DEVELOPMENT OF REAL TIME AIR QUALITY MONITORING SYSTEM

FINAL REPORT

Name: Ahmad Aideed Bin Zaini

ID Number: 18268

Supervisor: Dr. Huzein Fahmi Bin Hawari

Location: 23-03-29

Co-Supervisor: Dr. Mohamad Radzi Bin Ahmad

DEVELOPMENT OF REAL TIME AIR QUALITY MONITORING SYSTEM

by

AHMAD AIDEED BIN ZAINI
18268

Dissertation submitted as partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical and Electronic)

JANUARY 2017

Universiti Teknologi PETRONAS
32610 Bandar Seri Iskandar
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

DEVELOPMENT OF REAL TIME AIR QUALITY MONITORING SYSTEM

By

Ahmad Aideed Bin Zaini

18268

A project dissertation submitted to the
Electrical and Electronic Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (HONS)
ELECTRICAL AND ELECTRONIC

Approved by,

____

DR HUZEIN FAHMI BIN HAWARI

UNIVERSITI TEKNOLOGI PETRONAS

SERI ISKANDAR

JANUARY 2017

CERTIFICATION OF APPROVAL

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the reference and acknowledgements, and the original work contained herein have been undertaken or done by unspecified sources or persons.

____

AHMAD AIDEED BIN ZAINI

ABSTRACT

This dissertation presents a project entitled Development of Real Time Air Quality Monitoring System, which generally a project that develop a device that capable to detect and measure the air pollution index (API) in the surrounding area. The device developed is cheaper in cost, portable and reliable capability. The project strategy is to integrate the sensor components for detection and measurement, communication module for information output into the Arduino Microcontroller. The measurement is synchronized to the API system used in Malaysia and global Air Quality Index (AQI) system exclusively for $PM_{2.5}$ sensor. The device has capability to detect Good, Moderate, Unhealthy, Very Unhealthy and Hazardous API status. When Unhealthy API status detected, the device will inform the user through the communication module. The 5 weeks of API monitoring using the device successfully done and the data has been compiled and analyzed. This project extended its scope to explore the Internet of Things (IoT) trends by implementing IoT function to the remote sensing API device.

TABLE OF CONTENTS

LISTS OF FIGURES

LISTS OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Malaysia is one of the countries that have been severely affected by haze for the past 10 years. The number of acute respiratory disease cases is spiking approximately 60% because of haze [1]. In addition, studies shown that the long term of continuous exposure towards high surrounding pollution $PM_{2.5}$ promotes higher risks of cardiovascular disease [2].

Social awareness towards the surrounding air quality has increased the demand for real time air quality information. The incapability of gaining real time air quality results has made planning of activities challenging with unpredictable conditions. The curiosity about how good or bad the condition the air is simply common information needed to know by the humankind. Essentially, the development of Air Quality Index (AQI) or Air Pollution Index (API) is example of indicators and expressions towards the quality level of air surroundings.

In each country, the system readings for measuring the quality of air is different based on interpretation of the pollutant concentration related to the health effect. In addition, the pollutant type measured by each country different based on the pollutant that is more likely to affect the people in the country. Most commonly measured air pollutants to be expressed in the air quality measuring system including Ground Level Ozone (O_3), Particulate Matter ($PM_{2.5}$ or PM_{10}), Carbon Monoxide (CO), Sulphur Dioxide (SO_2) and Nitrogen Dioxide (NO_2) [3]. Additionally, Lead (Pb) has been one of the pollutants most inconsistently to be concern by the global.

The Air Pollutants divided into 2 types, which are gaseous pollutant and dust pollutant. For gaseous pollutant including ozone, carbon monoxide, sulphur dioxide and nitrogen dioxide, the main unit measurement which is in volumetric unit which is Part per Million (ppm) or Part per Billion (ppb) while also can be measured by using gravimetric units which is micrograms per cubic meter of air ($\mu g/m^3$). While for dust pollutant, Particulate Matter (PM) used to represents the size of the particle of dust. PM_{10} means dust particle, which sized 10 micrometre in diameter, or less while $PM_{2.5}$ is sized 2.5 micrometre in diameter or less. $PM_{2.5}$ recently to be concern by some of the country and included it in their AQI system. $PM_{2.5,}$ PM_{10} and Lead (Pb) measured by sensing its existence in micrograms per cubic meter of air ($\mu g/m^3$) unit.

Globally, the time averaging used to measure the air pollutants level to relate the short-term exposure each pollutant type to the humankind related to their health effect. In API or AQI, the concentration of the pollutant exists in the air measured are based on the given time average. The air quality level then will be indexed based on the pollutants' concentration can be exposed to the humankind by consideration of the health condition for the given averaging time [4].

Table 1. API Status in Kuala Lumpur from 1999 to 2007 [5]

Year	Number of Days Based on API		
	Good	Moderate	Unhealthy/Hazardous
1999	56	293	16
2000	137	217	12
2001	27	327	11
2002	3	217	30
2003	2	334	28
2004	23	280	63
2005	64	234	67
2006	67	293	5
2007	104	242	19

Similar to other countries, Malaysia also has developed own air quality monitoring system named Air Pollution Index (API). It is amendment on the previous system used, Malaysia Air Quality Index (MAQI) introduced through study by University Pertanian Malaysia in 1993 currently known as University Putra Malaysia. The first air quality guidelines produced by Department of Environment Malaysia in 1989, which been known as Recommended Malaysia Air Quality Guidelines (RMG). It has been the first reference towards the development of the Malaysian Air Quality Index (MAQI) [6].

The current system developed through study, which closely guided based on the Pollutant Standard Index (PSI) developed by the United States Environmental Pollution Agency (US-EPA) such as in the aspect of system computation technique [6]. The air pollutants included in the Malaysia's API system are Carbon Monoxide (CO), Ozone (O_3), Nitrogen Dioxide (NO_2), Sulphur Dioxide (SO_2) and Particulate Matter 10 (PM_{10}). The ranges of the API index values are categorised into five, which are Good, Moderate, Unhealthy, Very Unhealthy and Dangerous. Each of the index categories reflected to each of the air pollutants criteria, which are the concentration and averaging time.

