Faculty of Electrical Technology and Engineering

PROTOTYPE OF PARTICULATE MATTER DETECTION AND MONITORING SYSTEM IN AIR POLLUTION BY USING ARDUINO

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Bachelor of Electrical Engineering Technology (Industrial Automation & Robotics) with Honours

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Date : 16 February 2024

DEDICATION

I would like to express my gratitude to both of my parents, Abdul Muhaimin bin Ahmad and Sharifah Noordiran binti Syed Othman, for their unwavering support and motivation throughout the progression of my senior Final Year Project. They created a conducive environment for me to work in, enabling me to brainstorm ideas and stay motivated to fulfill my responsibilities. Furthermore, they consistently acknowledged small triumphs and offered uplifting words whenever I achieved milestones.

ABSTRACT

Air pollution poses a significant threat to both human health and the environment. Among its various pollutants, particulate matter (PM) stands out as a major concern. Monitoring and detecting the concentration of PM in the air are crucial for assessing air quality and implementing effective pollution control measures. This abstract introduces a prototype of a PM detection and monitoring system developed using Arduino, an open-source programmable board. The system leverages a dust sensor such as the Sharp GP2Y1010AU0F to detect and measure the concentration of PM 2.5 (particles with a diameter of 2.5 micrometers or less) in the surrounding air. The dust sensor employs an infrared LED and a photodetector to analyze the scattering of light caused by the particles. Additionally, a gas sensor, the MQ-2 is incorporated to provide support in areas where pollutants like Carbon Monoxide and Liquefied Petroleum Gas (LPG) are present. At the heart of the system, the Arduino board acts as the main controller, gathering data from the dust and gas sensors and processing it for display and analysis. The collected data is then presented in real-time on a liquid crystal display (LCD) screen. This user-friendly interface allows individuals even those with minimal technical expertise to easily assess air quality and monitor any changes over time. The prototype serves as an affordable solution, offering an accessible means for individuals, communities and organizations to monitor air quality and raise awareness about the potential health risks associated with high PM concentrations. Moreover, the feasibility of using Arduino for particulate matter detection and monitoring in air pollution is demonstrated. While the prototype shows promise, there is room for improvement and refinement to enhance accuracy and functionality. These advancements could pave the way for the potential implementation of the system in real-world air quality monitoring networks. Overall, this prototype contributes to the ongoing efforts to combat air pollution, promoting a healthier environment for all.

ABSTRAK

Abstrak ini membentangkan prototaip sistem pengesanan dan pemantauan bahan zarahan (PM) untuk pencemaran udara menggunakan Arduino. Sistem ini menggunakan sensor habuk dan papan Arduino untuk mengukur dan menganalisis kepekatan PM di udara. Data yang dikumpul dipaparkan pada skrin LCD dan boleh diproses selanjutnya untuk tujuan pemantauan. Prototaip ini bertujuan untuk menyediakan penyelesaian yang berpatutan dan mesra pengguna untuk memantau kualiti udara dan meningkatkan kesedaran tentang kesan bahan zarahan terhadap kesihatan manusia. Pencemaran udara, terutamanya kehadiran bahan zarah, menimbulkan ancaman besar kepada kesihatan manusia dan alam sekitar. Memantau dan mengesan kepekatan PM di udara adalah penting untuk menilai kualiti udara dan melaksanakan langkah kawalan pencemaran yang berkesan. Abstrak ini membentangkan prototaip sistem pengesanan dan pemantauan PM yang dibangunkan menggunakan Arduino, papan boleh atur cara sumber terbuka. Prototaip menggunakan penderia habuk seperti Sharp GP2Y1010AU0F, untuk mengesan dan mengukur kepekatan PM 2.5 (zarah dengan diameter 2.5 mikrometer atau kurang) di udara sekeliling. Penderia habuk menggunakan LED inframerah dan pengesan foto untuk menganalisis penyebaran cahaya yang disebabkan oleh zarah. Sensor gas MQ-2 hanya berfungsi sebagai sokongan kepada sesuatu tempat telah tercemar. Ia boleh mengesan Karbon Monoksida dan LPG (Gas Petroleum Cecair). Papan Arduino bertindak sebagai pengawal utama, mengumpul data daripada sensor habuk dan sensor gas dan memprosesnya untuk paparan dan analisis. Sistem ini menyediakan pemantauan masa nyata kepekatan PM dan gas, memaparkan data pada skrin paparan kristal cecair (LCD). Data yang dikumpul boleh dilihat oleh pengguna, membolehkan mereka menilai kualiti udara dan memerhati sebarang perubahan dari semasa ke semasa. Prototaip ini menawarkan sistem yang mesra pengguna, menjadikannya boleh diakses oleh individu yang mempunyai kepakaran teknikal yang minimum. Prototaip yang dibangunkan menunjukkan kebolehlaksanaan menggunakan Arduino untuk pengesanan dan pemantauan bahan zarahan dalam pencemaran udara. Sistem ini menyediakan penyelesaian kos efektif untuk individu, komuniti dan organisasi untuk memantaukualiti udara dan meningkatkan kesedaran tentang risiko kesihatan yang berkaitan dengan kepekatan PM yang tinggi. Penambahbaikan boleh dibuat untuk meningkatkan ketepatan dan kefungsian sistem, membuka jalan bagi potensi pelaksanaannya dalam rangkaian pemantauan kualiti udara dunia sebenar.

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CHAPTER 1

INTRODUCTION

1.1 Background

Air pollution resulting from the contamination of the environment by chemical, physical or biological agents presents a substantial environmental and health challenge particularly in urban areas, impacting millions of people worldwide. Among the various pollutants, particulate matter (PM) emerges as a significant contributor, comprising small particles of dust, smoke and other substances that when inhaled, can lead to respiratory and cardiovascular diseases. According to the World Health Organization (WHO), outdoor air pollution is responsible for 4.2 million premature deaths annually with PM2.5 being a prominent cause of air pollution-related fatalities. PM2.5 refers to fine particles with a diameter of less than 2.5 micrometers, capable of deeply penetrating the lungs and entering the bloodstream.

Monitoring PM concentrations in the air is vital for assessing air quality and safeguarding public health. However, current commercial PM detection and monitoring devices often prove costly, complex and inaccessible to individuals and communities. Therefore, it is crucial to adopt low-cost and user-friendly monitoring devices to track PM concentrations effectively. In recent years, the utilization of Arduino microcontrollers has gained popularity for developing such devices due to their affordability, versatility and ease of use. Arduino, an open-source microcontroller board, enables programming to control sensors and interact with the physical world. It finds extensive applications including environmental monitoring. Additionally, the open-source nature of the Arduino platform allows for the freedom to modify and customize its hardware and software.

Typically, Arduino-based PM detection and monitoring systems employ sensors capable of detecting PM in the air. These sensors can be connected to the Arduino board which processes the collected data and presents the PM concentration on an LCD screen or other output devices. Arduino-based systems are often characterized by their low cost, user-friendly nature and flexibility to cater to specific user requirements. Individuals, communities and organizations can utilize these systems to monitor air quality and adopt appropriate measures to mitigate the health risks associated with air pollution. By providing real-time data on PM concentrations, these systems empower individuals and communities to make informed decisions regarding their daily activities. For instance, they can identify optimal times for outdoor exercises or reduce exposure to air pollution by staying indoors.

In conclusion, addressing the pressing issue of air pollution and promoting public health awareness necessitates the adoption of affordable and user-friendly Arduino-based devices for monitoring PM concentrations in the air. These devices offer a viable solution to the limitations posed by expensive and complex commercial alternatives. By enabling real-time monitoring and informed decision-making, Arduino-based PM detection and monitoring systems contribute to mitigating the adverse health effects of air pollution on individuals and communities.

1.2 Problem Statement

The prototype of a particulate matter detection and monitoring system utilizing Arduino addresses the issue of limited accessibility and affordability of devices for measuring and monitoring PM2.5 concentration in the air. Current commercial options are often expensive, complex and not readily available to individuals and communities especially in developing nations. This limitation hampers the ability to monitor air quality effectively and take necessary measures to reduce exposure to harmful pollutants.

The Arduino-based prototype offers a cost-effective and user-friendly solution enabling accurate measurement and monitoring of PM2.5 levels. Designed to be portable, it empowers individuals, communities and organizations to assess air quality and make informed decisions to mitigate the risks associated with air pollution. Serving as a proof of concept, the prototype demonstrates the viability of employing Arduino for monitoring PM2.5 concentration. Further enhancements and scalability can be pursued to expand its deployment for comprehensive air quality monitoring systems. By providing accessible and affordable monitoring devices, the prototype contributes to promoting public health and reducing the adverse effects of air pollution.

1.3 Project Objective

The specific objectives of the project are as follows:

- Design and build a prototype of a PM2.5 detection and monitoring system using Arduino and PM2.5 sensors.
- Calibrate the PM2.5 sensors to ensure accurate and reliable measurements of PM2.5 concentration in the air.
- Develop a software program that can process the data from the sensors and display the PM2.5 concentration on an LCD screen or other output devices.
- Test the prototype in different environments and conditions to ensure its accuracy and reliability.
- Provide documentation and instructions for building and using the prototype, to enable others to replicate and improve upon the design.

The ultimate goal of the project is to develop a low cost and easy to use PM2.5 detection and monitoring system that can be deployed by individuals, communities and organizations to monitor air quality and take appropriate actions to reduce exposure to harmful air pollutants. By providing accessible and affordable devices for monitoring air quality, the project aims to contribute to improving public health and reducing the health risks associated with air pollution.

1.4 Scope of Project

The scope of this research entails the comprehensive design, development, rigorous testing and meticulous documentation of a prototype for a particulate matter detection and monitoring system in air pollution using Arduino. The primary objective of this project is to create an affordable and user-friendly device capable of accurately measuring and monitoring PM2.5 concentration in ambient air. By employing Arduino-based technology, this study seeks to validate the practicality and effectiveness of utilizing such devices for air quality monitoring, thereby making a valuable contribution towards enhancing public health.

The specific tasks and activities included in the project scope are:

- Researching and selecting suitable sensors for measuring PM2.5 concentration in the air.
- Designing and developing the hardware and software components of the Arduino based PM2.5 detection and monitoring system.
- Conducting experiments to evaluate the accuracy and reliability of the prototype by comparing its measurements to those obtained using commercially available PM2.5 sensors.
- Developing a user-friendly interface for the prototype that displays real time PM2.5 concentration measurements on an LCD screen or other output devices.
- Testing the prototype in various environments and conditions to ensure its robustness and ability to operate in a range of settings.
- Documenting the design, development and testing processes including creating schematics, code and user manuals to enable others to replicate and improve upon the prototype.

The project does not include large scale deployment of the prototype or commercialization of the device. The prototype is intended to be a proof of concept that demonstrates the feasibility of using Arduino based devices for monitoring air quality. The project scope may be expanded or revised based on the results of the experiments and feedback from stakeholders.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This research paper examines a study conducted within a timeframe of five years prior to the execution of the current project. The study is deemed suitable as a reference for the present investigation. The literature review will critically assess the selected study, evaluating its relevance and applicability to the current project. Additionally, the search strategy employed in the selected study will be scrutinized to determine its suitability for the present research. Furthermore, a comprehensive analysis of the advantages and disadvantages associated with the hardware and system choices will be conducted to make a more precise selection of components for integration into the project. Finally, a comparison and examination of previous research findings and methodologies will be undertaken to ensure the utilization of the most reliable and pertinent sources of information for the present project.

This section provides an overview of previous studies on the implementation and analysis of IoT-based particulate matter and air pollution detection and monitoring systems. Air pollution is a significant concern that affects both developing and developed nations with its profound impact on public health. The wide range of pollution sources and their diverse effects make understanding and addressing the health and environmental consequences of air pollution challenging. The presence of various chemicals in the air contributes to a multitude of human and ecological health problems associated with air pollution. To address this issue, a proposed system is presented, comprising an Arduino Uno Rev 3, MQ-2 Gas sensor, LCD, and LoRa Device. It is worth noting that previous and current research in IoT has predominantly followed a sequential and independent approach in implementing these components and methods.

2.2 Understanding global/current issues

2.2.1 Air Pollution

Each year, a significant number of lives are tragically lost as a result of prolonged exposure to outdoor air pollution, particularly in the Asian region. In Malaysia, respiratory illnesses accounted for 14.8% of total mortality in 2019, making it the second leading cause of death while cardiovascular diseases claimed 7.9% of lives within hospital settings. Research studies indicate that achieving an annual average fine particulate matter (PM2.5) concentration of 10 μg/m3 in Malaysia could potentially extend the average lifespan of its population by 1.8 years representing a remarkable 65% reduction from the current levels of air pollution. It is concerning to note that the State of Global Air 2020 report highlights a significant surge of nearly 30% in PM2.5-related fatalities in Malaysia over the past decade, estimating that approximately 10,600 lives were lost in 2019 alone due to the direct impact of air pollution. [1]

Pollutant	**Malaysian Ambient Air Quality Standards (2020)**	**WHO, 2005 Guidelines**	**WHO, 2021 Guidelines**
Fine Particle (PM2.5)	35	25	15
Coarse Particle (PM10)	100	50	45

Table 2.1 National Ambient Air Quality Standards in μg/m3 in 24 hours

Air pollution is characterized by the presence of detrimental substances or pollutants in the Earth's atmosphere. These pollutants encompass gases, particles and biological materials which contaminate the air and engender potential hazards to human health, ecosystems and the overall environment. While air pollution can arise from natural occurrences such as volcanic eruptions, dust storms, forest fires and biological decay, human activities are the predominant sources of air pollution. These activities include:

- Industrial emissions: Burning of fossil fuels from factories
- Transportation: Burning fossil fuels like gasoline and diesel from vehicles
- Residential and commercial combustion: The burning of fuels for heating, cooking and energy generation in households
- Waste Management: Improper disposal of waste including open burning of garbage

The pollutants released into the air can have adverse effects on human health such as respiratory problems, allergies and increased risk of cardiovascular diseases. Air pollution can also harm ecosystems including plants, animals and aquatic life and contribute to climate change. Common air pollutants include:

- Particulate Matter (PM): Particulate matter (PM) comprises small solid or liquid particles that remain in the atmosphere including substances like dust and aerosols. PM is categorized according to its size with specific focus given to PM10 (particles with a diameter of 10 micrometers) and PM2.5 (particles with a diameter of 2.5 micrometers) due to their propensity to infiltrate deeply into the respiratory system.
- Carbon Monoxide (CO): imperceptible and odorless gas generated through the incomplete combustion of fossil fuels. Elevated concentrations of CO can pose toxic effects, disrupting the transportation of oxygen within the body.
- Nitrogen Oxides (NOx): group of gases generated through the combustion of fossil fuels, predominantly emitted by vehicles and industrial activities. These compounds play a significant role in the creation of smog and the occurrence of acid rain.
- Sulfur Oxides (SOx): Gases emitted during the combustion of fossil fuels. These gases have the potential to cause respiratory ailments and are also implicated in the formation of acid rain

For out project we will use GP2Y1010AU0f dust sensor to detect PM2.5 as major sensor andMQ-2 sensor to detect Carbon Monoxide as minor sensor.

2.2.2 PM2.5

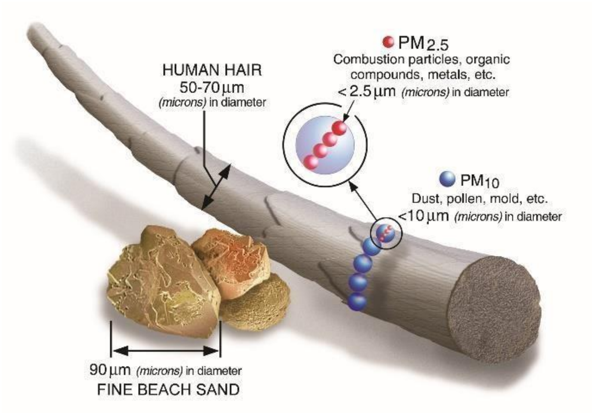


Figure 2.1 Size of Particulate Matter compare to beach sand and human hair

Particulate matter 2.5 (PM2.5) refers to the presence of fine particles suspended in the air, characterized by a diameter of 2.5 micrometers or less. Inhaling PM2.5 can pose risks to human health as these minute particles have the ability to penetrate deep into the respiratory system. PM2.5 is sourced from a variety of origins, encompassing both natural and anthropogenic factors. Natural sources encompass dust, pollen and sea salt while human activities including industrial emissions, vehicular exhaust, power generation and combustion of fossil fuels substantially contribute to atmospheric PM2.5 levels. The diminutive size of PM2.5 particles facilitates their prolonged suspension in the air and their potential for long-range transport. Consequently, PM2.5 represents a prominent concern in terms of air quality management and human well-being. Prolonged exposure to elevated levels of PM2.5 can have detrimental effects on the respiratory system, manifesting as respiratory symptoms, asthma exacerbations, respiratory infections and even cardiovascular complications.

The recurring annual haze issue encountered by Malaysia significantly influences the daily routines. Discrepancies in the Air Pollution Index (API) readings between Singapore and Malaysia arise due to variances in the measurement of particulate matter. It is widely acknowledged that PM2.5 has a more pronounced adverse impact on human health.

health than PM10. The primary objective of this study was to assess the levels of PM10 and PM2.5 concentrations during episodes of haze and non-haze conditions, followed by an evaluation of their correlation with meteorological parameters including temperature and humidity. Air samples were collected utilizing miniVol samplers during both haze and non-haze periods. The findings revealed significantly elevated concentrations of PM10 and PM2.5 during the haze period compared to the non-haze period with PM2.5 consistently demonstrating higher levels than PM10 in both scenarios. [2]

AQI	Level of healthy concern	CO (mg/m^3)	PM10 (µg/m^3)	PM2.5 (µg/m^3)
0-50	Good	0-1.0	0-54	0.0-15.4
51-100	Moderate	1.1-2.0	55-125	15.5-35.4
101-150	Unhealthy for specific groups	2.1-10	126-254	35.5-54.4
151-200	Unhealthy	10-17	255-354	54.5-150.4
201-300	Very unhealthy	17-34	355-424	150.5-250.4
300+	Hazardous	34+	425-504	250.5-350.4

Table 2.2 Air Quality Index (AQI) range category based on pollution

2.2.3 Carbon Monoxide

Carbon monoxide (CO) is an odorless gas generated through the incomplete combustion of carbon-based fuels. It is a highly toxic gas that poses substantial risks to human health. Carbon monoxide emissions predominantly arise from various sources including vehicular exhaust, industrial activities, power generation and residential heating systems. Upon inhalation, clinical manifestations associated with carbon monoxide poisoning encompass headaches, dizziness, nausea, cognitive impairment, asthenia and thoracic discomfort. Prolonged exposure to elevated carbon monoxide levels may precipitate loss of consciousness, cerebral impairment and fatality. Because carbon monoxide cannot be detected without specialized equipment, itis important to have carbon monoxide detectors. Our project will use MQ-2 sensor as carbon monoxide detection.

Figure 2.2 Poster of Danger Sign was created because of Carbon Monoxide dangerous by Occupational Safety and Health Administration (OSHA)

2.2.4 Relationship between COVID-19 and Air Pollution

The relationship between air pollution and COVID-19 is an area of ongoing research. While more studies are needed to fully understand the extent of the connection, there is evidence to suggest that air pollution can potentially worsen the impact of COVID-19 in several ways:

- Respiratory Health: The presence of air pollution, notably fine particulate matter (PM2.5) and pollutants such as Carbon Monoxide (CO) has been linked to the development respiratory ailment, including asthma, chronic obstructive pulmonary disease (COPD), and various respiratory infections. Individuals with pre-existing respiratory conditions are particularly susceptible to experiencing severe respiratory complications if they become infected with COVID-19.

- Weakened Immune System: Sustained exposure to air pollution has been associated with immunosuppression, rendering individuals more susceptible to respiratory infections including COVID-19. The compromised immune response resulting from prolonged exposure to air pollutants may impair the individual's capacity to effectively combat the virus, potentially increasing the likelihood of severe illness.

- Inflammation and Lung Function: Air pollution can cause inflammation in the respiratory system and reduce lung function. COVID-19 primarily affects the respiratory system and individuals with compromised lung function may face greater challenges in battling the virus.

- Transmission: Some studies suggest that air pollution particles could potentially act as carriers for the virus, allowing it to remain suspended in the air for longer periods and increasing the risk of airborne transmission in highly polluted areas. However, more research is needed to understand the significance of this potential transmission route.

It is a common knowledge that air pollution alone does not cause COVID-19. The primary mode of COVID-19 transmission is through respiratory droplets from infected individuals. However, the presence of air pollution may exacerbate the severity of the disease and increase the risk of complications, especially for vulnerable populations.

