SOLAR-POWERED AIR QUALITY MONITORING SYSTEM WITH ESP32

NUR AINA ZAKARIA BINTI ABDULLAH

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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NUR AINA ZAKARIA BINTI ABDULLAH

This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Computer Engineering Technology (Computer Systems) with Honours

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TS. DR. HASRUL NISHAM BIN ROSLY
Pensyarah Kanan
Fakulti Teknologi Dan Kejuruteraan Elektronik Dan Komputer (FTKEK)
Universiti Teknikal Malaysia Melaka (UTeM)

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DEDICATION

I would like to dedicate this project to my beloved family, whose unwavering faith in my abilities has been a constant source of inspiration. Your support and encouragement have motivated me to strive harder every day, leading to the successful completion of this endeavor. I extend my heartfelt gratitude to my supervisor Ts. Dr. Hasrul 'Nisham bin Rosly, for his invaluable guidance and support throughout this journey. To my friends and peers, your unwavering support during challenging times has been immensely appreciated, and your camaraderie has made this academic pursuit more enjoyable. I am deeply grateful to all those who have contributed to the realization of this vision, and this achievement would not have been possible without their hard work and dedication.

ABSTRACT

Air pollution poses a significant global threat, adversely impacting environmental health and human well-being, necessitating advanced monitoring solutions. The rising levels of air pollution caused by industrialization, urbanization, and open burning have intensified health risks and environmental degradation. Traditional air quality monitoring systems are often expensive, stationary, and lack real-time data accessibility, making them unsuitable for widespread adoption. The absence of cost-effective, portable, and energy-efficient alternatives further hinders effective air quality monitoring in various environments. This project aims to design and implement a solar-powered ESP32-based air quality monitoring system integrated with IoT capabilities, providing real-time and precise data on air pollutants. The system utilizes an MQ135 sensor to detect various air pollutants and a DHT22 sensor to measure temperature and humidity, thereby enhancing the understanding of atmospheric conditions. The ESP32 microcontroller serves as the central unit, coordinating the operation of sensors and other peripherals while also facilitating seamless data transmission and remote monitoring via the Blynk app. Additionally, a buzzer is incorporated to issue immediate alerts when air quality thresholds are breached. The inclusion of a solar panel ensures sustainable power generation, supporting prolonged system operation and reducing environmental impact. Tests were conducted under various environmental conditions to evaluate performance metrics such as data accuracy, power efficiency, and usability.

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ABSTRAK

Pencemaran udara merupakan ancaman global yang serius, memberi kesan negatif kepada kesihatan manusia dan alam sekitar, dan memerlukan penyelesaian pemantauan yang lebih maju. Peningkatan pencemaran udara akibat perindustrian, urbanisasi, dan pembakaran terbuka telah meningkatkan risiko kesihatan serta kerosakan ekosistem. Sistem pemantauan kualiti udara tradisional sering kali mahal, tidak mudah alih, dan tidak menyediakan data masa nyata, menjadikannya kurang sesuai untuk penggunaan secara meluas. Kekurangan alternatif yang kos efektif, mudah alih, dan cekap tenaga turut menyukarkan pemantauan kualiti udara di pelbagai persekitaran. Projek ini bertujuan untuk mereka bentuk dan membangunkan sistem pemantauan kualiti udara berasaskan ESP32 yang dikuasakan oleh tenaga solar serta dilengkapi dengan keupayaan IoT, yang mampu menyediakan data pencemaran udara secara masa nyata dan tepat. Sistem ini menggunakan sensor MQ135 untuk mengesan pelbagai pencemaran udara dan sensor DHT22 untuk mengukur suhu serta kelembapan, sekaligus meningkatkan pemahaman tentang keadaan atmosfera. Mikropengawal ESP32 berfungsi sebagai unit utama untuk menyelaras operasi sensor dan peranti lain serta memudahkan penghantaran data secara lancar dan pemantauan jarak jauh melalui aplikasi Blynk. Selain itu, buzzer turut disertakan untuk memberikan amaran segera apabila tahap kualiti udara melebihi had yang ditetapkan. Pemasangan panel solar memastikan penjanaan kuasa yang mampan, menyokong operasi sistem untuk jangka masa panjang serta mengurangkan kesan terhadap alam sekitar. Ujian telah dijalankan dalam pelbagai keadaan persekitaran bagi menilai prestasi sistem dari segi ketepatan data, kecekapan tenaga, dan kebolehgunaan.

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LIST OF SYMBOLS

±	-	Plus Minus Sign
%	-	Percentage

LIST OF ABBREVIATIONS

V	-	Voltage
I	-	Current
P	-	Power
W	-	Watt
A	-	Ampere
h	-	Hours
°C	-	Celcius
ppm	-	Parts Per Million
Min	-	Minutes
t	-	Time

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CHAPTER 1

INTRODUCTION

1.1 Background

Air quality monitoring is imperative for safeguarding both human health and the environment against the detrimental effects of pollutants such as particulate matter, volatile organic compounds (VOCs), and carbon monoxide (CO). As concerns regarding pollution and its repercussions intensify, there is a burgeoning demand for real-time monitoring systems that offer precise and immediate data. In response to this pressing need, this project undertakes the development of an innovative air quality monitoring system that seamlessly integrates advanced technology with sustainability principles. It aims to address the critical requirement for real-time air quality monitoring by leveraging ESP32 microcontroller technology and a suite of sensors adept at detecting various pollutants. Additionally, the system incorporates Internet of Things (IoT) connectivity, enabling remote access and control for enhanced functionality and data management.

The decision to incorporate solar panels into the system's design is driven by a dual commitment to mitigating environmental degradation and combating the escalating health concerns associated with poor air quality. With a noticeable rise in respiratory illnesses and cardiovascular problems attributed to air pollution, the project's focus aligns with efforts to address this alarming trend. By harnessing solar energy, the system not only reduces its carbon footprint but also ensures portability and resilience, rendering it suitable for deployment in diverse settings, including urban areas, industrial zones, and remote locations.

This strategic integration underscores the project's broader significance in tackling environmental challenges, promoting sustainable technology adoption, and contributing to the enhancement of public health through innovative air quality monitoring solutions.

1.2 Addressing Air Pollution Through Solar-Powered Air Quality Monitoring

Air pollution is a pressing environmental concern with far-reaching impacts on public health and the ecosystem. One of the primary contributors to air pollution is the emission of pollutants from various sources, including industrial activities, transportation, and energy production. To tackle this issue, it is essential to monitor air quality continuously and track the levels of pollutants in the atmosphere. This is where a solar-powered air quality monitoring project can play a vital role. By deploying monitoring systems equipped with advanced sensors to measure pollutants such as particulate matter, carbon monoxide, and volatile organic compounds, such a project can provide valuable insights into the extent and distribution of air pollution. Moreover, by harnessing solar energy for power, these monitoring systems can operate sustainably and autonomously, enabling continuous data collection even in remote or off-grid locations.

Figure 1:Air pollution in Klang[1]

Figure 1 illustrates the impact of air pollution in Klang, Malaysia, emphasizing the urgent need for effective monitoring and mitigation strategies [1]. Such visual representations highlight the real-time challenges posed by air pollution, underscoring the importance of implementing robust monitoring frameworks. By integrating solar-powered technologies, these monitoring systems not only contribute to environmental sustainability but also enable prompt regulatory responses to mitigate the adverse effects of air pollution on public health and the environment.

1.3 Problem Statement

The problem statement at the core of this project revolves around the pressing need for real-time air quality monitoring systems that are not only accurate but also sustainable. Presently, many air quality monitoring methods falter in their ability to deliver timely data, a deficiency that undermines efforts to promptly address pollution events or health hazards. Moreover, the reliance of existing systems on non-renewable energy sources exacerbates environmental concerns, contributing to increased carbon emissions and overall ecological impact. Considering these shortcomings, this project endeavours to bridge these gaps by pioneering an innovative air quality monitoring system that seamlessly integrates cutting-edge sensor technology with sustainable energy sources, while leveraging Internet of Things (IoT) connectivity for enhanced functionality and data management.

This project addresses several key challenges. Many current air quality monitoring systems cannot provide real-time data, making it hard to respond quickly to pollution or health risks. They also lack mobile access, making it inconvenient for users to check data remotely. Most systems rely on non-renewable energy, which harms the environment. Their high cost and limited portability make them difficult to use in remote areas or for people in low-income communities. Furthermore, the complexity of existing systems often discourages widespread adoption. These problems highlight the urgent need for a system that is real-time, mobile-friendly, affordable, easy to use, and powered by sustainable energy.

By tackling these challenges head-on, the envisioned project sets out to develop a transformative solution: a sustainable, cost-effective, and highly efficient air quality monitoring system capable of delivering real-time data across diverse environments. Through the strategic integration of ESP32 microcontroller technology, an array of advanced sensors, solar power, and IoT connectivity, the project seeks to transcend the limitations of conventional systems. By doing so, it aspires to not only enhance environmental health and sustainability but also to catalyze broader advancements in air quality monitoring technology, with far-reaching implications for public health and ecological resilience.

1.4 Project Objective

The aim of the project is to design and implement a solar-powered air quality monitoring system with ESP32 capable of providing accurate, real-time data on pollutant levels, thus contributing to environmental health and sustainability efforts:

a) To develop an air quality monitoring system using ESP32 microcontroller technology.
b) To collect data and analysis through cloud-based platforms.
c) To integrate solar power into the air quality monitoring system.

1.5 Scope of Project

The scope of this project are as follows:

a) Design and Requirement Analysis: Conduct a thorough review of existing air quality monitoring systems, sensor technologies, and sustainable energy solutions to define precise system requirements and develop a comprehensive architectural plan. This includes integrating IoT connectivity to enable seamless data transmission, remote monitoring, and management capabilities.

b) Development of system components: Selecting appropriate sensors and designing custom circuitry to interface seamlessly with ESP32 microcontrollers, implementing firmware for real-time data acquisition and transmission. Additionally, integrating IoT protocols and communication modules to facilitate remote access, data visualization, and cloud-based storage.

c) System Implementation: Assembling hardware components according to the meticulously crafted system architecture, configuring sensor placement, and calibration procedures to ensure optimal data accuracy and reliability. This includes integrating IoT protocols for remote management and monitoring of system performance.

d) Testing, validation, and deployment: Conducting comprehensive testing to evaluate system performance under various environmental conditions, confirming accuracy and effectiveness in detecting and analyzing air pollutants. Additionally, validating IoT functionalities for remote access, data visualization, and system management.

Following successful validation, deploying the monitoring system in target locations alongside comprehensive documentation, training sessions, and ongoing support, including IoT-specific troubleshooting and maintenance procedures.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In today's world, the need for sustainable solutions is increasingly urgent, with climate change, air pollution, and resource scarcity dominating global concerns. In response, technologies such as solar-powered systems have emerged as promising approaches to address these challenges. The creation of a solar-powered ESP32 air quality monitoring system signifies a significant advancement in using renewable energy to combat air pollution. This introduction sets the foundation for examining how sustainable energy solutions intersect with environmental monitoring technologies, emphasizing the critical role of precise data collection and real-time analysis in addressing air quality issues.

2.2 Understanding Air Quality Monitoring in Literature

Embarking on a journey through the literature surrounding air quality monitoring and sensor technologies, this section delves into how air quality monitoring projects contribute to our understanding of environmental pollution and guide strategies for mitigation. Established research demonstrates the pivotal role of air quality monitoring technologies in providing crucial insights into changes in pollutant levels such as particulate matter, volatile organic compounds (VOCs), and carbon monoxide (CO), reflective of environmental pollution impacts. These studies shed light on trends in pollutant concentrations over time, elucidating sources, and patterns of air pollution across diverse environments. Furthermore, air quality monitoring technologies play a vital role in assessing the effectiveness of pollution control measures and tracking improvements in air quality over time.

2.2.1 Overview of Air Quality in Malaysia

During the late 1990s, Malaysia faced substantial air quality challenges due to a combination of natural phenomena and human activities. In 1998, several regions, including Prai Industrial Estate, Prai Seberang Jaya, Johor Bahru, Pasir Gudang, and Nilai, recorded sulphur dioxide (SO_2) levels that exceeded the acceptable 24-hour limit of 0.04 parts per million (ppm). Concurrently, the absence of haze in 1998 led to increased photochemical oxidant formation, particularly ozone, affecting 50% of monitored locations. Cities such as Shah Alam, Gombak, Kajang, Klang, and Kuala Lumpur experienced significant exceedances of ozone levels. Nitrogen dioxide (NO_2) levels surpassed acceptable limits only in Kuala Lumpur. Data indicated that ozone formation posed the most severe localized air pollution issue, followed by SO_2, particulate matter (PM_{10}), carbon monoxide (CO), and NO_2.

The 1997 haze event in Malaysia was primarily driven by elevated concentrations of suspended particles, with PM_{10} levels significantly exceeding the Malaysian Ambient Air Quality Guidelines (MAQG) across most monitored areas. This severe pollution episode correlated with a notable increase in health issues, including respiratory tract infections, asthma exacerbations, and conjunctivitis, as documented by Hospital Kuala Lumpur and other medical facilities [2]. For instance, Selangor reported a substantial rise in respiratory disease cases during the haze period, with asthma and acute respiratory infections showing sharp increases. Similarly, Kuching experienced elevated health issues due to extreme Air Pollutant Index (API) readings. The health impacts were predominantly attributed to elevated PM_{10} levels, supported by a spirometry study of 16-year-old schoolchildren in Kuala Lumpur, revealing decreased lung function and increased respiratory symptoms due to prolonged exposure to $PM_{10.}$

Figure 2:Malaysia 1997 Haze[2]

Figure 2 illustrates the spatial distribution of air pollutant concentrations across Malaysia during the haze and pollution events of 1997-1998. The figure highlights significant exceedances of sulphur dioxide (SO_2), ozone, and particulate matter (PM_{10}) in key industrial and urban centers such as Prai Industrial Estate, Johor Bahru, and Kuala Lumpur. This visualization underscores the widespread nature of air quality issues during this period, emphasizing hotspots where pollutant levels exceeded regulatory limits. Such graphical representations are crucial for policymakers and environmental scientists to pinpoint areas requiring immediate mitigation strategies and to assess the efficacy of regulatory measures over time.

Management of air quality in Malaysia has involved establishing a continuous air quality monitoring network as part of the government's privatization initiative. Operated by Alam Sekitar Malaysia (ASMA), this network aims to provide cost-effective and timely air quality data to the Department of Environment (DOE) and other stakeholders. These data serve as a scientific basis for regulatory actions and industry self-regulation. The study underscores the importance of ongoing research into the health impacts of air pollution and advocates for stricter enforcement of environmental regulations, enhanced public transportation, reduced use of sulphur fuels, and increased public awareness to mitigate air pollution and its detrimental effects on public health.

2.3 Internet of things

The Internet of Things (IoT) is a dynamic paradigm that connects everyday objects via the internet, facilitating seamless communication and data exchange across diverse domains like healthcare, transportation, and smart environments [3]. Its pervasive influence spans from enhancing personal interactions with technology in smart homes to revolutionizing industrial automation and healthcare delivery. With applications ranging from home healthcare to smart cities and grid management, IoT is poised to reshape the fabric of modern internet infrastructure.

Table 1:The similarities and difference between IoT, Internet and WSN[3]

Characteristics	**IoT**	**Internet**	**WSN**
Comm, Protocol	Lightweight Comm. protocols	(TCP/IP)	Lightweight Comm. protocols.
Scale degree of Area	Cover wide area	Cover wide area	Cover local area
Networking Approach	Determine backbone	Determine backbone	Self-organization
Identify Objects	Must	Can not	Can
Type of nodes	Active and passive	Active	Active
Network design	WSN+ dynamic smart things+ Internet surrounded by intelligent environment	Set of networks contains set of fixed objects	Dynamic smart objects
Behavior	Dynamically	Fixed	Dynamically
Networking TIME	Timing synchronization	Unlimited	Unlimited

Table 1 illustrates the relationships between IoT, the Internet, and Wireless Sensor Networks (WSN), highlighting both similarities and differences. While the Internet forms the backbone of IoT, providing the global network infrastructure for data transmission, IoT extends this connectivity by integrating physical devices and objects into the digital realm. WSNs, on the other hand, are specialized networks of interconnected sensors that gather and transmit data wirelessly, often within constrained environments like industrial settings or environmental monitoring.

IoT architectures emphasize openness and interoperability, accommodating the varied devices and networks involved. Cloud computing and ad-hoc networks play pivotal roles by managing vast data streams and enabling flexible communication protocols tailored to IoT's unique requirements. Key challenges such as scalability, security, and energy efficiency underscore the need for efficient battery usage and energy harvesting technologies to sustain IoT devices over extended periods.

Security remains paramount in IoT ecosystems due to the increased risk of unauthorized access and data breaches. Robust security strategies encompass multiple layers, including encryption, data integrity, and privacy policies, crucial for safeguarding sensitive information and fostering user trust. Standardized interfaces and frameworks further enhance security and reliability, ensuring interoperability across diverse IoT environments.

In conclusion, IoT heralds a transformative era by bridging the digital and physical worlds through advanced technologies. Addressing challenges like security, standardization, and energy management will be pivotal in fully realizing IoT's potential to revolutionize modern living. Continued research and development are essential to further unlock the myriad benefits IoT promises across industries and everyday life.