Malaysia Air Pollution Index reading calculated for 24 hour of process cycle as the PM_{10} lowest averaging time is 24 hours [6]. The hourly API computed based on the air quality monitoring station located all over the country. The API readings for each located air quality monitoring station can be access on the Air Pollutant Index of Malaysia (APIMS) website. Currently, Malaysia does not have the API forecasting system as it is still in the development progress and expected to be implementing on 2020. Compared to the other AQI system like Singapore, where the $PM_{2.5}$ has been included in the air quality monitoring system, Malaysia is still in the process of finalizing the new Air Quality Guideline to come out with a system where $PM_{2.5}$ measurement considered in the monitoring process [7]. The research and development of the air quality indexing and monitoring system continuously progressed globally to ensure the system is acceptable and synchronize for the current situation for each country.

1.2 Problem Statement

Malaysia's API has been established since 1993 and still being used until today as reference to the level of the air pollution in the country. The higher number of the API represents the higher the severity towards human health. However, most of the existing API measuring systems are relatively massive in size and expensive [13].

Figure 1. An AQI Monitoring Station [12]

As the weather is unpredictable and the industrial activities are different for each area, the level of air pollution is also different. Hence, the information given from the DOE is not that accurate for each of the civilians throughout the country. Furthermore, the Malaysia Department of Environment (DOE) processed the data for every 24 hour [6] and only covers major cities and specific area which could result of inaccurate or delayed reading to the public [7]. According to The Star on September 16^{th}, 2015, Malaysians annoyed with the very short notice of school closing due to the unhealthy of haze level [8]. In addition, Malaysia's API still using PM_{10} measurement for haze while countries such as Singapore already using $PM_{2.5}$ measurement for the air quality monitoring.

1.3 Objectives

The main objectives of this study are:

1) To develop a low cost and portable air pollution index (API) device using microcontroller and sensors.
2) To develop a real time API monitoring system by integrates the Arduino microcontroller, sensors (gas, dust, temperature & humidity) with the communication module (GSM).
3) To establish an API monitoring system with $PM_{2.5}$ sensing capability in Malaysia.

1.4 Scope of Study

The scope of the project will be covering the study of the API measuring system to synchronize with the detection sensitivity capability of the prototype. The prototype air pollution detection will consists of Carbon Monoxide gas and dust particle pollution using $PM_{2.5}$ detection type. The project scope also includes the gas and dust sensor integration with the Arduino microcontroller and the temperature and humidity sensor. The development of data transmission method from GSM module to the mobile devices via short message service (SMS) will be includes in the study. Although it is not in the objectives, this project has been extended to perform monitoring using IoT.

CHAPTER 2

LITERATURE REVIEW

2.1 Metal Oxide Semiconductor Operating Principle

Metal Oxide Semiconductor (MOS) sensor is one of the widely gas sensor available. Concentration of gaseous such as CO is able to be measured by using MOS type of sensor such as Figaro TGS 2600 and MQ-7. The typical metal oxide used in Tin Dioxide (SnO_2). The oxidation process simply occurs when the combustible gases exposed towards the surface of the metal oxide [9]. This process results deceasing of sensor resistance as the electrons flow easily. Hence, the gas concentration measured based on the change of sensor resistance.

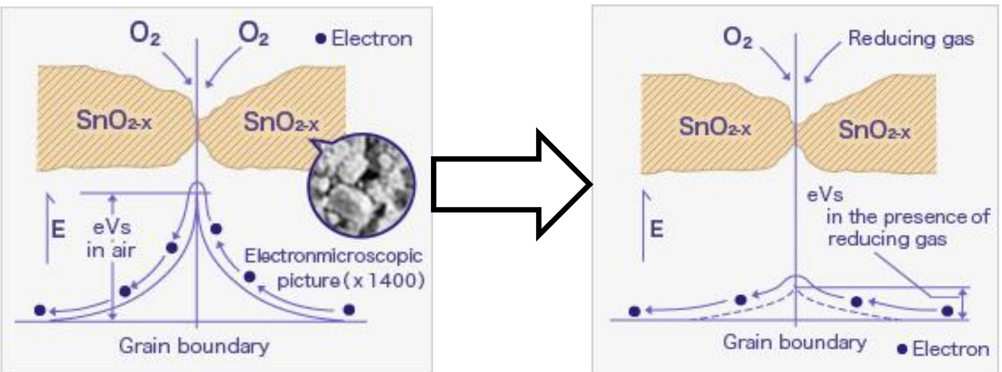


Figure 2. MOS Operating Principle [9]

2.2 Dust Concentration Measuring Principle

Dust concentration measured by using optical sensing technique. The optical sensing mechanism is using Light Emitting Diode or Infrared (IR) Emitting Diode [10]. The IR diode located diagonally with the photodiode and the presents of dust molecule passing through the light pathway, results the light reflected towards the photodiode and hence the output voltage generated [10].

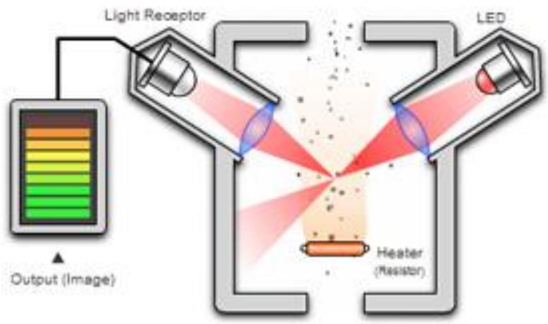


Figure 3. Dust Concentration Measurement based on Optical Sensing [10]

2.3 Air Quality Monitoring Existing Models

Ruslan N. had developed a low cost portable air quality monitoring system device based on real time system [11]. The system constructed by integrating the Sharp GP2Y1010AU0F sensor, Arduino Uno, ATMEL ATmega328-based microcontroller and LCD Keypad Shield. The system built will only measures the dust pollutant in the surroundings air and the system results compared to the Malaysia's Air Pollution Index (API) by measuring 5 different locations. However, the specifications of $PM_{2.5}$ and PM_{10} detection does not specified in this research and only the dust density range has been considered and compared to the Malaysia API system.

In 2012, a micro-scale version of air quality monitoring system for measuring the air quality in the urban areas has been developed [13]. The system featured with the wireless technology integrated with global system for mobile communication (GSM). Data transmission among the fixed air quality monitoring stations located throughout the urban area where the sensors equipped. The air quality information stored in the database through the gateway which accessible for the users. The air pollutant monitored by the system is temperature and humidity by using Weather Station Module (WS-2316) and Carbon Monoxide (CO) by using MiCS-5525 semiconductor based sensor. The Wireless Module integrated in the system is the Octopus II, TI MSP430-based microcontroller that can perform the digital and analogue conversion equipped with the General Pin Input Output (GPIO) to receive the data of CO, temperature and humidity measurement.