Addressing air pollution and reducing exposure to pollutants remains crucial for overall respiratory health especially during the COVID-19 pandemic. Implementing measures to improve air quality can help reduce the burden on healthcare systems and potentially mitigate the impact of respiratory infections including COVID-19.[3]

Cause (Covid-19 Comorbidities)	Risk Factor
Ischemic heart disease	13%
Stroke	13%
Tracheal, bronchus, and lung cancer	12%
Diabetes mellitus	13%
Cardiovascular diseases	6%

Table 2.3 Risk factors of deaths as a result of ambient particulate matter pollution in Malaysia, which are COVID-19 comorbidities

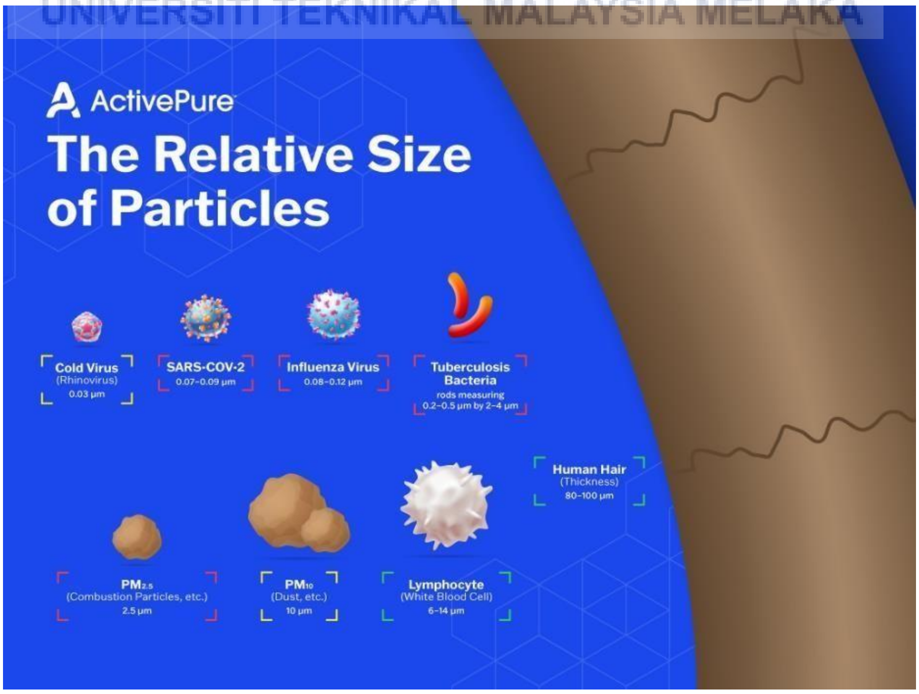


Figure 2.3 Comparison size between SARS-COV-2 particle compare to other particles.

2.3 Difference between Arduino and Raspberry Pi

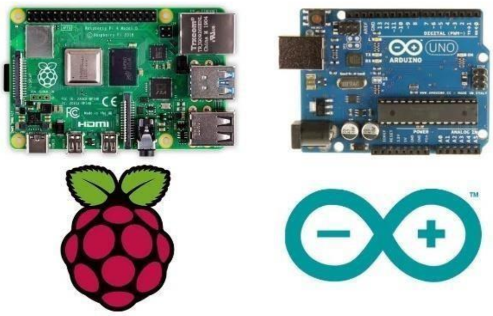


Figure 2.4 Raspberry Pi vs Arduino

Microcontrollers have gained significant importance in various industrial and scientific applications as well as in the development of graduation projects. Based on past project, there are so many differences way to make a **PROTOTYPE OF PARTICULATE MATTER DETECTION AND MONITORING SYSTEM IN AIR POLLUTION**. Therefore, understanding the distinctions between these boards is crucial for minimizing costs and optimizing performance. Raspberry Pi, although capable of functioning as a microcontroller like Arduino, surpasses it in terms of processing large datasets and handling graphics-intensive tasks. Moreover, Raspberry Pi provides effortless internet connectivity akin to that of aminiature computer. Conversely, Arduino, although less powerful compared to Raspberry Pi, assumes a pivotal role within computer systems. It represents a commendable option for electronic projects as it does not necessitate an operating system or software applications. Instead, a concise code snippet proves adequate for its utilization. Arduino encompasses a rangeof development boards, encompassing Arduino Uno.

Raspberry Pi	Model	Arduino
No limit	**Programming Language**	Arduini, C/C++
700 MHz	**Processor Speed**	16MHz
Not easy	**Internet connection**	Doable/Very easy
Closed source	**Hardware design**	Open source
Only hardware real-time	**Real-time**	In real-time
No	**Analog to Digital**	Yes

Table 2.4 Differences between Raspberry Pi and Arduino [4]

The table below are main advantages and main limitations of Raspberry Pi:

Advantages (Pros)	Disadvantages (Cons)
Easy to get the access to the internet	Real-time access to hardware is not guaranteed. In cases where the CPU is occupied with other tasks, the interaction with the hardware may experience delays.
Linux stack is available	The available power may be insufficient to adequately drive inductive loads.
Can program it using variety programming language.	An integrated Analog to Digital converter is not provided as a built-in feature

Table 2.5 Pros and Cons of Raspberry Pi [5]

How to find a suitable time to use Raspberry Pi or not

Determining the appropriate circumstances to utilize Raspberry Pi can be influenced by various factors. In instances where the project necessitates minimal hardware interaction but entails complexity in software implementation or necessitates internet connectivity, Raspberry Pi proves to be the optimal choice. Furthermore, if the objective entails programming in diverse languages, Raspberry Pi emerges as the preferred selection. Conversely, if the project mandates extensive hardware interfaces, data reading from numerous sensors or control of multiple devices, Raspberry Pi may not be the most suitable option.

The table below are main advantages and main limitations of Arduino:

Advantages (Pros)	Disadvantages (Cons)
Very easy to get started.	In terms of computing power, Arduino is relatively less potent compared to Raspberry Pi.
Arduino is suitable for real-time applications, encompassing both hardware and software components. Additionally, it benefits from an open-source Integrated Development Environment (IDE).	To operate Arduino, it is necessary to utilize programming languages such as Arduino or C/C++.
The Arduino platform offers straightforward means of expansion, boasting a vast array of user-contributed shields and libraries. These shields which are add-on boards, greatly enhance the capabilities of Arduino by providing specialized functionalities. The available shields can give us a wide range of requirements, enabling users to accomplish a multitude of tasks with relative ease.	Establishing internet connectivity with Arduino may present some challenges, albeit not insurmountable. It is indeed feasible to parse Arduino data using technologies such as YQL (Yahoo Query Language) and JSON (JavaScript Object Notation).

Table 2.6 Pros and Cons of Arduino

How to find a suitable time to use Arduino or not

When faced with a project that demands extensive interaction with external hardware components, Arduino emerges as a favorable choice. Conversely, if the project necessitates a substantial amount of software development, entailing complex software stacks or protocols, Arduino may not be the most optimal solution.

The selection of the board hinges on the nature of the project at hand and one's programming proficiency. Based on this comparison, I choose Arduino as microcontroller for this project. For individuals lacking experience in programming or electronics, acquainting themselves with both Arduino and Raspberry Pi simultaneously might pose a steeper learning curve, particularly in the case of Arduino. However, given Arduino's longevity, abundant tutorial resources exist to facilitate the initial steps. Conversely, those well-versed in programming will likely find it easier to promptly grasp the intricacies of Arduino. The Arduino operates on a hardware-based system, necessitating the inclusion of various components such as LCDs, LEDs, resistors and motors depending on the desired project. In contrast, the Raspberry Pi requires no prior experience or additional components to initiate functionality. It offers a plug-and-play experience. If one intends to embark on a hardware project, the Arduino stands as the optimal choice providing analog input, PWM output and broad compatibility that the Raspberry Pi lacks inherently. Furthermore, the Arduino's extensive I/O pins enable connections with multiple sensors and feedback components. However, it is worth noting that the Arduino's capabilities fall short compared to the Raspberry Pi as it lacks built-in support for video, audio or internet functionalities. Nonetheless, the Arduino can transmit data to a PC or Raspberry Pi via serial communication enabling the creation of programs to interpret and utilize this data. Conversely, if the objective is a software project, the Raspberry Pi emerges as the preferred option due to its superior video, audio, and internet capabilities. Its integrated features eliminate the need for external components, reducing the necessity to delve into electronics.

2.4 Arduino

Arduino is an open-source electronics platform consisting of hardware and software components that allow users to create and control interactive electronic projects. It is designed to be user-friendly, making it accessible for beginners while offering advanced features for experienced users.

Arduino platform comprises two main components:

- Arduino Hardware (Boards): These are physical microcontroller boards that serve as the brain of the Arduino system. Arduino boards come in various models such as Arduino Uno, Arduino Mega, Arduino Nan and more. These boards are equipped with microcontrollers from Atmel (now Microchip Technology), which provide the processing power and I/O capabilities for controlling electronic devices.

- Arduino Software (IDE): Serves as a software platform utilized for composing, compiling and uploading code onto the Arduino board. Designed to facilitate programming for individuals with varying levels of expertise, the Arduino IDE supports a simplified variant of the C++ programming language, ensuring accessibility for novices. Furthermore, it encompasses an extensive repository of pre-existing code examples and functions, streamlining the development workflow.

Key features and aspects of Arduino include [6]:

- Programming: Users can write code in the Arduino IDE to control the behavior of the connected hardware components. The code can be written to respond to inputs such as sensors and generate outputs such as controlling motors or LEDs.

- I/O Pins: Arduino boards are equipped with digital input/output (I/O) pins as well as analog input pins, enabling users to establish connections with a diverse array of electronic components and devices. These pins facilitate various functionalities including the acquisition of sensor data, manipulation of actuators, communication with external devices and numerous other applications.

- Shields: Arduino boards are compatible with "shields," which are additional modules that can be plugged into the board to extend its functionality. Shields can add capabilities such as Wi-Fi connectivity, motor control, GPS, LCD displays and more.

- Community and Documentation: Arduino has a large and active community of users, with forums, tutorials and project examples available online. This community support makes it easier for users to get help, learn and share their projects with others.

2.4.1 Arduino board

Arduino boards serve as the core hardware component of the Arduino platform and offer various functions and capabilities. Here are some set of Arduino boards [7]:

Arduino Board	Processor	Memory	Digital I/O	Analogue I/O
Arduino Uno	16Mhz ATmega328	2KB SRAM, 32KB flash	14	6 inputs 0 output
Arduino Due	84MHz AT91SAM3X8E	96KB SRAM, 512KB flash	54	12 inputs 2 outputs
Arduino Mega	16MHz ATmega2560	8KB SRAM, 256KB flash	54	16 inputs 0 output
Arduino Leonardo	16MHz ATmega32u4	2.5KB SRAM, 32KB flash	20	12 inputs 0 output

Table 2.7 The type of Arduino Board

I. Arduino Leonardo

Figure 2.5 Arduino Leonardo Board

The Arduino Leonardo distinguishes itself by utilizing an ATmega32U4 chip instead of the ATMega328P chip. The ATmega32U4 chip offers enhanced capabilities including a greater number of IO pins (20), PWM pins (7), and analog input pins (12). Notably, it incorporates integrated USB communication, negating the necessity for a secondary processor or a separate USB to UART bridge chip. Consequently, the Leonardo board can establish a direct Human Interface Device (HID) or Virtual (CDC) serial/COM port connection with a computer. The bootloader and this Virtual COM port are employed for programming the Leonardo board.

II. Arduino Nano

Figure 2.6 Arduino Nano Board

The Arduino Nano serves as a compact version of the Arduino UNO designed to be compatible with breadboards. While retaining most of the functionalities of the Arduino UNO, it offers a smaller form factor. The primary distinctions between the Nano and the UNO include the absence of a DC power jack, the utilization of a Mini USB port in lieu of a USB B port and the implementation of a different USB-TTL converter chip. Specifically, the Nano employs an FT232 chip, a dedicated USB-UART bridge chip manufactured by FTDI rather than the ATMega16U2 utilized in the UNO. Despite these variations, the Nano remains a favored choice among developers due to its diminutive size and affordable price.

III. Arduino Micro

Figure 2.7 Arduino Micro Board

The Arduino Micro board is primarily centered around the ATmega32U4 microcontroller, which offers 20 pins including 7 PWM pins and 12 analog input pins. Alongside these features, the board incorporates various components such as an ICSP header, an RST button, a compact USB connection and a 16MHz crystal oscillator. Notably, the Arduino Micro boasts an integrated USB connection and represents a condensed iteration of the Leonardo board.

IV. Arduino Due

Figure 2.8 Arduino Due Board

This Arduino board utilizes the ARM Cortex-M3 microcontroller, marking its significance as the first Arduino board to adopt this architecture. The board encompasses a range of features including 54 digital I/O pins, of which 12 are dedicated PWM output pins and 12 analog input pins. Additionally, it incorporates 4 UARTs, 84 MHz CLK, USB OTG support, 2 DACs, a power jack, 2 TWI interfaces, a JTAG header, an SPI header and reset and erase buttons. It is important to note that this board operates at 3.3V and exceeding this voltage on any I/O pin may result in damage to the board.

V. Arduino Diecimila

Figure 2.9 Arduino Diecimila Board

The Arduino Diecimila microcontroller board is primarily based on the ATmega168 microcontroller. It features a total of 14 digital I/O pins with 6 of these pins capable of functioning as both PWM outputs and analog inputs. Additionally, the board includes a USB connection, 16 MHz crystal oscillator, ICSP header for in-circuit programming and reset button and power jack for convenient operation. It powered by using a battery or an AC-DC adapter.

VI. Arduino Mega (R3)

Figure 2.10 Arduino Mega 2560 R3 Board

The Arduino Mega 2560 is the largest among the discussed Arduino boards designed to accommodate applications that require a multitude of input/output (I/O) pins. It is equipped with a more robust processor, the ATMega2560. Compared to other Arduino boards, the Arduino Mega 2560 offers an extensive range of I/O capabilities featuring 54 I/O pins (with 15 of them capable of functioning as PWM outputs), 16 analog inputs and 4 UARTs. Moreover, it possesses greater flash storage and SRAM capacities than most basic Arduino boards. Due to its impressive specifications, the Arduino Mega 2560 has gained significant popularity within the open-source CNC and 3D printer community, as well as the open-source PLC community.

VII. Arduino Zero

Figure 2.11 Arduino Zero Board

This board incorporates several essential components including 6 analog input pins, 14 digital I/O pins, a power jack, AREF button, UART port pins, USB connector, an In-Circuit Serial Programming (ICSP) header and a power header. Powering this board is the Atmel SAMD21 microcontroller, which serves as its core processing unit. Notably, the Arduino Zero board contain EDBG (Embedded Debugger) to provides a comprehensive debug interface.

VIII. Arduino Uno Rev 3 (This project’s microprocessor) [8]

Figure 2.12 Arduino Uno R3 Board

The Arduino Uno development board, powered by the ATMega328P microcontroller holds a prominent position as the most widely used and popular choice among the development board community. This popularity stems from its affordability, ease of learning and utilization as well as the extensive availability of pre-made modules that facilitate the development of new projects and prototypes. For our project, we have selected the Arduino Uno as the microcontroller due to these compelling reasons.

The Arduino Uno board encompasses essential components including 14 Digital I/O pins which 6 pins serve as 8-bit PWM (Pulse Width Modulation) pins. Additionally, it offers 6 pins for 10-bit Analog inputs. The board is equipped with a power jack, a USB connection, an In-Circuit Serial Programming header (ICSP), as well as fundamental communication ports such as SPI (Serial Peripheral Interface), I2C (Inter-Integrated Circuit) and UART (Universal Asynchronous Receiver-Transmitter). This comprehensive feature set provides all the necessary elements to support the microcontroller's functioning.

To begin utilizing the Arduino Uno, one can easily connect it to a personal computer using a standard USB cable. Moreover, power can be supplied to the board via an AC-to-DC adapter or a battery allowing for seamless initialization of projects.

Processor	Memory	Security	Peripherals	Power
ATMega328P	• AVR CPU at up to 16 MHz • 32KB Flash • 2KB SRAM • 1KB EEPROM	• Power On Reset (POR) • Brown Out Detection (BOD)	• 2x 8-bit Timer/Counter with a dedicated period register and compare channels • 1x 16-bit Timer/Counter with a dedicated period register, input capture and compare channels • 1x USART with fractional baud rate generator and start-of-frame detection • 1x controller/peripheral Serial Peripheral Interface (SPI) • 1x Dual mode controller/peripheral I2C • 1x Analog Comparator (AC) with a scalable reference input Watchdog Timer with separate on-chip oscillator Six PWM channels Interrupt and wake-up on pin change	2.7-5.5 volts

Table 2.8 Features for Arduino Uno Rev 3

2.4.2 Arduino IDE

. The ease of use is regarded as a prominent advantage offered by the Arduino platform. This advantage is notably facilitated by the Arduino IDE, an Integrated Development Environment that presents users with a user-friendly interface. Within this environment, users are able to seamlessly engage in tasks such as writing, compiling and uploading code to the Arduino board. The Arduino IDE is designed to provide a comprehensive and intuitive software platform, ensuring a smooth and accessible programming experience for individuals, regardless of their level of expertise. As a result, the Arduino platform has gained significant popularity and acceptance among users from diverse backgrounds. Programming language used in Arduino is based on wiring and the programs themselves are referred to as sketches. Additionally, there is a vast library of open-source code available which enables users to leverage existing projects and easily incorporate them into their own creations. The open- source nature of Arduino means that the hardware designs, software libraries and development tools are freely available. This fosters a collaborative and innovative community where users can share their projects, code and ideas. It also allows for customization and modification of the Arduino boards to suit specific requirements.

In conclusion, the Arduino platform emerges as a highly accessible and robust solution for the programming and management of diverse electronic projects. Its open-source characteristics, coupled with the presence of collaborative community, contribute to its status as an exceptional option for both novice and proficient developers. By leveraging the resources provided by the Arduino ecosystem, individuals are empowered to engage in the creation of electronic projects with enhanced ease and efficiency. The combination of its user-friendly interface, comprehensive documentation and versatile hardware capabilities position Arduino as an invaluable tool within the realm of electronic development.

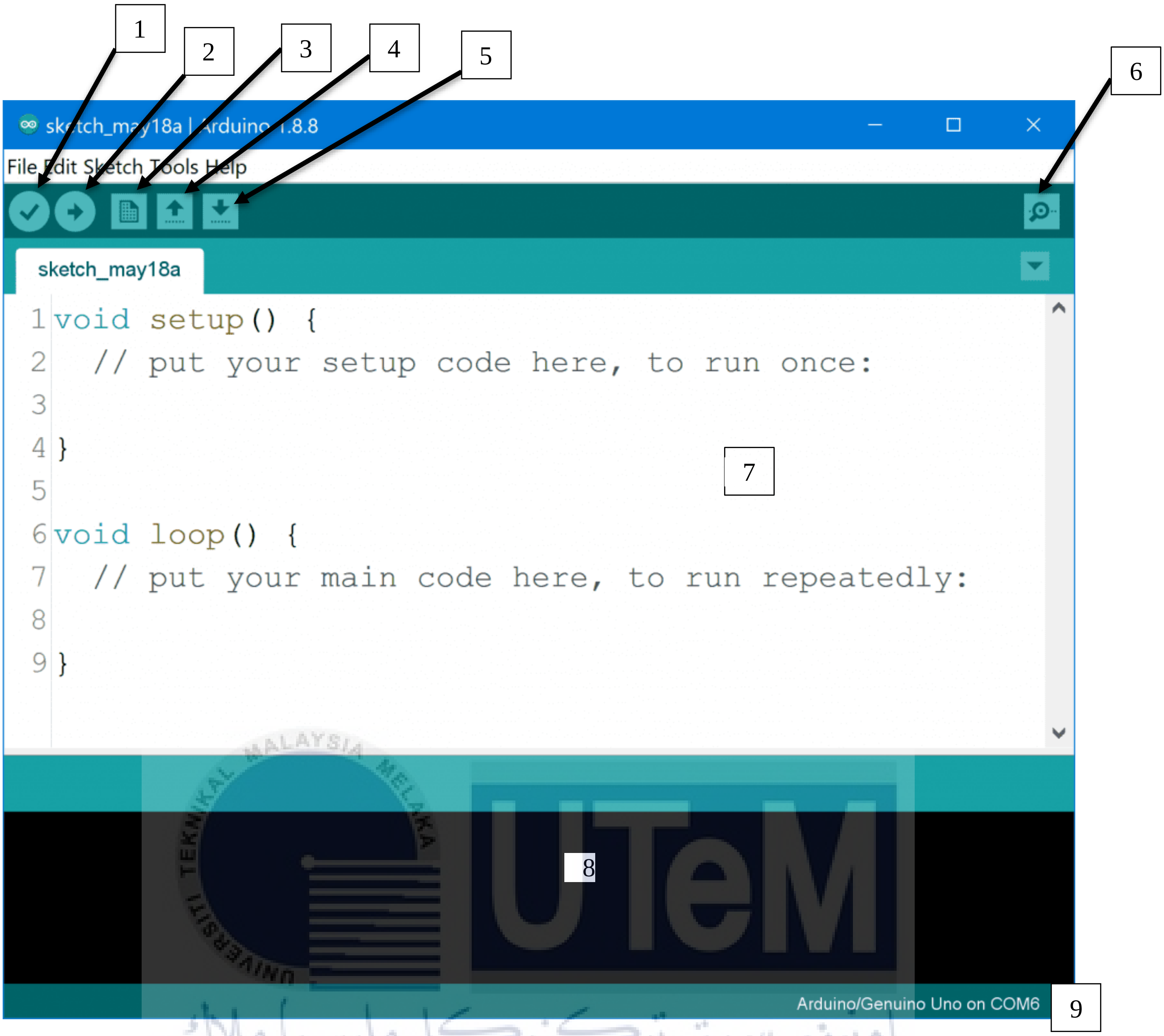


Figure 2.13 Arduino IDE software [9]

- 1: Verify – Compiles and checks your code for errors.
- 2: Upload - Compiles your code and uploads it to the configured board.
- 3: New - Creates a new sketch.
- 4: Open – Opens an existing sketch.
- 5: Save - Saves your sketch.
- 6: Serial Monitor - Opens the Serial Monitor.
- 7: Main Code Area - Area where you write your code.
- 8: Console - Displays the information about the status of the code.
- 9: Board and Serial Port Selections - Displays the Arduino board and COM port in use.