2.3.1 Architecture of Internet of Things

The proposed improved layered architecture for IoT expands upon traditional models by delineating functions across seven distinct layers. At its core, the architecture begins with the Hardware Layer, interfacing physical and digital realms through sensors like environmental and telemetric sensors. These devices capture real-time data on various physical attributes such as temperature and air quality, converting them into digital signals for further processing. The Environment Layer builds upon this foundation by detecting and monitoring objects and environmental conditions, ranging from moving vehicles to static buildings [4].

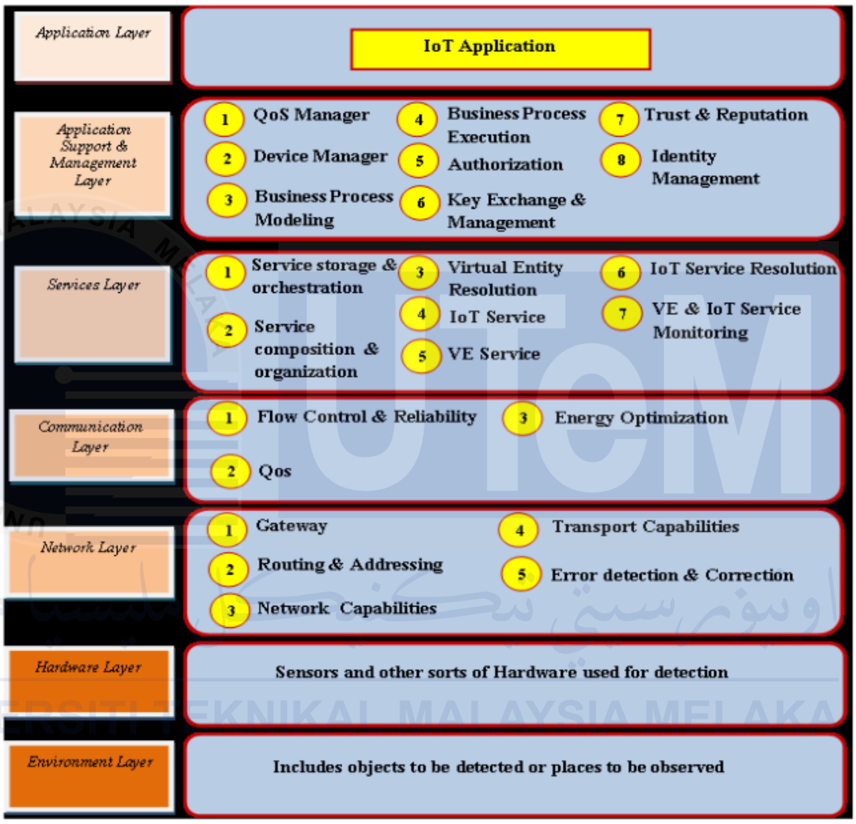


Figure 3:Improved Layer Architecure of IoT [4]

Figure 3, depicting the Improved Layer Architecture of IoT [4], illustrates how these layers interact seamlessly to facilitate data flow and application integration. The Communication Layer, for instance, manages data transmission across multiple networks while ensuring optimal performance through flow control and reliability mechanisms. Above it, the Services Layer orchestrates data storage, virtual entity resolution, and service composition, critical for handling the vast amounts of information generated by IoT devices.

These layers collectively support a robust framework that enhances scalability and flexibility, catering to diverse IoT applications in industries such as manufacturing, healthcare, and logistics.

Moving up the architecture, the Application Support & Management Layer focuses on managing IoT applications through functions like QoS management and identity management. It ensures secure and efficient application operation across various domains, from manufacturing to healthcare. Finally, the Application Layer represents the interface where end-users interact with IoT applications, spanning industries like logistics and public safety. This layer leverages the underlying architecture to deliver diverse applications, enabling users to access and utilize IoT-driven insights and services effectively.

Overall, the proposed architecture enhances the scalability and flexibility of IoT deployments by optimizing data management, improving network efficiency, and supporting a wide array of applications. Future research is poised to refine protocol standards, enhance data analytics capabilities, and bolster security measures to further advance the potential of IoT in transforming industries and daily life.

2.4 Concept of Arduino Air Quality Monitoring System

Air quality monitoring systems serve as essential tools in assessing and managing air pollution levels, providing invaluable data on pollutant concentrations in the atmosphere. These systems are comprised of a network of sensors strategically positioned across different locations to continuously measure key air quality parameters such as particulate matter (PM), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), and volatile organic compounds (VOCs). These sensors utilize various detection mechanisms, including optical, electrochemical, and semiconductor-based technologies, to accurately measure pollutant concentrations in real time. The collected data is then transmitted to a central database for analysis and interpretation, enabling stakeholders to monitor air quality conditions and make informed decisions to protect public health and the environment.

In addition to sensors, air quality monitoring systems incorporate data acquisition systems, communication networks, and data management software to facilitate the collection, processing, and analysis of sensor data. Data acquisition systems play a critical role in collecting and transmitting sensor data to a central server for analysis, while communication networks enable real-time data transmission between sensors and the central server. Data management software is used to organize, analyze, and visualize the collected data, providing stakeholders with actionable insights into air quality conditions. Overall, air quality monitoring systems play a vital role in providing timely and accurate information on air pollution levels, enabling policymakers, regulators, and the public to take proactive measures to improve air quality and protect public health.

2.5 Previous Related Project

2.5.1 Arduino Based Air Quality Monitoring System

The Arduino-based air quality monitoring system detailed in the study represents a pivotal approach to addressing the pervasive challenges of air pollution [5]. Utilizing advanced sensors like the DHT22 for temperature and humidity, as well as the MQ-4, MQ-9, and MG811 for detecting carbon monoxide, methane, and CO_2 respectively, the system captures real-time data essential for understanding and managing air quality dynamics. These sensors operate on the Arduino Uno microcontroller platform, facilitating precise measurements in parts per million (PPM) displayed both graphically on an LCD interface and numerically through serial monitoring.

The system's focus on measuring key pollutants is particularly significant given the sources of air pollution, predominantly vehicular emissions and industrial activities. These pollutants not only degrade air quality but also pose serious risks to ecosystems, human health, and climate stability. Monitoring these metrics provides critical insights into the extent of pollution, aiding in the development of targeted interventions and policies to mitigate its adverse effects.

By integrating multiple sensors with Arduino technology, the system offers a versatile solution capable of monitoring air quality across various environments. This comprehensive approach enhances our ability to track pollution trends over time and spatially, empowering decision-makers with essential data for implementing effective pollution control measures.

In conclusion, the Arduino-based air quality monitoring system serves as a robust tool in the ongoing battle against air pollution [5]. Its real-time monitoring capabilities not only inform immediate actions to safeguard public health but also support long-term strategies for environmental sustainability. By leveraging technology to enhance monitoring precision and accessibility, this system underscores its role in promoting healthier living environments and driving global efforts towards cleaner, more resilient cities.

2.5.2 Solar Based Air Quality Monitoring using Internet Of Things

The proposed system integrates advanced IoT technologies to monitor air quality effectively, addressing the critical issue of industrial air pollution. Utilizing sensors such as MQ135, MQ3, MQ5, and DHT11 connected to an ESP32 microcontroller, the system measures concentrations of harmful gases like CO_2, smoke, and benzene in parts per million (PPM). This data is transmitted to a cloud platform via MQTT protocol for real-time monitoring and analysis [6].

Key components of the system include a Blynk application that alerts users when pollution levels exceed safe thresholds, enhancing workplace safety and environmental stewardship [6]. The use of IoT not only facilitates remote monitoring but also provides a scalable and cost-effective solution compared to traditional monitoring systems [7]. Previous studies have shown similar IoT-based approaches to be effective in urban environments, highlighting the scalability and affordability of such systems [8].

Moreover, the system employs low-cost components and open-source platforms like Arduino IDE, making it accessible for widespread implementation across different industrial settings [6]. By continuously monitoring air quality parameters like humidity and temperature alongside gas concentrations, the system ensures early detection of environmental hazards, thereby mitigating health risks associated with air pollution [9].

In conclusion, the solar-powered IoT-based air quality monitoring system offers a robust solution to monitor and manage industrial emissions effectively. By leveraging IoT's connectivity and data analytics capabilities, the system not only meets regulatory standards but also contributes to sustainable development goals by promoting healthier work environments and reducing environmental impact. Future enhancements could involve integrating additional sensors or refining data analytics algorithms to further improve accuracy and usability in diverse environmental conditions [10].

2.5.3 Design of IoT Based Air Quality Monitoring Device with Optimal Solar-based Power Source

Air pollution poses a significant threat to urban areas, particularly in countries experiencing rapid economic growth like Malaysia. This issue not only jeopardizes public health but also impacts environmental sustainability and renewable energy sources such as solar power. The presence of dust and particulate matter in the air not only affects human health but also diminishes the efficiency of solar panels used for energy generation. Conventional air quality monitoring systems often rely on fixed power supplies, limiting their mobility and accessibility to real-time data. In response to these challenges, the study proposes a novel approach integrating Internet of Things (IoT) technology and solar energy to develop a flexible and mobile air quality monitoring system.

The proposed system utilizes low-cost MQ-series sensors to monitor levels of harmful gases like CO_2, CO, SO_2, and O_3, as well as environmental parameters such as dust concentration, temperature, and humidity. These sensors transmit data to an Arduino UNO microcontroller equipped with an ESP8266-01 WiFi module. This setup enables continuous data transmission to the cloud via the ThingSpeak IoT platform, facilitating real-time data visualization and analysis accessible through smartphones and laptops.

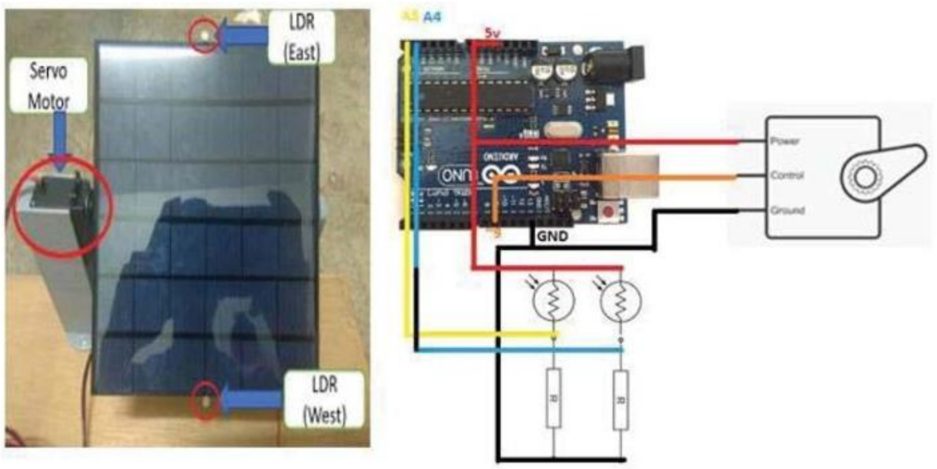


Figure 4: The solar tracker and connection to the Arduino[11]

Figure 4 illustrates the design and configuration of the solar tracker connected to the Arduino microcontroller. The solar tracker uses light sensors to determine the optimal angle for solar panels, ensuring maximum exposure to sunlight throughout the day. The connection to the Arduino allows for precise control and adjustment of the panel orientation, which is crucial for maintaining efficient energy collection. This setup not only supports the power needs of the air quality monitoring system but also demonstrates the innovative integration of renewable energy technology with IoT applications.

Additionally, the integration of a solar tracker enhances the system's efficiency by adjusting the orientation of solar panels based on sunlight intensity, thereby optimizing energy harvesting and system sustainability [11]. By leveraging IoT and solar technology, the system aims to overcome the limitations of traditional monitoring systems by providing enhanced mobility, cost-effectiveness, and data accessibility. This innovation is crucial for urban environments where air quality can vary significantly across different locations and times, impacting community health and environmental management strategies. The real-time nature of the data collection and analysis ensures timely responses to air quality changes, enabling authorities and communities to take proactive measures to mitigate health risks associated with air pollution [12].

In conclusion, the development of this IoT-based air quality monitoring system represents a significant advancement in environmental monitoring technology. It not only addresses current challenges in air pollution monitoring but also sets a precedent for sustainable urban development practices. By integrating low-cost sensors, renewable energy sources, and IoT connectivity, the system offers a scalable solution that can be adapted and implemented in various urban settings worldwide. This innovation underscores the potential of technology to improve public health outcomes and contribute to more effective environmental policies and regulations [13].

2.5.4 Air Quality Monitoring System Based on IoT

The IoT-based air quality monitoring system discussed in the study represents a significant advancement in environmental monitoring technology. Designed to evaluate real-time air quality conditions, the system integrates sensors capable of detecting key pollutants such as O_3, SO_2, CO, and particulate matter [14]. Utilizing Arduino microcontrollers, the system collects sensor data and transmits it to a cloud-based platform via WiFi, enabling remote access to air quality information through a web interface. This approach not only enhances data accuracy but also addresses the limitations of traditional monitoring methods, offering scalability and cost-effectiveness in environmental monitoring.

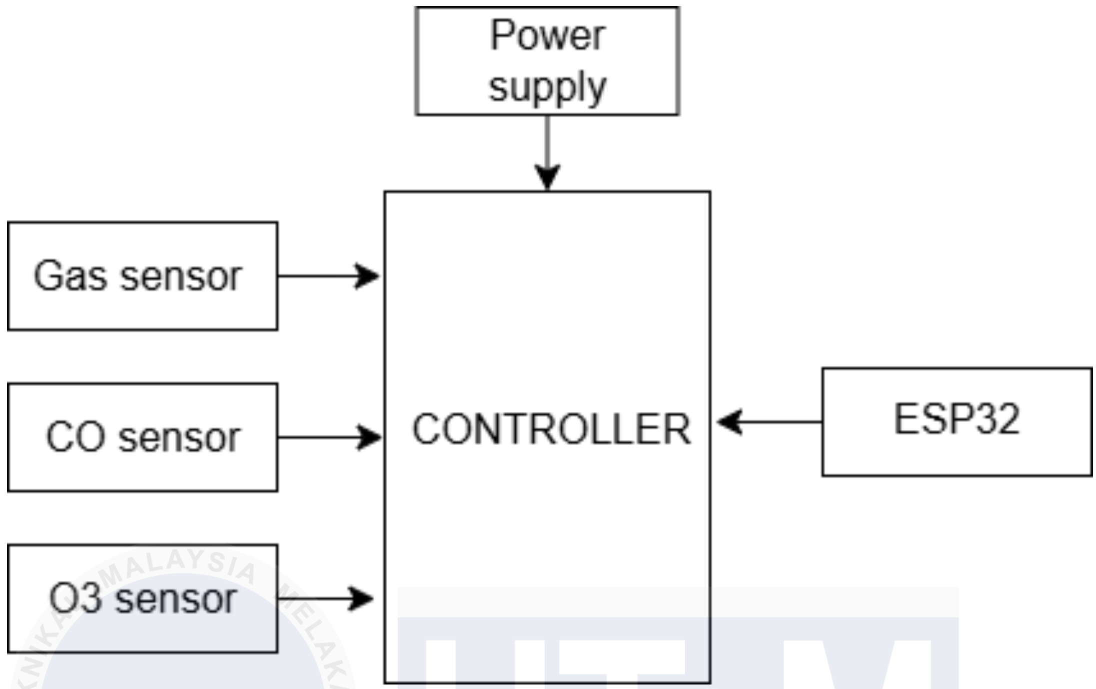


Figure 5:Design of the system[14]

According to Figure 5, the block design of the system outlines the overall architecture of the proposed IoT-based environmental monitoring system. It details the connections between the sensors, Arduino microcontroller, WiFi module, and cloud platform. The block design illustrates how data flows from the sensors to the microcontroller, which processes the information and transmits it via WiFi to the cloud for storage and analysis. This design ensures efficient data handling and real-time monitoring, which are essential for effective environmental management.

This integration of IoT technology into air quality management systems marks a pivotal shift in how environmental data is collected and utilized. Unlike conventional systems constrained by high costs and limited coverage, the IoT-based system leverages internet connectivity and cloud computing to provide real-time data across diverse locations. By using affordable sensors and Arduino microcontrollers, it facilitates timely interventions and informed decision-making in pollution control and public health initiatives, thereby improving overall environmental quality.

Field trials and simulations have demonstrated the practical efficacy of the IoT-based air quality monitoring system. Capable of accurately monitoring and reporting air quality metrics, the system proves its reliability in various environmental settings. This adaptability is crucial for addressing modern environmental challenges exacerbated by urbanization and industrialization. Moreover, its seamless integration with existing infrastructure underscores its potential for widespread adoption in both developed and developing regions, ensuring comprehensive and accessible air quality monitoring capabilities.

In summary, the study highlights the transformative impact of IoT technologies on contemporary air quality monitoring practices. By harnessing interconnected devices and cloud resources, the system provides a robust framework for continuous monitoring and proactive environmental management. Future research and development in IoT applications are essential to enhancing system capabilities, expanding coverage, and empowering global communities to participate actively in environmental stewardship and public health protection initiatives.

2.5.5 Smart Air Quality Monitoring System using Arduino Mega

This project aims to address the critical issue of air quality monitoring, crucial for human and environmental health. It proposes an innovative system utilizing Arduino technology to measure air quality parameters such as dust particle concentration and temperature. The system employs sensors and a liquid crystal display (LCD) to provide real-time data visualization, enabling users to monitor air quality levels effectively. When pollutant levels exceed safe thresholds, a passive buzzer alerts users, enhancing awareness and promoting proactive health measures.

