IOT-BASED AIR MONITORING SYSTEM

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IOT-BASED AIR MONITORING SYSTEM

By

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LIST OF SYMBOLS

mW	milliwatt
mg/m^3	milligram per cubic metre
ppm	part per million
μF	microfarad
V	Volt
Ω	Ohm
$	US dollar
°C	degree Celcius
%	percentage

LIST OF ABBREVIATIONS

DC	Direct Current
GND	Ground
GUI	Graphical User Interface
I/O	Input/Output
I^2C	Inter-Integrated Circuit
IAQ	Indoor Air Quality
IBM	International Business Machines
IoT	Internet of Things
IRED	Infrared Emitting Diode
LAN	Local Area Network
LCD	Liquid Crystal Display
LED	Light Emitting Diode
MCU	Microcontroller Unit
MQTT	MQ Telemetry Transport
PC	Personal Computer
PCB	Printed Circuit Board
SCL	Serial Clock
SD	Secure Digital

SDA	Serial Data
SoC	System-on-Chip
TSP	Total Suspended Particulate
USB	Universal Serial Bus

SISTEM PEMANTAUAN UDARA BERASASKAN IOT

ABSTRAK

Kajian ini membentangkan reka bentuk sistem elektronik untuk mengesan karbon dioksida, zarah dengan diameter 2.5μm ($PM_{2.5}$) dan pemaparan data dengan pelaksanaan internet benda ("internet of things", IoT). Kajian ini memberi tumpuan kepada pembangunan pengantaramukaan penderia gas MQ-135 dan penderia habuk GP2Y1010AU0F dengan pemproses Intel Galileo untuk melaksanakan sistem pengambilan bacaan data karbon dioksida, CO_2 dan zarah $PM_{2.5}$ masing-masing. Penderia gas MQ-135 diantaramukakan secara langsung dengan Intel Galileo, manakala penderia habuk GP2Y1010AU0F akan diantaramuka dengan platform perkakasan Arduino Pro Mini. Semua data dihantar kepada Intel Galileo melalui komunikasi I^2C. Untuk mengumpul data, 1 sampel sesaat diambil kira bagi penderia gas MQ-135, manakala 30 sampel sesaat untuk penderia habuk GP2Y1010AU0F. Data yang dipaparkan melalui penderia habuk GP2Y1010AU0F adalah data purata sebenar untuk 30 sampel sesaat. Mesej untuk penghantaran melalui internet akan dijana oleh Intel Galileo. Seterusnya, ia akan dihantar ke aplikasi MQTT di bawah perkhidmatan IBM Bluemix. Data yang diterima oleh MQTT akan dimasukkan kepada node-RED untuk pemaparan data. Antara muka pengguna grafik dihasilkan melalui kemudahan penyunting yang ada pada node-RED. Antara muka grafik dicipta pada halaman web yang diprogramkan dengan menggunakan bahasa html dan JavaScript. Hanya maklumat yang diperlukan akan dipaparkan dan garis panduan kualiti udara akan ditunjukkan pada antara muka grafik tersebut. Keputusan ujian penderia yang ditunjukkan mengambilkira 30 sampel sesaat untuk penderia habuk GP2Y1010AU0F bagi mendapatkan data yang

lebih stabil. Keputusan ujian penderia juga digambarkan penderia habuk GP2Y1010AU0F boleh digunakan untuk memapar status asap, manakala penderia gas MQ-135 boleh menunjukkan status kepekatan karbon dioksida. Selain itu, ujian keberkesanan sistem yang dihasilkan ini telah diujikajikan pada 6 lokasi yang berbeza dan membuktikan bahawa sistem itu berfungsi dengan baik. Kesimpulannya, penderia telah berjaya disepadukan dengan platform pemprosesan Intel Galileo di samping dengan pelaksanaan teknologi IoT. Penghasilan antara muka grafik yang mudah dan membantu pengguna untuk membayangkan dan memahami data yang ditunjukkan.

IOT-BASED AIR MONITORING SYSTEM

ABSTRACT

The study presents a preliminary design of an electronic system to detect carbon dioxide, CO_2 and particular matter with diameter of 2.5μm ($PM_{2.5}$) and data visualization with IoT implementation. This study focuses on the development on the interfacing MQ-135 gas sensor and GP2Y1010AU0F dust sensor with Intel Galileo processing platform to implement the data acquisition of CO_2 and $PM_{2.5}$ respectively. MQ-135 gas sensor direct interface with Intel Galileo, whereas GP2Y1010AU0F dust sensor direct interface with Arduino Pro Mini. All the data is sent to Intel Galileo via I^2C communication. To collect the data, 1 sample per second is taken for MQ-135 gas sensor, whereas 30 samples per second is taken for GP2Y1010AU0F dust sensor. The displayed data for GP2Y1010AU0F dust sensor is average data for actual of 30 samples per second. A message for sending to Internet is generated on Intel Galileo. Next, it will be sent to MQTT broker under the service of IBM Bluemix. The data received by the MQTT broker is subscribed by the node-RED for the visualization of data. The IoT technology is implemented by node-RED. The graphical user interface (GUI) developed by using node-RED flow editor. The GUI is created on a webpage which is programmed by using html and JavaScript languages. Only the highlighted information is displayed and the guideline of air quality is presented on the GUI. The results of the sensor test presented that taking 30 samples per second for GP2Y1010AU0F dust sensor will obtain a more stable signal. The results also illustrated that the GP2Y1010AU0F dust sensor can detect the present of smoke, whereas MQ-135 gas sensor can detect the present of high concentration of CO_2. Besides that, the functionality test of the proposed system is run on 6 different locations and prove that the system was functioning well. In conclusion, the sensors were

successfully integrated with Intel Galileo processing platform and implementation of IoT technology. Simple GUI helps users to visualize and understand the displayed data.