2.5 Dust sensor

Figure 2.14 Sharp GP2Y1010AU0F sensor

The Dust Sensor is an air monitoring module featuring the Sharp GP2Y1010AU0F sensor, which enables the detection of fine particles with a diameter larger than 0.8μm including substances like cigarette smoke. The sensor provides an analog voltage output that is directly proportional to the density of dust particles. This sensor has extremely low current consumption typically 11mA and 20mA max & it can be powered through up to 7VDC. Additionally, the module integrates a voltage boost circuitry capable of accommodating a broad spectrum of power supply inputs. This particular sensor is commonly referred to as an optical air quality sensor, denoting its capability to measure the quality of ambient air based on optical principles.

How does this sensor work:

The dust sensor utilizes the principle of light scattering, employing an infrared emitter LED as a transmitter and a photodiode as a receiver. To optimize the detection process, both the IR LED and photodiode are strategically positioned near the airflow path within the sensor. In this sensor, air through an air inlet valve and the dust particles within the air are illuminated by a light source, resulting in scattered light. This scattered light is converted into an electrical signal by a photodiode. To obtain the particle concentration, these signals are amplified through the amplifier circuity. The intensity of scattered light is primarily influenced by the presence of dust particles in the air, with higher concentrations leading to increased light intensity.

Sharp GP2Y1010AU0F features and specifications:

Sensor design	compact
Sensitivity	0.5V/(100µg/m3)
Measurement range	500µg/m3
Power	2.5V~5.5V
Operating temperature	-10℃~65℃
Storage temperature	-20℃~80℃
Operating current	20mA(max)
Lifetime	5 years
Dimension	63.2mm × 41.3mm × 21.1mm
Mounting holes size	2.0mm
Air hole size	9.0mm
size of detectable dust minimum	0.5µm
Sensing range of dust density	up to 580 µg/m3
Sensing time	< 1 Second

Table 2.9 Sharp GP2Y1010AU0F features and specifications

PM2.5 density value(µg/m3)	**Air quality index AQI**	**Air quality level**	**Air quality evaluation**
0-35	0-50	I	Excellent
35-75	51-100	II	Average
75-115	101-150	III	Light pollution
115-150	151-200	IV	Moderate pollution
150-250	201-300	V	Heavy pollution
250-500	≥300	VI	Serious pollution

Table 2.10 Comparable Sharp GP2Y1010AU0F result with Air Quality Index (AQI)

2.5.1 Difference between Sharp GP2Y1010AU0F and Shinyei PPD42NS[10]

Sharp GP2Y1010AU0F	Sensor	Shinyei PPD42NS
Grounded on the fundamental principle of light scattering, the sensor employs an infrared light-emitting diode (LED) and a photodetector to quantify the intensity of light scattering resulting from airborne particulate matter. By analyzing the scattering patterns, the sensor able measure the presence of dust particlessuspended in the surrounding air.	**Principle of Operation**	The functioning of the sensor is based on the principle of light scattering, employing an infrared LED and a photodetector to detect and analyze the scattered light resulting from the presence of dust particles.
capability to detect fine particles with a diameter exceeding 0.8 microns.	**Sensing Range**	Used for detecting larger particles, typically those with a size greater than 1 micron.
Provides an analog output voltage signal that is proportional to the dust concentration.	**Output Signal**	Offers a pulse output, where the frequency of the pulses indicates the dust concentration. It also provides an additional output for the duration of the high pulse which is related to the dust concentration.
More accurate and reliable in terms of dust particle detection and measurement. However, it may still require calibration for precise measurements.	**Accuracy and Calibration**	lower accuracy compared to some other dust sensors. It may require calibration to achieve more accurate readings.
Commonly used in air purifiers, HVAC systems, and industrial air quality monitoring applications where accurate dust measurements are required.	**Application and Usage**	often used in DIY air quality monitoring projects and can provide a basic indication of dust levels. It is suitable for applications where general dust detection is needed, but high accuracy is not critical.

Table 2.11 Difference between Sharp GP2Y1010AU0F and Shinyei PPD42NS

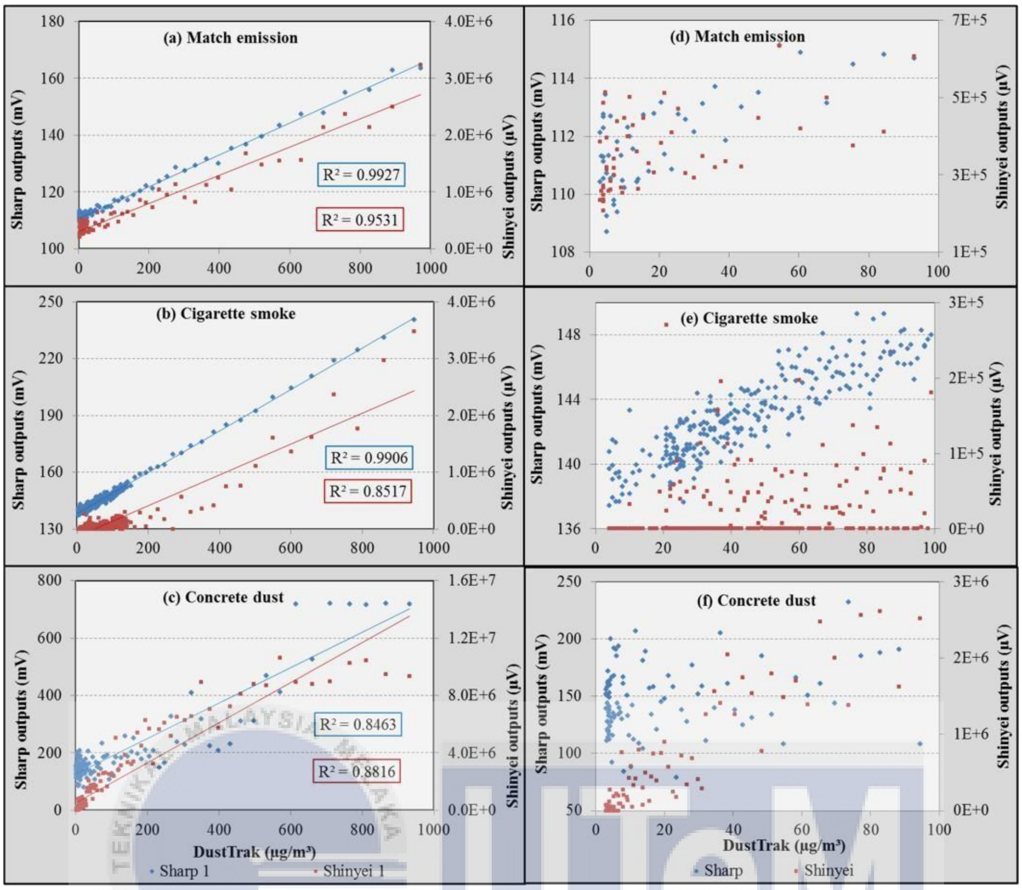


Figure 2.15 Scatter plots of Shinyei (red) and Sharp (blue) sensor readings against the DustTrak readings [11]

Based on table 2.11 and figure 2.15, when it comes to mini projects, both the Sharp GP2Y1010AU0F and Shinyei PPD42NS can be suitable choices depending on your specific requirements and preferences. But it can be seen that Sharp GP2Y1010AU0F is generally considered to provide more reliable and accurate readings than Shinyei PPD42NS. The GP2Y1010AU0F sensor is specifically engineered to detect and measure fine particles with a diameter exceeding 0.8 microns. Its capability to monitor such smaller particles renders it well-suited for applications that necessitate precise assessment of air quality and potential health implications. Furthermore, GP2Y1010AU0F provides a linear analog output voltage that directly corresponds to the dust concentration. This makes it easier to interface with microcontrollers and data acquisition systems for further analysis and processing of the data.

2.6 Gas sensor

Figure 2.16 MQ-2 Gas Sensor detection

The MQ2 gas sensor is an electronic device that exhibits the capability to detect a wide array of gases present in the atmosphere including LPG, propane, methane, hydrogen, alcohol, smoke and carbon monoxide. Its operational principle relies on the alteration in resistance of a sensing material upon encountering a particular gas. Utilizing a voltage divider network, the MQ2 sensor facilitates the quantification of gas concentrations within the range of 200 to 10,000ppm, thereby proving valuable in applications such as air quality monitoring, gas leak detection systems and adherence to environmental standards in healthcare facilities. In industrial settings, this sensor assumes a pivotal role in the identification of hazardous gas leaks. For specific applications, alternative sensors such as the MQ-6, M-306A and AQ-3 can be utilized as viable substitutes for the MQ2 sensor.

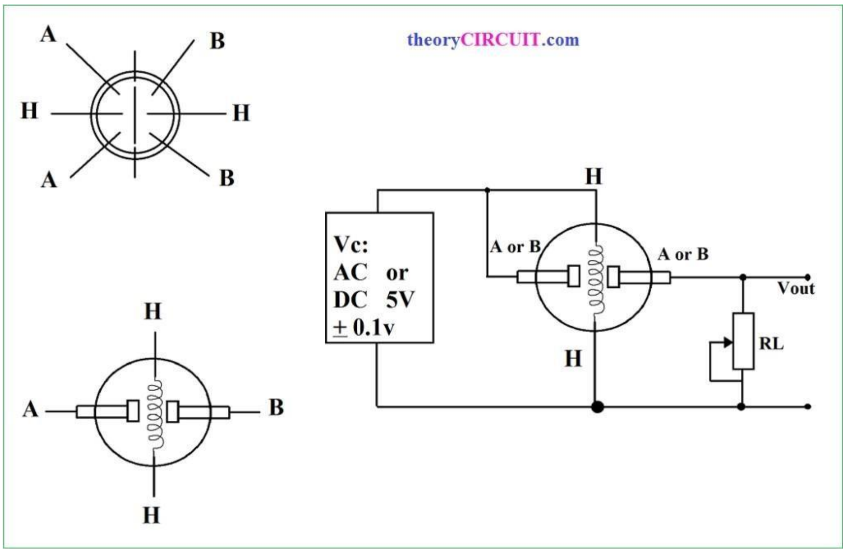


Figure 2.17 MQ gas sensor configuration [12]

To ensure proper functioning of the sensor, it is necessary to connect the A pins together and the B pins together. Applying a supply voltage of +Vcc to either the coupled A or B pins and grounding the remaining coupled A or B pins through a variable load resistor (RL) is recommended. Care should be taken not to interconnect the A and B pins or make any wiring errors as such mistakes could potentially damage the sensor. The use of breakout boards is advised for enhanced convenience and safety. The sensor operates based on the functioning of the heater coil. The sensor's heater requires a 5V DC supply or PWM pulses ranging from 2V to 5V amplitudes. It is important to directly connect the H pins (heater) to the microcontroller or Arduino board, as the heater draws a significant amount of current. The sensor is warmed up through the utilization of this heater and the duration required for the warm-up phase is known as the "burn-in time," which can take up to 3 minutes for MQ sensors. To obtain desired results, a load resistor (RL) is connected at the output to ground. The value of this load resistor may range from 2KΩ to 47KΩ. Lower values of RL result in reduced sensitivity while higher values provide greater sensitivity but may be less accurate for higher gas concentrations. It is advisable to use a variable resistor for RL to allow for adjustments and optimize the sensor's performance.

Name of Sensor	**Sensitive For**
MQ2	Sensitive for Methane-Butane-LPG-smoke and Carbon Monoxide.
MQ3	Sensitive for Alcohol- Ethanol- smoke.
MQ4	Sensitive for Methane- CNG Gas.
MQ5	Sensitive for Natural gas- LPG.
MQ6	Sensitive for LPG- butane gas.
MQ7	Sensitive for Carbon Dioxide.
MQ8	Sensitive for Hydrogen Gas.
MQ9	Sensitive for Carbon Monoxide- flammable gasses.
MQ131	Sensitive for Ozone.
MQ135	For Air Quality Sensitive for Benzene-Alcohol- smoke.
MQ136	Sensitive for Hydrogen Sulfide gas.
MQ137	Sensitive for Ammonia.
MQ138	Sensitive for Benzene-Toluene- Alcohol- Acetone- Propane- Formaldehyde gas- Hydrogen gas.
MQ214	Sensitive for Methane- Natural gas.
MQ216	Sensitive for Natural gas-Coal gas.

Table 2.12 Types of MQ gas sensor

2.7 Lora Module

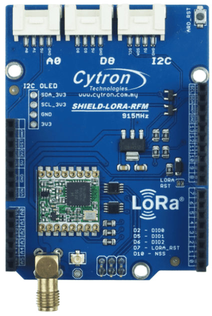


Figure 2.18 Lora Module size in 2D model

The RFM LoRa Shield achieving a sensitivity exceeding -148dBm. It is cost-effective components. Its integrated +20 dBm power amplifier results in an industry leading in link budget, ideal for applications requiring extended range or robustness. LoRa offers advantages in blocking, selectivity and energy consumption compared to traditional modulation techniques, addressing the trade-off between range, interference immunity and energy usage. Beyond supporting high-performance (G)FSK modes like WMBus and IEEE802.15.4g, the RFM LoRa Shield excels in phase noise, selectivity, receiver linearity and IIP3 ensuring lower current consumption compared to competitors. The shield features stackable side headers for compatibility with additional Arduino shields and includes built-in grove sensor connectors for easy integration of grove-based sensors. Additionally, it offers an option to incorporate an OLED for visual display.

Specifications:

- Integrated with RFM95W LoRa module operating in the 915 MHz frequency band.
- Receiver Sensitivity: down to -146 dBm.
- TX Power: adjustable up to +14 dBm high-efficiency PA.
- Low RX current of 10.3 mA, 200 nA register retention.
- FSK, GFSK, MSK, GMSK, LoRa, and OOK modulation.
- Interface via SPI with Arduino main board and option for OLED display.

2.7.1 **Lora module operation** [13]

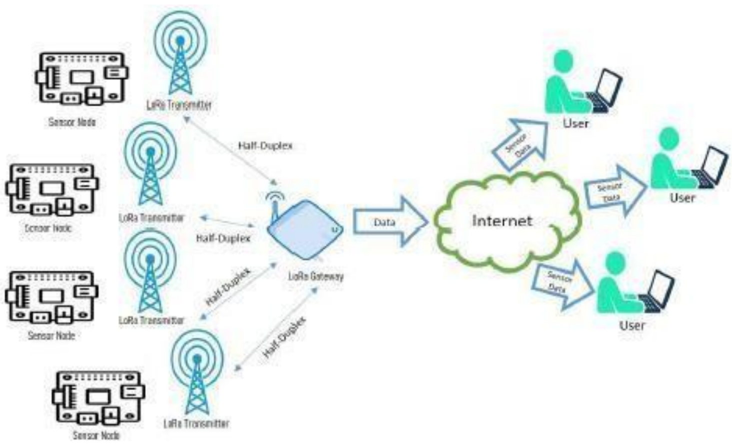


Figure 2.19 Transmitter and receiver operation for Lora Module

The IoT system based on LoRa communication as illustrated in the figure 2.19, involves a sensor node equipped with a LoRa transmitter to transmit sensing measurements. The half-duplex communication enables the transmission of data from the sensor node to the LoRa gateway which in turn acquires the data on behalf of the server acting as the cloud in the system. This allows users to effectively monitor the field's environment and utilize the recorded data to make informed decisions and take appropriate actions. The distinction between LoRa and LoRaWAN is often overlooked due to their similar names but it actually had different aspects of long-range wireless communication. LoRa refers to the modulation technique known as chirp spread spectrum which enables efficient transmission over extended distances. On the other hand, LoRaWAN represents a comprehensive framework consisting of communication protocols and system architecture specifically tailored for long-range networks utilizing the LoRa technology. While LoRa serves as the physical layer responsible for converting data into signals, LoRaWAN operates at the Media Access Control (MAC) layer, facilitating the utilization of LoRa signals across diverse applications. It is worth noting that LoRa has gained significant prominence as a leading Low Power Wide Area Network (LPWAN) technology, particularly in the context of Internet of Things (IoT) deployments and seamless integration of devices. [14].

2.7.2 Difference between LoRa and LORAWAN

LoRa (Long Range) and LoRaWAN (Long Range Wide Area Network) are two interconnected yet distinct technologies employed for facilitating low-power, wide-area communication in the realm of Internet of Things (IoT) applications. It is essential to recognize the fundamental distinctions between LoRa modules and LoRaWAN. Here are the contrasts between the two Long Range Module:

LoRa	Module	LoRaWAN
It provides long-range communication with low power consumption, enabling devices to transmit data over several kilometers.	**Technology**	It defines how devices can communicate with gateways and how gateways can communicate with a central network server.
LoRa technology itself allows for long-range communication, typically several kilometers in open environments, making it suitable for applications that require wide-area coverage.	**Communication Range**	The coverage range of LoRaWAN networks relies on strategic deployment gateways. In urban environments, it networks typically coverage several kilometers while in rural areas, the coverage up to ten of kilometers. Range of LoRaWAN networks can be expanded by implementing supplementary gateways at strategic locations. This approach extends the reach of the LoRaWAN infrastructure, enabling coverage for IoT.
Suitable for point-to-point applications, such as remote sensor data transmission, industrial monitoring, and asset tracking, where devices directly communicate with a receiver or gateway.	**Applications**	Designed for long-range IoT applications that need low-power communication and scalable network infrastructure. It is commonly used in smart cities, environmental monitoring and other IoT deployments.

Table 2.13 Difference between LoRa and LoRaWAN module

2.8 Suitable wireless network technologies selection

In the realm of Internet of Things (IoT), various technological solutions exist for data transmission across networks such as LoRa, NB-IoT, WiFi, Bluetooth, Zigbee and sub-1GHz. However, achieving a balance between long transmission distances and energy efficiency within wireless communication networks is often challenging. Longer transmission distances typically necessitate increased energy consumption. To address this concern, LoRa has been selected as the optimal choice for the current project. LoRa technology ensures both long-range connectivity and low-power consumption making it well-suited for scenarios that require transmitting relatively small amounts of data over extended distances. By leveraging LoRa, the project can achieve the desired balance between long-range communication and energy efficiency.

Wireless Network Technology	Distance	Velocity	Energy consumption	Construction cost	Communication cost	Application
LoRa	Longest	Slowest	Low	Median	Free	Outdoor sensors
3G/4G	Long	Fastest	High	High	Data flow charge	Call and internet
Wifi	Short	Fast	Highest	Low	Free	Home network
Bluetooth	Shorter	Median	Low	Low	Free	Phone accessories
Zigbee	Shortest	Slow	Low	Low	Free	In-door equipment

Table 2.14 Comparison between LR and many other commonly used wireless network technologies

2.9 Internet of Things (IoT)

The Internet of Things (IoT) encompasses a vast network infrastructure where numerous interconnected entities commonly referred to as "Things" engage in seamless communication. Rather than being a disruptive revolution, the IoT represents a culmination of existing technologies alongside the development of new communication paradigms. It effectively integrates the physical and virtual domains by incorporating diverse concepts and technical components such as pervasive networks, device consolidation, mobile communication and an evolving ecosystem. Within the IoT, the deployment of applications, services, middleware components, network and end nodes carefully orchestrated to facilitate innovative approaches providing insights into complex processes and interactions. This interconnectedness promotes symbiotic communication between the physical and digital realms allowing physical entities to possess digital counterparts and virtual representations. Such context-awareness empowers "Things" to perceive, communicate, interact and exchange data, information and knowledge. By leveraging the IoT, new possibilities aligned with specific business requirements emerge, enabling the creation of real-time services based on real-world data. The IoT also facilitates connectivity between the physical and virtual domains, fostering a paradigm shift towards shared connectivity and affordable accessibility as opposed to exclusive ownership. Consequently, successful implementation of the IoT necessitates considerations such as intelligent learning mechanisms, rapid deployment strategies, comprehensive understanding of information flows, safeguards against fraudulent activities and malicious attacks and preservation of privacy. These factors collectively contribute to the realization of the IoT's potential and its transformative impact in various domains [15].

2.9.1 Capability of Internet of Things (IoT) in this project

Capability	Function
Achieve information of specific location	The IoT system has the capability to collect location information from IoT stations and end nodes, enabling the provision of location-based services. This location information encompasses geographical position data obtained from bluetooth and other sources, as well as complete or relative positioning information between different entities.
Mobile asset tracking	The application effectively monitors and visually presents the real-time status of a product by leveraging a position sensing device and the inherent functionality integrated into the item itself.
Environment sensing and detection	The IoT system effectively acquires and analyzes a broad spectrum of physical and chemical environmental parameters through locally or widely distributed terminals. This comprehensive data collection encompasses various environmental indicators including but not limited to pollution indicators such as carbon monoxide (CO) and particulate matter.
Remote and Appliance control	IoT systems effectively manage and govern IoT terminals, employing application commands and integrating information acquired from connected devices and service demands. As a result, individuals can conveniently regulate the operational state of appliances remotely by utilizing the IoT system.
Disaster recovery	Based on the earlier mentioned monitoring data, users can remotely initiate disaster treatment facilities to mitigate the impact and minimize losses caused by disasters.
Secure Communication	In order to guarantee the secure transmission of data, the IoT system establishes a robust and encrypted communication channel between the application or service platform and the IoT terminals, adhering to the specific requirements of the respective service.