Suyuti et al. have designed a Carbon Monoxide Gas Detector in 2012, which the system based on ATMEGA8535 microcontroller [14]. The idea of the project is to integrate the gas sensor with ATMEGA8535 as data processing unit and visualize the output via LCD screen and computer through communication network. The sensor used in this project is Figaro TGS 2600 for Carbon Monoxide gas detection. The ATMEGA8535 programmed under CodeVision AVR V2.03.4 programming environment. While Microsoft Visual Basic used as the programming platform for the output visualization. The data transmission been proposed to use such as coaxial cable or GSM based on the capability of the microcontroller and it is not developed in this project. The device tested indoor and outdoor. For outdoor device testing, the results taken 30 minutes on the morning, noon and evening at the street and industrial area while the device tested in a room for indoor measurement.

An industrial air pollution monitoring system designed by Edward O. O. in 2014 by using microcontroller based data acquisition [15]. The microcontroller used in the project is the PIC18F4550 and the Carbon Monoxide sensor integrated in the system in the MQ-7 gas sensor. The aimed of the project is to measure the level of Carbon Monoxide in the steel company. The system comprised on three parts circuits, which are power supply unit, signal conditioning unit and alarm, display and MCU unit. The LCD display used as the output visualization.

Another indoor air quality monitoring developed by using mbed LPC1768 microcontroller based on 32-bit ARM cortex M3 processor. Witte T. F. considers the Volatile Organic Component (VOC) as the components to be measured which related to the air quality performance [16]. VOC generally comprised of several components, which cause on health effects. The Figaro TGS2602 used to detects the VOC, as it is capable to measure several different VOC components including

Hydrogen, Ammonia, Ethanol, Hydrogen Sulphide and Toluene while the Sense Air S8 optical sensor used in the system to measure the Carbon Dioxide concentration level. The system also equipped with temperature and humidity sensor, DHT22 to give a relative measurement for the air quality level.

An air quality monitoring reporting system developed by Shariff S. S. in 2015 by using Arduino Mega microcontroller [17]. The system has the capability to detect dust pollution in the air and give a text message to the mobile devices. The sensor used in the project is Sharp GP2Y1010AU0F. The system measurement has been interface to be according to the Malaysia Ambient Air Pollution Level.

Polluino, an air quality monitoring device enhanced with the implementation of Internet of Things (IoT) trends into it [18]. By using cloud data management, it is able to manage the monitoring data efficiently. For a device which not focusing on the low-cost aspect, it has eleven gas sensors attached for detection of Propane, Ethanol, Methane, Carbon Monoxide, Ozone, Benzene, Hydrogen Sulphide, Ammonia, Toluene, Carbon Dioxide, Nitrogen Dioxide and a PM sensor, SHARP GP2Y1010AU0F. Another five sensor attached are classified as environmental sensor, used for detection of Temperature, Humidity, Flames, Raindrops and Light Intensity. Using the Arduino Uno as microcontroller, ESP8266-01 wireless shield integrated to perform the wireless communication to the *ThingSpeak* Cloud Service for the IoT function. It stated somehow in the research that GSM or 3G communication network approaches considered to be implemented in the system as the Wi-Fi connection is not always available and the Wi-Fi connectivity itself has a shorter range.

A crowd-sensing based air quality monitoring device called AirSense is another slightly similar concept to the Polluino which use the cloud as data management medium [19]. This system use Bluetooth module HC-05 to connect the device to the smart phone. By using its mobile phone application, the data transferred to the cloud for data management. However, the range of Bluetooth connectivity of the devices still limited. The gas sensor used in the system is only MQ-135 air quality gas sensor.

An air quality monitoring device model embedded-based system proposed using integration of MQ-7 CO sensor, DHT22 temperature and humidity sensor and GP2Y1010AU0F PM Sensor [20]. However, the system CO severity index is set to 30ppm as the permissible exposure level. The level of the PM exposure of the device is vary depends on the user's sensitivity. Basically, the API of the system is not standardized to a fixed developed API by the country. The GSM module used in the system to trigger the user if the level of pollutants detected reached the maximum exposure allowed which has been set.

Table 2 shows the comparison of each of the projects that been reviewed in the project research as the basis of the implementation of the complete API monitoring system.

Table 2. Comparison of Related Studies

Project Title	Project Description	Advantages	Disadvantages
Air Pollution Index (API) Real Time Monitoring System [11]	• Arduino Uno • PM detection • LCD Keypad Shield.	• Portable • Inexpensive	• No gas detection • No network connectivity
An Air Quality Monitoring System for Urban Areas Based on the Technology of Wireless Sensor Network [13]	• MSP430 microcontroller • CO detection • Octopus II Wireless • WS-2316 Weather Station Module • GSM Module	• Wide monitoring area and data transmission	• Non-portable • Very expensive • No PM detection
Microcontroller ATMEGA8535 based Design of Carbon Monoxide (CO) Gas Detector [14]	• ATMEGA8535 microcontroller • CO detection • Propose a data transmission system.	• Portable • Inexpensive	• No PM detection • No network connectivity

A Microcontroller Based Data Acquisition System for Industrial Air Pollution Concentration Measurement in Nigeria [15]	• PIC18F4550 microcontroller • CO detection • LCD.	• Portable • Inexpensive	• No PM detection • No network connectivity
Development of An Indoor Air Quality Monitoring System based on a Microcontroller [16]	• LPC1768 microcontroller • Figaro TGS2602 • Sense Air S8 CO optical sensor • DHT22.	• Portable • Inexpensive	• No PM detection • No network connectivity
Real Time Air Quality Reporting System [17]	• Arduino Mega microcontroller • PM Detection • GSM module	• Portable • Inexpensive	• No gas measurement • No $PM_{2.5}$ detection
Polluino: An efficient cloud-based management of IoT devices for air quality monitoring [18]	• Arduino Uno • 11 Gas Sensors • PM detection • 5 Environmental Sensor • ESP8266-01 Wireless Shield	• Portable • Cloud-based management	• Short Range of Connectivity • Very Expensive • No $PM_{2.5}$ detection
AirSense: Opportunistic crowd-sensing based air quality monitoring system for smart city [19]	• Arduino Pro Mini • Bluetooth • 6 Gas Detection • Android Application	• Portable • Inexpensive	• Short Range of Connectivity • No PM detection

An embedded system model for air quality monitoring [20]	• Arduino • CO, Temperature, Humidity and PM detection • GSM Module	• Portable • Inexpensive	• No $PM_{2.5}$ detection

CHAPTER 3

METHODOLOGY

3.1 Introduction to API Monitoring System

For the completion of this project, a set of steps required in order to make sure that the project implemented properly. The project started with the review of International AQI System as well as existing Malaysia AQI system. Research methodology and review of literature was carried out throughout the project completion. To ensure that latest information gained about the project scope, the hardware selection carried out through equipment review.