CHAPTER 1

INTRODUCTION

1.1 Overview

Air pollution is currently the largest environmental health risk in both urban and rural area. More than 5.5 million people worldwide died due to pollution every year [1]. Hence, it is essential to know the air quality of our living environment to protect our health. Moreover, the household might be alert earlier when the air pollutants reached the dangerous level and some precautionary steps can be taken to minimize the effect of air pollutants to human body.

There are two concern regarding to indoor air quality (IAQ), which are carbon dioxide, CO_2 and particular matter, PM. Another concern of the IAQ is the concentration of particular matter. Students and workers spent most of their waking time at school or work. Therefore, the maintaining of IAQ become top priority for building operating engineers and building manager. The association of high level concentration of CO_2 causes the increased health symptoms and impaired work performance. In current research, 22 participants was divided into six groups to exposed to CO_2 at 600 ppm, 1000 ppm and 2500 ppm in an office-like chamber in three 2.5 hours sessions, and result in the higher concentration of CO_2 lead to the large and statistically reduction occurred in seven scales of decision-making performance [2].

Particular matter is widespread air pollutants, it consists of mixture of liquid and solid particles in the air. The mass concentration of particles with a diameter of less than 10µm (PM_{10}) and 2.5µm ($PM_{2.5}$) commonly used as the indicators describing PM that are relevant to health. $PM_{2.5}$ particles are very harmful to the climate, environment and human health. In latest finding, approximate 1.1 million life years lost from $PM_{2.5}$ exposure among population aged 65–99 [3]. The results reveal that current levels of $PM_{2.5}$ still pose a nontrivial risk to public health even though some improvement on air quality had been achieved recently.

There is the trend of Internet of Things (IoT) nowadays. Many recent research is done on it and found that there is benefits in monitoring, autonomously communicate, exchange information and take intelligence decisions [4-7]. Nevertheless, it would be needed to add some components or external shield to integrate the system to internet [8]. However, a microcontroller that run Linux and support Ethernet or Wi-Fi connection will be a better solution for IoT. It can be work as a Linux-based embedded system which has a similar functionality with the computer. Its framework has a greater potential to integrate with more platform on Internet as compare with microcontroller.

Besides that, there is some drawbacks of wired system. To visualize the data, a medium is needed to transfer the data and display it on other devices. The USB cable is used in the system as the medium of transferring data [9]. The length of the USB cable limited how far the computer can be apart from the system. It is not convenient for acquire data from the system. To solve it, IoT framework can be implement on it. All the data will send to the internet via the framework, and developer can visualize the data easily by access the data sent to the internet.

In this study, IoT-Based air monitoring system is proposed for household uses to continuously examine the air quality in the indoor living environment. The main goal of the work is to develop a low cost, multi-sensor and IoT-based air monitoring system with sufficient sensitivity. To examine the air quality, two sensors, that is CO_2 and $PM_{2.5}$ are integrated in this system. For data acquisition, the selected sensors are interfaced with

Linux-based embedded system to implement air monitoring. After the air quality data are acquired, the system will send it to the gateway to access internet cloud platform. Then, a graphical user interface (GUI) is used to perform live display of data on a webpage.

The project highlights on the deployment of IoT as the framework of entire monitoring system. The data acquired from the sensor is published to MQ Telemetry Transport (MQTT) broker to allow more connected client (devices and application) to access the data. The application is built on a cloud platform to subscribe the data from MQTT broker and display it on a webpage.

1.2 Problem Statement

A human could go days without food and hours without water, but humans would last only a few minutes without air. Over 3,000 gallons of air was consumed by each citizen on average each day [10]. Hence, air is an essential to living. However, breathing in tiny solid or liquid particles will increase the risk of heart disease, respiratory complaints, stroke and even cancer. In this past few decades, this problem addressed to made a great stride while developed nations. Furthermore, the number of citizens dying as a result of poor air quality in developing countries is still increasing [1]. Therefore, it is very important to monitor the air quality in the living environment. So that some precautionary steps can be taken to minimize the effect on health when the air pollutants reached a dangerous level.

However, human's eyes are not capable to monitor the air quality due to tiny air and dust particles. The gas and dust sensors are used instead to measure the air quality. In previous study on the air quality monitoring system, there is both low and high cost sensors integrated in the system. Some of it even can achieved high accuracy of data acquisition by using low cost sensors. Besides that, a microcontroller is integrated as the host of most of the systems. It is easy to be program and great to be implement into the system. However, most of the systems rarely integrated to the internet.

Moreover, some of the graphical user interface (GUI) implements on the system is not user friendly for users. In [9, 11, 12], the information is displayed graphically and show the data in details. These is good enough for researcher to analyze the data but not for users. The GUI created for users should be simple and easy to understand. Only the highlighted and important message will be shown. In addition, the air quality guide need to be provided on it, in case for the users to referring on it. These issues are highlighted in this thesis.

1.3 Objectives

Regarding to the problem stated in section 1.2, there is few studies that can be cover for the development of the system of air monitoring. In order to overcome the issues, the following objectives have been defined:

1. To study and implement different peripheral interfacing between specified sensors and Intel Galileo processing platform.
2. To implement an IoT framework in the proposed air monitoring system.
3. To develop a GUI that able to present highlighted information of air quality to users.

1.4 Project Scope

This project focuses on applying the IoT technology to an air monitoring system. Sensors will be used to acquire the concentration of CO_2 and $PM_{2.5}$ dust particles, that is MQ-135 gas sensor and GP2Y1010AU0F dust sensor. Upon the data collected by the sensors, the calculation and analysis are being processed, then the result will be display on GUI in a webpage. Besides that, the guideline of the air quality is presented in the webpage.

The microcontroller boards, Intel Galileo and Arduino Pro Mini will be interfaced with the sensors to perform the data acquisition. It is programmed by Intel XDK IoT Edition and Arduino IDE. The data analysis and calculation have performed the microcontroller after the data is acquired. The calculated data will be generated to a message and sent by Intel Galileo to the MQTT broker in IBM Bluemix.