Table 2.15 Capability IoT in this project [16]

2.9.2 Internet of Things (IoT) programming tool in this project

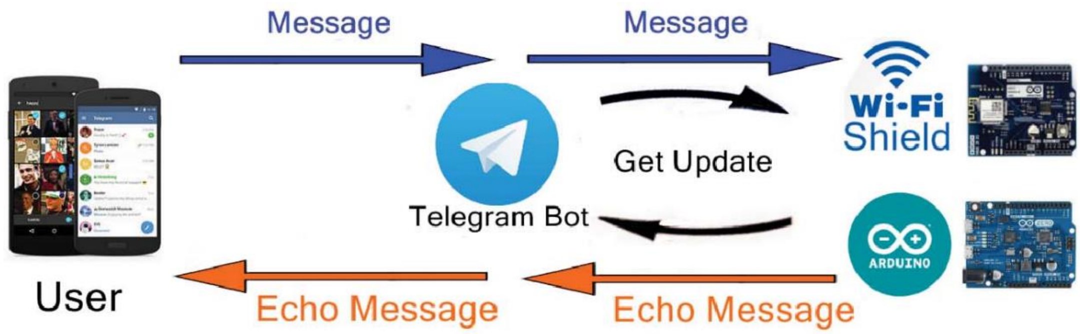


Figure 2.20 Telegram as IOT

Telegram can be used in conjunction with IoT (Internet of Things) applications for various purposes. Telegram provides a convenient and secure messaging platform that can be leveraged in IoT systems for communication, control, and monitoring. Telegram required OS android 6.0 above to install. It compatible with this project because it can receive data from internet. In this project, Telegram use to monitor dust and gas sensor data at someplace by using Telegram bot. A Telegram bot is a small program you embed on Telegram channels work as automated multifunctional assistant that can receive and send triggered messages. They are designed to simulate human interaction and conversation. Telegram Bot is used in this project to automate customer service. They can quickly and efficiently handle inquiries 24/7 and automatically data about dust and gas at someplace after had been link to ESP8266. [17].

How to send data using Telegram Bot:

- HTTP Requests to the Telegram bot
- Telegram bot Libraries or SDKs
- Integration Platforms and Services
- Webhooks for Real-time Updates

2.10 Aspect commercialization

Explore commercially available hardware components used for the propose project. Discuss cost and analyze their applicability to our project in aspect performance and potential for real-world application. The prices of hardware based on Lazada and Shopee online shop (Lowest price range).

Hardware components	Cost (Online shopping)	Performance	Why we should choose it
Arduino Uno Rev 3	RM 25.00	Easy to use, low price, tons of libraries and cross platform support.	Had so many documentations other Arduino that make it is really suitable for learning to make a prototype projects.
GP2Y1010AU0F sensor	RM22.00	The photo-sensor effectively identifies and measures small particles such as those found in cigarette smoke by detecting the reflected infrared (IR) LED light from dust particles present in the surrounding air.	As a major sensor to detect Particulate matter (PM2.5) that can cause air pollution.
MQ-2 Sensor	RM6.00	The sensor exhibits a heightened sensitivity towards propane and smoke enabling the detection of natural gas and other flammable vapors.	A minor sensor to detect Carbon Monoxide, LPG and smoke to support that someplace had been Polluted.
16x2 LCD I2C	RM10.00	Power consumption is less so it is energy efficient, low cost and long lasting that other display device (up to 60000 hours)	To display result from sensors.

Table 2.16 Commercially available hardware components used for the propose project

2.11 Previous Related Project

To gain a better understanding of this project, I continue my research on previous related projects that are largely focused on using IoT. This information will assist in the project's implementation and completion. As a result, this section will provide some background information on a similar effort with a similar purpose of air pollution monitoring system.

2.11.1 Room Environment Monitoring System form PDA Terminal

A research team consisting of Sung, J.O. and Wan, Y.C. has developed an RF wireless sensor module designed to facilitate efficient monitoring of indoor air quality within room or office environments. The system incorporates a web-based monitoring platform and integrates seamlessly with other home networking systems including Personal Digital Assistant (PDA) devices. The sensor module is equipped with multiple sensors including temperature, humidity, Carbon Dioxide and flying dust sensors, all integrated within the RF transmitter board to effectively monitor the environmental conditions of the room. In order to control the power switches of consumer electronics, an Intel 8051 microcomputer is utilized which receives signals from a personal computer (PC) or PDA device. [18]

2.11.2 InAir: Sharing Indoor Air Quality Measurements and Visualization

Kim and Paulos have developed a novel system named inAir, which offers comprehensive capabilities for measuring, visualizing and sharing indoor air quality information. The core components of the system include a DC 1100 air quality monitor for accurate pollutant measurement, an AVR-based Arduino microcontroller seamlessly integrated within the monitor and an iPod Touch device for efficient data processing, visualization, and wireless transmission to the Arduino. Data transmission occurs at regular intervals of 15 seconds with the Arduino encoding the data into a sequence of audio tones resembling a modem signal which is then captured by the iPod Touch via the dedicated microphone port. To facilitate real-time data sharing, the inAir system leverages Wi-Fi networking technology to establish a connection with a central server. This enables users to instantly access and disseminate the gathered air quality data. [19]

2.11.3 Room Dust Monitoring System

Phang has developed an innovative dust monitoring system for measuring the concentration of dust particles within a room environment. The system employs an Arduino Uno controller in conjunction with a Shinyei PPD20V particle sensor, ensuring accurate dust concentration measurements. Real-time data readings are seamlessly transmitted to a personal computer, where they are presented through Graphical User Interface (GUI) developed using a Visual Basic program. The efficacy of the system was thoroughly evaluated across different room conditions, encompassing scenarios such as clean rooms, dusty rooms, rooms with cooking haze and rooms affected by cigarette smoke. The obtained results demonstrated significant variations in dust concentration levels. By providing valuable insights into the impact of human activities on indoor pollutants, this device aims to enhance awareness regarding the potential implications for human health. [20]

2.11.4 Air Quality Monitoring and Controller that utilizes a TGS 2600 dust sensor

Ab Rahman has introduced an innovative Air Quality Monitoring System and Controller that utilizes the TGS 2600 dust sensor. This system effectively measures and monitors the concentration of dust particles providing users with convenient access to real-time information. The measured dust concentration is prominently displayed on an LCD screen which is programmed using MPLAB and operated through the PIC16F877A microcontroller. Additionally, an LED indicator visually displays the dust concentration status. A green light signifies a "normal" condition within the range of 0- 100ppm, while a yellow color indicates a "care" condition between 101-200ppm. In the case of a "danger" condition, with a dust concentration of 201ppm and above, a redlight illuminates, accompanied by a buzzing sound from the integrated buzzer. [21]

2.11.5 Plantation Monitoring System using Multiple Sensor and Arduino Uno

Taharim has developed a monitoring system that integrates multiple sensors and Zigbee modules to facilitate precise measurements of temperature, humidity and moisture. This system operates by analyzing the surrounding conditions of the air and soil providing valuable insights into environmental parameters. The monitoring system incorporates various sensors capable of measuring temperature in degrees celsius, relative humidity in percentage and soil moisture in percentage. To enable data transmission, an Arduino Uno microcontroller is employed to convert the measured values into digital signals. These signals are then wirelessly transmitted through Zigbee modules, establishing a communication link between the system's transmitter and receiver components. To facilitate data visualization, Taharim's monitoring system utilizes Visual BASIC software, which enables the collected data to be displayed on a computer screen. This user-friendly interface allows for easy reference and continuous monitoring of the measured parameters. [22]

2.11.6 Rice Hust/Dust Air Particle sensor using Zigbee Wireless Network

Zakaria presented a cost-effective solution to monitor air quality in a Rice Mill Factory located in Pering, Kedah Darul Aman, with the aim of ensuring a favorable environment for employees and nearby residents. To achieve this, a Rice Husk/Dust Air Particle Sensor was developed, incorporating the SHARP GP2Y1010AU0F optical dust sensor, along with an Arduino Fio board for expansion capabilities utilizing ZigBee Wireless Modules. Data transmission followed a point-to-point approach, employing the reading of HEX string data through a serial port. The Parallax Microcontroller Acquisition to Excel (PLX DAQ) software facilitated data acquisition and storage in Microsoft Excel, while real-time visualization of the dust measurement was enabled through a Visual Basic Application integrated within Excel. Overall, the effectiveness of the sensor and implemented methods were demonstrated in effectively monitoring dust density and mitigating dust pollution within the Rice Mill Factory. [23]

Previous endeavors have effectively devised air quality monitoring systems that employ dust or particle sensors measure air quality indicators within their operational environments. These sensors enable the collection of air quality readings which are subsequently transmitted to dedicated output systems through communication mediums such as wireless technology resulting in a comprehensive input and output air monitoring system. The integrated nature of these systems not only facilitates the continuous monitoring of air quality but also enables the real-time display of measurement results. The instantaneous nature of these systems enhances their practicality in our everyday lives considering that air quality values are subject to fluctuation due to multiple factors. By placing emphasis on real-time monitoring, it becomes feasible to develop a well-designed system that effectively addresses the diverse air quality challenges encountered in our daily routines.

2.11.7 Similar projects

Table 2.17 comparison of related project that has been researched in order to implement API monitoring system.

Table 2.17 Comparison table of previous projects

Bil	Reference	Features	Advantage	Disadvantage
1.	**Room Environment Monitoring System formPDA Terminal**	• Control by PDA terminal • RFwireless sensor module	Easily replaced	Difficult to control more than one sensor
2.	**InAir: Sharing Indoor AirQuality Measurementsand Visualization**	• Arduino • Ipod Touch	Increased awareness of reflection on air quality	Limited for indoor
3.	**Room Dust MonitoringSystem**	• Shinyei PPD 20V particle sensor • VisualBasic	Detected condition of the room	Limited area
4.	**Air Quality Monitoring and Controller that utilizes a TGS 2600 dust sensor**	• TGS2600 • PIC16F877A	Display the condition of dust concentration which is normal care and danger	Program memory is not accessible
5.	**Plantation MonitoringSystem using MultipleSensor and Arduino Uno**	• Multiplesensor • Arduino • Zigbee/ Modules	Capable to measure the value of temperature, relative humidity in the air andpercentage of moisture in the soil	Wired cable and sensor are not practical used
6.	**Rice Hust/Dust Air Particle sensor using Zigbee Wireless NetworkSensor**	• Opticaldust sensor (Sharp) • Zigbee Module	Practical Low cost	Only limited for measuring the respirable dust in a Rice Mill factory to maintain its good air quality policy PT

2.12 Sustainable development for air pollution

The pursuit of sustainable development in this project to minimize effects of pollution on both the environment and human health. This approach emphasizes the need for a comprehensive framework that considers the interplay between economic, social and environmental factors. Sustainable development endeavors to achieve long-term progress while ensuring the preservation of natural resources and the well-being of present and future generations. Based on our prototype project, here are some key aspects of sustainable development goals that we can achieve for air pollution global issues: [24]

- Environmental Impact: By accurately detecting and monitoring particulate matter in the air, the system can provide real-time data on the levels and sources of pollution. This information can be used to assess the environmental impact of various activities and make informed decisions to mitigate pollution sources.

- Health Protection: Particulate matter, particularly fine particles such as PM2.5 and PM10, has been widely recognized for its detrimental impacts on human health. By continuously monitoring PM levels, the system can help identify high-risk areas and trigger actions to protect public health. This promotes sustainable development by ensuring the well-being of individuals and communities.

- Pollution Source Identification: With precise monitoring, the system can aid in identifying specific sources of particulate matter pollution such as industrial emissions, vehicle exhaust or construction activities. This information is valuable for policy makers and urban planners to implement targeted interventions and regulations that reduce pollution from these sources, leading to sustainable development.

- Awareness and Behavioral Change: The availability of real-time data on PM levels can raise awareness among individuals and communities about the air quality in their surroundings. This can promote behavioral changes such as reducing personal exposure to pollution choosing sustainable transportation options or supporting initiatives for cleaner energy sources.

- Policy Support: The data obtained through the PM detection and monitoring system serves as valuable evidence that can inform the formulation and execution of impactful policies aimed at controlling air pollution. It can support decision-makers in formulating regulations, setting emission standards and allocating resources to address air pollution issues. This contributes to sustainable development by ensuring the implementation of evidence-based policies and measures.

- Technology Innovation: The use of Arduino and other low-cost, open-source hardware and software platforms for PM detection and monitoring promotes technological innovation and accessibility. This allows for wider adoption of monitoring systems, empowering communities and individuals to take an active role in monitoring air quality and contributing to sustainable development.

2.13 Summary

Based on the research that was conducted as part of a previous relevant project, we can state that there are numerous ways that can be used to protect human health from air pollution. The information acquired can help achieve the major objectives throughout the project's life cycle to avoid global issues. Many elements must be considered including the type of components used, the cost of those components and how they will be deployed. As a result, we can see that every project has benefits and drawbacks but as long as it benefits society, it should be implemented. Last but not least, implementing a particulate matter detection and monitoring system using Arduino aligns with sustainable development goals by providing accurate data for environmental impact assessment, protecting public health, identifying pollution sources, promoting behavioral changes, supporting policy development and fostering technological innovation.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter elucidates the research methodologies in the construction of the project and the attainment of its objectives. To ensure the sustained progress of the project, meticulous research was conducted on the utilized hardware aiming to enhance proficiency in its handling and determine the most suitable model for the project's requirements. Furthermore, acquiring a comprehensive understanding of the project's flowchart was deemed imperative. The process flow is delineated in detail, accompanied by a thorough exposition of the hardware specifications.

3.2 Project Flowchart

To optimize the efficiency of a project, the establishment of a structured workflow chart is importance. A designed plan serves as a pivotal determinant of activity success. Subsequent to the planning phase, undertaking comprehensive research becomes imperative. By implementing a well-structured project, the complexity of the endeavor can be mitigated enabling the identification and avoidance of potential issues. This exhaustive research endeavor leads to the development of a project design which is subsequently executed. Following project completion, a thorough analysis is conducted to assess its effectiveness.

3.2.1 Project Implementation Flowchart

Figure 3.1 Project Workflow

The identification of project objectives serves as the primary phase within the planning process, ensuring clarity and alignment with the desired execution goals. In this particular project, the primary objective revolves around the development of an air pollution notification system capable of collecting data from both gas sensor and PM2.5 dust sensor. To fulfill the established objectives, a comprehensive analysis and review of relevant factors are undertaken. Furthermore, the project scope is precisely defined, delineating the boundaries within which the project operates.

3.2.2 Project Development Flowchart

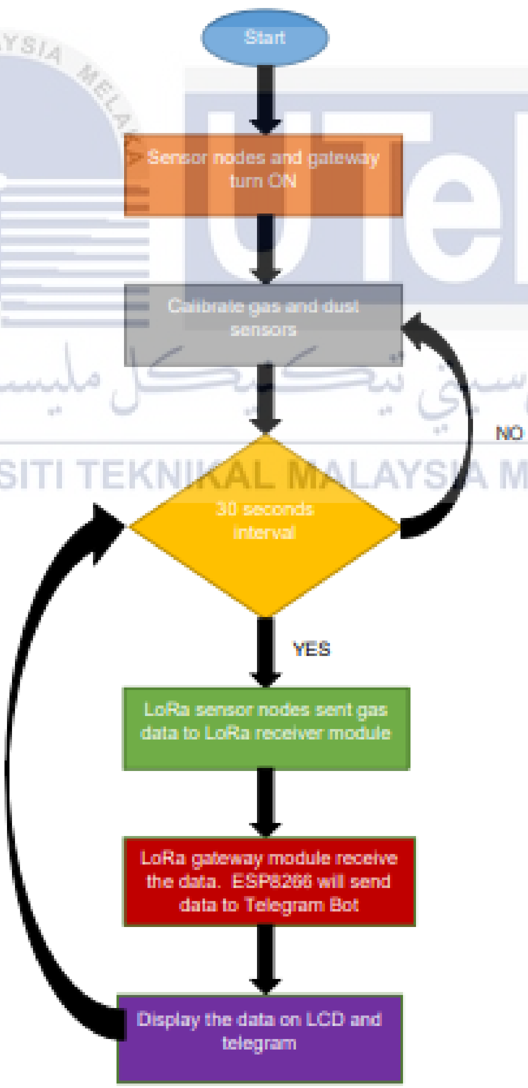


Figure 3.2 Flowchart of the Project

According to Figure 3.2, the operational flow of the developed air pollution monitoring system can be depicted through the flowchart. The system initiates by activating both the sensor nodes, serving as the transmitters and the gateway functioning as the receiver. Upon powering ON the sensor node, the calibration of the gas sensor namely the MQ-2 and GP2Y1010AU0f dust sensor takes place. Subsequently, the sensor node proceeds to continuously measure the gas concentration level and transmit the corresponding measured values in parts per million (ppm) to the gateway every 30 seconds. Upon receiving the data, the gateway processes it to extract pertinent information. The processed data, representing the gas concentration level in ppm is then exhibited on the LCD display and updated on the Telegram application. Additionally, the Telegram Bot sends a notification to the responsible individual through the Telegram application. This entire sequence of operations is reiterated until the system is powered OFF.