The core part on the project completion is on the development of functional device. The process flow started with the circuit integration and programming followed with the system calibration and functionality test. Data collection and statistical analysis was carried out using the device developed and the documentation for the post project towards the end of the project.

The implementation of API monitoring system will have the capability of measure, visualize the information processed and transfer the information via the SMS. Figure 4 shows the block diagram of the proposed API monitoring system.

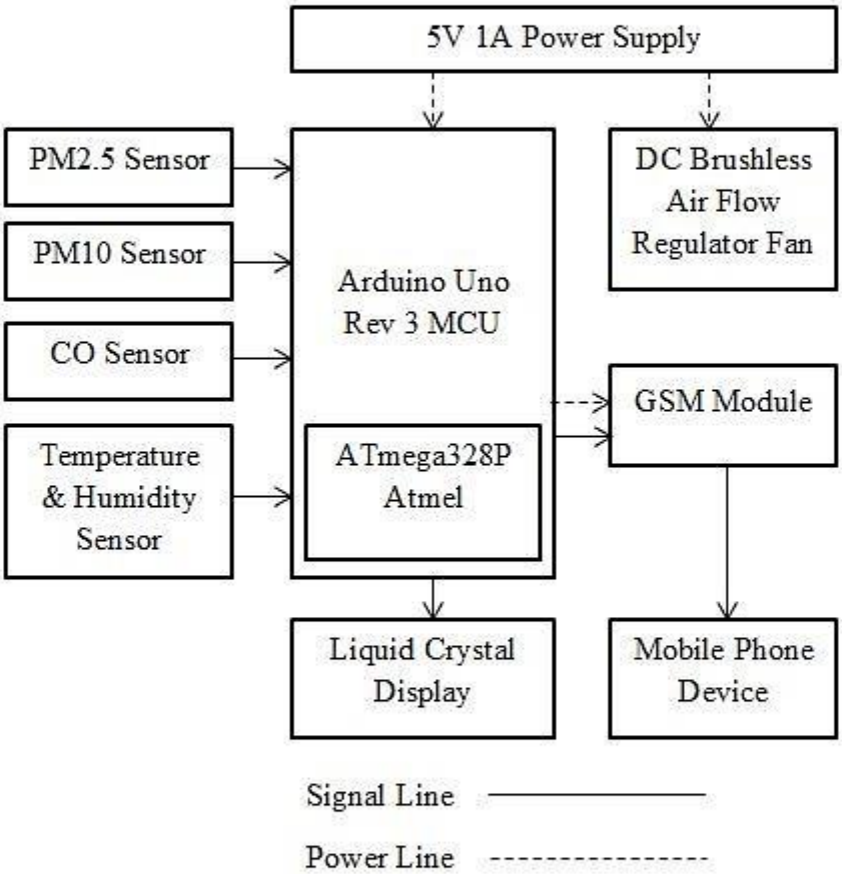


Figure 4. API Monitoring System Block Diagram

The Figure 5 below represents the process flow of the study. The project process flow covering the task planned throughout the completion of the project.