The data received by the MQTT broker will be called by a node in node-RED flow editor. The node will be interfaced with other nodes to display the data on GUI. The GUI will be programmed by html and JavaScript language.

1.5 Thesis Outline

The thesis is divided into five main chapters. This part, chapter 1 is the introduction of this thesis. The overview gives a background and the summary to the purpose of writing this thesis. The problem under investigation is highlighted and the identification of the requirement and specification of the project. The objectives and scopes of projects have been set and stated. This chapter is concluded with the outline of the thesis.

In Chapter 2, a comprehensive literature review of this study is presented. The relative study is the previous work of air monitoring system on air quality and air pollution. Next, various types of gas sensor and dust sensor will be compared and highlight its advantages and drawbacks. The processing platform of the system will be discussed. The review on the IoT implementation and design of GUI will be presented at the end of chapter.

Chapter 3 details the methodology. The overall project flow is presented. The activities and studies performed in each stage are described in detail. The main content of this chapter includes the sensor interfacing / signal conditioning system prototyping, IoT implementation and GUI design.

Chapter 4 presents the results and discussions. In this chapter, it can be divided into 3 main parts, which are the results of sensor test, the results of functionality test and the layout of GUI design. The data acquired by sensors will be analyzed in sensor test and the overall performance of the proposed system will be evaluated in functionality test. The result of the GUI design will be showed in this chapter.

Chapter 5 draws the conclusion and highlights the achievements of this research. Some of the limitations in the developed system are explained as well. A number of interesting directions is suggested for future works and improvements.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Over the past decade, air pollution has increased at quite a tremendous rate. Humans stay most of the time indoor to rest, study and work. Even though it is safe to be stay indoors, it will also possible to be exposed to air toxins. So it is important to examine the exposure of people to different air toxins, especially for children, aged people and persistently ill people. The association of ventilation rates and carbon dioxide concentration in non-residential and non-industrail buildings with health and other human outcomes. It causing the respiratory illness and sick builiding syndrome symptoms [13]. World Health Organization (WHO) estimates that approximately 800,000 premature death was contributed by the particulate matter (PM) air pollution that is in the ranking of 13th leading cause of mortality worldwide [14]. In this project, there are 2 concerns of indoor air quality will be studied, which are carbon dioxide, CO_2 and particular mattter with diameter of 2.5µm, $PM_{2.5}$.

2.2 Potential Health Effect of Carbon Dioxide

The first concern of this study is CO_2. It is odorless and colorless gas that has a faint acid taste. It will be exhaled when people breathe. It also can be found naturally in spring water and is released when volcanoes erupt or trees are cut down. Everyone is exposed to low concentration of carbon dioxide in its gas form by breathing indoor and outdoor air. Low concentration of carbon dioxide is harmless. However, exposure to concentration of 10 percent or more of carbon dioxide will cause unconsciousness, convulsions, or death [15].

A high concentration can be displaced in the air. The symptoms can be causing by less oxygen is available to breathe, such as rapid heart rate, rapid breathing, emotional upsets, clumsiness and fatigue. Symptoms occur faster with physical effort. Lack of oxygen even causes permanent damage to organs including the heart and brain.

2.3 Potential Health Effect of Particular Matter

The second concern of this study is $PM_{2.5}$. Particular matter, PM is a widespread air pollutant, consisting of mixture of liquid and solid particles suspended in the air. There are 2 diameter of PM used as the reference for health which are PM_{10} and $PM_{2.5}$. $PM_{2.5}$ often called fine PM. $PM_{2.5}$ includes the inhalable particles that are small enough to penetrate the thoracic region of the region of respiratory system. The health effect of inhalable PM for short term and long term included respiratory and cardiovascular morbidity, such as respiratory symptoms, aggravation of asthma and an increase in hospital admissions. $PM_{2.5}$ is a stronger risk factor than the coarse part of PM_{10}. All-cause daily mortality is estimated to increase by 0.2 – 0.6% per 10 $\mu g/m^3$ of PM_{10} [16, 17]. Long term exposure to $PM_{2.5}$ is associated with an increase in the long term risk of cardiopulmonary mortality by 6 – 13% per 10 $\mu g/m^3$ of $PM_{2.5}$ [18, 19]. Hence, more concern on $PM_{2.5}$ is needed for air quality monitoring.

2.4 Previous Project Related to Air Quality Monitoring

Recent years, there are many projects done related to air quality monitoring. Some of the recent projects within 2012 to 2015 are summarized in Table 2.1. The project

Table 2.1: Summary of studies for the past decades that are related to air quality monitoring

Year	Application	Processing Platform	Sensors	Remarks	Reference
2013	WSN Based Air Pollution Monitoring System	AtMega16 microcontroller	• MG811 gas sensor • MQ6 gas sensor • MQ135 gas sensor	Monitoring CO_2, NO_2 and SO_2	[20]
2013	Low-cost Wireless Dust Monitoring System	Microcontroller (MCU) PIC18F4550	• Sharp GP2Y1010AU0F dust sensor	Monitoring dust density	[21]
2014	Zigbee Based Wireless Weather Monitoring System	AtMega16 microcontroller	• MG811 gas sensor • MQ135 gas sensor	Monitoring CO_2 and NO_2	[22]
2014	Air Impurity Measurement System	AtMega16 microcontroller	• MQ7 gas sensor • MQ135 gas sensor	Monitoring CO and CO_2	[23]
2014	Smart Sensor Nodes For Airborne Particulate Concentration Detection	Arduino Uno	• Sharp GP2Y1010AU0F dust sensor • Shinyei PPD4NS dust sensor	Monitoring dust density	[24]
2015	Air Quality Monitoring with Arduino and Android	Arduino Mega 2560	• MQ7 gas sensor • MQ135 gas sensor • Sharp GP2Y1010AU0F dust sensor	Monitoring CO, CO_2 and dust density	[25]
2015	Design and Implementation of Indoor Environmental Quality Monitoring System Based on ZigBee	Arduino Uno	• Sharp GP2Y1010AU0F dust sensor	Monitoring dust density	[26]

summarized in the table related with the measurement of either CO_2 or dust particles, or both.