3.2.3 Project Block Diagram

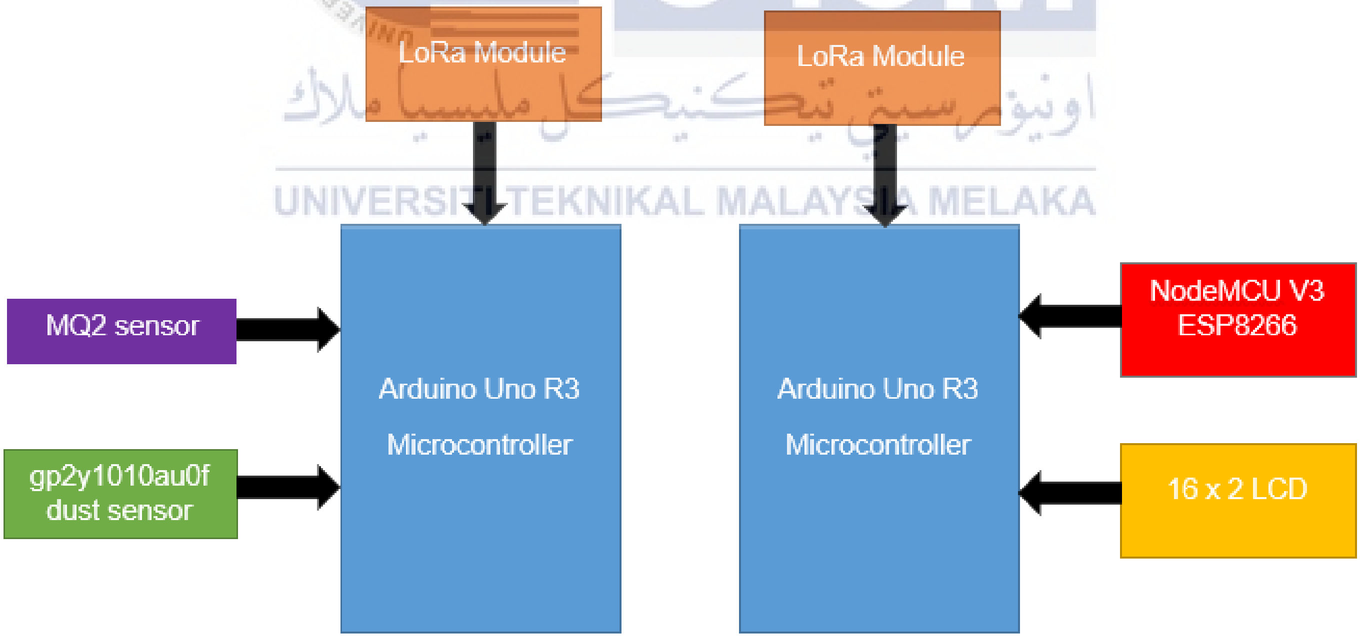


Figure 3.3 Block Diagram of the Project

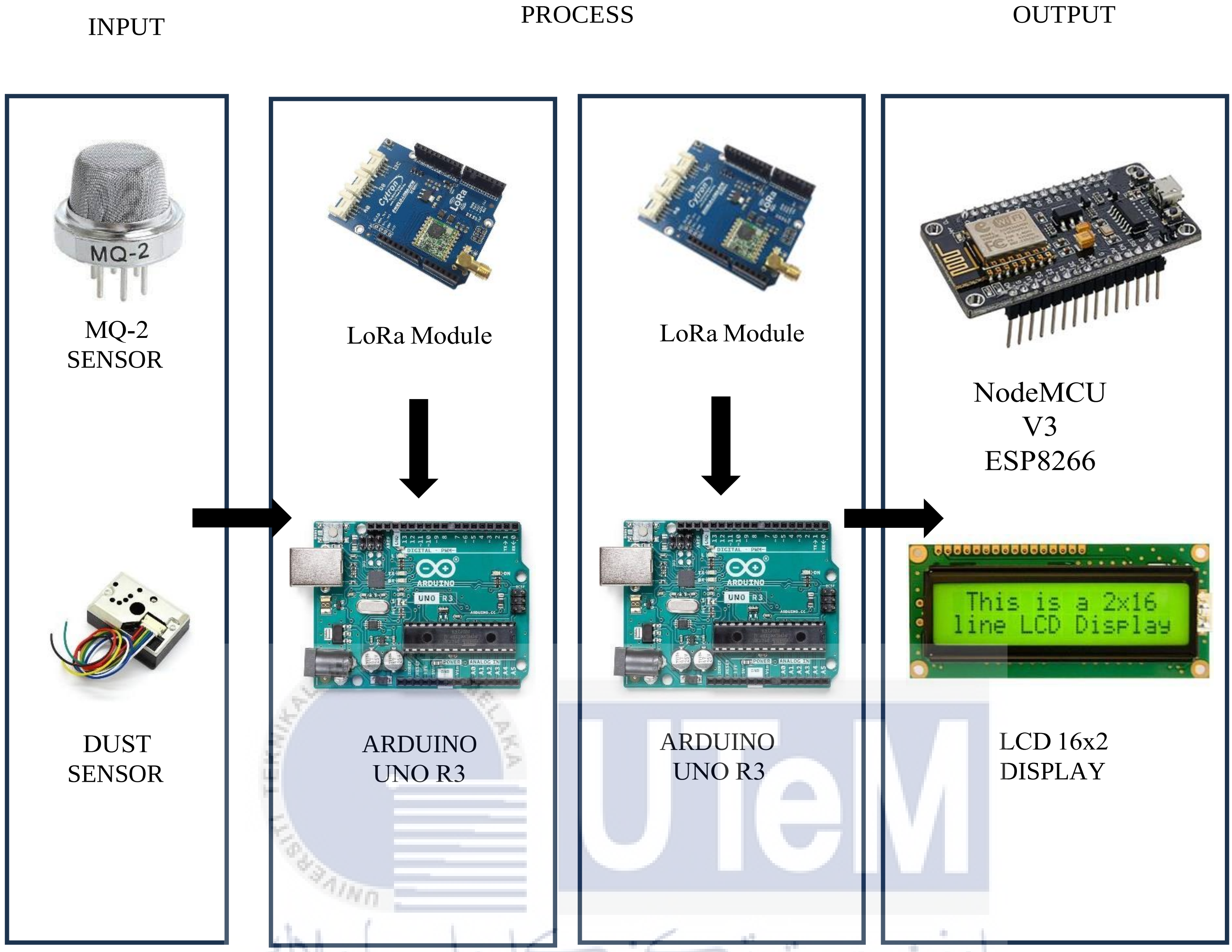


Figure 3.4 Block Diagram of the Project

Based on Figure 3.4 and 3.5, the proposed system comprises two primary components namely the transmitter and the receiver. The controller for both the transmitter and receiver is implemented using Arduino Uno R3. In this study, the transmitter corresponds to the sensor nodes situated in the monitored area. These sensor nodes are equipped with two gas sensors, namely the MQ-2 sensor and GP2Y1010AU0f dust sensor. The MQ-2 sensor enables the measurement of various gases such as Liquefied Petroleum Gas (LPG) and Carbon Monoxide (CO). On the other hand, the GP2Y1010AU0f dust sensor detects PM2.5 and counts particles. I should note that the MQ-2 sensor is capable of detecting gas concentrations ranging from 300 to 10,000 parts per million (ppm) which allows us to address the presence of Particulate Matter in polluted areas.

The receiver, on the other hand, corresponds to the gateway responsible for aggregating all the monitored data. The gateway is equipped with an LCD display and a NodeMCU V3 ESP8266. Therefore, once the gateway receives the monitored data, ESP8266 will process the data and upload the processed data to the Telegram Bot. Then, Telegram Bot will send a notification to the in-charge person. Furthermore, the processed data is uploaded to the LCD for display. As discussed earlier, the LoRa module is being consider to use in this project because the communication medium between the transmitter (sensor node) and the receiver (gateway) due to its long-range communication capabilities and low power consumption.

3.3 Hardware Specification

3.3.1 Arduino UNO R3

Figure 3.5 Arduino Uno R3

Referring Figure 3.6, this microcontroller board that is based on the ATmega328P chip microcontroller, which operates at a clock speed of 16MHz. The ATmega328P microcontroller possesses 32KB of flash memory, which is utilized for program storage, along with 2KB of SRAM and 1KB of EEPROM. The Arduino Uno R3 is specifically designed to ease of use, catering to a diverse array of projects. Its purpose involves serving as a platform for the development and execution of programs (sketches) that interact with a wide range of electronic components and sensors.

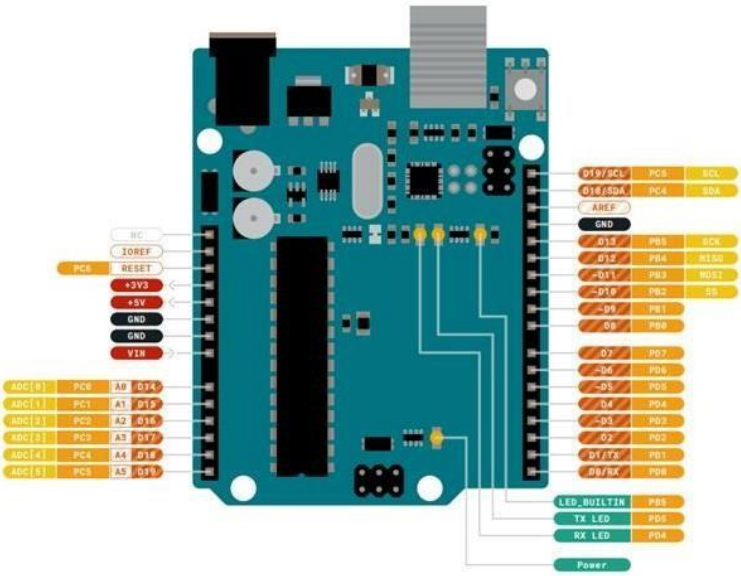


Figure 3.6 Pin-Out Configuration for Arduino Uno Rev 3

Pin	Function	Type	Description
1	NC	NC	Not connected
2	IOREF	IOREF	Reference for digital logic V - connected to 5V
3	Reset	Reset	Reset
4	+3V3	Power	+3V3 Power Rail
5	+5V	Power	+5V Power Rail
6	GND	Power	Ground
7	GND	Power	Ground
8	VIN	Power	Voltage Input
8	A0	Analog/GPIO	Analog input 0/GPIO
10	A1	Analog/GPIO	Analog input 1/GPIO
11	A2	Analog/GPIO	Analog input 2/GPIO
12	A3	Analog/GPIO	Analog input 3/GPIO
13	A4/SDA	Analog input/I2C	Analog input 4/I2C Data line
14	A5/SCL	Analog input/I2C	Analog input 5/I2C Clock line

Table 3.1 Pin-Out Configuration JANALOG description Arduino Uno Rev 3

Pin	Function	Type	Description
1	D0	Digital/GPIO	Digital pin 0/GPIO
2	D1	Digital/GPIO	Digital pin 1/GPIO
3	D2	Digital/GPIO	Digital pin 2/GPIO
4	D3	Digital/GPIO	Digital pin 3/GPIO
5	D4	Digital/GPIO	Digital pin 4/GPIO
6	D5	Digital/GPIO	Digital pin 5/GPIO
7	D6	Digital/GPIO	Digital pin 6/GPIO
8	D7	Digital/GPIO	Digital pin 7/GPIO
9	D8	Digital/GPIO	Digital pin 8/GPIO
10	D9	Digital/GPIO	Digital pin 9/GPIO
11	SS	Digital	SPI Chip Select
12	MOSI	Digital	SPI1 Main Out Secondary In
13	MISO	Digital	SPI Main In Secondary Out
14	SCK	Digital	SPI serial clock output
15	GND	Power	Ground
16	AREF	Digital	Analog reference voltage
17	A4/SD4	Digital	Analog input 4/I2C Clock line (duplicated)
18	A5/SD5	Digital	Analog input 5/I2C Clock line (duplicated)

Table 3.2 Pin-Out Configuration JDIGITAL description for Arduino Uno R3

3.3.2 LoRa Module

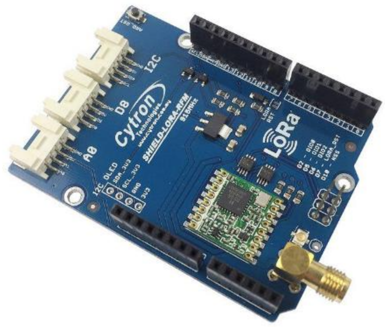


Figure 3.7 LoRa Module

The LoRa Cytron RFM Shield was developed by Cytron Technologies is purpose-built to effortlessly incorporate LoRa functionalities into Arduino-based projects. Offering a straightforward setup, this shield enables direct attachment to compatible Arduino boards, eliminating complex wiring requirements. Equipped with an RFM95 LoRa module, it grants users the capacity for extended the distance, energy efficient wireless communication, potentially accompanied by added functionalities and support from Cytron. This shield presents an optimal solution for individuals seeking uncomplicated LoRa integration within their Arduino projects.

Table 3.3 Pin configuration of LoRa Module

Pin Name	**Description**
Stackable Digital I/O header	This header pin is Digital I/O pin stacked to the Arduino main board.
Stackable Analog Input pin header	This header pin is Analog Input pin stacked to the Arduino main board.
Arduino Reset button	For user to reset the Arduino main board.
Grove Connectors	1st grove connects to A0 and A1, 2nd to D8 and D9 and 3rd for I2C pins.
SMA 90 deg Antenna Connector	It comes with Antenna 915MHz 50 Ohm.
Through Hole Antenna Connector	A single through hole for wire antenna.
U. FL SMD Antenna Connector	Connect it with pigtail and antenna.

3.3.3 MQ-2 Gas Sensor

Figure 3.8 MQ-2 Gas Sensor

As illustrated in Figure 3.8, the MQ-2 gas sensor represents a widely employed gas detection module renowned for its ability to detect and measure diverse gases within the surrounding environment. This sensor exhibits commendable sensitivity to combustible gases across a broad spectrum, rendering it an invaluable tool for detecting and monitoring levels of Liquefied Petroleum Gas (LPG), propane, methane, butane, hydrogen, alcohol, smoke and carbon monoxide gas. This sensor has many advantages such as simple drive circuit, long life and low cost. Its compact size, high sensitivity and analog output make it suitable for integration into various electronic systems and IoT applications that require gas monitoringand safety measures.

The sensor that was recommended has four input pins, and these are denoted by the letters VCC, GND, digital pin D0, and analogue pin A0 respectively. The digital pin D0 is the one responsible for sending the signal from the sensor to the microcontroller in the event that instantaneous signalling reactions are required.

Table 3.4 Pin configuration of MQ-2 Sensor

Name	Function
VCC	Connects supply voltage of 5V
Ground	Connects to ground
Digital Out	Digital pin to get digital output
Analog Out	Analog pin to get analog output

3.3.4 GP2Y1010AU0F Dust Sensor

Figure 3.9 GP2Y1010AU0F Dust Sensor

Based on Figure 3.9, the GP2Y1010AU0F sensor commonly referred as a dust sensor is a compact and cost-effective module specifically designed for the detection and measurement of airborne dust particles. This sensor is capable of measuring the concentration of particles in the air with diameters ranging from 0.5 µm to 2.5 µm, specifically categorized as PM2.5 particles. The GP2Y1010AU0F sensor generates ananalog output voltage that is directly proportional to the dust concentration in the surrounding environment. This analog voltage can be acquired by employing an analog-to- digital converter (ADC) or a microcontroller equipped with an integrated ADC. Through calibration of the sensor response, the analog output can be utilized to estimate the concentration of dust particles. The GP2Y1010AU0F dust sensor offers a solution for the detection and measurement of airborne dust particles across diverse applications. Its compactform factor, ease of integration and provision of analog output render it highly suitable for integration into air quality monitoring systems necessitating real-time monitoring of dust concentrations.

Table 3.5 Pin configuration of GP2Y1010AU0F Dust Sensor

S. NO.	Pin Name	Pin Description
1	V-LED	LED VCC Pin. Connect to 5V through 150Ω Resistor
2	LED-GND	LED Ground Pin. Connect to GND
3	LED	Used to Toggle LED On/Off. Connect to any digital pin of Arduino
4	S-GND	Sensor Ground Pin. Connect to GND of Arduino
5	VOUT	Sensor Analog Output Pin. Connect to any Analog Pin
6	VCC	Positive Supply Pin. Connect to 5V of Arduino

3.3.5 16x2 LCD Display

Figure 3.10 16x2 LCD Display

In Figure 3.10, the 16x2 LCD (Liquid Crystal Display) is a popular display module that consists of 16 columns and 2 rows, capable of displaying alphanumeric characters. It is commonly used in various electronic devices and microcontroller projects. The main function of a 16x2 LCD display is to provide a visual output by displaying text, numbers, and symbols. It can display a total of 32 characters (16 in each row) at a time. It commonly interfaced with microcontrollers or other devices using a parallel interface. It requires multiple data lines for sending commands and data, along with control lines for enabling and signaling data transfer. The LCD display typically operates at a supply voltage of 5V, although there are also versions available that support 3.3V. The 16x2 LCD display offers a simple and cost-effective solution for adding visual output capabilities to electronic projects. Its compact size, ease of interfacing, and availability of software libraries make it widely adopted in the maker and electronics communities.

Table 3.6 Pin Configuration for 16x2 LCD Display

Pin No.	Pin Name	Pin Description	Pin Connection
1	Ground	This is a ground pin of LCD	Connected to the ground of the power source
2	VCC	This is the supply voltage pin of LCD	Connected to the supply pin of Power source
3	V0/VEE	Adjusts the contrast of the LCD.	Connected to a variable POT that can source 0-5V
4	Register Select	Toggles between Command/Data Register	Connected to a MCU pin and gets either 0 or 1. 0 -> Command Mode 1-> Data Mode
5	Read/Write	Toggles the LCD between Read/Write Operation	Connected to a MCU pin and gets either 0 or 1. 0 -> Write Operation 1-> Read Operation
6	Enable	Must be held high to perform Read/Write Operation	Connected to MCU and always held high
7-14	Data Bits (0-7)	Pins used to send Command or data to the LCD.	In 4-Wire Mode 4 pins (0-3) are connected to MCU In 8-Wire Mode All 8 pins (0-7) are connected to MCU
15	LED Positive	Normal LED like operation to illuminate the LCD	Connected to +5V
16	LED Negative	Normal LED like operation to illuminate the LCD connected with GND.	Connected to ground

3.3.6 NodeMCU V3 ESP8266

Figure 3.11 NodeMCU V3 ESP8266

Figure 3.11 showcases the The ESP8266 is a WiFi module featuring an integrated IP/TCP protocol stack and a standalone chip (SOC). This device grants access to any microcontroller via WiFi connectivity, capable of managing various programs or handling all WiFi networking tasks. Renowned for its robustness, it can withstand rigorous industrial conditions. This microcontroller possesses significant built-in processing power and storage capacity, making it suitable for sensor integration and various application uses.

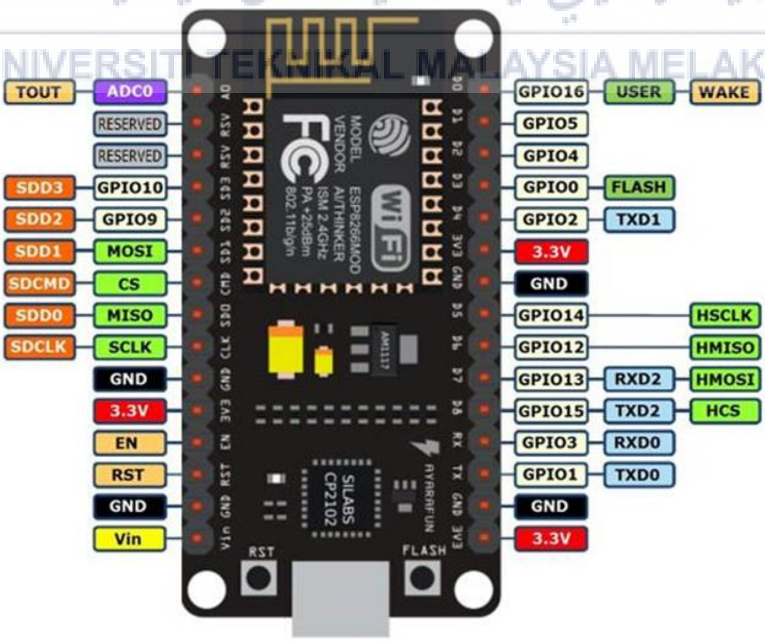


Figure 3.12 Pin-Out Configuration for NodeMCU V3 ESP8266

Pin Category	Name	Description
Power	Micro-USB, 3.3V, GND, Vin	**Micro-USB:** NodeMCU can be powered through the USB port **3.3V:** Regulated 3.3V can be supplied to this pin to power the board **GND:** Ground pins **Vin:** External Power Supply
Control Pins	**EN, RST**	The pin and the button resets the microcontroller
Analog Pin	A0	Used to measure analog voltage in the range of 0-3.3V
GPIO Pins	GPIO1 to GPIO16	NodeMCU has 16 general purpose input-output pins on its board
SPI Pins	SD1, CMD, SD0, CLK	NodeMCU has four pins available for SPI communication.
UART Pins	TXD0, RXD0, TXD2, RXD2	NodeMCU has two UART interfaces, UART0 (RXD0 & TXD0) and UART1 (RXD1 & TXD1). UART1 is used to upload the firmware/program.
I2C Pins		NodeMCU has I2C functionality support but due to the internal functionality of these pins, you have to find which pin is I2C.

Table 3.7 Pin configuration of NodeMCU V3 ESP8266

3.4 Software Specification

3.4.1 Arduino IDE

Figure 3.13 Arduino IDE Startup

Figure 3.10 showcases the Arduino Integrated Development Environment (IDE) which is a software application developed using the Java programming language. This IDE provides a platform for users to create and upload programs to the Arduino board, thereby facilitating control over various mechanical and electrical devices. The Arduino IDE specifically supports programming languages such as C and C++ and adheres to its own code structure conventions. Additionally, it incorporates a software library derived from the wiring project encompassing a diverse range of input and output functions commonly employed in programming activities.

3.4.2 Telegram

Figure 3.14 Telegram Application Icon

Telegram is a cloud-based instant messaging application that provides users with a wide array of communication functionalities including text messaging, voice and video calls, as well as the ability to share various media files such as photos, videos and documents. Telegram has garnered significant recognition due to its emphasis on security, privacy and comprehensive feature set. Its robust security measures and privacy-focused approach have contributed to its growing popularity among users seeking secure and reliable messaging services. Telegram is available on various platforms, including mobile devices (iOS and Android), desktop (Windows, macOS, and Linux) and through web browsers. It offers synchronization across devices, allowing users to access their chats and files from multiple devices seamlessly. Telegram required OS android 6.0 above to install.

In addition to its messaging features, Telegram provides a platform for developers to create bots and integrate them into chats. These bots can perform various tasks such as providing news updates, weather forecasts, language translation, games and more. We will use this bot as a monitored to air pollution at certain place by given notification to the person in charge.

CHAPTER 4

RESULT AND ANALYSIS

4.1 Introduction

Result refers to the outcome or findings obtained from a particular experiment, study or investigation. It is the factual information or data that is collected and observed during the research process. Results are typically presented in a raw or organized form such as measurements, observations, statistics or measurements.

On the other hand, analysis involves the interpretation and evaluation of the collected data to draw meaningful conclusions and derive insights. It involves examining the results, identifying patterns, relationships and trends and making connections to the research objectives or hypotheses. Analysis often involves statistical techniques, data visualization, and qualitative or quantitative methods to extract meaningful information from the raw data.

This chapter describes the development of a Particulate Matter Detection and Monitoring System in Air Pollution by using Arduino. It covers the outcomes of simulation tests conducted before data collection, operational scenarios and data analysis. The simulation test and hardware's wiring test had been findings from these assessments and evaluations act as benchmarks to determine the achievement of the project's goals. The test results of these reviews and evaluations serve as references for our project development.

4.2 Project Schematic Diagram

Figure 4.1 Arduino Uno R3 and LoRa Cytron RFM Shield Pin Layout

The LoRa Cytron RFM Shield is typically designed to work with Arduino Uno R3 boards. It has a pin layout compatible with the Arduino Uno in terms of its physical dimensions and connectivity. The LoRa module is specifically designed to be placed on top of an Arduino Uno, aligning with the standard pin layout to ensure compatibility. However, it is important to note that the pin assignments and functionalities for communication and control might not be entirely the same as the default pins on an Arduino Uno. Usually, it come with documentation specifying which pins are utilized for various purposes like communication for SPI and I2C.

