlining system administration and operation.

All things considered, the optocoupler and Blynk integrated LoRa based cable theft detection system provides a complete defense against cable theft in street lighting infrastructure. The system's cutting-edge technology offers a proactive approach to detecting and preventing theft, guaranteeing the continuous provision of public lighting services. The use of Blynk increases user accessibility and convenience, while the inclusion of optocoupler technology improves system dependability. Authorities and utility companies may greatly reduce the effects of cable theft by putting this creative approach into practice, which will enhance safety and security in metropolitan areas.

5.3 Future Works

For future works, the LoRa Based Cable Theft Detection System for Street Lighting can be enhanced as follow:

I. Integrate cable theft detection system with other smart city applications: For instance, integrating the system with a centralized platform for managing smart cities might offer a comprehensive perspective of different elements of urban infrastructure, such as traffic control, public safety systems, and street lighting. Better coordination of emergency response, more economical resource allocation, and better urbanization.

II. Further investigation into the capabilities of machine learning algorithms and predictive analytics: Through the examination of past data and trends, the system may be able to pinpoint regions or times when there is a greater chance of cable theft, enabling preventative actions to be implemented. Furthermore, if new patterns of cable theft emerge, machine learning algorithms may be able to continually learn from them and adjust, ultimately increasing the efficacy of the system. management would be made possible by this connection.

III. improving the detection system's sensitivity and accuracy for future development: This might involve more study and testing to improve the optocoupler's performance and adjust the detection algorithms. The efficiency of the system may be greatly increased by reducing errors and enhancing its capacity to identify even minute indications of cable theft.

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APPENDICES

Appendix A

WI-FI KEY FEATURES FOR ESP32:

1. 802.11 b/g/n

2. 802.11 n (2.4 GHz), up to 150 Mbps

3. WMM

4. TX/RX A-MPDU, RX A-MSDU

5. Immediately Acknowledged Block ACK

6. Defragmentation

7. Continuous automatic monitoring of beacons (hardware TSF)

8. 4 × virtual Wi-Fi interfaces

9. Support for all three operating modes simultaneously: Infrastructure Station, SoftAP, and Promiscuous. Take note that the channel of the SoftAP will shift whenever the ESP32 is operating in Station mode and carrying out a scan.

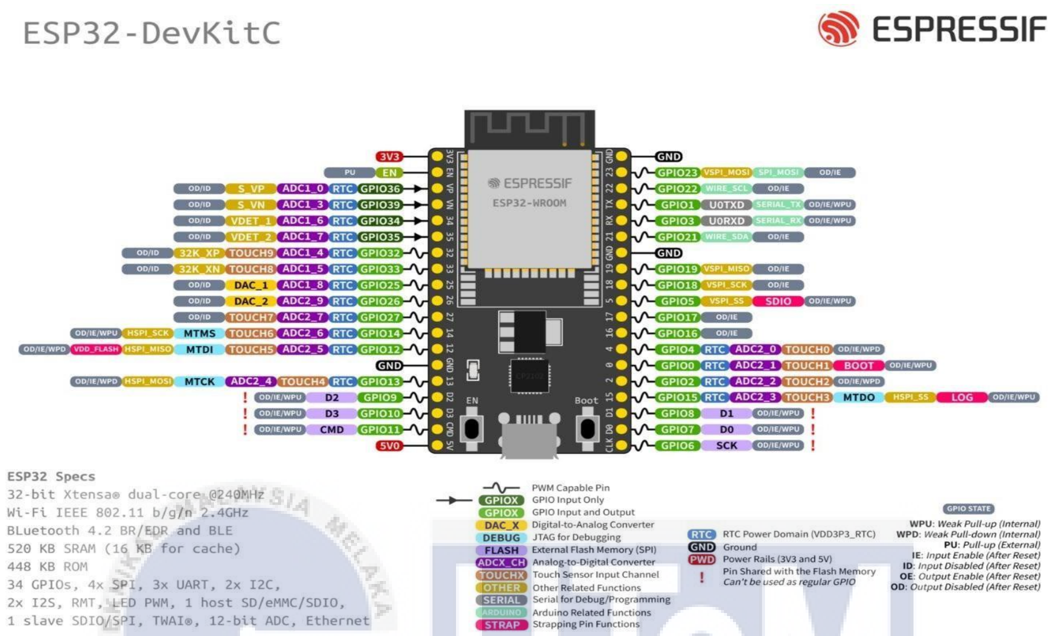
10. Antenna diversity

ESP32 Pinout Layout:

https://docs.espressif.com/projects/esp-idf/en/latest/esp32/_images/esp32-devkitC-v4-pinout.png

Appendix B

ESP32 PINOUT LAYOUT:



Appendix C

ESP32-DEVKIT PIN DESCRIPTION:

Key Component	**Description**
ESP32-WROOM32	A module with ESP32 at its core. For more information, see ESP32-WROOM-32 Datasheet.
EN	Reset button.
Boot	Download button. Holding down **Boot** and then pressing **EN** initiates Firmware Download mode for downloading firmware through the serial port.
USB-to-UART Bridge	Single USB-UART bridge chip provides transfer rates of up to 3Mbps.
Micro USB Port	USB interface. Power supply for the board as well as the communication interface between a computer and the ESP32- WROOM-32 module.
5V Power On LED	Turns on when the USB or an external 5V power supply is connected to the board. For details see the schematics in Related Documents.
I/O	Most of the pins on the ESP module are broken out to the pin headers on the board. You can program ESP32 to enable multiple functions such as PWM, ADC, DAC, I2C, I2S, SPI, etc.