The motivation behind this project stems from alarming statistics on air pollution-related health impacts globally, highlighted by the World Health Organization (WHO). Airborne pollutants are linked to various respiratory and cardiovascular disorders, contributing to millions of premature deaths annually worldwide. Existing research underscores the inadequacy of current monitoring systems, necessitating more accessible and accurate solutions to safeguard public health.

Methodologically, the project employs Arduino Mega for data acquisition and processing, demonstrating its utility in real-world environmental monitoring applications. Through rigorous testing and experimentation, conducted over a full day in a Malaysian setting, the system successfully recorded and analyzed temperature and dust density data. Results were compared with established Air Pollution Index (API) readings to validate accuracy, showing moderate pollution levels that prompt timely alerts via the buzzer module.

In conclusion, the project achieves its objectives by providing a cost-effective and efficient air quality monitoring solution tailored for urban environments. By leveraging Arduino's versatility and accessibility, the system not only detects environmental hazards promptly but also empowers communities with actionable data to mitigate health risks posed by air pollution. Future enhancements could focus on expanding sensor capabilities and integrating with broader data analytics frameworks to enhance monitoring precision and scalability in diverse geographical contexts.

2.5.6 Arduino Based Real Time Air Quality and Pollution Monitoring System

The Arduino-based air quality monitoring system described integrates sensors like the MQ-135 to monitor real-time metrics such as carbon monoxide (CO) and nitrogen dioxide (NO_2), offering a cost-effective solution adaptable to diverse environments [15]. By incorporating robust components like the LM393 chip and MQ135 sensor, the system ensures precise pollutant detection, crucial for ongoing environmental and public health management efforts. This setup enables efficient monitoring of gases like ammonia (NH_3) and benzene, enhancing its utility across residential and industrial settings.

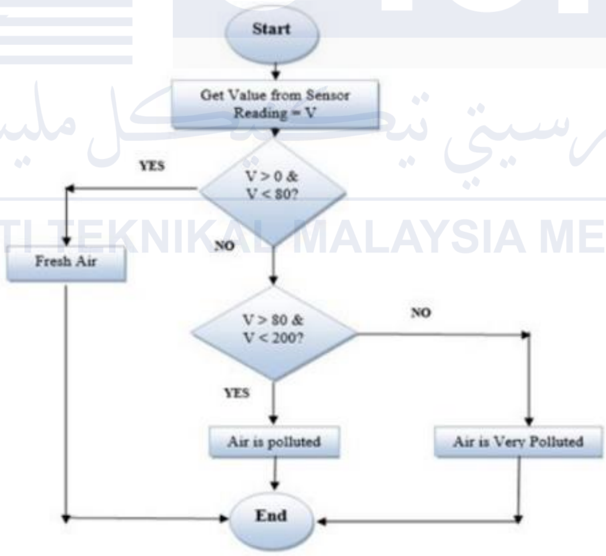


Figure 6: Flowchart of the system [15]

Figure 6 illustrates the system's operational flowchart designed to distinguish between polluted and fresh air conditions. It details how sensor data from the MQ-135 and other components are processed by the Arduino microcontroller. The system triggers alerts based on pollutant levels, indicating the need for environmental adjustments. This data is then transmitted via the WiFi module to a cloud platform for real-time monitoring and analysis. This structured approach supports timely decision-making and regulatory compliance, pivotal for effective pollution control strategies.

The system's software component allows for customizable data collection and visualization processes, facilitating real-time transmission of pollution data to computer systems [16]. This capability empowers stakeholders with timely information for decision-making and policy formulation, supported by a user-friendly interface and data visualization tools provided by the Arduino platform. These features enable effective monitoring of pollution levels, empowering stakeholders to implement targeted interventions and ensure regulatory compliance.

In conclusion, the Arduino-based air quality monitoring system presents a portable, cost-efficient, and efficient solution for assessing environmental pollution [17]. Its integration of advanced sensor technologies with customizable software capabilities enhances accuracy and applicability across diverse environmental contexts. Future developments could focus on expanding sensor capabilities and improving data analytics to further enhance effectiveness in air quality monitoring and management. Overall, this system represents a significant advancement towards accessible and reliable air quality monitoring, with potential applications ranging from individual health awareness to governmental policy-making aimed at mitigating air pollution's adverse effects on public health and the environment [16].

2.5.7 AirQmon: Indoor Air Quality Monitoring System Based on Microcontroller, Android and IoT

The importance of indoor air quality (IAQ) cannot be overstated, as it directly impacts human health and well-being. Unlike outdoor environments where pollutants disperse more readily, indoor spaces can trap and accumulate harmful substances like dust, formaldehyde, and volatile organic compounds (VOCs) from various sources such as building materials, cleaning products, and human activities. Poor IAQ has been linked to a range of health problems, including respiratory issues like asthma, allergies, headaches, and even long-term cardiovascular complications in some cases.

To address these concerns, the AirQmon system was developed using Arduino microcontroller technology and MQ135 sensors. This system enables continuous monitoring of IAQ parameters crucial for human health. By integrating IoT capabilities, AirQmon connects to the ThingSpeak platform, where sensor data is uploaded and stored. This data is then accessible through an Android application interface, providing users with real-time updates and historical trends of indoor air quality metrics directly on their smartphones.

One of the standout features of AirQmon is its ability to alert users to hazardous air conditions via a sound buzzer. This immediate notification system ensures that individuals are promptly informed when pollutant levels exceed safe thresholds, allowing for timely intervention and mitigation measures. The system's reliance on Arduino and MQ135 sensors ensures accurate detection of various pollutants, enhancing its reliability and effectiveness in diverse indoor environments.

In conclusion, AirQmon represents a significant advancement in IAQ monitoring systems by combining advanced sensor technology with user-friendly IoT integration. By empowering users with real-time data and actionable insights, the system not only promotes awareness but also enables proactive management of indoor environments to safeguard health. This holistic approach to IAQ monitoring underscores its potential to improve overall well-being and quality of life by fostering healthier indoor spaces for individuals and communities alike.

2.5.8 IoT-Based Air Pollution Monitoring with MQ135 Sensor and Arduino

This IoT-based air pollution monitoring system utilizes the MQ135 gas sensor and Arduino controller to detect harmful gases such as CO_2, smoke, and NH3, displaying real-time air quality data on an LCD and web interface [18]. The system monitors air quality by detecting harmful gases such as CO_2, smoke, alcohol, benzene, and NH_3. It operates by measuring gas concentration through changes in resistance, generating a corresponding output voltage. The MQ135 sensor is chosen for its ability to accurately detect a variety of gases crucial for monitoring air quality.

The system displays air quality readings in parts per million (PPM) on both an LCD screen and a web interface accessible via the internet. It features an alarm that activates when air quality drops below safe thresholds. Additionally, the system can interface with devices like exhaust fans or send notifications (SMS or email) to users when pollution levels exceed predefined limits.

Arduino Uno serves as the microcontroller for this system, offering a robust platform for integrating sensor data and controlling outputs. It provides 14 digital I/O pins, 6 PWM pins, 6 analogue input pins, and operates at 5V. The board facilitates communication with other devices through UART, SPI, and I^2C interfaces, making it suitable for IoT applications.

Overall, this project aims to enhance air quality monitoring in various environments, from homes and offices to industrial settings, using accessible technology that ensures real-time data monitoring and alerts for maintaining healthy indoor air conditions.

2.6 Comparison of previous related project

Table 2: Table comparison of previous related topic

No	Reference	Component	Method	Advantages	Disadvantages
1	Low-Cost Portable Air Quality Monitoring System [19]	Arduino Uno, MQ 2, MQ-9, MQ-135 sensors, GSM Module, OLED Display	Monitors air quality with MQ sensors, alerts via SMS or call.	Portable, low-cost design	-Dependency on GSM network for real-time alerts and notifications, which may be limited in remote or uncovered areas. -High power consumption when GSM module is active, impacting battery life.
2	IoT-Based Indoor Air Quality Monitoring System [20]	Arduino, Gas sensors, Buzzer, Internet connectivity (ThingSpeak), Web based dashboard	Real-time monitoring and analysis of indoor air quality parameters. Alerts via buzzer and web platform.	Provides historical data logging and trend analysis for long-term air quality assessment.	-Relies on conventional energy sources, increasing costs and environmental impact compared to solar-powered systems

3	AirQMon:Indoor Air Quality Monitoring System[21]	Arduino, MQ135, Ethernet Shield, Android app (AirQMon)	Data collection, IoT integration	Low-cost, mobile app interface, real-time data visualization	-Requires stable Ethernet connection -Limited to indoor use
4	Smart Air Quality Monitoring System using Arduino Mega [22]	Arduino Mega, MQ135, DHT22	Real-time monitoring of air quality parameters. Data visualization via LCD.	Real-time monitoring and analysis of air quality parameters. Alerts for unhealthy conditions	-Using Arduino Mega results in higher power consumption, potentially increasing operational costs and environmental impact.
5	Arduino Microcontroller-based Air Quality Monitoring System [23]	Arduino Uno, DHT22, MQ-4, MQ-9, MG811	Measurement of CO, temperature, humidity, methane using sensors. Data displayed via LCD/serial monitor.	Real-time monitoring of multiple air quality parameters.	-Limited Gas Detection Range: MQ-9 and MQ-4 sensors detect only Carbon Monoxide and Methane, compared to MQ135 could lead to incomplete air quality data, especially in environments with diverse pollutant types.

2.7 Summary

Air quality monitoring plays a critical role in safeguarding human health and the environment against harmful pollutants such as particulate matter, volatile organic compounds (VOCs), and carbon monoxide (CO). With growing global concerns over pollution, there is an increasing demand for real-time monitoring systems capable of providing accurate and immediate data. This literature review explores a range of IoT-based air quality monitoring systems that utilize advanced technologies such as Arduino microcontrollers, Raspberry Pi, ESP32, Particle Photon, and NodeMCU, integrated with various sensor arrays. These systems utilize transmission methods such as WiFi, GSM, LoRa, and Bluetooth to enable real-time data collection and remote monitoring.

Key advantages highlighted in these systems include sustainable power solutions employing solar panels, reliable data transmission via GSM networks, and low-power consumption facilitated by LoRa technology. However, the review also addresses challenges such as initial setup costs, dependency on network coverage for communication methods, and the impact of weather conditions on the efficiency of solar energy systems. This synthesis emphasizes the importance of integrating technological innovations with sustainability principles to effectively tackle environmental challenges and enhance public health through robust air quality monitoring solutions.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This project uses a structured approach to ensure accurate and reliable real-time air quality monitoring, focusing on sustainability. The core of the methodology is the integration of sensors with the ESP32 microcontroller, supported by solar power for continuous operation. The process covers hardware setup, sensor selection, and calibration steps to ensure the system works effectively in various environmental conditions.

The hardware setup includes the ESP32 microcontroller, solar panels, and high-precision sensors positioned to detect different air quality parameters. The ESP32 is chosen for its processing power, built-in Wi-Fi for wireless communication, and energy efficiency, making it ideal for this project. Solar panels provide renewable energy, enabling the system to operate sustainably and making it suitable for remote or off-grid locations.

The sensors, including the MQ135 air quality sensor and the DHT22 temperature and humidity sensor, are selected for their compatibility with the ESP32, accuracy, and low power usage. The system measures air quality indicators like gas levels, temperature, and humidity and sends the data to the Blynk IoT platform for real-time monitoring and analysis.

To ensure accurate measurements, calibration is performed to account for factors like temperature and humidity, which can affect sensor performance. The system's accuracy is further validated by comparing its data with readings from professional-grade instruments. These steps ensure that the data collected is reliable and suitable for making informed decisions and improving environmental management.

3.2 Project Flow Chart

The flowchart illustrates the sequential process involved in implementing the Solar-Powered Air Quality Monitoring System project. It covers stages ranging from literature review and hardware selection to software development and system testing.

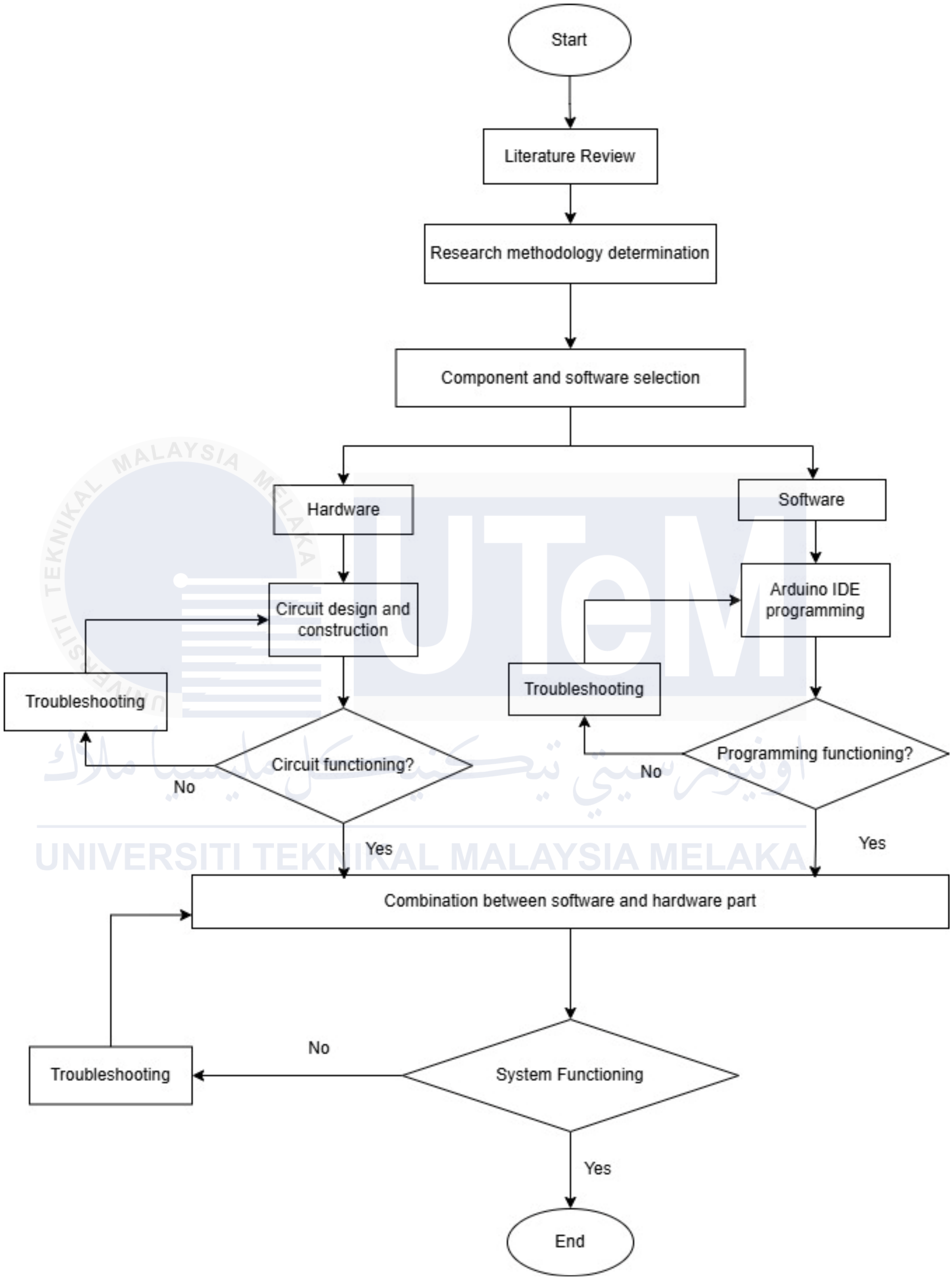


Figure 7:Project Flowchart

Figure 7 illustrates the development process of a system, starting with a literature review to gather relevant knowledge, followed by determining the research methodology. Next, the selection of components and software tools takes place, leading to two parallel paths: hardware and software development. In the hardware path, circuit design and construction are performed, with troubleshooting conducted if the circuit does not function. In the software path, programming using the Arduino IDE is carried out, with troubleshooting applied if programming issues arise. Once both hardware and software are functional, they are integrated. The final step involves verifying the system's functionality, and if issues persist, further troubleshooting is conducted until the system operates correctly, concluding the process.