In most projects, MQ135 gas sensor is the widely used to monitoring CO_2. There is another sensor for monitoring CO_2 that is MG811 gas sensor. Both of these sensors are interfaced with Atmega 16 microcontroller or Arduino Mega 2560, which is allows to program by using Arduino IDE. By using these 2 sensors, the cost effective system for measuring air quality can be achieved. Although the same sensor is used in the developed system, but the different visualize system is implemented. The data obtained in the system is displayed on the LCD and interface with the GUI created in Microsoft Visual studio [23]. The data visualize on the GUI is plotted and displayed as real time graph. It helps developers to understand the collected data. In another study, the developed system has been interfaced with mobile device to display data [25]. This interfacing of portable system helps developers collect the data easier and it allows developers to save and load the data on mobile device.

Another sensor for monitoring the air quality is dust sensor. The widely used dust sensor is Sharp GP2Y1010AU0F dust sensor. The sensor is interfaced with Atmega16 microcontroller, Arduino Uno and Microcontroller (MCU) PIC18F4550. Three of these controllers are programmed by using C or C++ language. The monitoring of dust density is low power consumption and to be fairly inexpensive. The proposed solution is capable of measuring dust density up to $0.5mg/m^3$. The real time data is visualized on the GUI developed by using LabVIEW [21]. In addition, the results can be saved in form of an Excel file format for further processing in different application.

2.5 Type of Sensors

There are various type of sensors can be implemented for air monitoring system. To develop a low cost, multi-sensor and IoT-based air monitoring system with sufficient sensitivity, the sensors will be compared and discussed.

2.5.1 Carbon Dioxide, CO_2

Three CO_2 sensors found on the website, SainSmart are compared as shown in the Table 2.2. These 3 sensors generate analog output. MQ135 and MH-Z14 compatible to interface with the microcontroller which is operates at 5V. MH-Z14 has the lowest operating power, shortest preheat time and widest detection amongst 3 sensors. However, it is the most expensive sensor. MQ135 and MG811 can be used to implement a low cost and sufficient sensitivity system. MQ135 has a lower operating power, wider detection range than MG811. The working temperature is suitable to operate in Malaysia because the normal room temperature is average at 32.4 ºC. Besides that, it is lowest cost and has the widest range of working humidity amongst 3 sensors. Moreover, it is suitable to integrate with microcontroller as it has been used in many previous studies for air monitoring as shown in Table 2.1.

2.5.2 Dust Particles, PM

The dust sensors found on website, Amazon are compared as presented in Table 2.3. These 3 sensors generate analog output and compatible to inteface with microcontroller which is operates at 5V. Besides that, these 3 sensors have the similar specification for working temperature and humidity. Only PPD42NS has a lower range of working temperature but it is suitable to operate at room temperature in Malaysia. The detection range of dust particles are accending in the order of GP2Y1010AU0F, PPD42NS and DSM501A. The prices are also ascending in the same order. According to Malaysia Ambient Air Pollution Level, the total suspended particulate (TSP) maximum level is 0.26mg/m^3 [27]. The rating level is within the specified range of 3 sensors. GP2Y1010AU0F dust sensor can be used to implement lost cost and low power consumption system because it is cheapest and lowest power consumption amongst the 3 sensors. Besides that, it is also suitable to integrate with microcontroller as it has been used in many previous studies as shown in Table 2.1.

Table 2.2: Comparison of CO_2 gas sensors

Model of Sensor	MQ135	MG811	MH-Z14
Price ($)	10.25	49.99	80.51
Operating Voltage (V)	5 ± 0.1	6 ± 0.1	4 ~ 6
Operating Power (mW)	800	1200	300
Preheat Time	24 hrs	undefined	3 mins
Detection Range (ppm)	10 ~ 10000	350 ~ 10000	0 ~ 10000
Working Temperature (ºC)	-10 ~ 45	-20 ~ 50	0 ~ 50
Working Humidity (%)	0 ~ 95	undefined	0 ~ 90
Output	Analog	Analog	Analog
Reference	[28]	[29]	[30]

Table 2.3: Comparison of dust sensors

Model of Sensor	GP2Y1010AU0F	PPD42NS	DSM501A
Price ($)	9.14	24.88	28.98
Operating Voltage (V)	5 ± 0.5	5 ± 0.5	5 ± 0.5
Operating Power (mW)	200	450	450
Detection Range (mg/m^3)	0 ~ 0.5	0 ~ 0.8	0 ~ 1.4
Working Temperature (ºC)	-10 ~ 65	0 ~ 45	-10 ~ 65
Working Humidity (%)	0 ~ 90	0 ~ 95	0 ~ 95
Output	Analog	Analog	Analog
Reference	[31]	[32]	[33]

2.6 Processing Platform

In the previous studies, microcontroller was the preferred processing platform, and the development on this research is presented in Table 2.1.

In current development, Intel Galileo is a kind of microcontroller board based on the Intel® Quark SoC X1000 Application Processor, a 32-bit Intel Pentium class system on a chip. It is capable to run both Arduino program and Linux-based application. It is designed to compatible with Arduino shield for Arduino Uno R3 and having the similar with Arduino board. Some of the libraries created to be compatible compile and upload to it such as Ethernet, WiFi and servo.

Besides that, it can write a Linux Operating System Image to micro SD Card to boot the Yocto-built Linux into the board. Yocto-built Linux includes even more libraries and resources to ease developers to create application in their favorite programming language [34]. The authors have chosen the JavaScript as the programming language to create the application in order to integrate with the sensor. The diagram of the Intel Galileo is shown in Figure 2.1.