Appendix D

ESP32-DEVKIT J1 PIN FUNCTION:

No.	Name	Type	Function
1	3V3	P	3.3 V power supply
2	EN	I	CHIP_PU, Reset
3	IO36	I	GPIO36, ADC1_CH0, S_VP
4	IO39	I	GPIO39, ADC1_CH3, S_VN
5	IO34	I	GPIO34, ADC1_CH6, VDET_1
6	IO35	I	GPIO35, ADC1_CH7, VDET_2
7	IO32	I/O	GPIO32, ADC1_CH4, TOUCH_CH9, XTAL_32K_P
8	IO33	I/O	GPIO33, ADC1_CH5, TOUCH_CH8, XTAL_32K_N
9	IO25	I/O	GPIO25, ADC1_CH8, DAC_1
10	IO26	I/O	GPIO26, ADC2_CH9, DAC_2
11	IO27	I/O	GPIO27, ADC2_CH7, TOUCH_CH7
12	IO14	I/O	GPIO14, ADC2_CH6, TOUCH_CH6, MTMS
13	IO12	I/O	GPIO12, ADC2_CH5, TOUCH_CH5, MTDI
14	GND	G	Ground

15	IO13	I/O	GPIO13, ADC2_CH4, TOUCH_CH4, MTCK
16	IO9	I/O	GPIO9, D2
17	IO10	I/O	GPIO10, D3
18	IO11	I/O	GPIO11, CMD
19	5V0	P	5 V power supply

Appendix E

ESP32-DEVKIT J3 PIN FUNCTION:

No.	**Name**	**Type**	**Function**
1	GND	G	Ground
2	IO23	I/O	GPIO23
3	IO22	I/O	GPIO22
4	IO1	I/O	GPIO1, U0TXD
5	IO3	I/O	GPIO3, U0RXD
6	IO21	I/O	GPIO21
7	GND	G	Ground
8	IO19	I/O	GPIO19

9	IO18	I/O	GPIO18
10	IO5	I/O	GPIO5
11	IO17	I/O	GPIO17
12	IO16	I/O	GPIO16
13	IO4	I/O	GPIO4, ADC2_CH0, TOUCH_CH0
14	IO0	I/O	GPIO0, ADC2_CH1, TOUCH_CH1, Boot
16	IO2	I/O	GPIO2, ADC2_CH2, TOUCH_CH2
17	IO15	I/O	GPIO15, ADC2_CH3, TOUCH_CH3, MTDO
17	IO8	I/O	GPIO8, D1
18	IO7	I/O	GPIO7, D0
19	IO6	I/O	GPIO6, SCK

P: Power supply; I: Input; O: Output.

Appendix F

LORA RFM95 MODULE KEY PRODUCT FEATURES:

1. LoRaTM Modem.

2. 168 dB maximum link budget. 3. +20 dBm – 100 mW steady RF output vs. V supply.

4. A high-efficiency amplifier with +14 dBm output.

5. Bit rate of up to 300 kbps that may be programmed.

6. Extremely sensitive, measuring as low as -148 dBm.

7. Front end that is impervious to projectiles: IIP3 = -12.5 dBm

8. Outstanding resistance to being blocked.

9. A low RX current of 10.3 milliamperes and a register retention of 200 nanoamperes

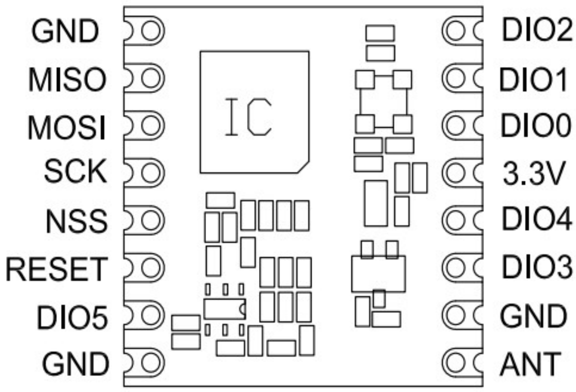
10. a synthesizer that is fully integrated and has a resolution of 61 Hz.

11. Modulation techniques using FSK, GFSK, MSK, GMSK, LoRaTM, and OOK.

Appendix G

LORA RFM95 MODULE PIN DIAGRAM:

The following diagram shows the pin arrangement, top view.



Appendix H

LORA RFM95 MODULE PIN DESCRIPTION:

Number	Name	Type	Description Stand Alone Mode
1	GND	-	Ground
2	MISO	I	SPI Data output
3	MOSI	O	SPI Data input
4	SCK	I	SPI Clock input
5	NSS	I	SPI Chip select input
6	RESET	I/O	Reset trigger input
7	DIO5	I/O	Digital I/O, software configured
8	GND	-	Ground
9	ANT	-	RF signal output/input.
10	GND	-	Ground
11	DIO3	I/O	Digital I/O, software configured
12	DIO4	I/O	Digital I/O, software configured
13	3.3V	-	Supply voltage
14	DIO0	I/O	Digital I/O, software configured
15	DIO1	I/O	Digital I/O, software configured
16	DIO2	I/O	Digital I/O, software configured