It is strongly advised to consult the datasheet or provided documentation by Cytron for the RFM Shield. This ensures accurate pin connections and proper usage when integrating it with an Arduino Uno R3. Doing so will prevent conflicts or incorrect connections that could potentially harm the components or lead to improper functioning.

LoRa Cytron RFM Shield	Arduino Uno	Explanation
D13	D13	Serial Clock (SCK)
D12	D12	Master Out Slave In (MOSI)
D11	D11	Master In Slave Out (MISO)
D10	D10	Chip Select (CS)

Table 4.1 Pin Configuration between Arduino Uno R3 and Lora RFM Shield

In communication between an Arduino Uno R3 and a LoRa Cytron RFM Shield, the Serial Clock (SCK) pin assumes the crucial role of providing the clock signal, which synchronizes the data exchange between the devices. The Master Out Slave In (MOSI) pin assist the transmission of data from the microcontroller to the LoRa module. Conversely, the Master In Slave Out (MISO) pin enables the transfer of data from the LoRa module back to the microcontroller. Additionally, the Chip Select (CS) pin allows the microcontroller to choose and communicate specifically with the LoRa module among several connected devices, enabling seamless and controlled data transmission between the two entities. These pins, forming the Serial Peripheral Interface (SPI) communication protocol, facilitate efficient and reliable communication essential for exchanging data and instructions between the Arduino and the LoRa module.

4.2.1 Transmitter Schematic Diagram

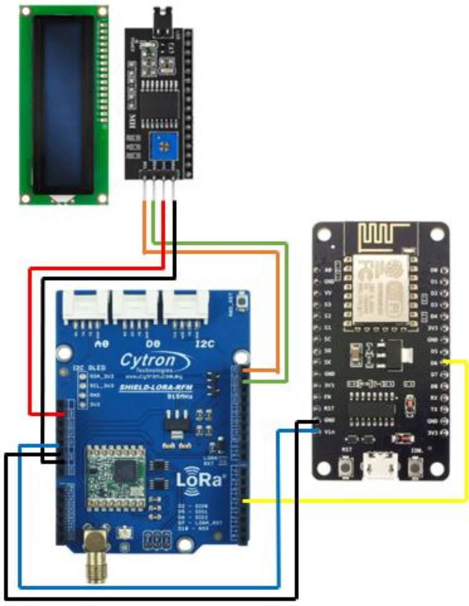


Figure 4.2 Wiring Schematic Diagram for Transmitter

LoRa Cytron RFM Shield	Arduino Uno	LCD 16x2	Wire colour
SCL	I2C (CLOCK)	SCL	Orange
SDA	I2C (DATA)	SDA	Green
IOREF	IOREF	Vcc	Red
GND	GND	GND	Black

Table 4.2 Pin Cnnection between LoRa Cytron, Arduino Uno and LCD 16x2

According to Table 4.2, the SCL pin serve as a Serial Clock Pin (SCL) on the Arduino Controller board generating regular pulses at predefined intervals. SCL for Arduino Uno R3 is used to synchronize data transmission between the Arduino (master) and connected Inter-Integrated Circuit (I2C) devices (slaves). While SCL pin in LoRa module typically refer as Serial Clock (SCK) serve as providing the clock signal for synchronous data transfer between the microcontroller and the LoRa module. SCK in LoRa module, primarily use SPI (Serial Peripheral Interface) for communication.

Next, the SDA pin serves as a dedicated serial data pin (SDA) responsible for the transmission of data between two devices. Furthermore, the Input/Output Reference Voltage (IOREF) pin for LoRa module work by adapt to different voltage levels used by various Arduino boards. By using, Arduino Uno R3 IOREF pin, it can provide the reference voltage for shields or external devices that might need to adapt to the operating voltage of the Arduino. In this connection, if the Arduino Uno is powered with 5V, the IOREF pin would also output 5V. The Vcc pin on the LCD module, providing a stable 5V DC power supply for its operation. Lastly, the ground pin plays a crucial role in the Arduino board and LoRa module enabling voltage measurement and adjustment. Ground is use for LCD module to limit the voltage imposed by lightning events.

LoRa Cytron RFM Shield	**Arduino Uno**	**NodeMCU V3 ESP8266**	**Wire colour**
D4	D4	D6	Yellow
5V	5V	Vin	Blue
GND	GND	G	Black

Table 4.3 Pin Connection between LoRa Cytron, Arduino Uno and ESP8266

According to Table 4.3, in the context of Arduino programming, pin D4 typically refers to a digital pin with the number 4 on an Arduino board. This notation is use to specify the physical pin on the microcontroller that you want to interact with. In this project, pin D4 from Arduino Uno and LoRa RFM Shield connect to pin D6 NodeMCU V3 ESP8266. Next, 5V pin from Arduino Uno is connected to the supply voltage Vin of ESP8266. The 5V pin on the Arduino Uno functions as a regulated power output, delivering a steady 5-volt supply. It serves as a convenient source for powering external components like ESP8266. This pin is directly linked to the internal voltage regulator of the Arduino Uno, ensuring a consistent and regulated voltage output. Lastly The G (Ground) pin on the ESP8266 serves as the common ground reference for the microcontroller.

4.2.2 Receiver Schematic Diagram

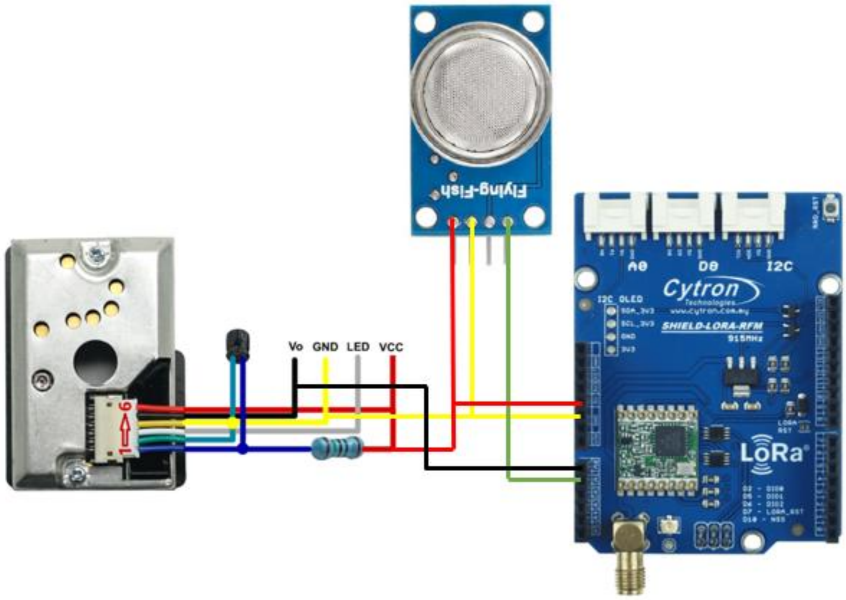


Figure 4.3 Wiring Schematic Diagram for Receiver

LoRa Cytron RFM Shield	Arduino Uno	MQ-2 Gas Sensor	Wire colour
A1	A1	A0	Green
5V	5V	Vcc	G
GND	GND	GND	Yellow

Table 4.4 Pin Connection between LoRa Cytron, Arduino Uno and MQ-2

Based on table 4.3, in the context of Arduino programming, pin A1 typically refers to an analog pin with the number 1 on an Arduino board. This notation is use to specify the physical pin on the microcontroller that you want to interact with. In this project, pin A1 from Arduino Uno and LoRa RFM Shield connect to pin A0 MQ-2 gas senor. Next, 5V pin from Arduino Uno is connected to the supply voltage Vin of MQ-2 gas sensor. The 5V pin on the Arduino Uno functions as a regulated power output, delivering a steady 5-volt supply. It serves as a convenient source for powering external components like MQ-2. Lastly, GND pin from Arduino Uno, LoRa Cytron and MQ-2 together. GND pin serve as the common ground. Ground pin is important for safety features.

LoRa Cytron RFM Shield	Arduino Uno	GP2Y1010AU0F	Wire colour
5V	5V	Wire 1	Blue
5V	5V	Wire 2	Green
D3	D3	Wire 3	White
GND	GND	Wire 4	Yellow
A0	A0	Wire 5	Black
5V	5V	Wire 6	Red

Table 4.5 Pin Connection between Shield, Arduino Uno and GP2Y1010AU0F

Based on table 4.5, GP2Y1010AU0F dust sensor have its own plug and play wire that can be use to connect to microcontroller board. In this project, GP2Y1010AU0F dust sensor connect to Arduino Uno R3 and Lora Cytron RFM Shield. Dust sensor blue wire connect to resistor 150Ω and positive lead (anode) capacitor 220µF while green wire connected to negative lead (Cathode) capacitor 220µF. Next, connect both wire that go to capacitor to 5V pin from Arduino Uno. Dust sensor white wire connect to digital pin 3 (D3) Arduino Uno. Furthermore, connect dust sensor yellow wire to ground pin (GND) that connect Arduino Uno, LoRa module and MQ-2 sensor. Ground pin is important to power and ground the IC chip and provide a means for the IC to interface with the rest of the electronic circuit. It is also important to create emergency path to protect me and this project devices from electrical shock. Moreover, connect analog pin 0 (A0) with black wire from dust sensor. Analog pin 0 is use to examine the voltage levels present on a pin as an analog pin. After that, the voltage value will convert analog input into digital form. Lastly, connect dust sensor red wire with resistor 150Ω and 5v pin that connect Arduino Uno, LoRa module and MQ-2 sensor. The 5V pin on the Arduino Uno will supply 5-volt as power output for other components.

4.3 Software Development

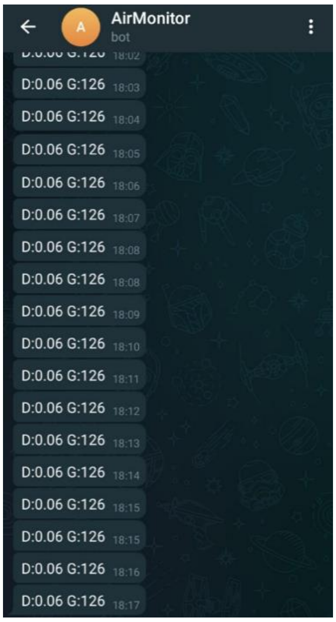


Figure 4.4 Telegram Interface

Figure 4.4 shows the project Telegram Bot message on Mobile Application using Telegram. The Telegram is a cloud-based instant messaging app that focuses on speed and security. Telegram offers users the capability to transmit messages, images, videos and various files, along with the option to establish groups and channels for communication purposes. Recognized for its emphasis on privacy and security, Telegram implements features like end-to-end encryption for confidential conversations. Its widespread appeal can be attributed to its rapid functionality, adaptability and distinctive features that set it apart from other messaging applications. In this project, Telegram Bot is utilised to display values obtained from the input sensors and notify users when it becomes clear that it is air pollution. Telegram can communicate with what we programmed in Arduino IDE by using an authentication token that is suited only for one device. Once the Telegram is connected, the value from sensors is collected and immediately displayed to Telegram application. In addition to displaying the value of sensors that are being utilized for this project, this Telegram interface is equipped with two values for dust and gas sensor.

Telegram Bot Messages	Function
	Display dust density to user for monitor. The unit for dust density is Microgram per Cubic Meter µg/m3
	Display gas to user for monitor. The unit for gas is Parts-Per-Million (PPM)

Table 4.6 Telegram Bot Messages on Telegram Application

Table 4.6 shows the list of Telegram messages used in developing the software part of this project. Each of the messages used have their own functions in making this project a success. The result in Telegram Bot messages show the same value with the value that appear in LCD screen. D in Telegram Bot messages and at LCD screen stand for dust density while G in Telegram Bot messages and at LCD screen stand for gas.

4.4 Hardware Development

4.4.1 Transmitter Hardware Configuration

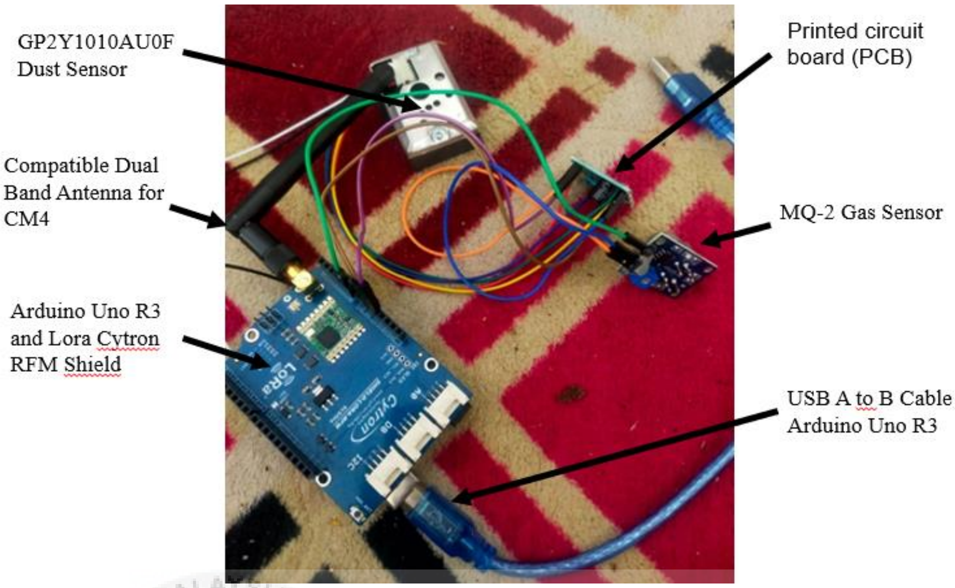


Figure 4.5 Hardware Configuration of the Project Transmitter

Figure 4.5 shows the hardware configuration of the project transmitter that are soldered onto a Printed circuit board (PCB). On this board, the wire of GP2Y1010AU0F dust sensors and MQ-2 Gas sensor are made longer, so that these two sensors can be placed outside of the enclosure box to read inputs and transmit output respectively. The size of circuit is sized down in order to fit into the enclosure box 4x6x3 in the final design of the prototype.

4.4.2 Receiver Hardware Configuration

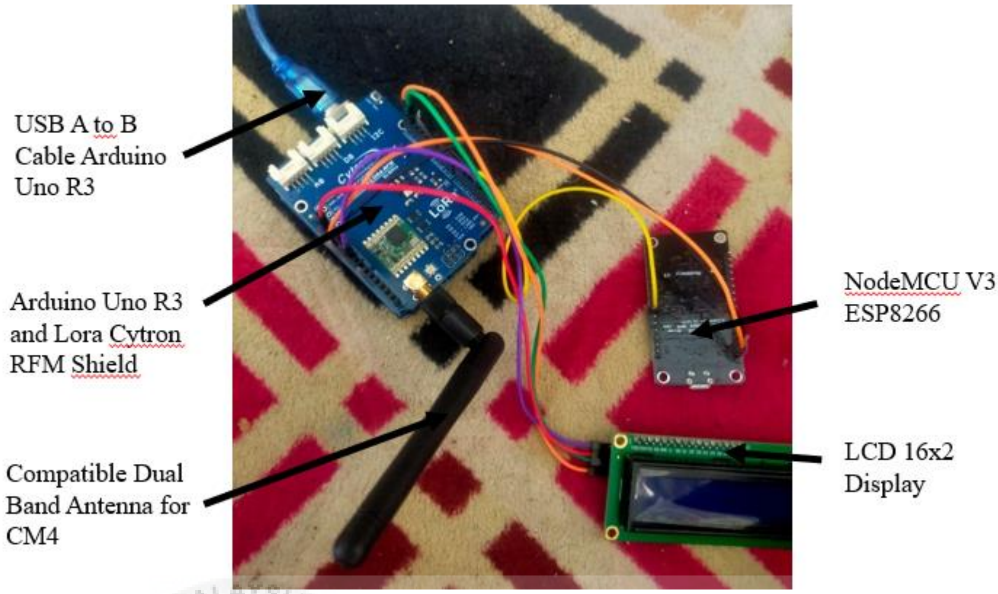


Figure 4.6 Hardware Configuration of the Project Receiver

Figure 4.6 shows the hardware configuration of the project receiver that connect four different devices. In this connection, wires of ESP8266 are made shorter to put in enclosure box because its operation only for provide Wi-Fi, while LCD 16x2 are made longer, so that these LCD screen can be placed outside of the enclosure box to display the dust and gas sensor data that being receive from this project receiver. The size of circuit is sized down in order to fit into the enclosure box 4x6x3 in the final design of the prototype.

4.5 Prototype Development

4.5.1 Transmitter Prototype

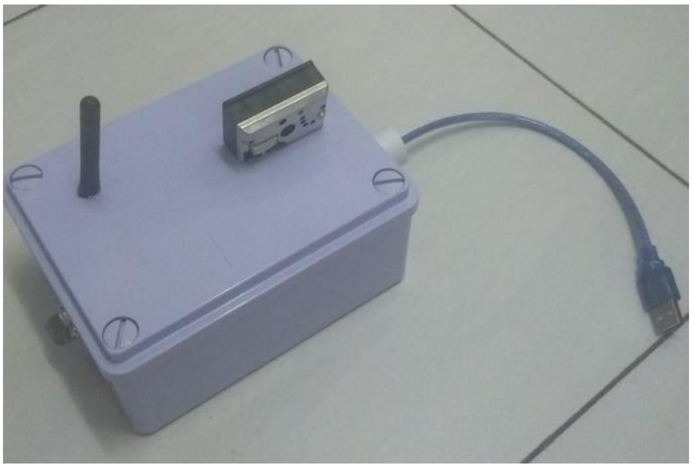


Figure 4.7 Prototype for Project Transmitter

The prototype for project transmitter in Figure 4.5 was made by enclosure box 4x6x3 inches. An enclosure box also known as junction box, work as a protective casing designed to contain and safeguard sensitive electronic components, devices or systems from environmental hazards. Enclosure boxes provide physical protection against external elements such as dust and accidental contact. This is suitable for prototype for project transmitter that use dust for testing to maintaining the longevity of electronic components and preventing damage from environmental factors.

For this transmitter prototype, I make four holes at the box. One, for MQ2 sensor to sense gas. Its head must be put at the outside to sense gas Next, for dust sensor cable to go out so that it can connect to GP2Y1010AU0F sensor. This sensor must put standing so that dust can enter and exit the sensor. If the sensor is lay down, it cannot show the correct result for dust density. This sensor also required cleaning to avoid errors in final data. Furthermore, LoRa Cytron RFM Shield antenna need to get outside of enclosure box just like antenna for car’s radio to avoid signal loss. Lastly, the fourth hole are uses for USB A to B Cable Arduino Uno R3 to get through. This cable can be connected with powerbank for power supply.

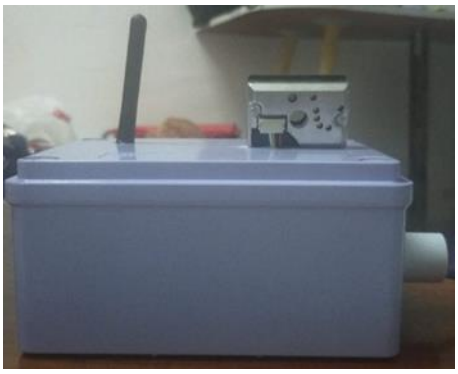
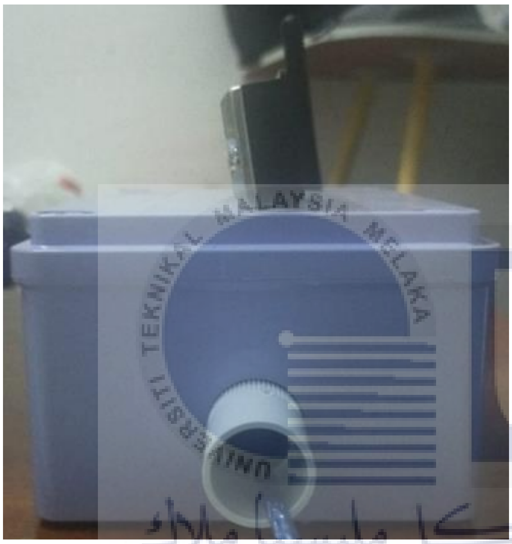
 Top view	 Front view
 Right view	 Left view

Table 4.7 Different Views of Transmitter Prototype

Table 4.7 presents the view from different sides on the transmitter prototype. It is important to highlighting the optimal placement of the microcontroller and the sensors to ensure that the device performs precisely as intended by the software.

4.5.2 Receiver Prototype

Figure 4.8 Prototype for Project Receiver

The prototype for project receiver in Figure 4.8 was made by enclosure box. Enclosure boxes can be designed for portable or mobile applications providing a protective housing for electronics while being transported or used in different locations. Size for enclosure box use in this prototype is 4x6x3 inches. It has smaller size compare to other enclosure boxes. When using a small enclosure box for this prototype, its suit really well because this project can be put in many different places or can be transported from one place to another. Apart from functionality, enclosure boxes contribute to the overall appearance of a project, providing a professional and finished look. They can be designed to match the aesthetic preferences of the project or its environment.

For this receiver prototype, I make two holes at the box. One for LoRa Cytron RFM Shield antenna while another one for USB A to B Cable Arduino Uno R3. Antenna need to get outside the enclosure box to make the signal strong. USB A to B Cable Arduino Uno R3 need to get through hole so that it can connect Arduino Uno R3 with powerbank for power supply.