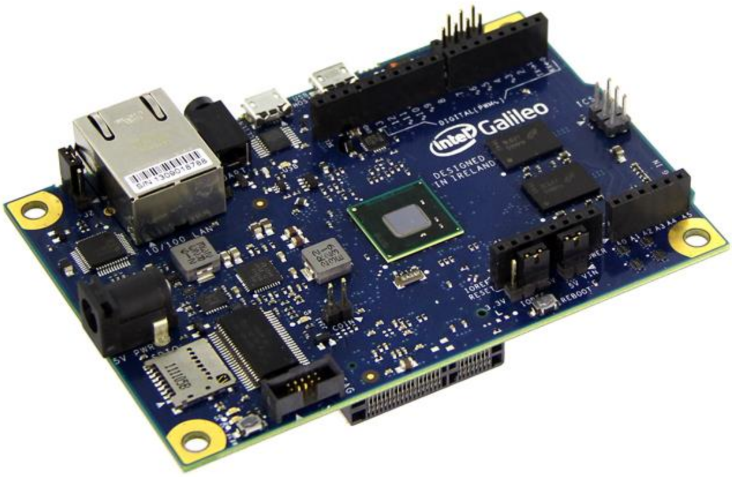

Figure 2.1: Intel Galileo Board

2.7 Internet of Things (IoT) Implementation

The technology of IoT is implemented to the air monitoring system to make it portable and easier to collect data. Many systems require a wire or a cable to connect the system to the computer for data collection. The distance of the computer with the system is limited by the length of wire or cable. It is not convenient for developers to collect data. To solve it, the data is published to internet for real time visualization. The data is accessed via the internet and then save on the cloud server. Then the data can be loaded and displayed on the GUI of YeeLink [26]. Both computers and mobile devices can be access to YeeLink to display the data. The real time monitoring by using YeeLink is shown in Figure 2.2. The data monitoring in graph will ease the task of developers to analyze the data. However, it is not a good idea to display data to users. The design of GUI will be discussed in next section.

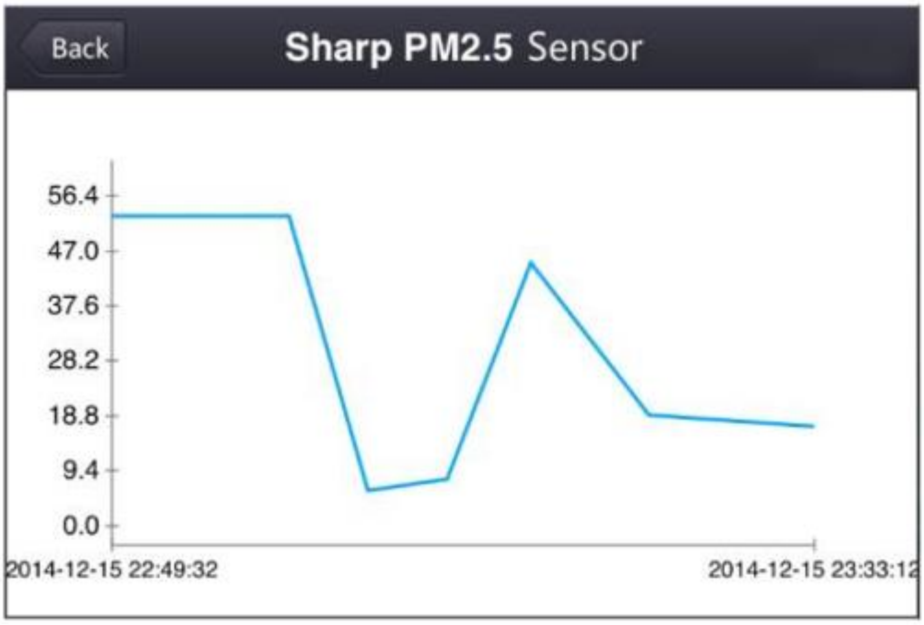

Figure 2.2: Real-time display on YeeLink ($PM_{2.5}$ AQI) [26]

2.8 Design of GUI

To ease users to understand the data in a better way, a simple GUI with highlighted data is needed as illustrated in Figure 2.3. The data is visualized with a gauge. The gauge is divided into 6 parts with different colors. Different colors indicate different levels of pollution of the environment. The guideline of air quality is presented in the figure as the reference for the users to understand the pollution level of the environment. Besides that, a simple GUI with a diagram will be more attractive as compare with adding a graph on it. More attractive GUI will be getting interest from users and it will become a preferable choice for users.

Figure 2.3: AQI module showing Air Quality Index Report [35]

2.8 Summary

This chapter review the previous work related with the air quality monitoring. The sensors that has been used in this project are compared, and highlighted the advantages and drawbacks of each sensor. The processing platform of this system is also been discussed. Finally, the review on the IoT implementation is discussed and the improvement of the GUI is described in design of GUI.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Both hardware and software developments are involved in this project. The outline of this chapter will be the description of the method of development in hardware and software. It will start with the project development, then following by project description, sensor modules, data acquisition system, data visualization system and introduce the experimental setup at the end of this chapter.

3.2 Project Development

The first stage of the project starts with the literature review. Some cases and findings related to current techniques for the detection of CO_2 and $PM_{2.5}$ has been done to enhance the knowledge and identify the possibility and the potential of using an electronic system to measure the concentration of CO_2 and $PM_{2.5}$. The planning activities take place after the literature review. The activity in next stage is identify project specification. The selection of the materials and hardware components that planned to be used in the project is decided in this stage.

After the planning, the development of the project goes into the design phase. In this study, the design tasks are further divided into several components or phases. The details of each design are discussed in the following sections. After completing the design, each components or system developed is tested and the performance of the system is verified based on several criteria. After completing the requirements of the study, some suggestion and future works are recommended at the end of the project development stage for future improvement. The flow chart of the project development is presented is Figure 3.1.