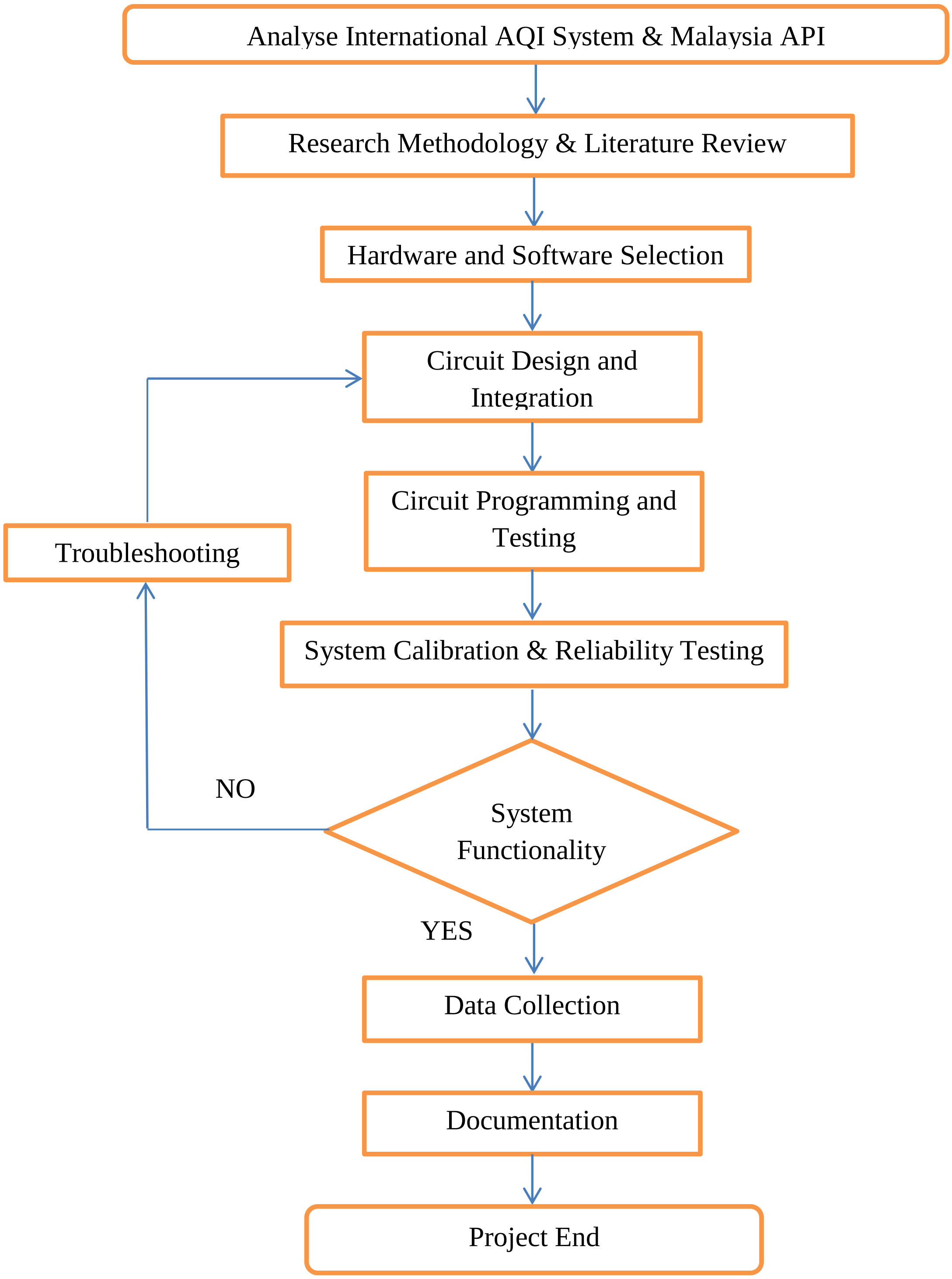


Figure 5. Process Flow of the Study

3.2 Hardware and Software Selection

The hardware integrated in the system selected based on the specifications, which is capable to fulfil the requirements of the API pollutants concentrations scale. The sensors selected ensured to be capable of detecting the concentration range, which covered in the API scale. The Table 6 below shows the sensors selected and detection capability.

Table 3. Sensors Detection and API Pollutants Concentration Range

Sensors	Type of Pollutants	Detection Range	API Pollutants Concentration Range [6][21]
Figaro TGS 2600 [22]	Carbon Monoxide	1 – 100 ppm	0 – 57.5 ppm
SHARP DN7C3CA006 [23]	$PM_{2.5}$	25 – 500 µg/m^3	0 – 500 µg/m^3
SHARP GP2Y1010AU0F [24]	PM_{10}	0 – 500 µg/m^3	0 – 600 µg/m^3
DHT22 [25]	Temperature & Humidity	Humidity: 0-100% Temperature: -40-80˚C	-

There are also modules used to implement the system including Arduino Microcontroller, LCD Keypad Shield and GSM Shield. Each of the modules selected to fit its functions in the API Monitoring System. The Table 7 below shows the modules used and its specifications.

Table 4. Modules and Specifications

Module	Function	Specifications
Arduino Uno Microcontroller	Processing Unit	ATmega328P Based
LCD Keypad Shield	Output Display	16x2 Display
GSM Module	Communication Unit (Sending Text Message)	SIM900 Series

3.2.1 Figaro TGS2600

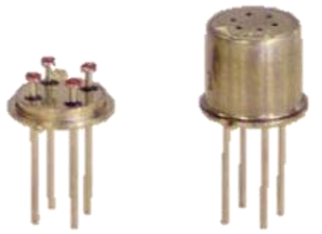


Figure 6. FIGARO TGS 2600 Air Contaminants Sensor [22]

The Figaro TGS 2600 is a sensor that has sensing mechanism of a metal oxide semiconductor. It is a contaminants sensor that capable of measuring the concentration of Methane, Carbon Monoxide, Iso-Butane, Ethanol and Hydrogen. The applications of this sensor are for Air Cleaners, Ventilation Control and Air Quality Monitors [22]. In order to integrate the sensor in a system, a simple circuit implemented as shown in the Figure 7 below.

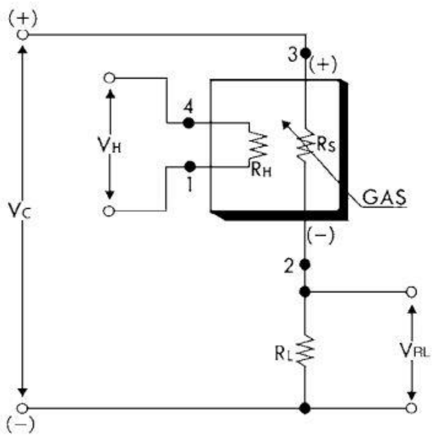


Figure 7. TGS 2600 Circuit [22]

Where: 1 & 4: Heater Pin

2 & 3: Sensor Negative and Positive Electrode

Vc: Supply Voltage

RL: Load Resistance (Used is 10kΩ) with Voltage across it as Output Voltage, V_{RL}.

3.2.2 SHARP DN7C3CA006

Figure 8. SHARP DN7C3CA006 $PM_{2.5}$ Sensor [23]

The SHARP DN7C3CA006 is the latest dust sensor manufactures by SHARP Corporation. The sensor’s system block shown in Figure 9 below.

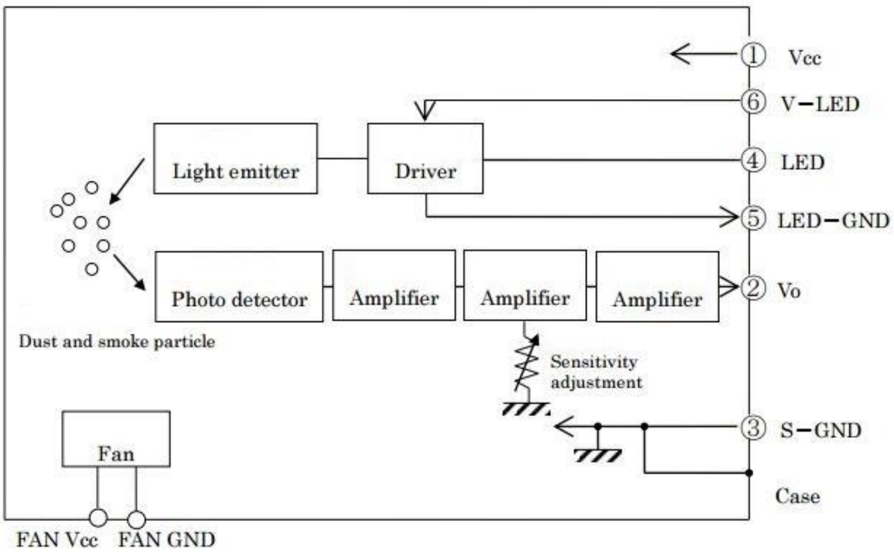


Figure 9. SHARP DN7C3CA006 $PM_{2.5}$ Sensor System Block Diagram [23]

Based on the system block diagram above, the $PM_{2.5}$ sensor has a fan that helps to circulate the dust through the detection channel. The operating voltage is rated at 5 V, which is compatible to integrate with Arduino Uno Microcontroller.