 Top view	 Front view
 Right view	 Left view

Table 4.8 Different Views of Receive Prototype

Table 4.7 presents the view from different sides on the receiver prototype. It is important to focus on the LCD 16x2 display screen placement so that people who are not used to telegram or people who are not using smartphone can receive the same information about dust and gas through this screen.

4.6 Project Integration

4.6.1 Connection of NodeMCU V3 ESP8266

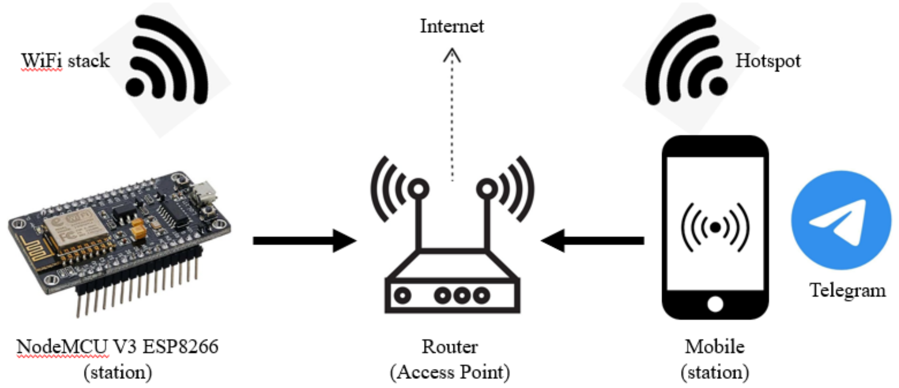


Figure 4.9 Block Diagram of Internet Connection with NodeMCU ESP8266

Block diagram in Figure 4.7 shows how NodeMCU ESP8266 is connected to the internet to communicate with the Telegram Application in the user's mobile. NodeMCU ESP8266 as the microcontroller will read all the data from input sensors after been transmitted by LoRa Cytron RFM Shield then send it to the user via Internet of Things (IoT).

4.6.2 Login Telegram

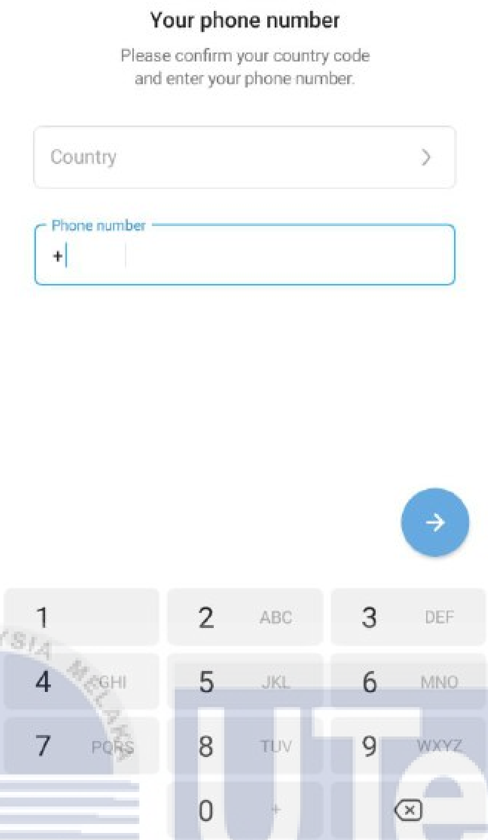


Figure 4.10 Login Page on Telegram Application

First of all, user must have their own Telegram account to use this project. User will then have to log into their Telegram account with their mobile phone number for security purposes as shown in Figure 4.10. User can get access to their account using multiple devices so they can still monitor air pollution even with a different mobile phone.

4.6.3 Create Telegram Bot

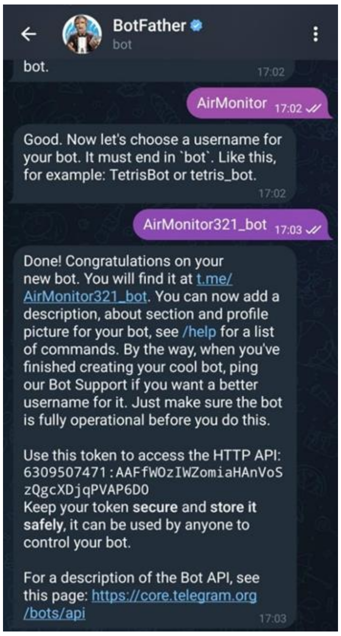


Figure 4.11 Create Telegram Bot

BotFather is a bot created by Telegram that allows you to create and manage your own bots. To connect to BotFather, user need to search for "@BotFather" in the Telegram app and click on the result to start a conversation. Start the conversation with BotFather by sending “/start” to make BotFather response. In the conversation with BotFather, user need to select the "New Bot" option to start creating user new bot. BotFather will guide you through the rest of the process. Finally, BotFather will ask user to provide a name for my bot. It will be more suitable to choose a name that accurately reflects the purpose of my bot and is easy to remember. BotFather will also ask user to choose a username for new bot. This username will be used to create a unique URL that people can use to access this bot. People also can enter this bot by using QR code. It is preferable to create a username that is easy to remember and related to the bot's purpose so other people who might need this monitor can enter this bot and help them to avoid air pollution.

4.6.4 Telegram Bot Notifications with Dust Sensor

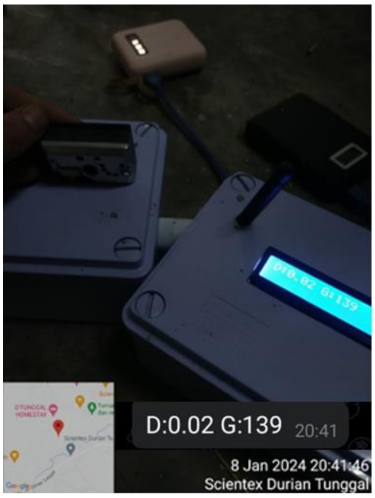


Figure 4.12 LCD screen and Telegram notification when dust no detected

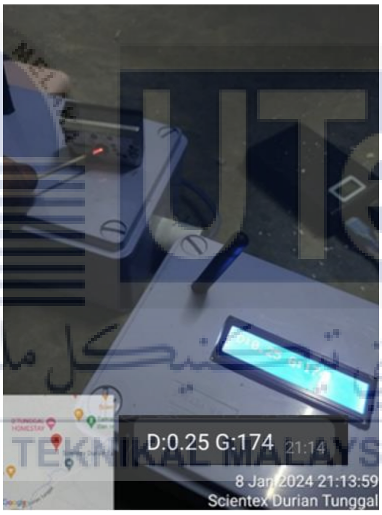


Figure 4.13 LCD screen and Telegram notification when dust is detected

Figure 4.12 and Figure 4.13 shows the demonstration of how the dust sensor works with LCD screen and Telegram bot. Smoke from matchstick flow through GP2y1010AU0F dust sensor to supply pm2.5 dust particles. When the dust sensor detects dust particles from smoke, the dust values will increase. Telegram bot messages notification show the same value with the value that appear in LCD screen. Note that, D in Telegram bot message and at LCD screen stand for dust density.

4.6.5 Telegram Bot Notifications with Gas Sensor

Figure 4.14 LCD screen and Telegram notification when gas no detected

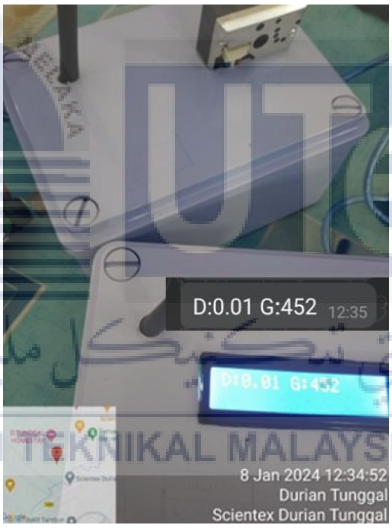


Figure 4.15 LCD screen and Telegram notification when gas is detected

Figure 4.14 and Figure 4.15 shows the demonstration of how the MQ-2 gas sensor works with LCD screen and Telegram Bot. Gas from lighter work as gas supplier. When the gas sensor detects gas from lighter, the gas values will increase. Telegram Bot messages notification show the same value with the value that appear in LCD screen. G in Telegram Bot message and at LCD screen stand for gas.

4.7 Data Analysis

4.7.1 CO and PM2.5 Analysis at Scientex Durian Tunggal

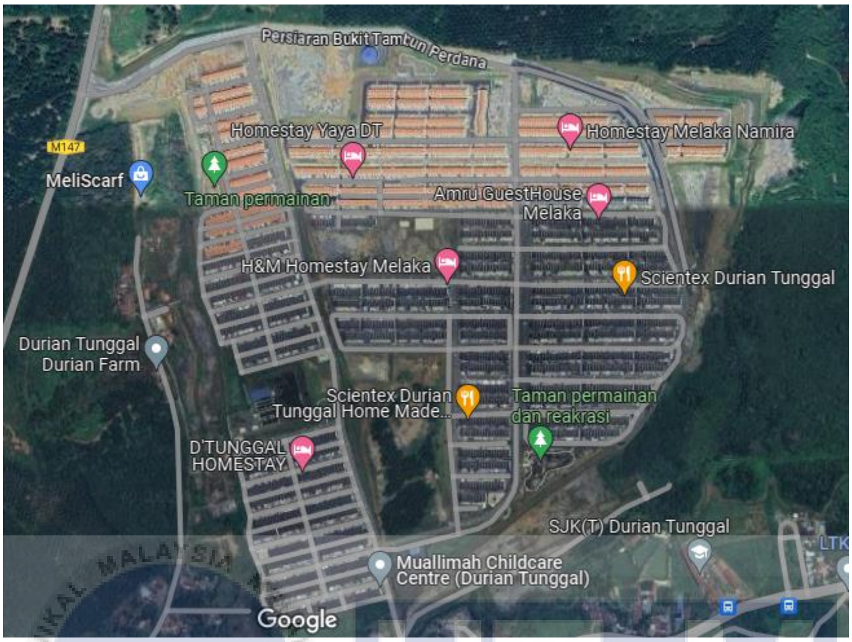


Figure 4.16 API Monitoring Location

The integrated prototype has been used to monitor the air quality at Taman Scientex, Durian Tunggal, Melaka, Malaysia for 3 days straight from 6 January 2024 to 8 January 2024. The data acquired plotted to 3 different bar graphs by days representing the measurement for Carbon Monoxide while 1 line graph for PM2.5.

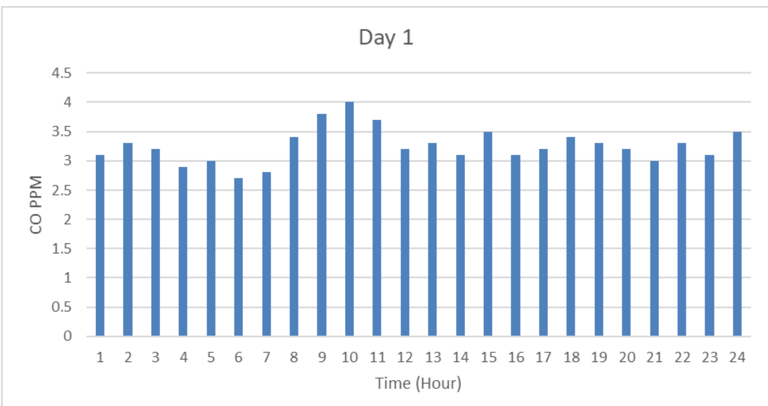


Figure 4.17 CO Concentration Versus Day 1

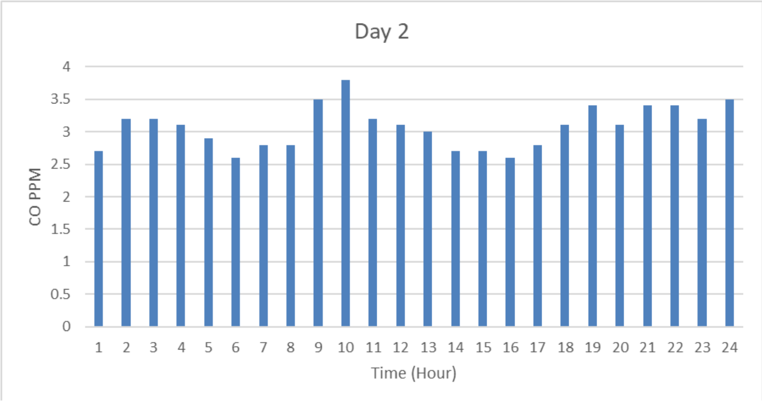


Figure 4.18 CO Concentration Versus Day 2

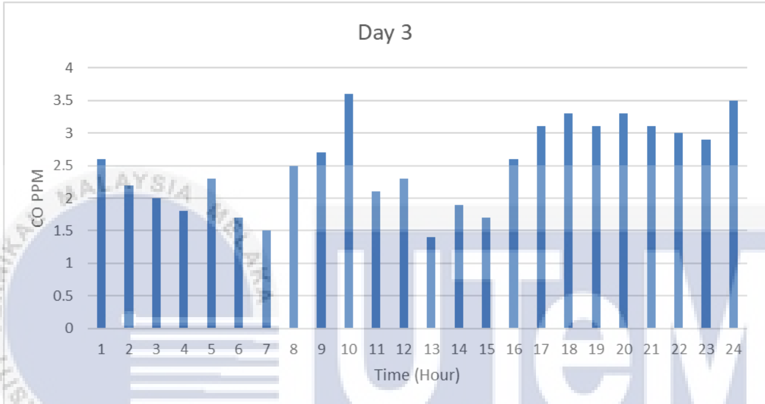


Figure 4.19 CO Concentration Versus Day 3

Figures 4.17 to 4.19 display a 3 days record of CO concentrations. Each 3 days illustrates the mean CO concentration for each hour. The figures present consistent trends, indicating stability in sensor performance. The overall pattern reveals a decrease from 0100 to 0600 hours, followed by an increase until the peak at 1000 hours likely influenced by peak working hours. A significant decrease is observed from 1100 to 1500 hours possibly due to human activities decrease. We can see the values increase from 1500 to 1800 hours, followed by increase and decrease from 1800 to 0000 hours. Among the results obtained over the 3 days period, the data from the day 3 stands out due to slight changes in CO concentration levels. The divergent of CO concentration levels observed influenced by the weather conditions, human activities, wind directions and its sources.

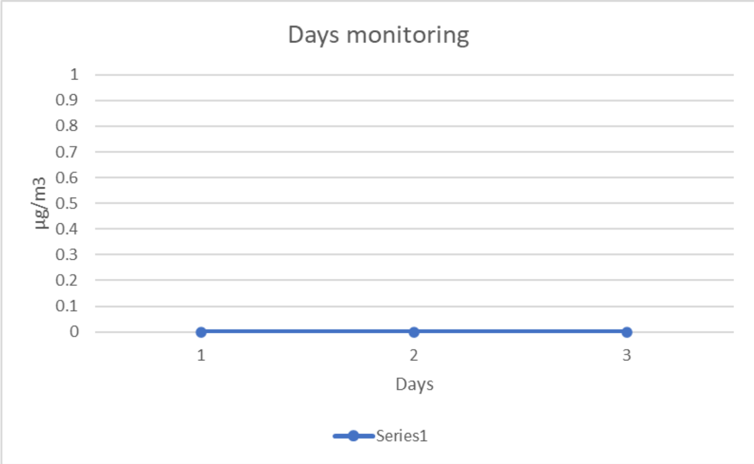


Figure 4.20 PM2.5 Dust Particles in 3 Days

Figure 4.20 displays the PM2.5 monitoring data over a span of 3 days at Taman Scientex, Durian Tunggal, Melaka. Across 3 days, the results indicate an absence of measurable PM levels just like in Figure 4.21 below. This is attributed to the monitoring location having minimal industrial activities. Additionally, the sensor exhibits lower sensitivity and necessitates a considerable change in the environment to enhance its detection capabilities.

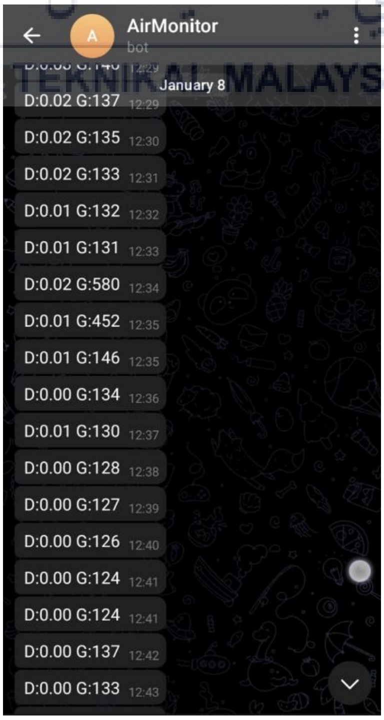


Figure 4.21 Telegram Bot Messages on 8 January 2024

4.7.2 Smoke From Burning Effect Towards PM2.5 Detection

Figure 4.22 Testing Burning Effect Towards Prototype

As PM2.5 detection was absent in the 3 days monitoring, an investigation was conducted to assess the PM2.5 sensor's responsiveness to dust particles from burning effects. To test this, a paper was burned and the GP2Y1010AU0F PM2.5 dust sensor was exposed to the resulting smoke. Fan is also use in this testing to let the smoke flow through hole so that photodiode can detect the dust. In Table 4.9, the sensor initiate detection and reacted to the presence of smoke within 9 minutes. Next, the fan was positioned approximately 1 meter away from the sensor, leading to data drastic decrease at 21.56.00 to 21.58.00, influenced by the changing smoke direction due to wind. Between 63 and 84 seconds, as the distance increased, the data decreased. When the burning paper was brought close to the dust sensor's hole, the detection results increase significantly were obtained at 22.08.00 to 21.00.00. In conclusion, the PM2.5 sensor is functional but requires direct triggering or a high level of exposure for stable detection. The result can see clearly from Table 4.9 and Figure 4.23 below.

Time	Componet Detection	Component Value
20:56:00	PM2.5 (µg/m3)	0.00
	Smoke (PPM)	126
20.57.00	PM2.5 (µg/m3)	0.13
	Smoke (PPM)	140
20.58.00	PM2.5 (µg/m3)	0.12
	Smoke (PPM)	138
20.59.00	PM2.5 (µg/m3)	0.12
	Smoke (PPM)	135
21.00.00	PM2.5 (µg/m3)	0.12
	Smoke (PPM)	128
21:01:00	PM2.5 (µg/m3)	0.12
	Smoke (PPM)	128
21.02.00	PM2.5 (µg/m3)	0.12
	Smoke (PPM)	128
21.03.00	PM2.5 (µg/m3)	0.11
	Smoke (PPM)	123
21.04.00	PM2.5 (µg/m3)	0.12
	Smoke (PPM)	121
21:05:00	PM2.5 (µg/m3)	0.11
	Smoke (PPM)	124
21.06.00	PM2.5 (µg/m3)	0.07
	Smoke (PPM)	126
21.07.00	PM2.5 (µg/m3)	0.07
	Smoke (PPM)	230
21:08:00	PM2.5 (µg/m3)	0.19
	Smoke (PPM)	168
21.09.00	PM2.5 (µg/m3)	0.25
	Smoke (PPM)	159
21.10.00	PM2.5 (µg/m3)	0.32
	Smoke (PPM)	150

Table 4.9 Data of PM2.5 and Smoke from Burning Effects

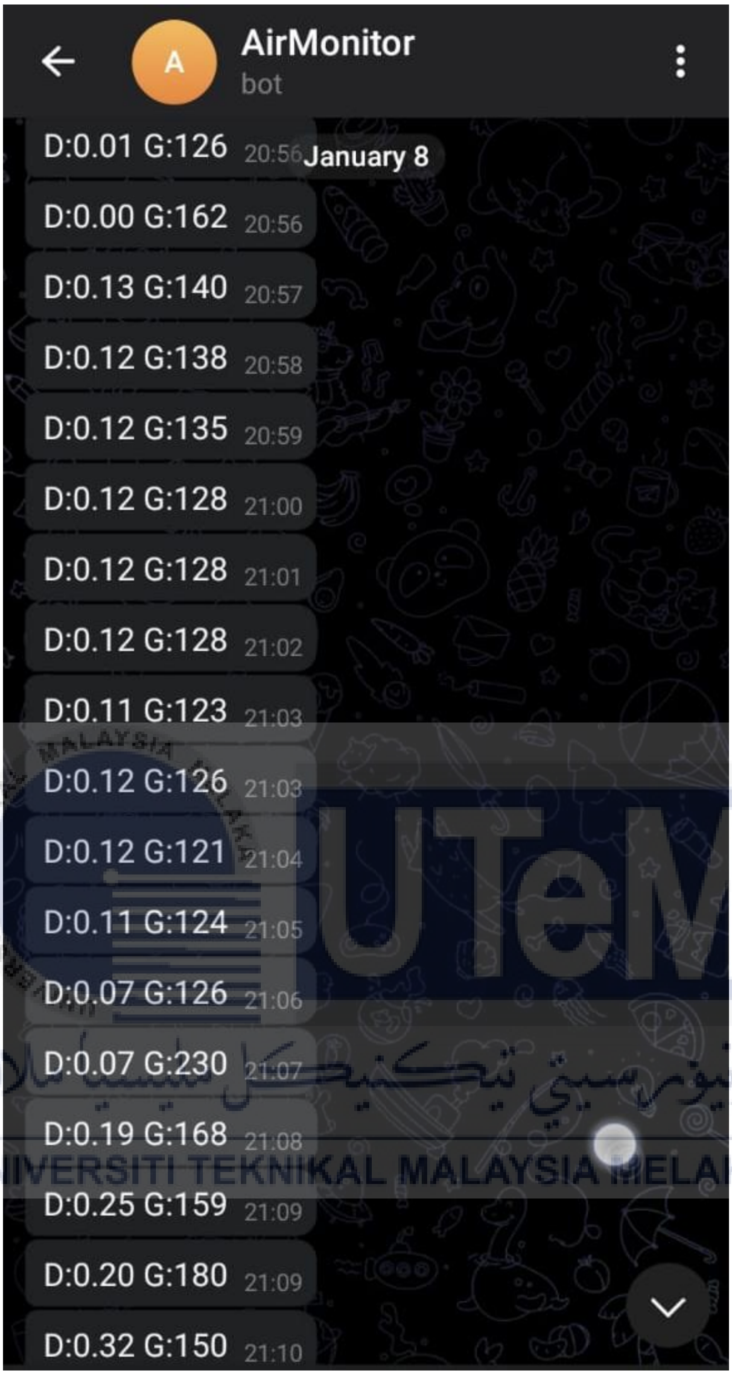


Figure 4.23 Telegram Bot Notifications for Burning Paper Effects

4.8 Signal Range Analysis

4.8.1 Smartphone Application Use in Signal Range Testing

Application	Application Interface	Function
Timestamp Camera		This application used to take the picture for this testing operation as a record. It provides exact day and time with any times zone. Most importantly, it come up with GPS signal with correct GPS coordinates.
Fields Area Measure		This application used to measure distance between one place to another place in kilometer and meter. It can provide straight line measurement in kilometer that will be use as signal range for this testing.