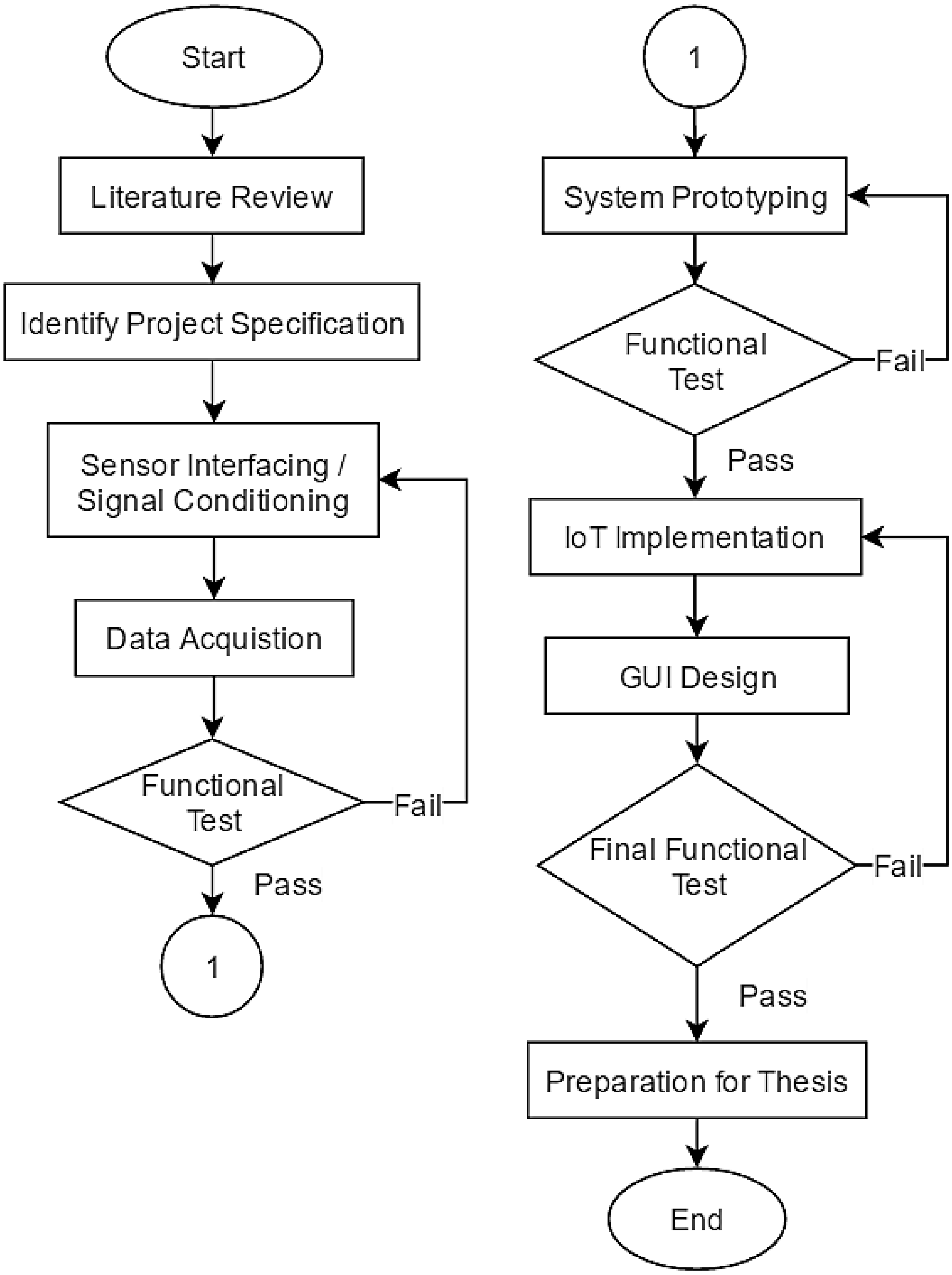

Figure 3.1: Flow chart of the project development

3.3 Project Description

In this study, there is two sensors used for monitoring the air quality. MQ-135 and GP2Y1010AU0F sensors used for monitoring the concentration of CO_2 and $PM_{2.5}$ respectively. First step in this project is to determine the circuit implementation of the sensors from the datasheets provided on Internet. Next, the formula of data acquisition by using the sensors need to be determined. The formula is transformed into the program code to integrate with two microcontrollers that are Intel Galileo and Arduino Pro Mini. The program code is written in JavaScript and Arduino IDE for Intel Galileo and Arduino Pro Mini respectively. The data acquisition and analyzing will be done on both processing platforms, and the data from Arduino Pro Mini will be sent to Intel Galileo via I^2C after analyzed. The analyzed data from both sensors will be displayed on the LCD1602.

To visualize the data on Internet, the analyzed data collected by Intel Galileo will publish to MQTT for the integration with the cloud platform, IBM Bluemix. In the IBM Bluemix, Node-RED Starter is used to create a webpage to visualize the data. In the Node-RED editor, ibmiot input node is used to subscribe the data from MQTT. Then, the data is send to the websocket output node to integrate with the webpage created by the html and JavaScript codes. The data will be received and updated continuously to the webpage to implement as live display of data. The GUI of the webpage is designed to be user friendly that is only important information will be highlighted and displayed. The block diagram of the IoT-Based air monitoring system is illustrated in Figure 3.2.

In addition, all the components used in the hardware development is listed in Appendix. All the chosen components are based on the availability in the Online China Market (Taobao).