3.2.3 SHARP GP2Y1010AU0F

Figure 10. SHARP GP2Y1010AU0F PM_{10} Sensor [24]

The PM_{10} dust sensor operating based on optical sensing system of Infrared Emitting Diode (IRED) [24]. It is the first version of dust sensor by SHARP that is before the implementation of SHARP DN7C3CA006. It is very effective on measuring very fine particle in the air. The working principle is the same as the $PM_{2.5}$ sensor which converting the sampling of output pulse into analogue output voltage. The characteristic of Output Voltage in relation to the Dust Density is as shown as Figure 11 below.

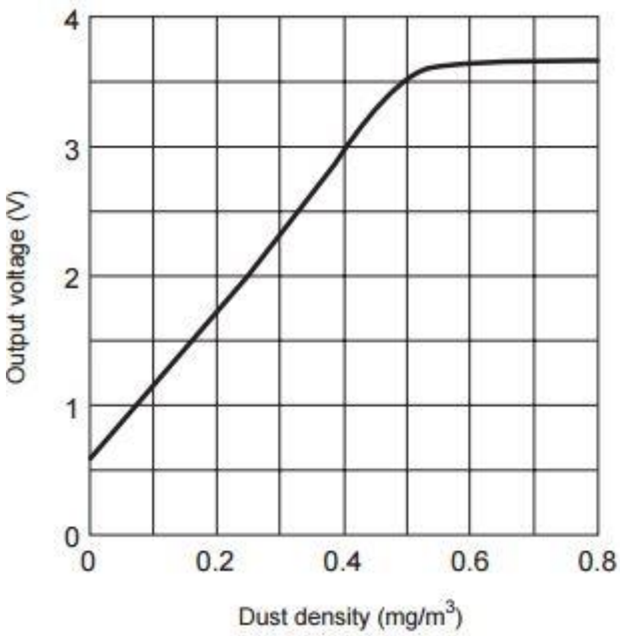


Figure 11. Output Voltage versus Dust Density for PM_{10} Sensor [24]

3.2.4 Arduino Uno Microcontroller

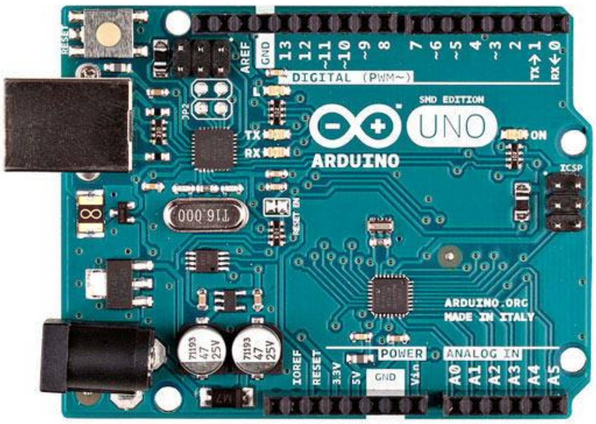


Figure 12. Arduino Uno

The Arduino Uno is ATmega328P based microcontroller. It has operating voltage of 5V with recommended Supply Voltage ranging from 7V to 12V [29]. Equipped with 14 Input Output pins consisting six analogue pins and 6 PWM digital pins, it is sufficient to handle the Air Monitoring Device system. Its small dimension of 68.6mm by 53.4 mm is ideal for portable system implementation. TGS 2600 and SHARP GP2Y1010AU0F sensors both use the Analogue pins while DHT22 use Digital pin to give input signal to Arduino Uno.

3.2.5 GSM Module

Figure 13. GSM SIM900A Module

The GSM Module shown in Figure 13 built with Dual Band of 900/1800 MHz based on the SIMCOM SIM900A modem [26]. The module can be controlled by the Arduino Microcontroller by using modem commands called AT commands. Voltage supply specification of 5V makes it compatible to integrate with Arduino Uno microcontroller.

3.3 System Integration

The system based on Arduino Uno MCU has been integrated with sensors hardware selected which are consists of TGS2600 CO sensor, GSM SIM900A modem, LCD Keypad Shield, DHT22 temperature and humidity sensor, GP2Y1010AU0F PM sensor and DN7C3CA006 $PM_{2.5}$ sensor. A closed hard case of the device will be developed later which will be equipped with air low regulator to promote suction of air from surroundings.