3.2.1 Flowchart of the System

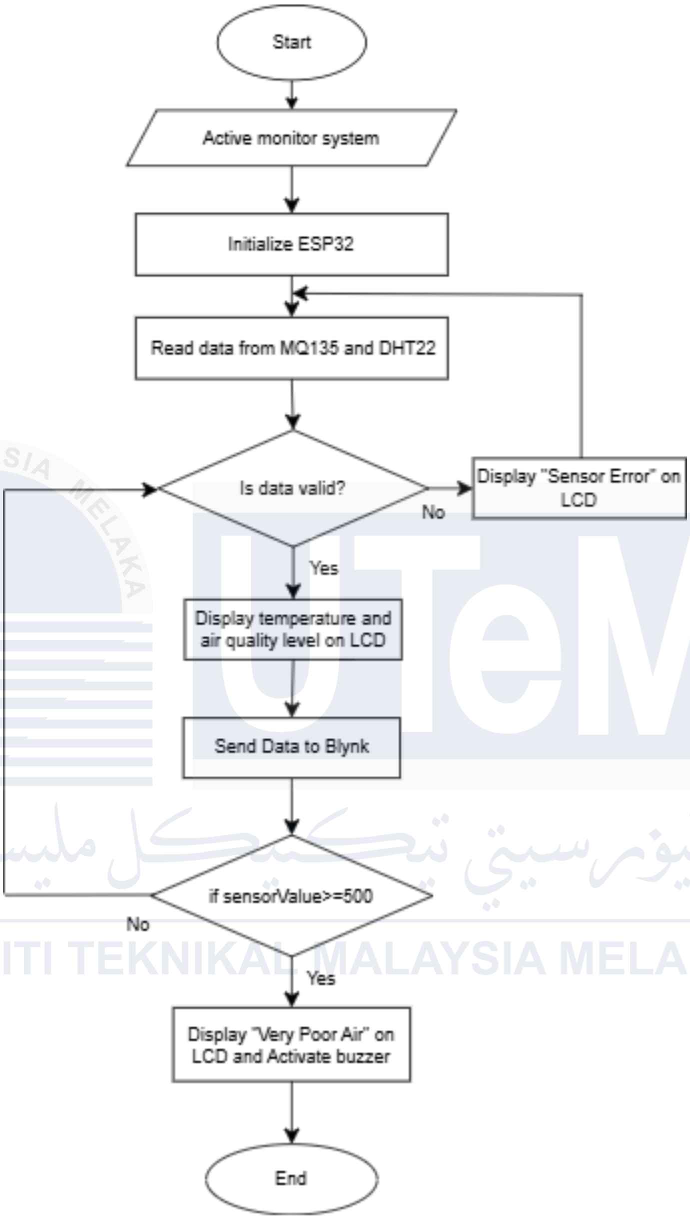


Figure 8:System Flowchart

Figure 8 depicts the operational flow of the air quality monitoring system. The process starts by activating the monitoring system, followed by initializing the ESP32 microcontroller. The system then reads data from the MQ135 and DHT22 sensors. If the data is invalid, a "Sensor Error" message is displayed on the LCD. If the data is valid, the system displays temperature and air quality levels on the LCD and sends the data to the Blynk platform. A condition checks whether the sensor value exceeds 500, indicating poor air quality. If true, the system displays "Very Poor Air" on the LCD and activates the buzzer. The process ends after these steps are completed.

3.2.2 Flowchart of the Iot System

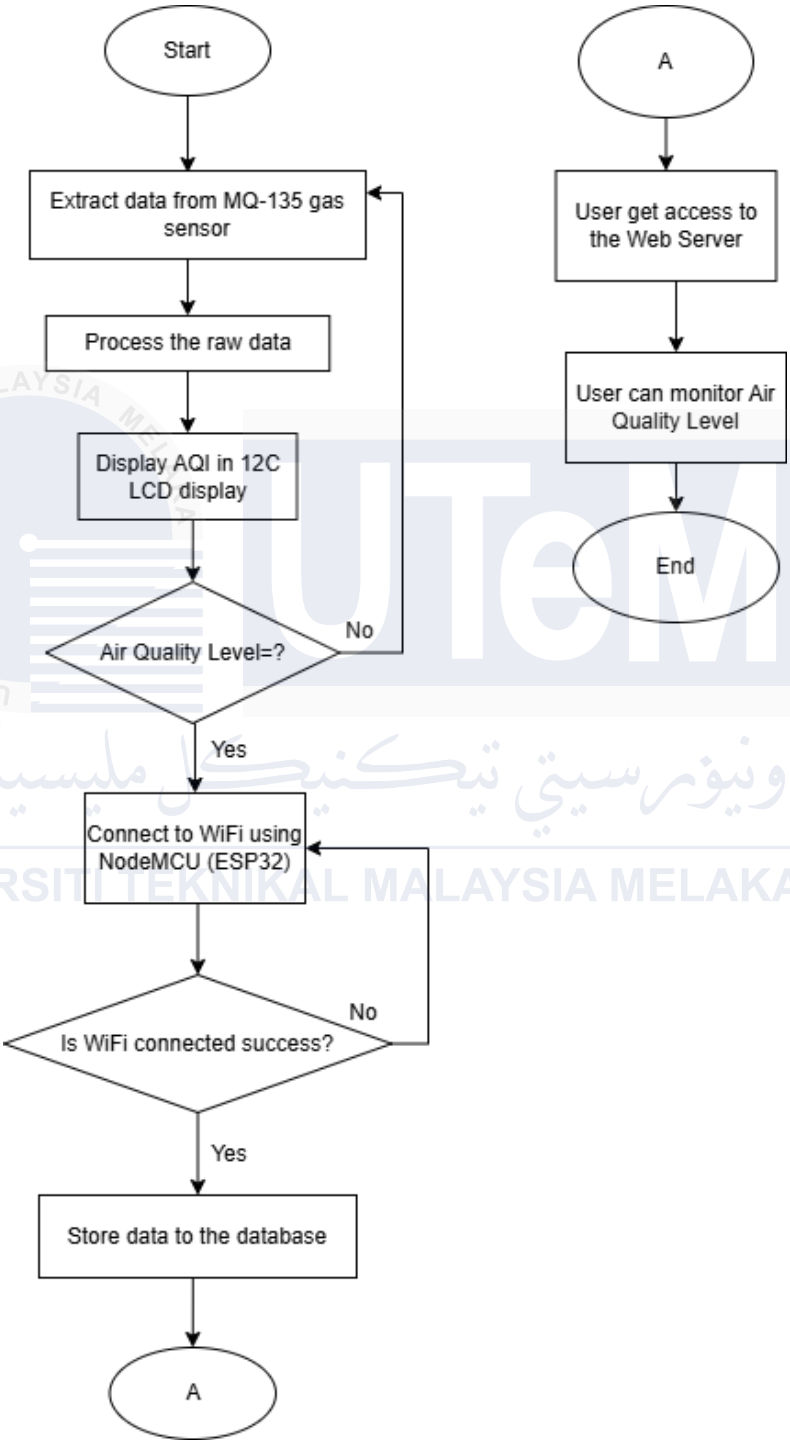


Figure 9: Iot System Flowchart

Figure 9 illustrates the flowchart for an air quality monitoring system using an MQ-135 gas sensor, NodeMCU (ESP32), and an I2C LCD display. The process starts with extracting air quality data from the MQ-135 sensor, which is then processed to calculate the Air Quality Index (AQI). The AQI is displayed on the I2C LCD for real-time local monitoring. The system evaluates the air quality level, and if necessary, it connects to WiFi using the NodeMCU (ESP32). Once a successful connection is established, the data is stored in a database, enabling users to access and monitor air quality levels remotely through a web server. The process concludes with users being able to view air quality data via the web interface.

3.3 System Design

The depicted system layout and construction in Figure 10 can be categorized into two primary components: the hardware section and the software section.

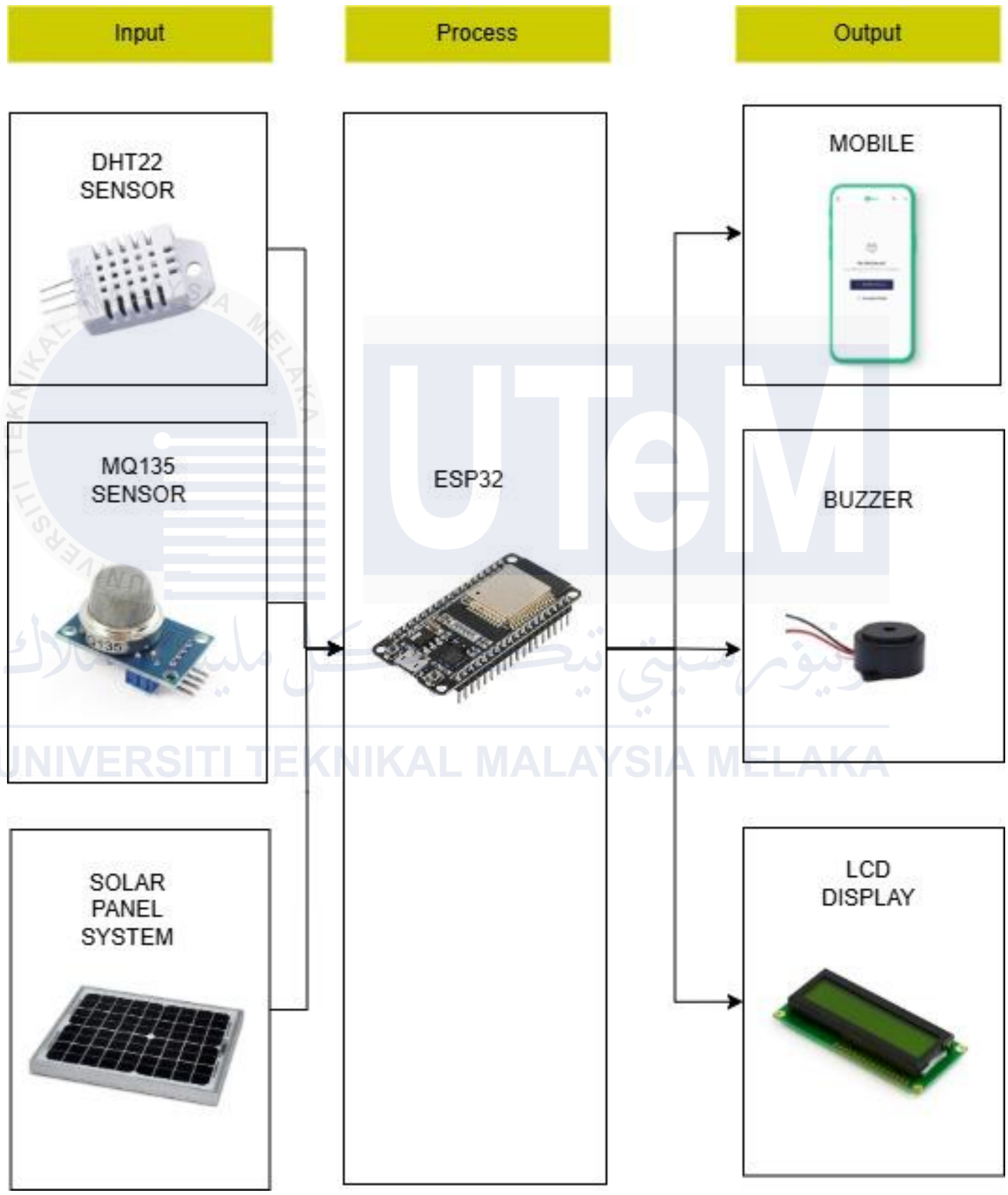


Figure 10:Block Diagram

Figure 10 presents a block diagram of a solar-powered air quality monitoring system utilizing ESP32. The system is divided into three sections which are input, processing, and output. In the input section, the DHT22 sensor collects temperature and humidity data while the MQ135 sensor measures air quality. A solar panel system powers the entire setup to ensure energy efficiency and sustainability. The processing section features the ESP32 microcontroller which processes the sensor data and manages communication. In the output section, an LCD displays the air quality data for real-time monitoring while a buzzer provides alerts in case of poor air quality. Additionally, the system supports remote monitoring by transmitting data to a mobile application via IoT connectivity.

3.3.1 Hardware

The hardware setup for this project integrates essential components to ensure comprehensive air quality monitoring. The MQ135 sensor detects a range of air pollutants, providing critical environmental insights. Alongside, the DHT22 sensor contributes vital data on temperature and humidity, enhancing the system's understanding of atmospheric conditions. The ESP32 microcontroller serves as the primary processing unit, managing sensor operations, peripherals, and enabling seamless data transmission to the Blynk platform for remote monitoring. A buzzer provides immediate alerts upon surpassing specific air quality thresholds, enhancing system responsiveness. Furthermore, a 16x2 LCD display with an I2C module displays real-time sensor readings locally. Additionally, the inclusion of a 12V solar panel paired with a GP rechargeable battery supports sustainable power generation and storage, enabling prolonged and uninterrupted operation while minimizing environmental impact. Together, these hardware components form an efficient and robust air quality monitoring system that effectively addresses environmental challenges.

3.3.1.1 MQ-135 Sensor

Figure 11:MQ-135 Sensor

Figure 11 depicts the MQ-135 sensor, a crucial component within the air quality monitoring system, renowned for its precise detection capabilities of various pollutants including ammonia, benzene, alcohol, smoke, and CO2. Operating on a chemiresistor principle, this sensor adjusts its resistance based on changes in gas concentrations, enabling accurate detection and measurement of air quality parameters. Its compact design and compatibility with ESP32 microcontrollers facilitate straightforward integration into monitoring systems, delivering real-time data on pollutant levels. With simple wiring and calibration procedures, the MQ-135 sensor ensures optimal performance, leveraging its high sensitivity and quick response time to support environmental health and sustainability efforts effectively. For data collection, I used smoke from burning paper to validate the success of the project, with the sensor detecting varying concentrations of smoke at different distances from the source. This method allowed me to gather reliable air quality data for the monitoring system.

3.3.1.2 DHT-22 Sensor

Figure 12:DHT22 Sensor

The DHT22 sensor, shown in Figure 12, is essential for air quality monitoring systems due to its exceptional accuracy and reliability in measuring temperature and humidity. It utilizes a thermistor for temperature sensing and a capacitive humidity sensor, offering comprehensive data collection in a compact and user-friendly design. With a wide measurement range of -40°C to 80°C for temperature and 0% to 100% relative humidity, it accommodates varied environmental conditions with high precision. Compared to alternatives like the DHT11, the DHT22 excels with temperature accuracy of ±0.5°C and humidity accuracy of ±2% RH, making it ideal for applications that demand precise environmental monitoring. Its compatibility with microcontroller platforms such as Arduino facilitates seamless integration into sophisticated monitoring systems, supporting efficient data acquisition and analysis.

Table 3: Comparison DHT-11 and DHT-22

Feature	DHT11	DHT22
Measurement Range	Temperature: 0°C to 50°C Humidity: 20% to 90% RH	Temperature: -40°C to 80°C Humidity: 0% to 100% RH
Accuracy	Temperature: ±2°C Humidity: ±5% RH	Temperature: ±0.5°C Humidity: ±2% RH
Response Time	2 seconds	2-5 seconds
Sampling Rate	1 Hz	0.5 Hz
Current Consumption	1-1.5 mA (during conversion)	0.3 mA (average during active measurement)
Operating Voltage	3.5V - 5.5V	3.3V - 6V
Price	Relatively Lower	Relatively Higher
Applications	Basic temperature and humidity monitoring	High-precision temperature and humidity monitoring, HVAC systems, Industrial applications

Table 3 presents a comparison of the DHT11 and DHT22 sensors, highlighting their distinct performance characteristics and suitability for various applications. The DHT22 excels in several aspects: it offers a wider measurement range, higher precision in temperature and humidity readings, and lower power consumption during active measurements. These qualities make the DHT22 well-suited for applications demanding precise environmental monitoring, such as in HVAC systems and industrial settings. Despite being slightly more expensive than the DHT11, the DHT22's enhanced performance justifies its adoption in projects that prioritize accurate data collection and analysis. This comparison underscores the importance of selecting the appropriate sensor based on specific project requirements to ensure optimal functionality and reliability in air quality monitoring and other environmental sensing applications.

3.3.1.3 ESP32

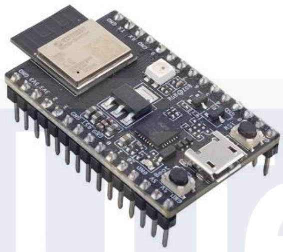


Figure 13:Esp32

Figure 13 depicts the ESP32, known for its versatility and strong capabilities as a Wi-Fi and Bluetooth chip developed by Espressif Systems. It operates within the 2.4 GHz frequency range and features a dual-core Xtensa LX6 32-bit microprocessor with clock speeds up to 240 MHz. With integrated Wi-Fi and Bluetooth functionalities, it supports seamless networking, enabling efficient device communication and internet connectivity. Compliant with standard 802.11 b/g/n protocols and Bluetooth 4.2, the ESP32 ensures dependable wireless connections across various IoT applications. It also offers a wide range of peripheral interfaces such as GPIO pins, SPI, I2C, UART, and ADC/DAC, facilitating straightforward integration with diverse sensors and actuators.

Due to its advanced capabilities, which include high processing power, low power consumption, and user-friendly programming interfaces, the ESP32 is widely preferred for IoT projects spanning from home automation to industrial monitoring. Its ability to deliver reliable performance and adaptability makes it a top choice for developers seeking robust connectivity solutions in diverse IoT environments.

3.3.1.4 Buzzer

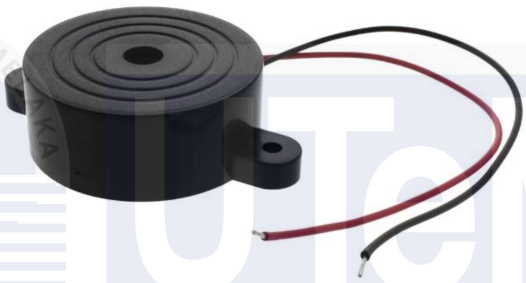


Figure 14:Buzzer

According to Figure 14, the buzzer used in this project serves as a crucial auditory alert system, providing real-time notifications based on predefined air quality thresholds. It operates by converting electrical signals from the microcontroller into audible alerts, effectively signaling users about significant changes in environmental conditions. The buzzer's small size and low energy consumption make it ideal for inclusion in portable air quality monitoring systems. Through careful programming, developers can configure the buzzer to emit specific sound patterns corresponding to different levels of air pollution, ensuring clear and intuitive communication with users. Its simple design and easy integration also contribute to improving the overall functionality and user interaction of the monitoring system.