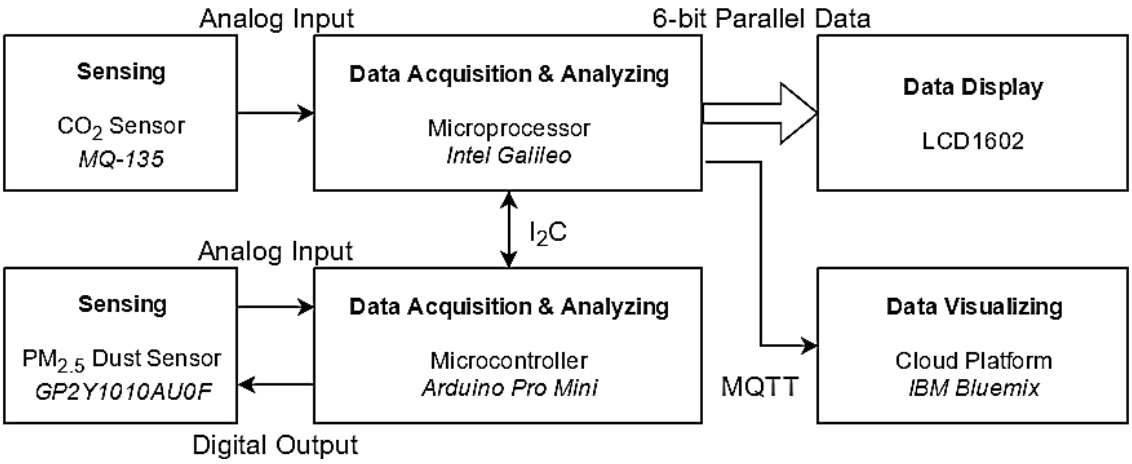

Figure 3.2: Block diagram of IoT-Based air monitoring system

3.4. Sensor Modules

To implement low cost and sufficient sensitive system, the MQ-135 gas sensor and GP2Y1010AU0F dust sensor will be integrated in this system. The circuit implementation and formula to obtain the accurate data from the sensor will be discussed in the following section.

3.4.1 MQ-135 Gas Sensor

MQ-135 is a metal oxide semiconductor gas sensor which uses SnO_2 semiconductor as the sensing element. It has a low conductivity with clean air. The sensor's conductivity is much higher along with the gas concentration rising when the target combustible gas exists. MQ-135 gas sensor has high sensitivity to Ammonia, Sulfide, Benzene, Carbon Dioxide and also sensitive to smoke. It is low cost and capable to use for long life. Only simple electro-circuit is needed to convert change of conductivity to correspond output signal of gas concentration. The recommended load resistance (R_L) for the circuit is about 20 kΩ (10kΩ to 47 kΩ) [28].

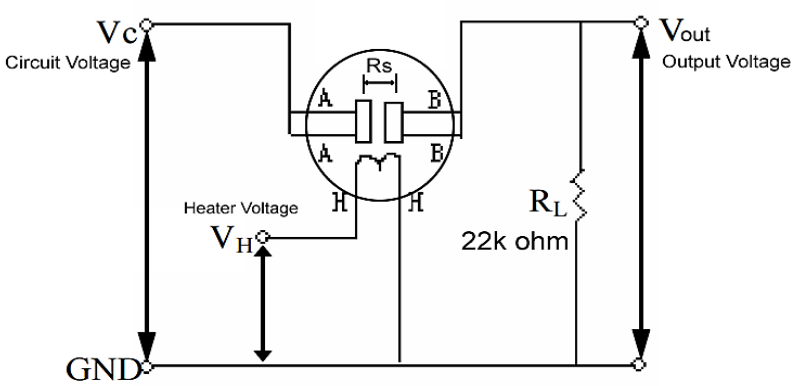

Figure 3.3: Measuring circuit for MQ-135 gas sensor [28]

The connection of the circuit for MQ-135 gas sensor to perform measurement is shown in Figure 3.3. A constant 5V DC is supplied as the power source of the circuit voltage (V_C) and the heater voltage (V_H). The resistance of the sensor (R_S) will decrease in high concentration of CO_2. The load resistance (R_L) is connected in series with R_S, the output voltage across R_L increases as R_S decreases. The relationship between the output voltage, load resistor and the resistance of the sensor is expressed by the Equation 3.1 [36].

$$V_{out} = \left(\frac{R_L}{R_L \times R_S}\right) \times V_C \tag{3.1}$$

To convert the raw data to the parts per million (ppm) for CO_2, a calculation is needed. The relationship between the resistance of the sensor (R_S), load resistance (R_L), sensor resistance at 100ppm of NH_3 at the clean air (R_O), voltage output (V_{out}) and *ppm* of CO_2 is expressed in the Equation 3.2 and 3.3 [36].

$$R_S = (1023/V_{out} - 1) \times R_L \tag{3.2}$$

$$CO_2\ [ppm] = 116.6020682\ (R_S/R_O)^{-2.769034857} \tag{3.3}$$

The calibration is needed to determine the value of R_O. It is obtained by running the test at open area for 1 hour with set the ppm to the current amount of CO2 gas in atmosphere.

3.4.2 GP2Y1010AU0F Dust Sensor

GP2Y1010AU0F is a dust sensor by optical sensing system. It measures the dust density by the reflected light of dust in air with sensitivity of 0.5V/0.1µg/m^3 (micrograms per cubic metre). The light is emitted by an infrared emitting diode (IRED) which is arranged diagonally with phototransistor into this device. It is effective to detect very fine particle especially the cigarette smoke. The measured range of dust density is from 10µg/m^3 to 500µg/m^3 [31].