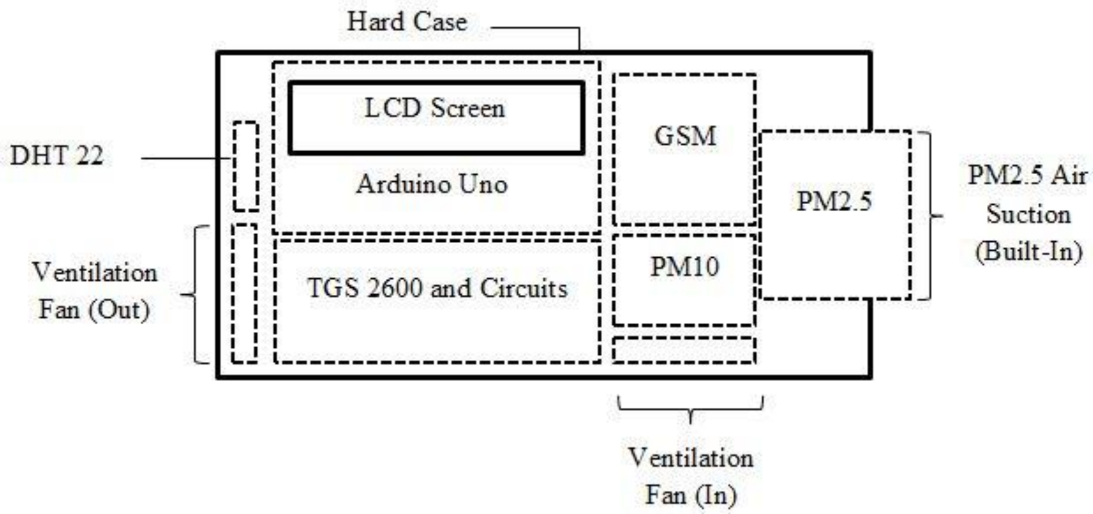


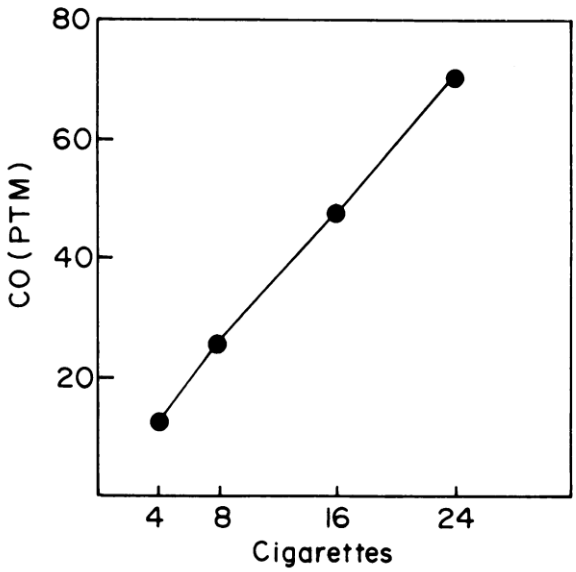
Figure 14. System Integration

Figure 15. Developed API Monitoring Device Prototype

The device will stabilizing first right after it turned on for 15 minutes in order to make sure the TGS 2600 CO sensor to be ready. During the system stabilizing, the results of surroundings air quality still able to monitor via the LCD Keypad Shield. It is important to let the sensor ready to ensure results accuracy. If it is able to stabilize less than 10 minutes, it will proceed to monitor the surroundings air quality with reliable results. The system will send text message for a certain time interval if the API status changed to Unhealthy, Very Unhealthy and Hazardous.

3.4 Sensor Calibration

To ensure the readings from sensors is consistent with measurements, TGS 2600 need to be calibrated. The other sensors integrated in the system not need to be calibrated as they are already calibrated by the manufacturer. The TGS 2600 sensor calibrated by referring to the information gathered in a research paper [27] and TGS 2600 sensor datasheet [22].



*Erratum of PPM instead of PTM on Y-axis

Figure 16. CO Concentration in 25m^3 of Closed Space [27]

The TGS2600 has two resistance parameter related to the CO concentrations. There are sensor resistance, Rs, and sensor's MOSFET constant resistance parameter, Ro. The Rs value changed due to the change of CO concentration while Ro is a constant resistance value of the MOSFET layer. Thus, Ro value has to be determined. The Ro value can be determine by giving a surroundings with a certain CO concentration, which done by referring to the Figure 15 above. Then, the relativity of the CO concentration to the Rs and Ro ratio values can be referring in the Figure 16 below.

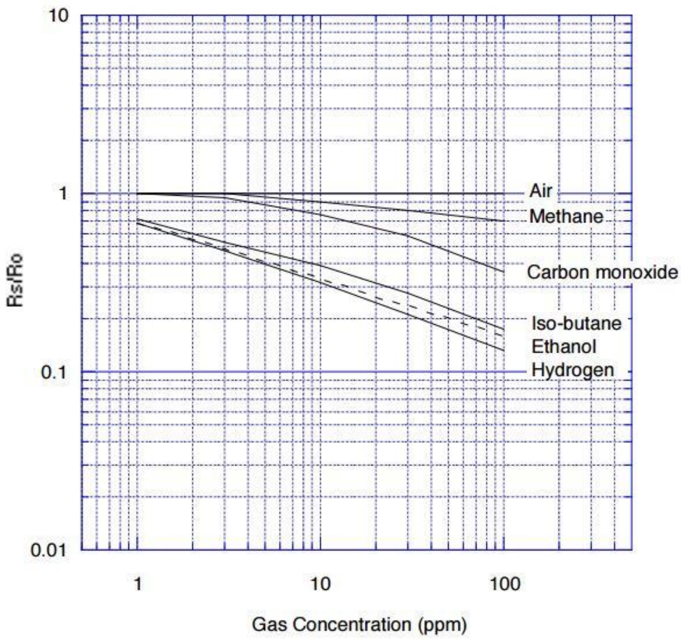


Figure 17. TGS2600 Characteristics Curve [22]

To determine Rs and Ro ratio value, we use the formula of $\alpha = \frac{\frac{Vc \times RL}{Vout} - RL}{Ro}$

Where: α = Rs and Ro Ratio value

Vc = Supply Voltage

RL = Load Resistance (used is 10kΩ)

Vout = Output Voltage

By referring to the CO concentration characteristic curve shown in the Figure 17 above, there are 4 equations that has been derived to represents the curve into 4 different gradients. Each equation used to calculate CO concentration relative to α value.

For α between 1.00 to 0.94,

$$CO_{PPM} = \alpha^{-\frac{1}{0.05632}}$$

For α between 0.93 to 0.85,

$$CO_{PPM} = \left(\frac{\alpha}{1.16716}\right)^{-\frac{1}{0.19702}}$$

For α between 0.84 to 0.48,

$$CO_{PPM} = \left(\frac{\alpha}{1.26734}\right)^{-\frac{1}{0.24818}}$$

For α between 0.47 to 0.375,

$$CO_{PPM} = \left(\frac{\alpha}{1.93335}\right)^{-\frac{1}{0.35614}}$$

By referring to the experimental condition to create a specific CO concentration in a closed spaced environment [27], 24 cigarettes smoked in a 25m^3 of closed space and Rs value measured after 3 hours. Knowing that the condition will result a 69.8 ppm CO concentration, Ro value obtained which is 27335.77Ω.

In order to ensure that the Ro value obtained is correct, a calibration test done. A number of cigarettes sequenced of 4, 8, 16 and 32 lighted up with each session respectively. For each session of cigarettes lighted up, CO concentration measured after 3 hours the cigarettes lighted up. The measured results are then compared to the actual results to observe the deviation of values. The results are as shown in the Table 5 and Figure 18.