3.3.1.5 Solar panel

Figure 15:Solar panel

Figure 15 depicts the integration of a solar panel into this project, providing a sustainable energy solution to power the air quality monitoring system. By harnessing solar energy, the system achieves self-sufficiency and reduces its environmental impact by minimizing dependence on traditional power sources and lowering carbon emissions. This choice reflects the project's commitment to environmental responsibility and reducing its ecological footprint. Furthermore, solar power enhances the system's versatility, enabling deployment in remote or off-grid locations with limited access to conventional electricity. Solar panels also offer durability and require minimal maintenance, ensuring prolonged reliability and operational efficiency. Overall, integrating a solar panel represents a strategic decision that enhances the system's performance and supports broader sustainability goals.

3.3.1.6 Solar Charge Controller

Figure 16:Solar Charge Controller

Figure 16 illustrates the PWM (Pulse Width Modulation) solar charge controller used in the project. A PWM solar charge controller regulates the voltage and current from the solar panel to ensure safe and efficient charging of the battery. It works by gradually reducing the power delivered to the battery as it approaches full charge, preventing overcharging and extending the battery's lifespan. The controller is cost-effective and commonly used in small-scale solar systems. It also provides basic protections, such as preventing reverse current flow from the battery to the solar panel during nighttime. While efficient for many applications, PWM controllers are less effective in maximizing energy harvest compared to MPPT controllers, especially under varying sunlight conditions.

3.3.2 Software

In the software aspect of this project, two main components are utilized to enhance the functionality of the air quality monitoring system. The Arduino Integrated Development Environment (IDE) acts as the programming platform, providing a user-friendly interface for coding and uploading to the ESP32 microcontroller. Through the Arduino IDE, developers can write and debug code in C/C++, enabling precise customization and control of the monitoring system's operations. Additionally, the Blynk mobile application plays a pivotal role in facilitating remote monitoring and control of air quality data. By integrating the Blynk app with the ESP32's Wi-Fi capabilities, users can access real-time air quality information, receive alerts, and visualize data graphs from any location with internet access. This seamless integration of software components enhances the system's accessibility and usability, empowering users to make informed decisions and respond promptly to environmental concerns.

The Arduino Integrated Development Environment (IDE) plays a crucial role in developing the air quality monitoring system for this project. Chosen for its user-friendly interface and extensive library support, the IDE simplifies the coding process for the ESP32 microcontroller. It provides a robust platform for writing, compiling, and uploading code, equipped with a comprehensive set of functions and libraries tailored for sensor integration, data processing, and communication protocols. Its compatibility with the ESP32 ensures seamless integration with other modules and sensors, facilitating system expansion and functionality improvements. By utilizing the Arduino IDE, developers can accelerate prototyping and iterate on the design more efficiently, ultimately achieving a sophisticated air quality monitoring system that meets project requirements effectively

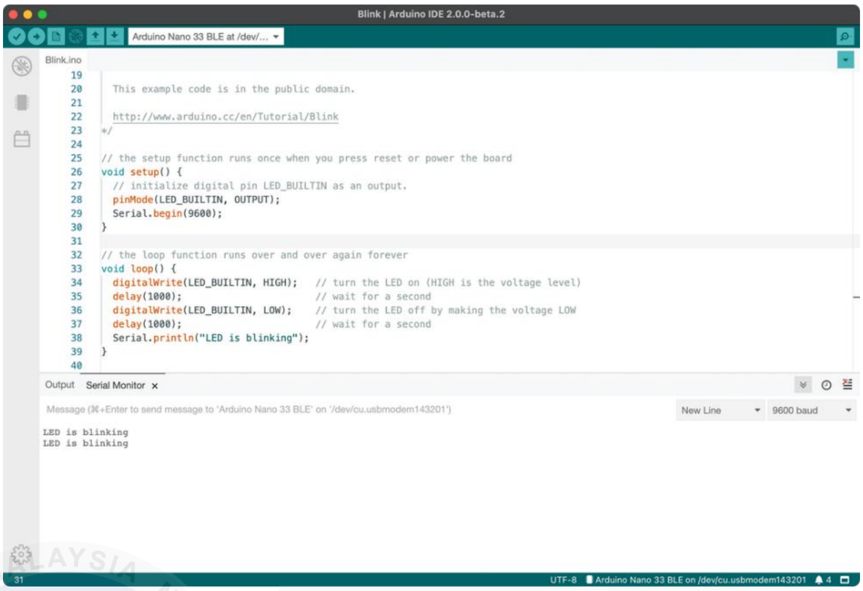


Figure 17:Arduino IDE interface

Figure 17 represents the Arduino IDE interface, a key tool used in the development of the air quality monitoring system. This environment serves as the workspace where developers create, compile, and debug code for the ESP32 microcontroller. Its intuitive design includes features like syntax highlighting, auto-completion, and error detection, which streamline the programming process. The IDE's extensive library support enables seamless integration of components such as sensors and communication modules, allowing for efficient handling of tasks like data acquisition, processing, and transmission. This platform ensures compatibility with various hardware components and supports iterative testing, making it an essential resource for building and refining the system to achieve optimal performance.

3.3.2.1 Blynk Cloud and Application

The Blynk mobile application plays a pivotal role in the software framework of this project, serving as a streamlined interface for remote supervision and management of the air quality monitoring system. By integrating with the Blynk platform, users can access a range of widgets and tools that simplify real-time data visualization, analysis, and system control. Its user-friendly interface allows for easy customization of dashboards to meet specific monitoring requirements. Furthermore, Blynk's cloud infrastructure ensures seamless data synchronization and access across different devices, enabling users to monitor air quality metrics from any location with internet connectivity. With its robust features and broad compatibility, the Blynk app enhances the accessibility and functionality of the air quality monitoring system, empowering users to address environmental concerns proactively.

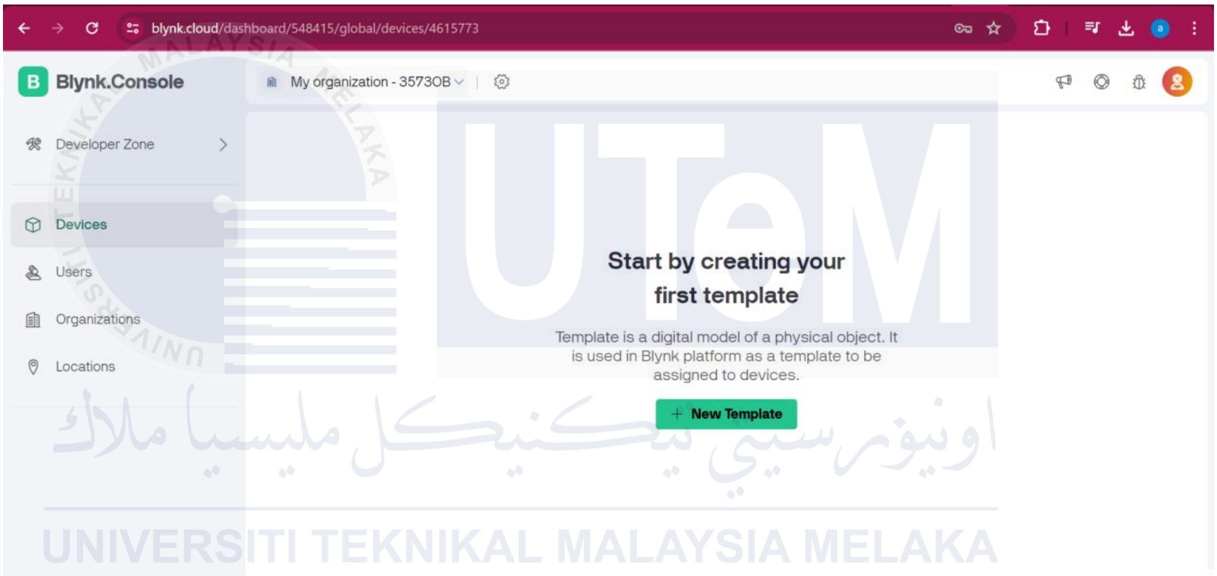


Figure 18:Blynk Interface

3.4 Software Design Setup

Table 4:Software Setup

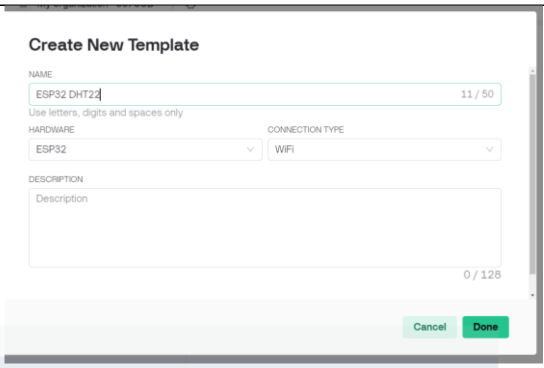
<table>
<tr><td>No</td><td>Process</td><td>Picture</td></tr>
<tr><td>1</td><td>Figure 19 shows the creation of a new template at Blynk Cloud.</td><td>


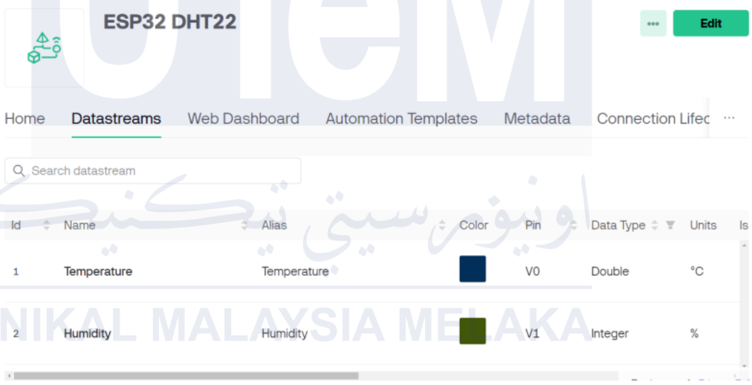
Figure 19:New template Blynk
</td></tr>
<tr><td>2</td><td>Figure 20 shows the addition of datastreams to the template at Blynk Cloud.</td><td>


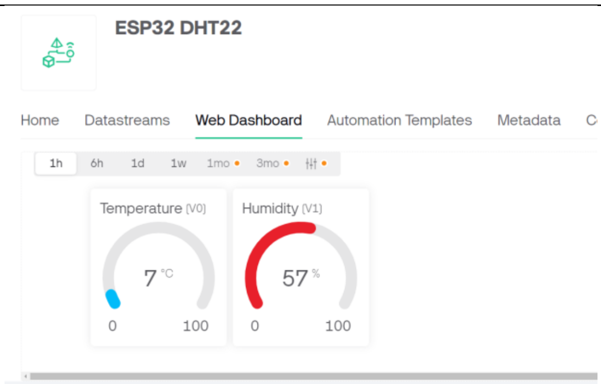
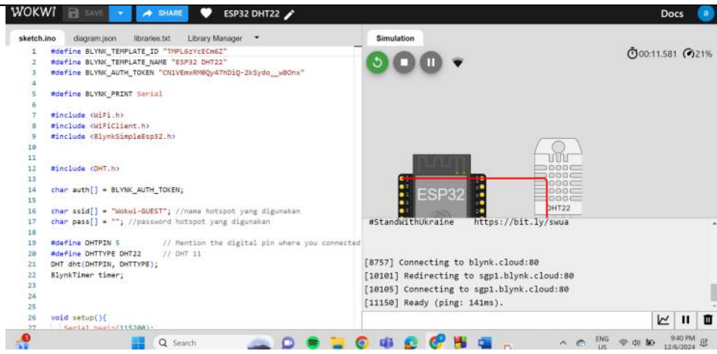
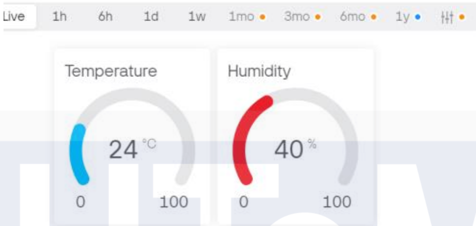
Figure 20:Datastreams
</td></tr>
<tr><td>3</td><td>Figure 21 shows the addition of a gauge to the web dashboard.</td><td>


Figure 21:Adding gauge
</td></tr>
</table>

4	The ESP32 and DHT22 sensor were run at Wokwi.	 **Figure 22:Wokwi**
5	Observed the output on Blynk.	 **Figure 23:Output at Blynk**

3.5 Material Purchase

All the necessary equipment and materials for this project will be purchased before the implementation process begins. The components used in the project, along with their prices, are displayed in Table 5.

Table 5:Bill of Materials

No	Component	Quantity	Price	Total
1	ESP32	1	RM32.90	RM32.90
2	MQ-135	1	RM6.90	RM6.90
3	DHT22	1	RM14.90	RM14.90
4	Solar Panel	1	RM35.00	RM35.00
5	Buzzer	1	RM2.40	RM2.40
6	LCD Display	1	RM15.00	RM15.00
7	Battery 12V	1	RM39.50	RM39.50
8	PWM Solar Charge Controller	1	RM21.30	RM21.30
			Total	RM 167.90

3.6 Summary

The methodology chapter outlines the structured approach used to design, develop, and assess the solar-powered air quality monitoring system with IoT integration. It begins with an overview of existing technologies for air quality monitoring, sensor capabilities, and sustainable energy solutions to determine the system's specific requirements. Hardware components, including the ESP32 microcontroller, DHT22 sensor, MQ135 sensor, buzzer, and solar panel, are carefully selected and integrated to form a cohesive system. Software development involves programming using the Arduino IDE, while IoT features are incorporated through the Blynk mobile application for remote monitoring and control. Prototyping and rigorous testing are performed to ensure the system's functionality, precision, and reliability in various environmental conditions. Finally, the system's performance is evaluated based on factors such as data accuracy, energy efficiency, ease of use, and portability to optimize its effectiveness and enhance user experience, ultimately ensuring its potential for broader application and sustainability

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents and analyzes the results from the development and implementation of the solar-powered air quality monitoring system using ESP32, integrated with IoT. The system's performance is evaluated based on accuracy, energy efficiency, portability, and user-friendliness. Data collected from the MQ135 and DHT22 sensors is processed by the ESP32 and transmitted to the Blynk application, ensuring effective real-time air quality monitoring. The integration of a 12V solar panel and a GP battery enhances the system's sustainability and operational durability, supporting continuous functionality even in remote areas. Furthermore, IoT connectivity significantly improves remote monitoring capabilities and data accessibility, demonstrating the potential for practical real-world applications. This chapter also discusses the alignment of experimental results with initial project goals and identifies areas for future enhancement.

4.2 Hardware Connections

Before prototyping, the system's design and connections were meticulously constructed to allow for simulation and testing. This step ensured that components were accurately interconnected, minimizing the risk of malfunctions or failures after prototyping.

4.2.1 MQ-135 sensor to ESP32

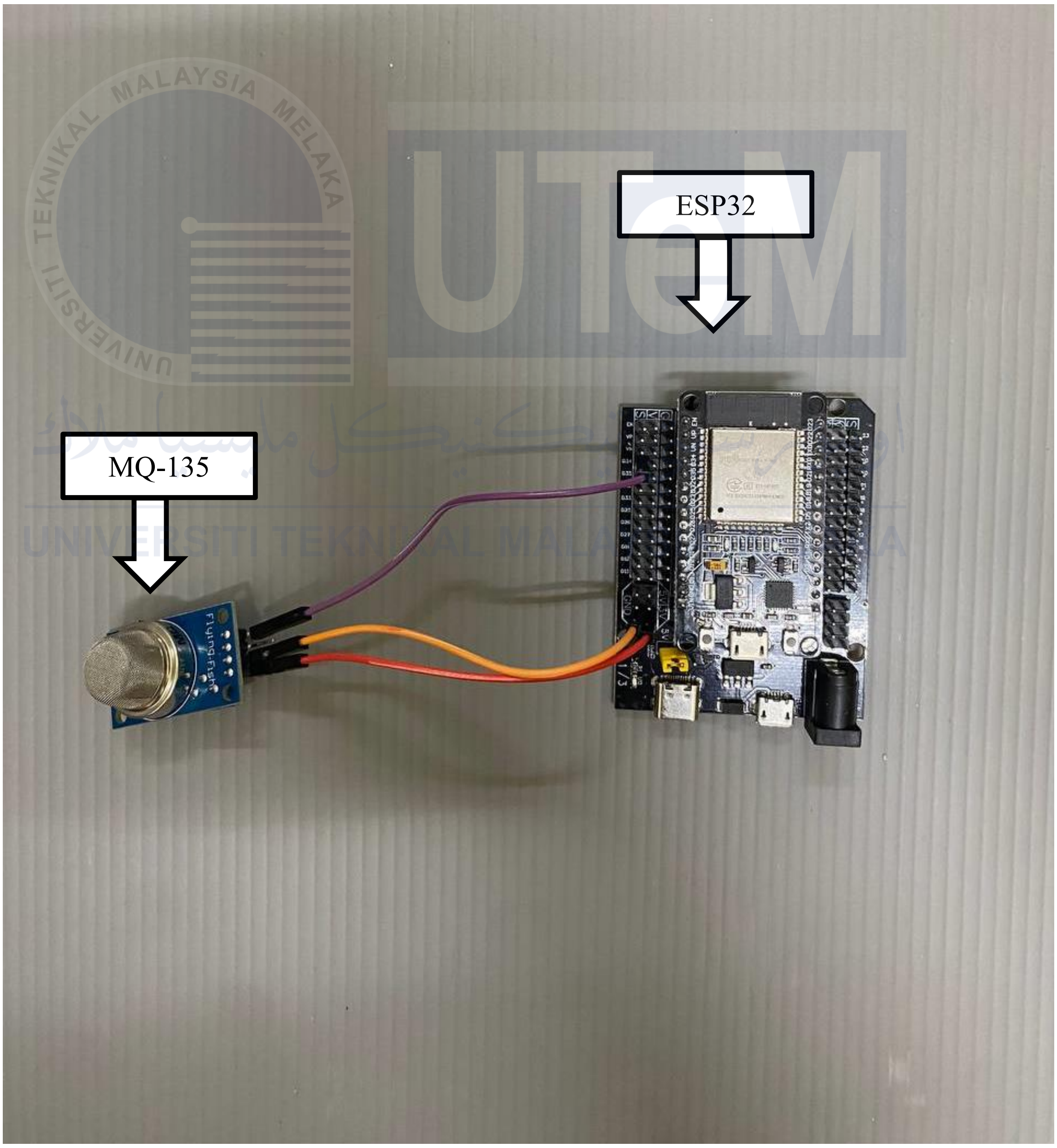


Figure 24:MQ-135 Sensor to ESP32 Connection

Figure 25 shows how the MQ-135 sensor is connected to the ESP32 microcontroller for air quality monitoring. The sensor gets power from the 3V pin on the ESP32, providing a steady power supply. Its analog output is connected to pin D34 on the ESP32, allowing the microcontroller to read and process the data from the sensor. This simple setup ensures the components work well together, enabling the ESP32 to measure air pollutant levels accurately.