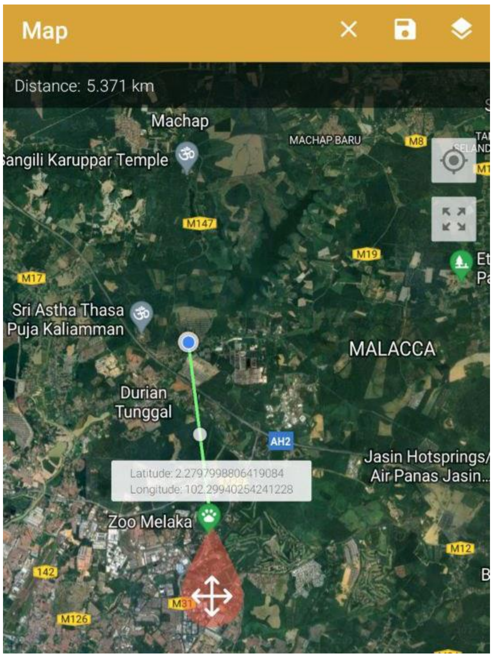
Table 4.10 Application use for Signal Range Testing

4.8.2 LoRa Signal Testing at four different places

Receiver Locations	Componet Detection	Component Value	Transmitter Locations	Signal Range (Kilometers)	Signal
Taman Scientex	PM2.5 (μg/m3)	0.00	Taman Scientex	0	Strong
	Smoke (PPM)	126			
UTeM Archway	PM2.5 (μg/m3)	0.13	Taman Scientex	3.482	Strong
	Smoke (PPM)	140			
Zoo Melaka	PM2.5 (μg/m3)	0.12	Taman Scientex	5.371	Loss
	Smoke (PPM)	138			
Hospital Pantai Ayer Keroh	PM2.5 (μg/m3)	0.12	Taman Scientex	9.674	Loss
	Smoke (PPM)	135			

Table 4.11 Signal Range Test

According to the LoRa Development Portal, the range provided by LoRa can be up to 3 miles (4.8 km) in urban areas and up to 10 miles (16 km) or more in rural areas (line of sight). This examination was supervised to check LoRa Cytron RFM Shied signal strength at 4 different places in Melaka. The places were conducted at urban areas. To test this, project transmitter prototype had been put in my house at Taman Scientex, Durian Tunggal, Melaka while I brought the receiver prototype with me to 3 different places. Note that, this experiment work only for distance, not sensors value. In Table 4.11, the signal can operate as usual within 0 km to 5 km range. The sensor data results in Telegram bot messages and LCD can still slightly changes although there is no dust and gas for sensor's detection test. The signal loss problem will occur when distance more than 5 km. Display at LCD will show the same result as before the signal loss and serial monitor in Arduino IDE cannot show any transmit data result. Thus, it is known that the range of LoRa module sensor is between 0 km to 5 km and it is tally with the datasheet given. In conclusion, as the distance increased, the signal strength decrease. There are so many possible reasons that influence signal loss such as transmit power, environmental conditions and line of sight. Table 4.12 below show the picture of signal loss at Hospital Pantai Ayer Keroh.



GPS Interface in Fields Area Measurement Application

Receiver Prototype at Zoo Melaka

Transmitter Prototype at Taman Scientex, Durian Tunggal

Signal loss in Arduino IDE

Table 4.12 Signal Range Test for 5.371 km

4.9 Hardware Total Cost

Explore commercially available hardware components used for this project. Discuss cost and analyze their applicability to this project in aspect performance and potential for real-world application. This experiment had to be done to achieve project objectives. The price range that had been taking of based on Lazada and Shopee online shop at lowest price range. The total cost analysed in Table 4.13 it is found that this prototype cost lower than others Particulate Matter Detection and Monitoring System in Air Pollution prototypes. However, both of the system has low total cost of development.

Hardware components	**Cost (Online shopping)**	**Quantity**	**Total Cost**
Arduino Uno Rev 3	RM 25.00	2	RM 50.00
GP2Y1010AU0F sensor	RM22.00	1	RM 22.00
MQ-2 Sensor	RM6.00	1	RM 6.00
16x2 LCD I2C	RM10.00	1	RM 10.00
NodeMCU V3 ESP8266	RM10.00	1	RM 10.00
LoRa Cytron RFM Shield	RM99.00	2	RM 198.00
			RM 296.00

Table 4.13 Total Cost for Prototype

4.10 Summary

According to the findings of the study presented above, it is clear that each sensor is performing as expected in light of its assigned role. Since the experiment includes varying the dust particles and gas, using a fire burning paper was helpful in producing accurate findings. This is important because the amount dust particles in atmosphere always varies and is never the same. In addition to this, it is essential to cleaning the GP2Y1010AU0F dust sensor because dust might remain on the sensor even after the smoke stopped. As a result, dust density can calculate the AQI values by using AQI Calculator from web browser to check the air pollution dangerous levels.

When using LoRa module such as LoRa Cytron RFM Shield, it is helpful to compare the findings from multiple locations over the same time period. This ensures that the signal strength still connected between prototype transmitter and prototype receiver. By taking into account, we can see how accurate sensor data between two or more locations. The result that we obtain is tally with the datasheet given that the range provided by LoRa module can be up to 3 miles (4.8 km) in urban areas. There are so many possible reasons that influence signal loss such as transmit power, environmental conditions and line of sight.

As an experiment put the dust and gas sensor at one specific locations over the three days period, the data from the day three stands out due to slight changes in CO concentration levels for gas sensor. The divergent of CO concentration levels observed influenced by the weather conditions, human activities, wind directions and its sources. While for dust sensor. It can see that across 3 days, the results indicate an absence of measurable PM levels. This is attributed to the monitoring location having minimal industrial activities. Thus, the sensor displays reduced sensitivity and requires a significant alteration in the surroundings to improve its detection capabilities. Overall, it can see that endurance of dust and gas sensor are strong enough to system can be on for three days straight.

Last but not least, the price range to build this prototype is slightly lower compare to others Particulate Matter Detection and Air Monitoring System. Project Objective to create PM2.5 detection prototype lower than ready made prototypes had been achieved.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the presented prototype of the Particulate Matter Detection and Monitoring System, implemented using Arduino, demonstrates a practical and economically viable approach for the monitoring of air pollution. The system effectively measures and provides real-time data on particulate matter (PM) concentrations, enabling continuous assessment of air quality. By leveraging the capabilities of Arduino and a particulate matter sensor, the prototype system offers an alternative to traditional and expensive air pollution monitoring methods. It provides users with accurate and timely information about PM levels, allowing for informed decision-making and proactive measures to mitigate the health and environmental risks associated with air pollution.

The developed prototype system holds potential for deployment in diverse environments, educational and industrial settings where in it can effectively monitor air quality and evaluate the efficacy of pollution control initiatives. By promoting awareness of the detrimental effects of air pollution, the system empowers individuals and communities to undertake proactive measures aimed at enhancing air quality. Its versatile application highlights its capacity to contribute to the collective understanding of air pollution impacts. The prototype system thus serves as a valuable tool in facilitating informed decision-making and fostering a culture of environmental responsibility. Overall, the prototype demonstrates the potential of Arduino-based systems in addressing air pollution challenges. It serves as a foundation for further advancements and innovations in air quality monitoring, paving the way towards a healthier and more sustainable environment for all.

5.2 Future Works

Further enhancements can be made to the system such as integrating additional sensors to measure other pollutants and environmental parameters. The data collected can be analyzed using machine learning techniques to predict pollution trends and develop early warning systems. Additionally, efforts can be made to optimize the system's power consumption and develop user-friendly interfaces for easy data interpretation.

Keywords: Air pollution, Particulate matter, Arduino, Sensor, Monitoring system, Real-time data.

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APPENDICES

Appendix A **Example of Appendix A**

No.	Parameters	No.	Parameters
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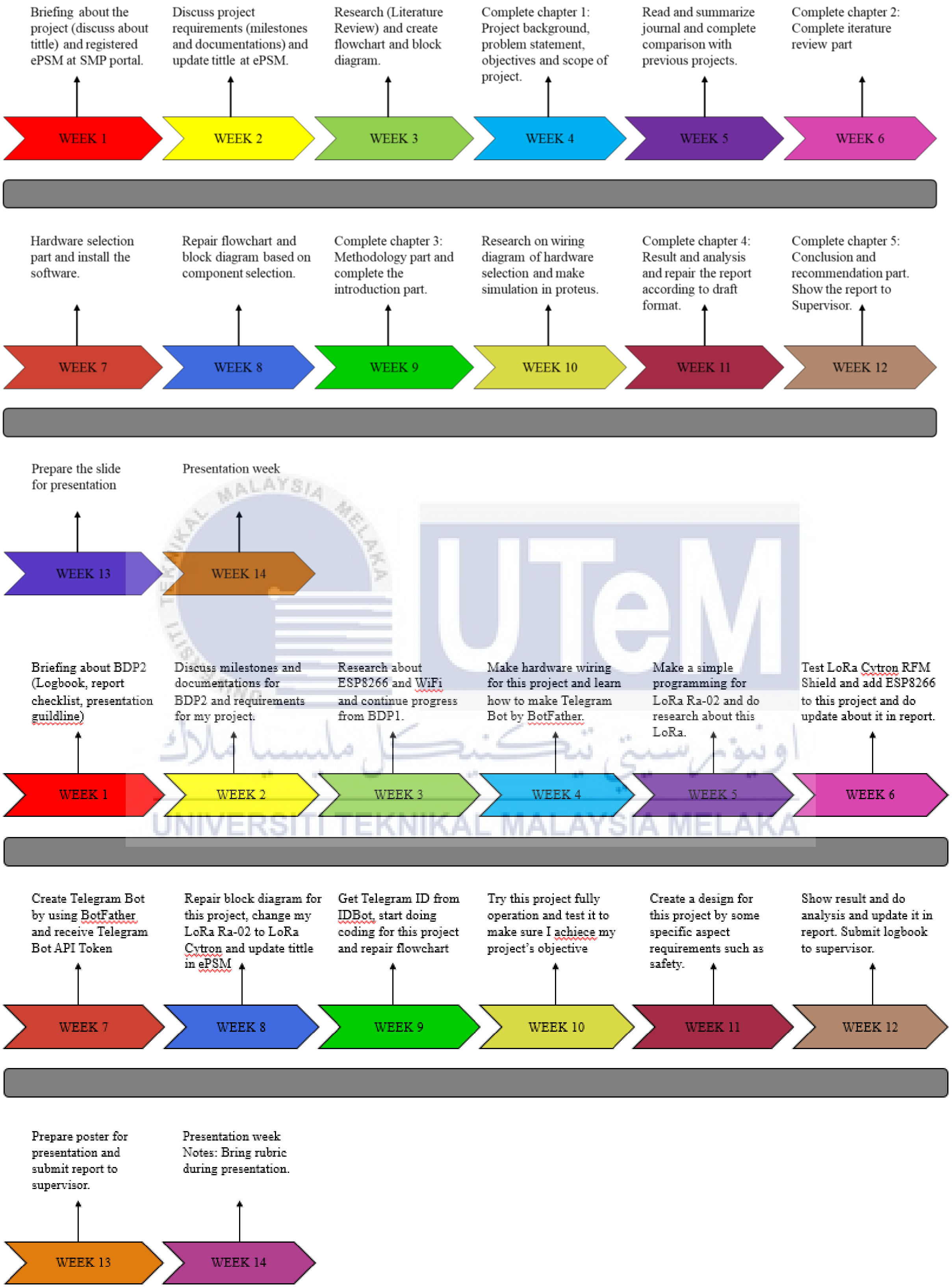
23.			
24.			

Appendix 1 Gantt Chart



Appendix 2 Source Code 1

LoRa Transmitter Source Code

```
#include <SPI.h>
#include <RH_RF95.h>

#define RFM95_CS 10
#define RFM95_RST 7
#define RFM95_INT 2
#define node_id "B"

// Change to 434.0 or other frequency, must match RX's freq!
#define RF95_FREQ 915.0

// Singleton instance of the radio driver
RH_RF95 rf95(RFM95_CS, RFM95_INT);


float set = 30.00;
float Data;
char CharMsg[10];
long onMillis = 0;          // will store last time LED was updated


int measurePin = A0;
int ledPower = 2;
int gas;
unsigned int samplingTime = 280;
unsigned int deltaTime = 40;
unsigned int sleepTime = 9680;

```

```
float voMeasured = 0;
float calcVoltage = 0;
float dustDensity = 0;
String setval;

void setup(){
  Serial.begin(9600);
    pinMode(ledPower,OUTPUT);
  pinMode(A1,INPUT);
  pinMode(RFM95_RST, OUTPUT);
   digitalWrite(RFM95_RST, HIGH);
    Serial.println("Arduino LoRa TX Test!");

  // manual reset
  digitalWrite(RFM95_RST, LOW);
  delay(10);
  digitalWrite(RFM95_RST, HIGH);
  delay(10);
    while (!rf95.init()) {
    Serial.println("LoRa radio init failed");
    while (1);
  }
  Serial.println("LoRa radio init OK!");

  // Defaults after init are 434.0MHz, modulation GFSK_Rb250Fd250, +13dbM
  if (!rf95.setFrequency(RF95_FREQ)) {
    Serial.println("setFrequency failed");
    while (1);
```

```
  }
  Serial.print("Set Freq to: "); Serial.println(RF95_FREQ);

  rf95.setTxPower(23, false);

}

void loop(){
  digitalWrite(ledPower,LOW);
  delayMicroseconds(samplingTime);

  voMeasured = analogRead(measurePin);

  delayMicroseconds(deltaTime);
  digitalWrite(ledPower,HIGH);
  delayMicroseconds(sleepTime);

  calcVoltage = voMeasured*(5.0/1024);
  dustDensity = 0.17*calcVoltage-0.1;

  if ( dustDensity < 0)
  {
    dustDensity = 0.00;
  }

   gas = analogRead(A1);

  /*Serial.println("Dust Density:");
```

Appendix 3 Source Code 2

LoRa Receiver Source Code

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
//sda D2, SCL D1
//I2C pins declaration
LiquidCrystal_I2C lcd(0x27, 2, 1, 0, 4, 5, 6, 7, 3, POSITIVE); //0x3F

#include <SoftwareSerial.h>
SoftwareSerial SMESerial (3, 4);

#include <SPI.h>
#include <RH_RF95.h>

#define RFM95_CS 10
#define RFM95_RST 7
#define RFM95_INT 2

// Change to 434.0 or other frequency, must match RX's freq!
#define RF95_FREQ 915.0

// Singleton instance of the radio driver
RH_RF95 rf95(RFM95_CS, RFM95_INT);

uint8_t buf[RH_RF95_MAX_MESSAGE_LEN];
    uint8_t len = sizeof(buf);

void setup()
{
  pinMode(RFM95_RST, OUTPUT);
```

```
  digitalWrite(RFM95_RST, HIGH);
  SMESerial.begin(9600);
  while (!Serial);
  Serial.begin(9600);
  lcd.begin(16,2);//Defining 16 columns and 2 rows of lcd display
lcd.backlight();//To Power ON the back light
lcd.setCursor(0,0);
  delay(100);

  Serial.println("Arduino LoRa RX Test!");

  // manual reset
  digitalWrite(RFM95_RST, LOW);
  delay(10);
  digitalWrite(RFM95_RST, HIGH);
  delay(10);

  while (!rf95.init()) {
    Serial.println("LoRa radio init failed");
    while (1);
  }
  Serial.println("LoRa radio init OK!");

  // Defaults after init are 434.0MHz, modulation GFSK_Rb250Fd250, +13dbM
  if (!rf95.setFrequency(RF95_FREQ)) {
    Serial.println("setFrequency failed");
    while (1);
  }
```

```
  Serial.print("Set Freq to: "); Serial.println(RF95_FREQ);

  // Defaults after init are 434.0MHz, 13dBm, Bw = 125 kHz, Cr = 4/5, Sf = 128chips/symbol, CRC on

  // The default transmitter power is 13dBm, using PA_BOOST.
  // If you are using RFM95/96/97/98 modules which uses the PA_BOOST transmitter pin, then
  // you can set transmitter powers from 5 to 23 dBm:
  rf95.setTxPower(23, false);
}

void loop()
{
  if (rf95.available())
  {
    // Should be a message for us now


    if (rf95.recv(buf, &len))
    {
      //RH_RF95::printBuffer("Received: ", buf, len);
      //Serial.print("Got: ");
      Serial.println((char*)buf);
      /*Serial.print("RSSI: ");
      Serial.println(rf95.lastRssi(), DEC);*/

    }
    else
    {
```

```
      Serial.println("Receive failed");
    }
  }
  lcd.setCursor(0,0);
 lcd.print((char*)buf);
delay(3000);
//SMESerial.print("R");
 SMESerial.print((char*)buf);
 lcd.clear();


}

```

Appendix 4 Source Code 3

Telegram Source Code

```
#include <SoftwareSerial.h>
SoftwareSerial SMESerial (D6, D7);
String teststr;
int count = 0;
#include <ESP8266WiFi.h>
#include <WiFiClientSecure.h>
#include <UniversalTelegramBot.h>
#include <ArduinoJson.h>

// Replace with your network credentials
const char* ssid = "project";
const char* password = "1111aaaa";

// Initialize Telegram BOT
#define BOTtoken "6309507471:AAFfWOzIWZomiaHAnVoSzQgcXDjqPVAP6D0"  // your Bot Token (Get from Botfather)

// Use @myidbot to find out the chat ID of an individual or a group
// Also note that you need to click "start" on a bot before it can
// message you
#define CHAT_ID "1148731692"

X509List cert(TELEGRAM_CERTIFICATE_ROOT);
WiFiClientSecure client;
UniversalTelegramBot bot(BOTtoken, client);

const int motionSensor = 14; // PIR Motion Sensor
bool motionDetected = false;

```

```
// Indicates when motion is detected
void ICACHE_RAM_ATTR detectsMovement() {
  //Serial.println("MOTION DETECTED!!!");
  motionDetected = true;
}

void setup() {
  Serial.begin(9600);
    SMESerial.begin(9600);
  configTime(0, 0, "pool.ntp.org");      // get UTC time via NTP
  client.setTrustAnchors(&cert); // Add root certificate for api.telegram.org

  // PIR Motion Sensor mode INPUT_PULLUP
  pinMode(motionSensor, INPUT_PULLUP);
  // Set motionSensor pin as interrupt, assign interrupt function and set RISING mode
  attachInterrupt(digitalPinToInterrupt(motionSensor), detectsMovement, RISING);

  // Attempt to connect to Wifi network:
  Serial.print("Connecting Wifi: ");
  Serial.println(ssid);

  WiFi.mode(WIFI_STA);
  WiFi.begin(ssid, password);

  while (WiFi.status() != WL_CONNECTED) {
    Serial.print(".");
    delay(500);
  }
```

```
  
  Serial.println("");
  Serial.println("WiFi connected");
  Serial.print("IP address: ");
  Serial.println(WiFi.localIP());

  bot.sendMessage(CHAT_ID, "Bot started up", "");
}

void loop() {

  while (SMESerial.available())
  {
   teststr = SMESerial.readString();  //read until timeout
  Serial.print(teststr);
  }

  count++;

  Serial.print("Count: ");
  Serial.println(count);

  if(count == 30)
  {
    bot.sendMessage(CHAT_ID, teststr, "");
    Serial.println("Data Logged");

    count = 0;
```

```
  }


  delay(1000);

}
```