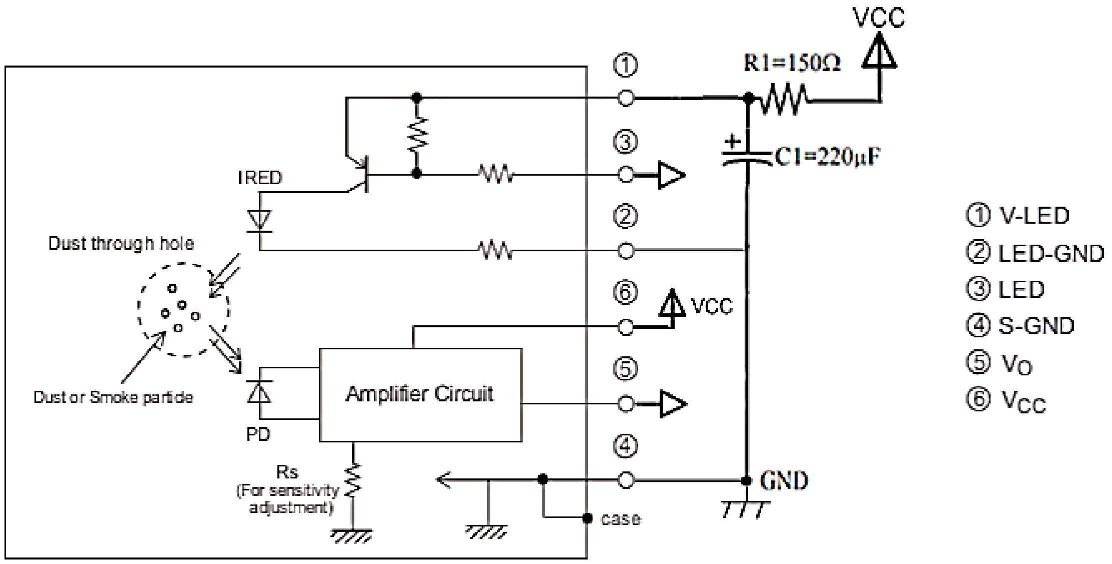

Figure 3.4: Measuring circuit for GP2Y1010AU0F dust sensor [31]

The circuit for GP2Y1010AU0F dust sensor is constructed as shown in Figure 3.4 to measure the dust density. A resistor and capacitor are connected series between voltage supply (V_{CC}) and ground (GND) for the purpose of voltage level stabilization. This connection is required for the pulse drive for the IRED which is connected to V-LED. These component cannot work without this connection. A constant 5V DC is supplied to the circuit voltage (V_{CC}), whereas the LED-GND and S-GND is grounded. To drive the IRED, a digital pulse-driven wave of 0.32ms and a period of 10ms is send to Pin 3 (LED) as shown in the Figure 3.5.

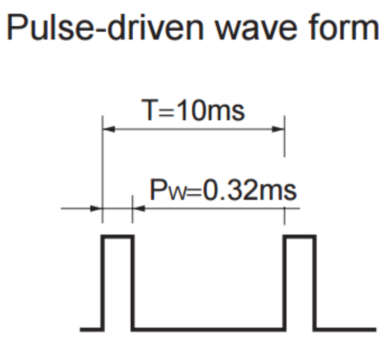

Figure 3.5: Input condition for LED input terminal [31]

The sampling time of output pulse is 0.28ms as illustrated in Figure 3.6. Hence, the data is read from V_O as analog input during 0.28ms after drive the IRED to HIGH.

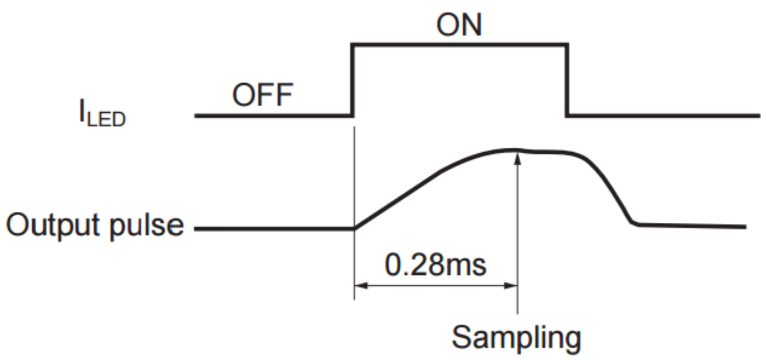

Figure 3.6: Sampling timing of output pulse [31]

The relationship between the analog output, A_O and dust density [μg/m^3] is expressed in the Equation 3.4 [37].

$$Dust\ Density\ [\mu g/m^3] = (0.1714 \times (A_O/1023 \times 5) - 0.1) \times 1000 \qquad (3.4)$$

This equation is limit to the range of 0.583V to 3.76V as shown in Figure 3.7.

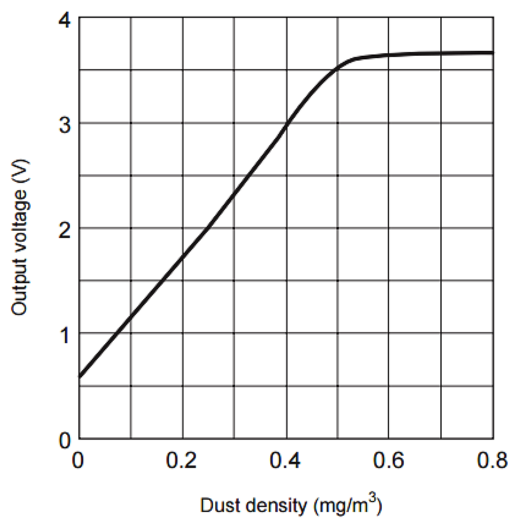

Figure 3.7: Graph of output voltage versus dust density [31]

3.5 Data Acquisition System

The data acquisition system is separated into 2 parts. Both parts also involved a microcontroller. One is Arduino Pro Min, whereas another one is Intel Galileo. Each of them will be integrated with one sensor to acquire data. The reason of using two processing platform instead of using only the Intel Galileo is that it takes a long period to perform analog read. It causes error while takes reading from GP2Y1010AU0F dust sensor. Hence, Arduino Pro Mini needs to be used to integrate with GP2Y1010AU0F dust sensor, whereas Intel Galileo is used to integrate with MQ-135 gas sensor. The block diagram of the data acquisition system is illustrated in Figure 3.2. More details will be discussed in subsequent section.

3.5.1 GP2Y1010AU0F Dust Sensor Measurement

The measurement of GP2Y1010AU0F dust sensor is done by integrate with Arduino Pro Mini. It is programmed by using Arduino IDE. Its schematic and flow chart of the behavior of the system will be discussed in subsequent sections.