4.2.2 DHT22 sensor to ESP32

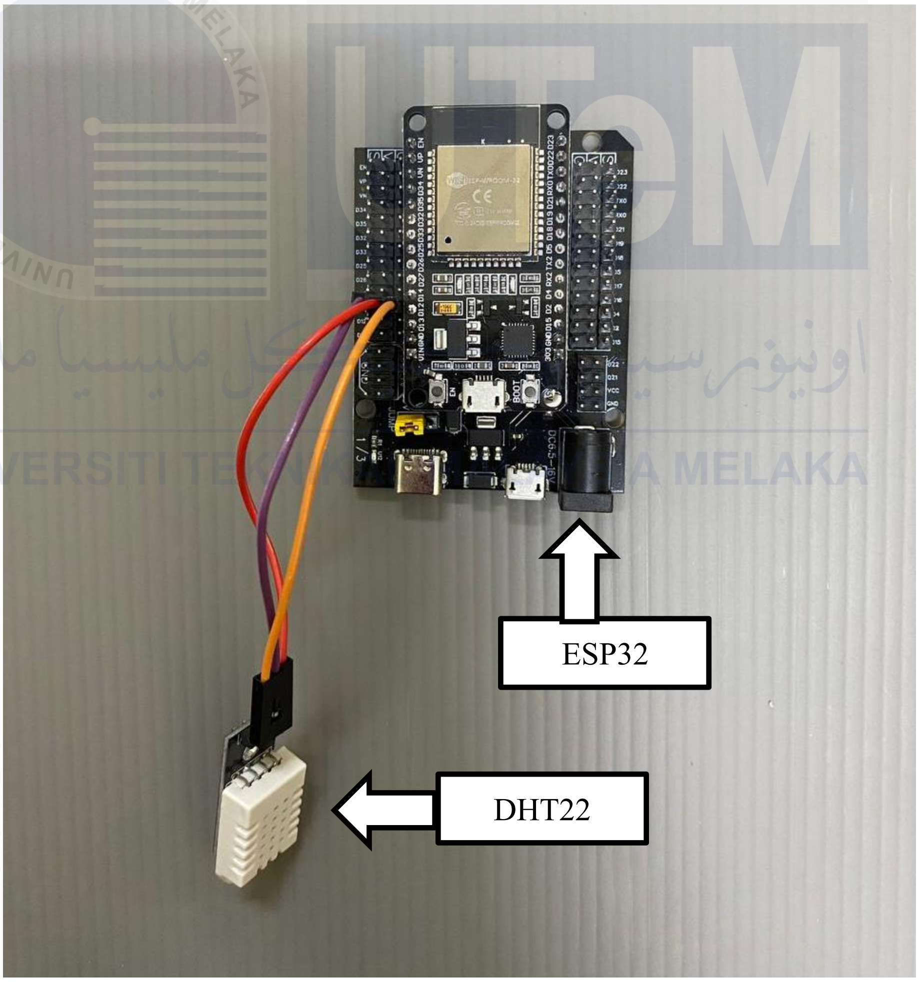


Figure 25:DHT22 Sensor with ESP32 Connection

Figure 26 shows the connection between the digital DHT22 sensor and the ESP32 microcontroller, used for measuring temperature and humidity. The DHT22 is powered by the 3V pin on the ESP32, ensuring a stable power supply for its operation. Its data pin is connected to pin D14 on the ESP32, selected for its flexibility as a GPIO pin. This configuration allows the microcontroller to receive accurate digital readings of temperature and humidity, ensuring reliable environmental monitoring.

4.2.3 Buzzer to ESP32

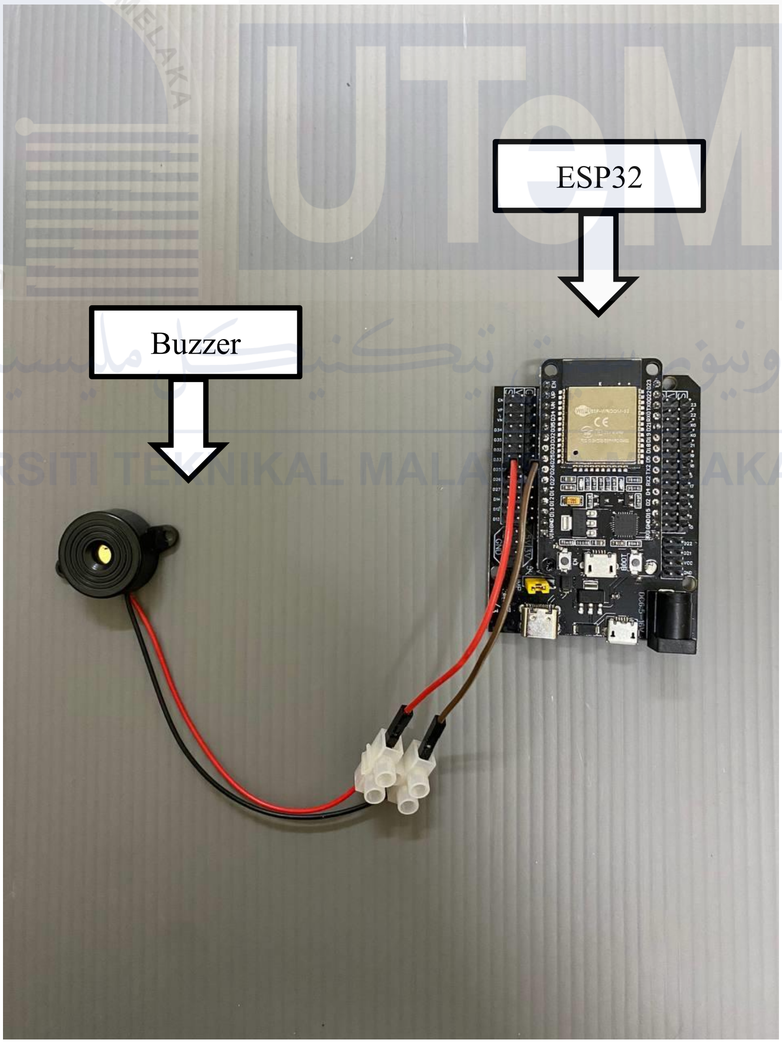


Figure 26:Buzzer to ESP32 Connection

Figure 27 shows the connection between the digital buzzer and the ESP32 microcontroller, used for audible alerts in the system. The buzzer is powered through the 3V pin on the ESP32, ensuring a consistent power supply for operation. Its control pin is connected to pin 25 on the ESP32, chosen for its flexibility as a GPIO pin. This setup allows the microcontroller to trigger the buzzer when specific conditions are met, providing immediate auditory feedback for air quality alerts.

4.2.4 LCD to ESP32

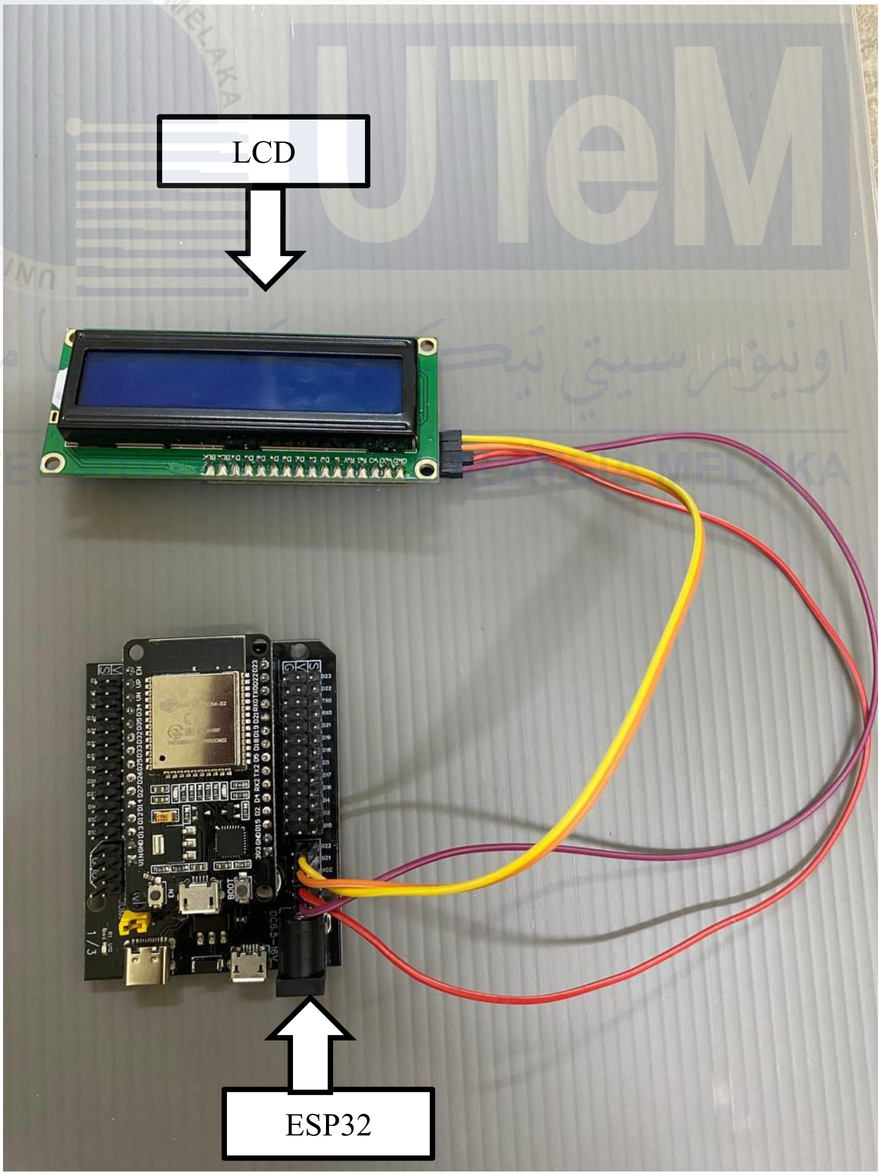


Figure 27: LCD to ESP32 Connection

Figure 28 shows the connection between the 16x2 LCD display and the ESP32 microcontroller, used for displaying real-time air quality data. The LCD's SDA (data line) is connected to pin 21, while the SCL (clock line) is connected to pin 22 on the ESP32. These pins are chosen because they are dedicated I2C pins on the ESP32, providing efficient and reliable data transfer between the microcontroller and the LCD. This I2C communication setup allows for clear and accurate display of essential information such as pollutant levels, temperature, and humidity.

4.3 Prototype Preparation

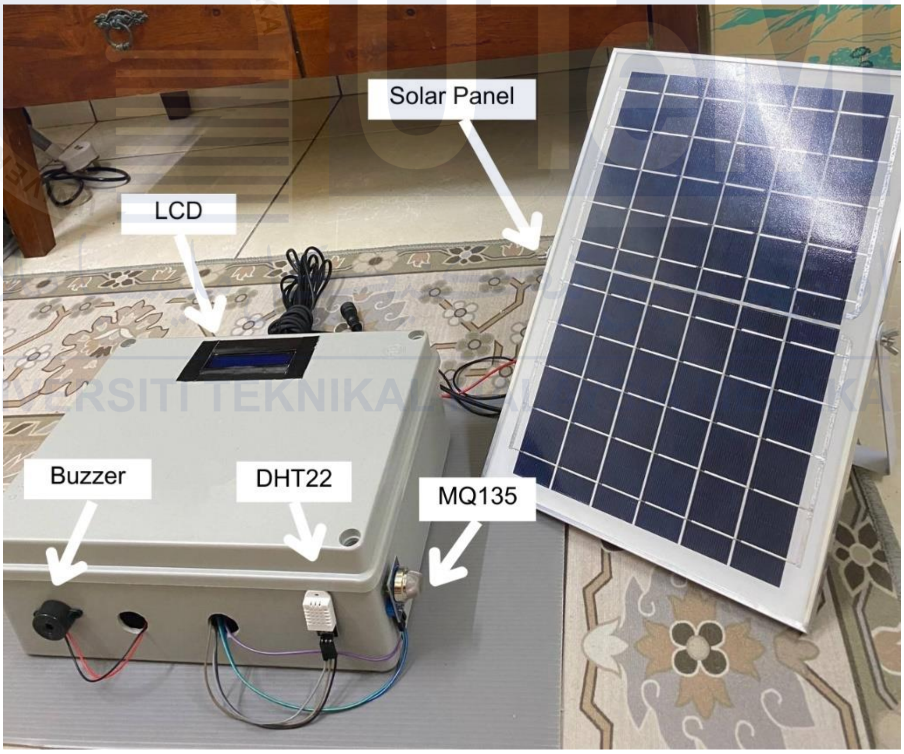


Figure 28:Prototype of IoT Based Solar Powered Air Quality Monitoring

Figure 29 shows the final prototype of the solar-powered air quality monitoring system, designed for efficient and reliable operation. The prototype features an MQ-135 sensor for detecting air quality levels and a DHT22 sensor for measuring temperature and humidity. A 16x2 LCD screen displays real-time data, providing clear and immediate feedback on environmental conditions. The system includes a buzzer that activates when air quality drops below safe thresholds, ensuring timely alerts. Powered by a solar panel, the prototype is both energy-efficient and environmentally friendly. Its compact and portable design allows for easy deployment in various locations for air quality monitoring.

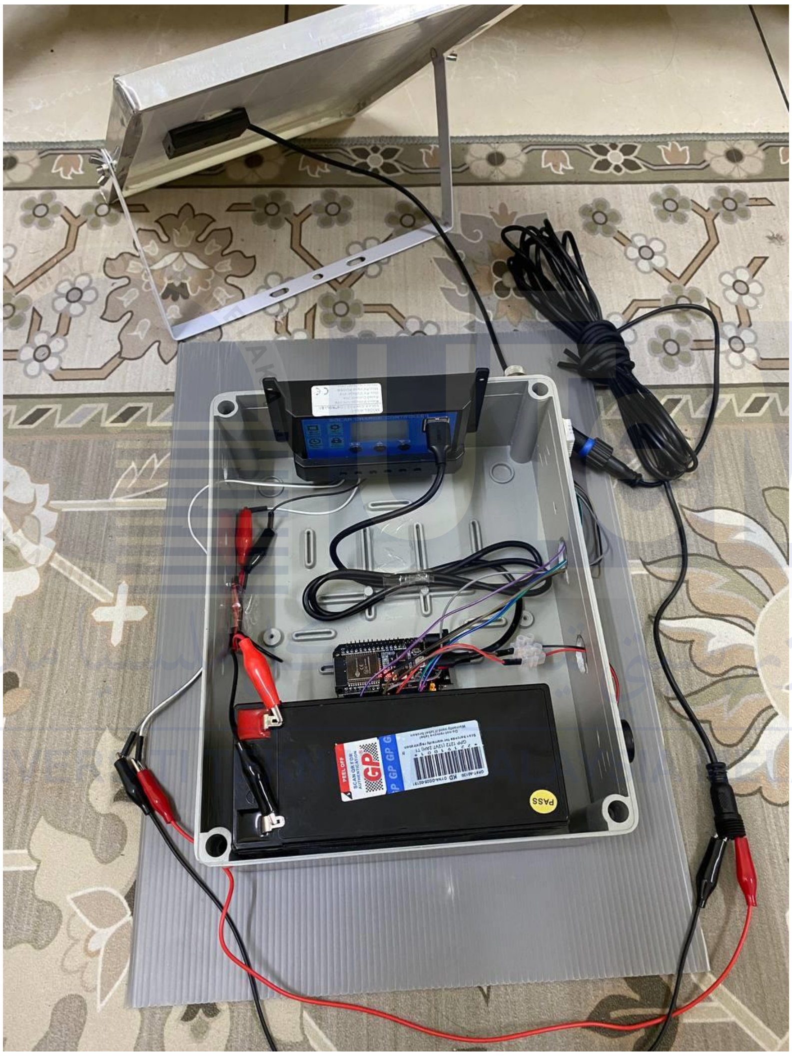


Figure 29:Prototype Full View

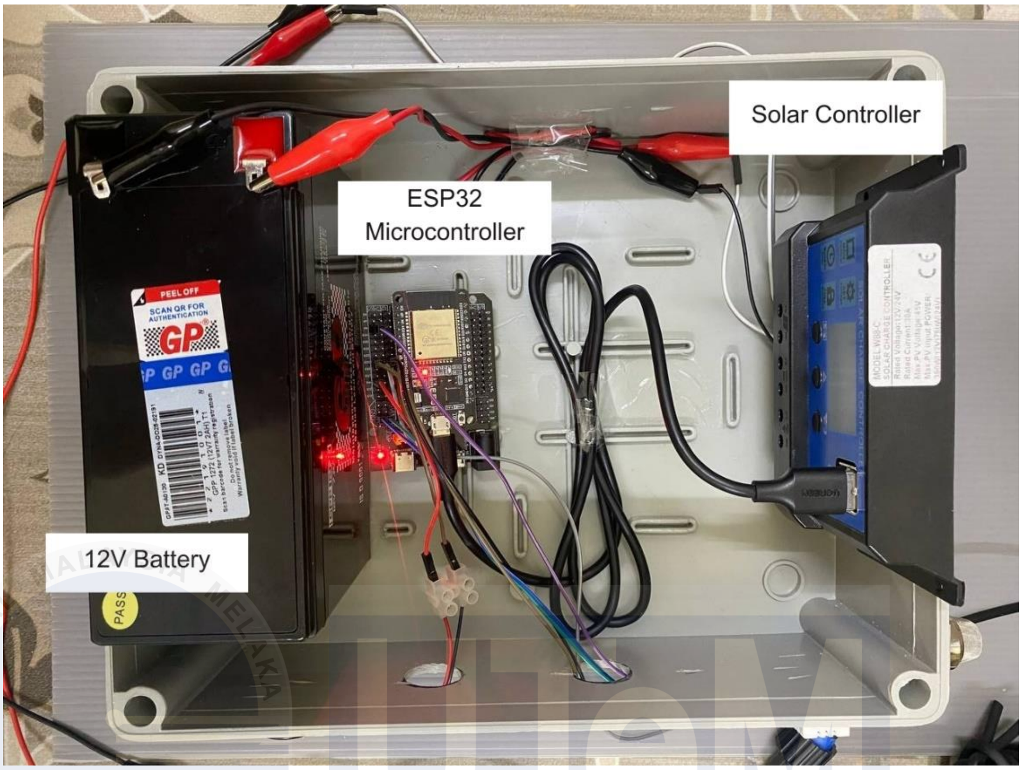


Figure 30: Making All Component in Prototype Box

Figure 30 and Figure 31 shows the internal arrangement of all components in the prototype box for the solar-powered air quality monitoring system. The ESP32 microcontroller is placed at the centre, handling data processing and communication. Next to it is the solar charge controller, which controls the flow of energy from the solar panel to the 12V battery. The battery is positioned securely to provide steady power to the system. The components are neatly arranged to optimize space and ensure the system operates effectively.

Figure 31:Solar Panel Placed Under Direct Sunlight.

Figure 32 illustrates the deployment of the solar panel under direct sunlight to maximize energy absorption. This setup ensures optimal power generation for the system by aligning the solar panel's surface with the sun's rays. Proper positioning enhances the panel's efficiency, enabling it to effectively convert solar energy into electrical power. The energy captured is then stored in the rechargeable battery, ensuring an uninterrupted power supply for the air quality monitoring system. This configuration highlights the importance of direct sunlight exposure in achieving the system's energy requirements while demonstrating the integration of renewable energy for sustainable environmental monitoring.

4.4 Calibration Result

In the project, the MQ135 sensor was calibrated using a baseline value to account for the environmental conditions, ensuring more accurate measurements of air quality. The baseline value was set at 500 PPM, which is considered the reference value under clean air conditions.

```
// Baseline and scaling factor for MQ-135
float mq135_baseline = 500.0;        // Baseline reset to 500
float mq135_scaling_factor = 0.3;    // Original scaling factor

// Function to calculate the adjusted PPM value
float calculateMQ135PPM(int analogValue) {
  float adjustedValue = (analogValue - mq135_baseline) * mq135_scaling_factor;
  return (adjustedValue < 0) ? 0 : adjustedValue;
}
```

Figure 32: Coding for MQ135

Figure 33 illustrates the formula used to adjust the sensor readings in the air quality monitoring system. To ensure accurate air quality data, the raw analog value from the MQ-135 sensor is first adjusted by subtracting a baseline value of 500, which represents the sensor's output under clean air conditions. This subtraction removes baseline noise or sensor variations. Next, the adjusted value is multiplied by a scaling factor of 0.3 to convert the raw data into a more precise parts per million (PPM) value. This scaling factor helps calibrate the sensor's response to match expected air quality levels. Finally, any negative results are set to zero to prevent invalid readings. This method allows the system to deliver reliable, real-time air quality measurements, providing valuable data on pollutant concentrations in the monitored environment.

4.5 Results and Analysis

4.5.1 Real Time Data Reading

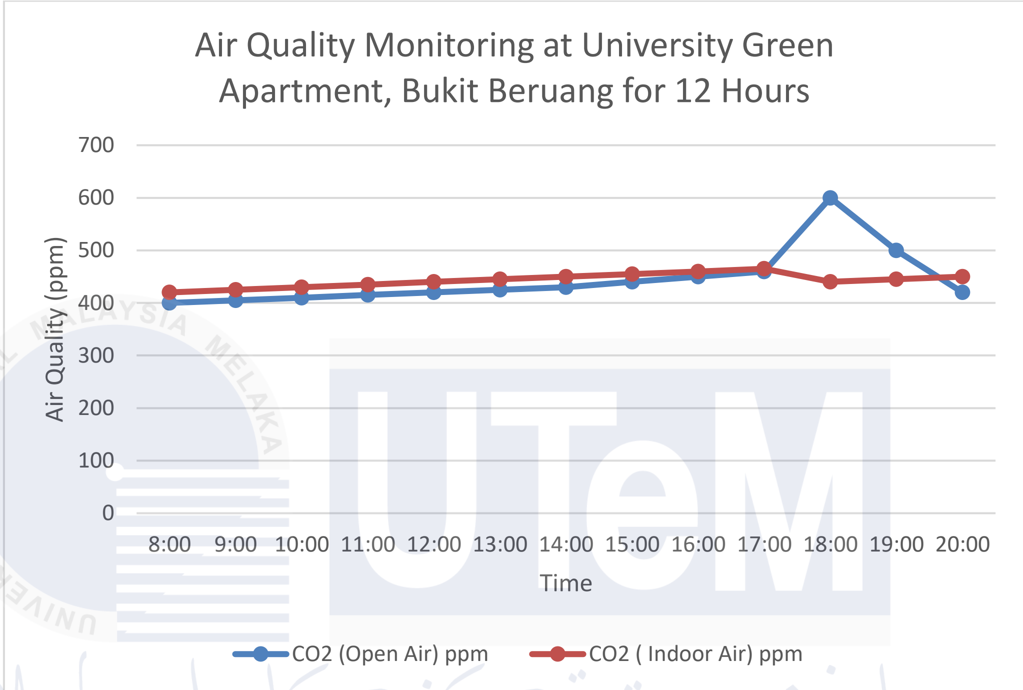


Figure 33:Air Quality Monitoring Analysis

Figure 34 shows the air quality levels recorded at University Green Apartment, Bukit Beruang, over a 12-hour period, comparing outdoor and indoor air. The graph shows a steady increase in air quality degradation in the open air, with levels starting at 400 ppm at 8:00 AM and gradually rising throughout the day, peaking at 600 ppm around 6:00 PM. This sharp rise in the late afternoon could be attributed to local activities, such as neighbors burning trash, which are common at that time. In contrast, the indoor air quality starts at a slightly higher level at 420 ppm and increases more gradually, reaching 465 ppm by 5:00 PM. The indoor air quality shows less fluctuation compared to outdoor air, likely due to the controlled indoor environment with fewer external factors influencing the air quality.

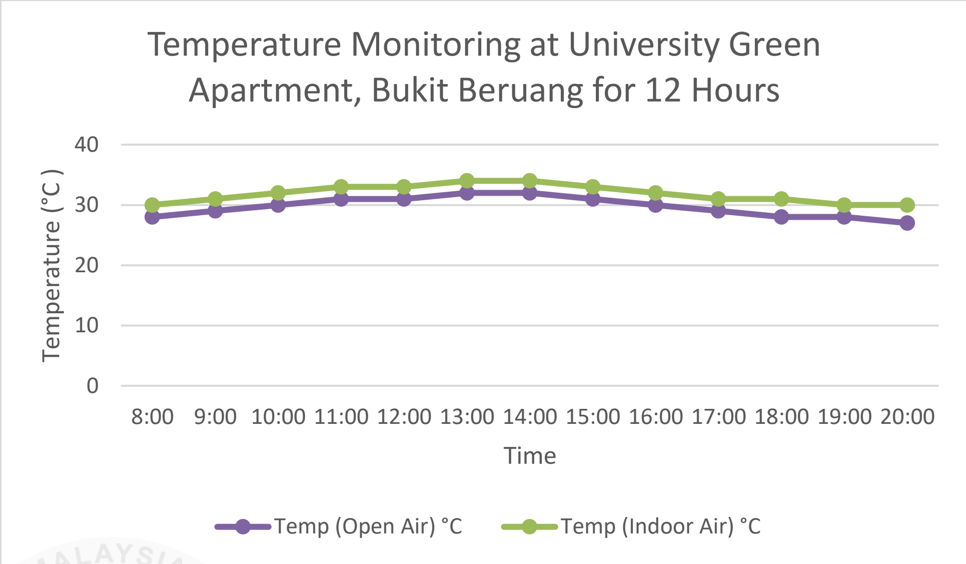


Figure 34 : Temperature Monitoring Analysis

Figure 35 shows the temperature levels recorded at University Green Apartment, Bukit Beruang, over a 12-hour period, comparing outdoor and indoor air. The graph reveals a consistent rise in temperature during the day, with outdoor temperatures starting at 28°C at 8:00 AM and gradually reaching 32°C by 2:00 PM. Similarly, indoor temperatures increase from 30°C in the morning to 34°C in the afternoon. After 2:00 PM, both indoor and outdoor temperatures begin to decrease, with outdoor temperatures falling to 27°C by 8:00 PM, while indoor temperatures remain at 30°C. The data suggests that the indoor environment experiences less variation in temperature compared to the open air, likely due to the insulation and limited exposure to external weather factors.

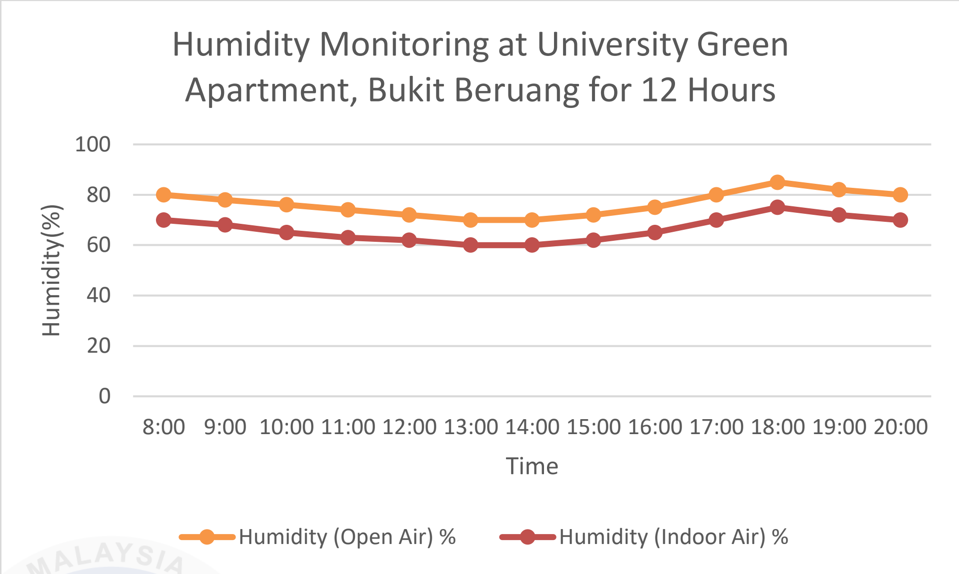


Figure 35: Humidity Monitoring Analysis

Figure 36 shows the humidity levels recorded at University Green Apartment, Bukit Beruang, over a 12-hour period, comparing outdoor and indoor air. The humidity in the open air starts high at 80% at 8:00 AM and gradually decreases throughout the day, reaching 70% by 8:00 PM. This decrease reflects typical daily patterns, influenced by factors such as temperature and outdoor activities. Indoor humidity starts at 70% and also decreases over time, ending at 70% by 8:00 PM. Indoor humidity is generally more stable, with less fluctuation due to the controlled indoor environment. The graph highlights the difference in humidity behavior between the outdoor and indoor settings, showing greater variability outdoors and a more consistent pattern indoors.

Table 6:Detection Ranges and Smoke Concentraion Levels of MQ135

Attempt	Distance(centimeters)	Smoke Concetration (ppm)	Detection Outcome	Remarks
1	1.0	600	Detected	Strong smoke easily detected.
2	2.0	400	Detected	Smoke still detected with good accuracy.
3	3.0	150	Weak	Detection may be inconsistent.
4	4.0	50	Not detected	Smoke concentration too diluted.

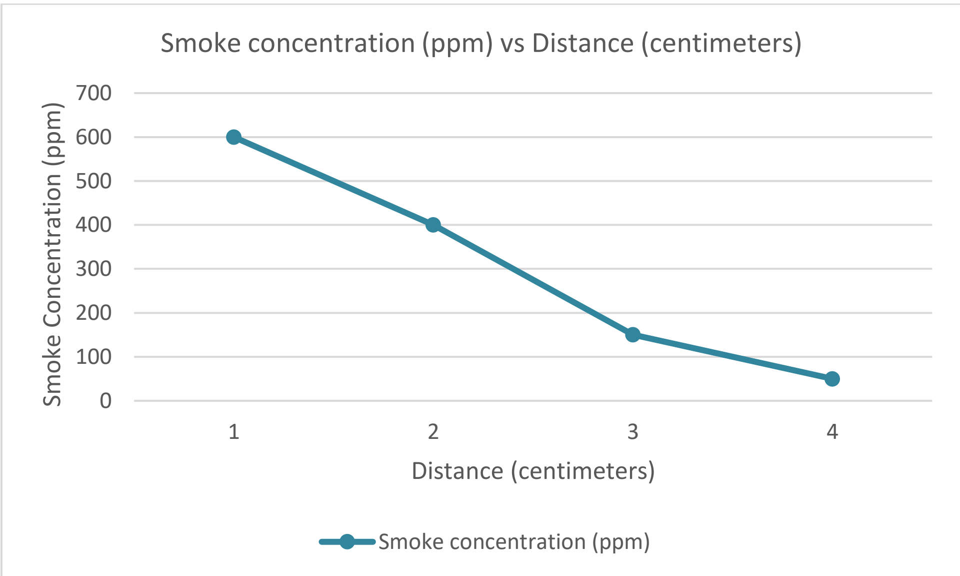


Figure 36: Distance Analysis

Table 5 shows the results of air quality concentration measurements taken at four different distances from the air quality source using the MQ135 sensor. At 1.0 centimeters, the sensor recorded the highest concentration, with values around 600 PPM. At 2.0 centimeters, the concentration values decreased but remained detectable, averaging 400 PPM. At 3.0 centimeters, the readings showed a further decline, with an average concentration of 150 PPM. Finally, at 4.0 centimeters, the sensor failed to detect significant air quality concentration, averaging 50 PPM. These results demonstrate how the MQ135 sensor's ability to detect air quality decreases as the distance from the source increases, as shown in Figure 37.

4.5.2 Solar Panel and Battery Analysis

4.5.2.1 Solar Panel Performance

The analysis of the solar panel and battery system determines the energy efficiency of the project. A 10W, 12V solar panel, connected to a 12V, 7.2Ah rechargeable battery via a solar charge controller, ensures a continuous power supply to the system.

The maximum current output of the solar panel is calcualated as:

$$I = \frac{P}{V} = \frac{10W}{12V} = 0.83A$$

- Maximum power (Pmax) = 10W (ideal sunny condition)
- Actual Output:

$$6V \ x \ 0.23A = 1.38W$$

- Efficiency (%):

$$n = \frac{1.5W}{10W} \ x \ 100 = 13.8\%$$

4.5.2.2 Battery Charging Analysis

- Battery Capacity is 12V, 7.2Ah
- Find Watt hour for Battery Capacity

$$I\ x\ V = P$$

$$7Ah\ x\ 12V\ = 86.4Wh$$

- Charging Efficiency

  Assume 85% efficiency due to losses in the charge controller and internal resistance.

$$Effective\ Power = 1.5W\ x\ 0.85 = 1.3W$$

- Calculate Estimated Charge Time

$$Time\ (hours) = \frac{Power\ discharge\ hours\ (Wh)}{Effective\ power\ (W)}$$

  Actual day:

$$T = \frac{86.4Wh}{1.3W} = 66.5\ hours$$

$$= \frac{66.5hours}{24} = 2.77days$$

For a 12V, 7.2Ah battery with 85% charging efficiency, the estimated charge time would be approximately 2.77 days.

4.5.3 Software Development

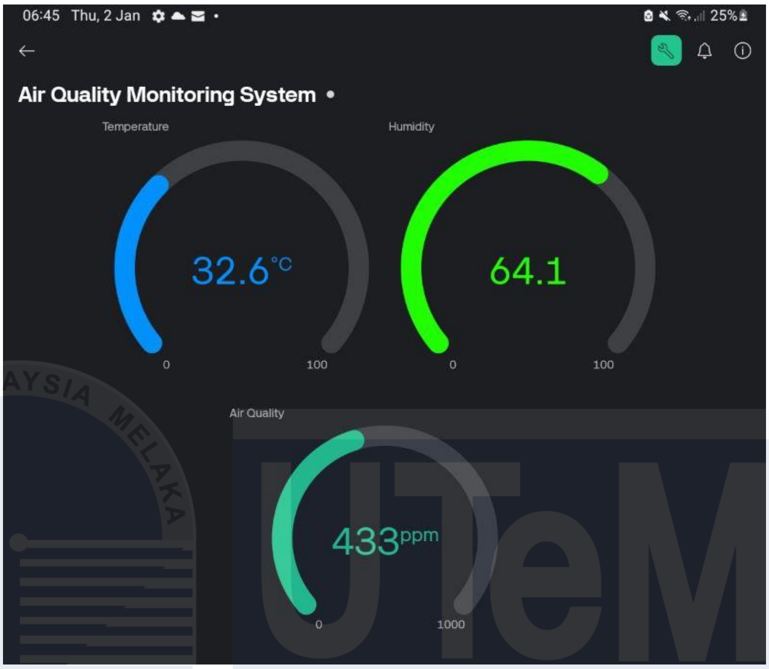


Figure 37:Blynk connected to smartphone

The Blynk app, shown in Figure 38, connects effortlessly with a smartphone, providing an intuitive interface for real-time air quality data monitoring. Integrated with the solar-powered ESP32 system, it gives access to metrics such as temperature, humidity, and gas concentrations. The app features custom-designed gauges and widgets that display these metrics clearly, allowing users to quickly assess air quality levels. This immediate feedback is essential for prompt decision-making, especially in environments where air quality can change rapidly. Utilizing the Blynk app on a smartphone enhances accessibility and convenience, enabling users to monitor air quality conditions from any location.

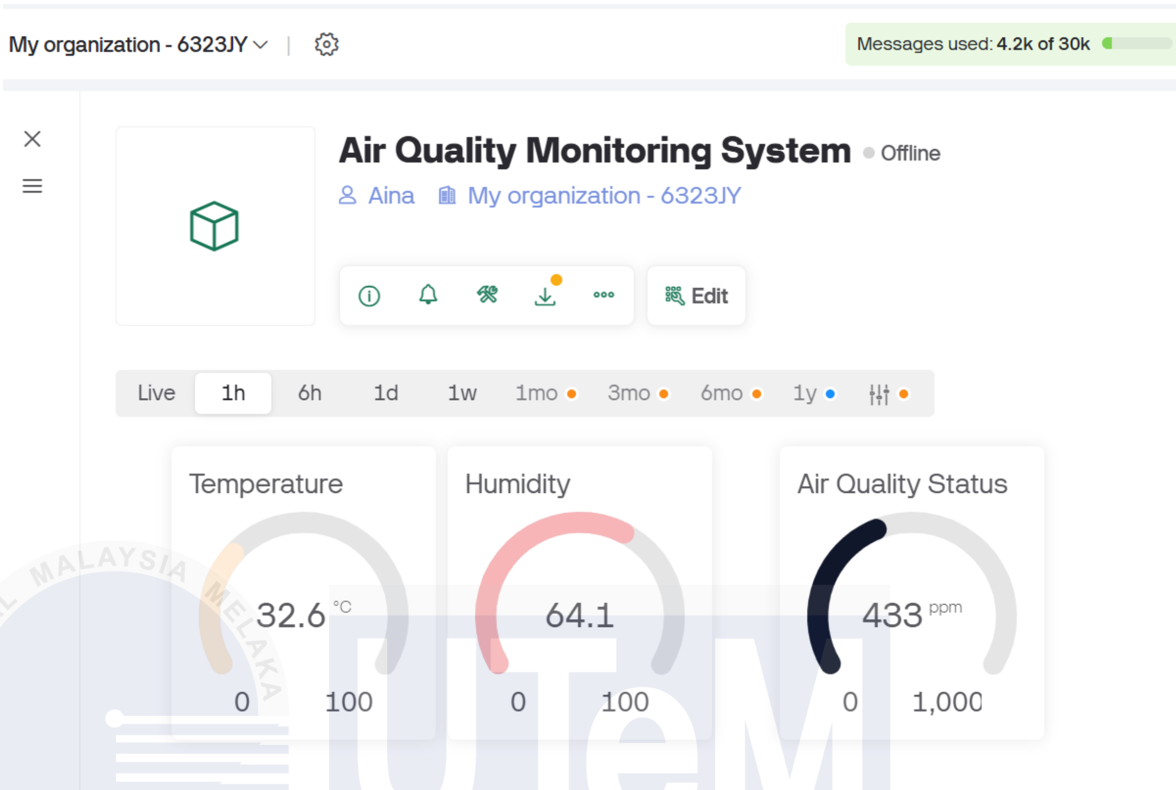


Figure 38:Blynk at laptop

Figure 39 demonstrates the integration of the air quality monitoring system with Blynk on a laptop, offering a comprehensive and efficient approach for real-time data visualization and analysis. By designing and implementing a gauge on the Blynk platform, the system can effectively monitor air quality parameters like CO2 levels, temperature, and humidity. This gauge displays real-time data received from sensors connected to the ESP32 microcontroller. This setup enables continuous monitoring and provides a user-friendly interface to visualize data trends and fluctuations. The ability to remotely track these parameters enhances the system's usability, making it a robust solution for air quality monitoring in various environments. Blynk integration ensures data accessibility from any location, offering flexibility and scalability to the monitoring system.

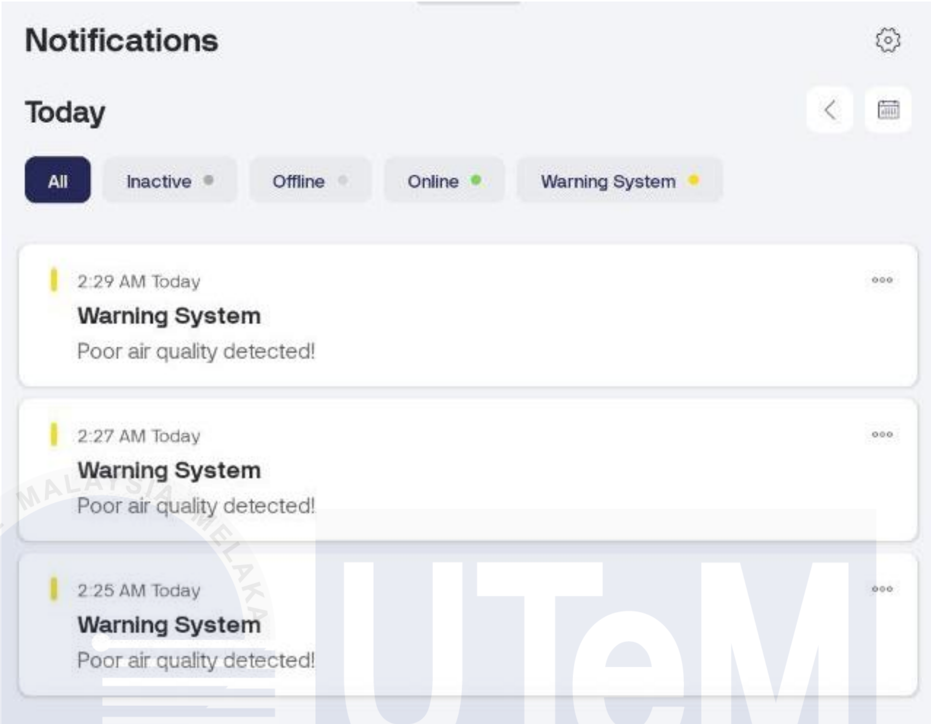


Figure 39: Notifications from Blynk

Figure 40 shows the notification for poor air quality in the Blynk app. When the system detects that the air quality exceeds a threshold, specifically when the PPM (parts per million) from the MQ135 sensor goes beyond 500, a notification is triggered on the Blynk app. This alert informs users of the presence of poor air quality, prompting them to take necessary actions. The notification helps users stay informed in real-time about the air quality status in their environment. The system automatically monitors air quality and ensures that any significant change in pollutant levels is immediately communicated.

4.6 Summary

In this chapter, the results from the implemented air quality monitoring system are presented and analyzed. It starts with a comprehensive overview of the hardware and software components utilized in the system, followed by a presentation of the collected data. The analysis examines the accuracy and reliability of the sensor readings, considering factors like environmental conditions and sensor calibration. The chapter also discusses any observed trends or anomalies in the data and assesses the system's performance against predefined criteria. Overall, this chapter offers insights into the effectiveness of the developed system in monitoring air quality and identifies areas for potential improvement or optimization.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, this project has successfully developed a solar-powered air quality monitoring system using ESP32 with IoT integration, addressing environmental concerns and promoting sustainable technology adoption. Through careful design, implementation, and evaluation, the system has demonstrated effectiveness in real-time monitoring of air quality parameters such as pollutant levels, temperature, and humidity. The integration of ESP32 microcontroller technology, the MQ135 sensor, the DHT22 sensor, a buzzer, and a solar panel enables robust and reliable operation. Incorporating IoT connectivity through the Blynk app facilitates remote monitoring and data transmission. The three objectives of this project have been achieved, which are developing an air quality monitoring system using ESP32 microcontroller technology, collecting and analyzing data through a cloud-based platform, and integrating solar power into the system. The solar-powered system can operate for up to 66.48 hours without sunlight, ensuring continuous functionality. With the solar system, the project functions without concerns about battery depletion for extended periods. This project highlights the significance of interdisciplinary approaches in tackling environmental challenges and showcases the potential of innovative solutions to advance environmental sustainability and public health. Further research and development are encouraged to improve the system's capabilities.

5.2 Potential for Commercialization

The developed solar-powered air quality monitoring system using ESP32 with IoT integration shows promising potential for commercialization across various sectors. Its versatility makes it suitable for deployment in urban areas, industrial zones, and remote locations, addressing diverse market needs. Potential commercial applications include smart cities, environmental monitoring agencies, industrial plants, and residential settings. By providing real-time data on air quality metrics such as pollutant levels, temperature, and humidity, the system enables proactive decision-making and targeted interventions to improve environmental conditions and public health. Its sustainable design, powered by solar energy for enhanced efficiency, aligns with growing consumer demand for eco-friendly solutions. With scalability in production and customizable features, the system offers opportunities for collaboration with government agencies, private enterprises, and research organizations. Strategic marketing highlighting its reliability, effectiveness, and environmental benefits could foster widespread adoption and commercial success in the expanding market for smart environmental monitoring technologies.

5.3 Future Works

Looking ahead to enhancing the capabilities of the solar-powered air quality monitoring system using ESP32 with IoT integration, several avenues for future improvements can be explored:

i. Investigating a wider range of air quality parameters, including additional pollutants and environmental factors, to achieve a more thorough understanding of atmospheric conditions.

ii. Incorporating advanced machine learning algorithms to augment the system's predictive abilities, enabling early detection of trends in air quality deterioration and facilitating proactive intervention strategies.

iii. Developing mobile apps and web platforms for real-time data visualization and user interaction, promoting greater public engagement and awareness of environmental concerns.

iv. Implementing automated calibration and maintenance processes to ensure sustained accuracy and reliability of sensor measurements, minimizing the need for manual oversight.

v. Collaborating with urban planning authorities and environmental agencies to integrate the monitoring system into smart city initiatives, supporting data-driven decision-making and policy development for sustainable urban growth.

These future directions hold the potential to significantly enhance the functionality and impact of the solar-powered air quality monitoring system, contributing to improved environmental health and quality of life on a global scale.

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APPENDICES

Appendix A Gantt Chart PSM1

GANTT CHART PSM1															
Activities	WEEK														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Prepare and confirm project tittle and hardware to be use								M I							
Research on tittle for the project								D							
Circuit and components								T							
Proposal writing								E							
Chapter 1 Report Writing								R							
Chapter 2 Report Writing								M							
Chapter 3 Report Writing															
Project simulation								B							
Implementation project								R							
Report progress 1								E							
Slides preparation								A							
Draft and Report Submission								K							
Report Progress 2															
Submit Report															
BPD Presentation															
Submit final report															

Appendix B Gantt Chart PSM2

GANTT CHART PSM2															
Activities	WEEK														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project briefing by JK PSM								M I							
Present latest progress to supervisor								D							
Design prototype and hardware								T							
Data collection								E							
Shows supervisor data collection								R							
Make demo for supervisor								M							
Updating Chapter 3: Methodology								B							
Updating Chapter 4: Result & Discussion								R							
Implementation project								E							
Report progress 1								A							
Poster preparation								K							
Draft and Report Submission															
Report Progress 2															
Submit Report															
BPD Presentation															
Submit final report															

Appendix C Full Coding

Airquality.ino

```
#define BLYNK_TEMPLATE_ID "TMPL6EECTU2wM"
#define BLYNK_TEMPLATE_NAME "Air Quality Monitoring System"
#define BLYNK_AUTH_TOKEN "PMXlJUQjed9DsvR80XGqW8hERM5aa-Cl"
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <DHT.h>
#include <WiFi.h>
#include <BlynkSimpleEsp32.h>
// Pin Definitions
#define MQ135_PIN 34                    // MQ135 sensor connected to GPIO34 (Analog Input)
#define DHT_PIN 14                      // DHT22 sensor connected to GPIO14
#define DHT_TYPE DHT22                  // Define DHT sensor type
#define BUZZER_PIN 25                   // Buzzer connected to GPIO25
// LCD 16x2 I2C setup
LiquidCrystal_I2C lcd(0x27, 16, 2);
// DHT sensor setup
DHT dht(DHT_PIN, DHT_TYPE);
// Blynk authentication and WiFi credentials
char auth[] = BLYNK_AUTH_TOKEN;
char ssid[] = "Aina";
char pass[] = "nakapani";
// Baseline and scaling factor for MQ-135
float mq135_baseline = 300.0;          // Baseline reset to 500
float mq135_scaling_factor = 0.3;      // Original scaling factor
// Function to calculate the adjusted PPM value
float calculateMQ135PPM(int analogValue) {
  float adjustedValue = (analogValue - mq135_baseline) * mq135_scaling_factor;
  return (adjustedValue < 0) ? 0 : adjustedValue;
```

```
}
void setup() {
  Serial.begin(115200);
  // Initialize DHT sensor
  dht.begin();
  // Initialize I2C communication
  Wire.begin(21, 22);
  lcd.init();
  lcd.backlight();
  // Initialize buzzer pin
  pinMode(BUZZER_PIN, OUTPUT);
  digitalWrite(BUZZER_PIN, LOW);
  // LCD startup message
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print(" AIR QUALITY");
  delay(2000);
  // Connect to WiFi and Blynk
  WiFi.begin(ssid, pass);
   while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println("\nWiFi connected");
  Blynk.begin(auth, ssid, pass);
}
void loop() {
  int analogValue = analogRead(MQ135_PIN);
  float mq135_ppm = calculateMQ135PPM(analogValue);
  float temperature = dht.readTemperature();
  float humidity = dht.readHumidity();
  if (isnan(temperature) || isnan(humidity)) {
    Serial.println("Failed to read from DHT sensor!");
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("Sensor Error!");
    delay(2000);
    return;
  }
  // Print values to Serial Monitor
  Serial.print("Raw Analog Value (MQ135): ");
  Serial.println(analogValue);
  Serial.print("PPM: ");
  Serial.println(mq135_ppm);
  Serial.print("Temperature: ");
  Serial.println(temperature);
  Serial.print("Humidity: ");
  Serial.println(humidity);
  // Trigger buzzer and LCD warning if PPM >= 500
  if (mq135_ppm >= 500) {
    digitalWrite(BUZZER_PIN, HIGH);
    Blynk.logEvent("warning_system", "Poor air quality detected!"); // Trigger Blynk event
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("Very Poor Air!");
    lcd.setCursor(0, 1);
```

```
    lcd.print("PPM: ");
    lcd.print(mq135_ppm);
    delay(2000);
  } else {
    digitalWrite(BUZZER_PIN, LOW);
    // Display normal readings on LCD
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("Temp: ");
    lcd.print(temperature);
    lcd.print(" C");
    lcd.setCursor(0, 1);
    lcd.print("Air: ");
    lcd.print(mq135_ppm);
    lcd.print(" ppm");
}
// Send data to Blynk
Blynk.virtualWrite(V0, temperature);
Blynk.virtualWrite(V1, humidity);
Blynk.virtualWrite(V2, mq135_ppm);
Blynk.run();
delay(2000);
}
```

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8% Publications
5% Submitted works (Student Papers)

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