Table 5. Percentage Difference between Measures and Reference Data [27]

No. Of Cigarettes	Reference CO PPM	Measured CO PPM	Percentage Difference (%)
4	12.21	13.06	6.96
8	25.65	24.90	2.92
16	47.63	46.10	3.21
24	69.80	67.73	2.97

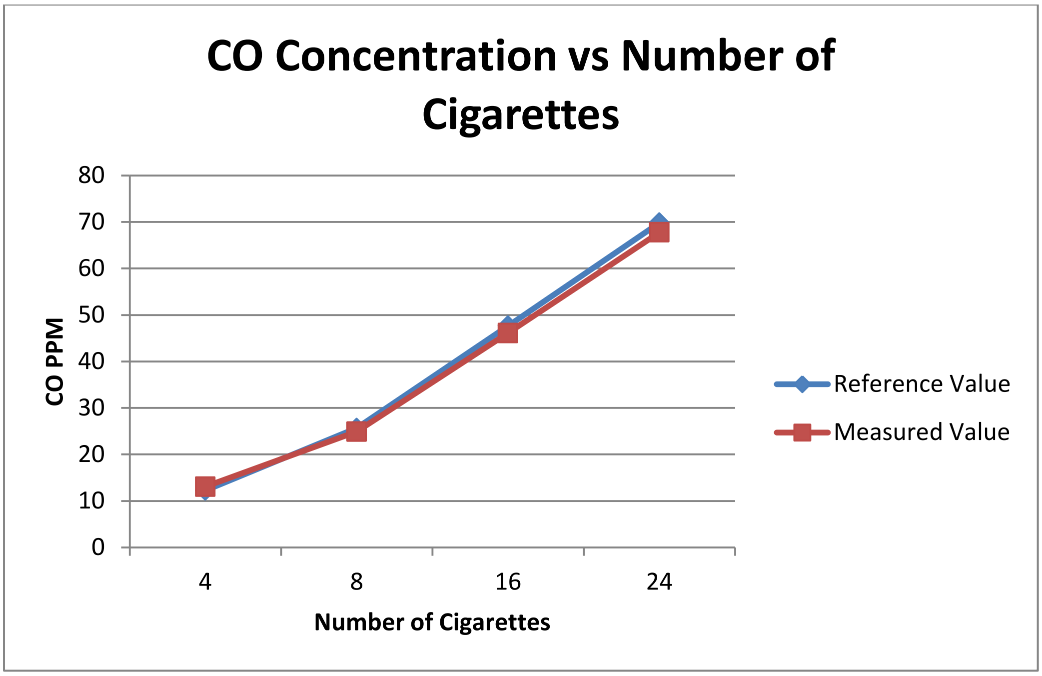


Figure 18. CO Concentration versus Number of Cigarettes [27]

Referring to the results above, it is shown that there are deviations ranged between 2.92% to 6.96%. The resulted deviations are considered small and comparable. Based on these results, the TGS 2600 is calibrated and are able to measure accurately.

3.5 Internet of Things (IoT) Implementations on API Monitoring System

In order to align with the current IoT trend, the API monitoring system had been explored its possibilities to come out with IoT function. With the implementations of IoT on the system, the API monitoring system becomes a remote API monitoring device which people can be accessed its data through the website. People can monitor the data of pollutants measured at the remote area to further analyse the trends plotted via their internet connected devices.

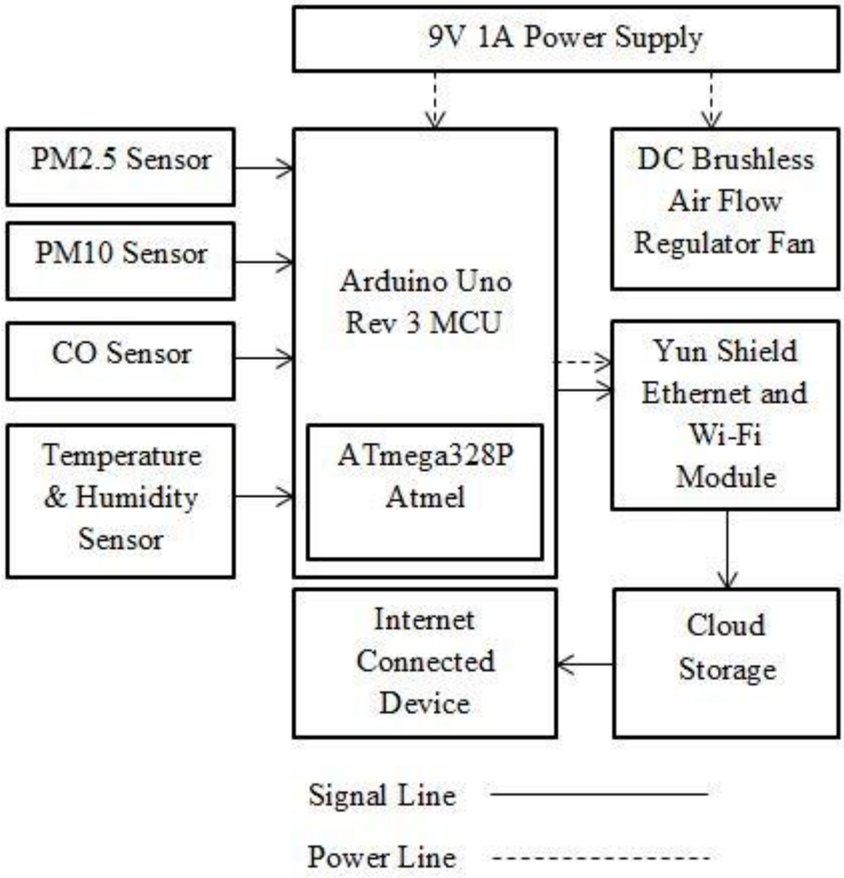


Figure 19. API Monitoring Device IoT System Block Diagram

In the Figure 19, it is shown that the GSM module and LCD replaced with the Yun Shield Ethernet and Wi-Fi module for IoT function.

3.5.1 Yun Shield Wi-Fi and Ethernet Module

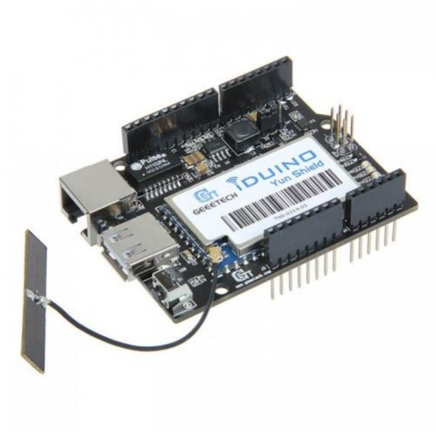


Figure 20. Yun Shield Wi-Fi and Ethernet Module

The Wi-Fi and Ethernet module integrated in the API monitoring system to perform its functions to connect the device to the Internet. Thus, the data measured uploaded to the cloud storage under the ThingSpeak website.

3.5.2 ThingSpeak Cloud Settings

In order to use the ThingSpeak website to publish the data, some configurations need to be done.

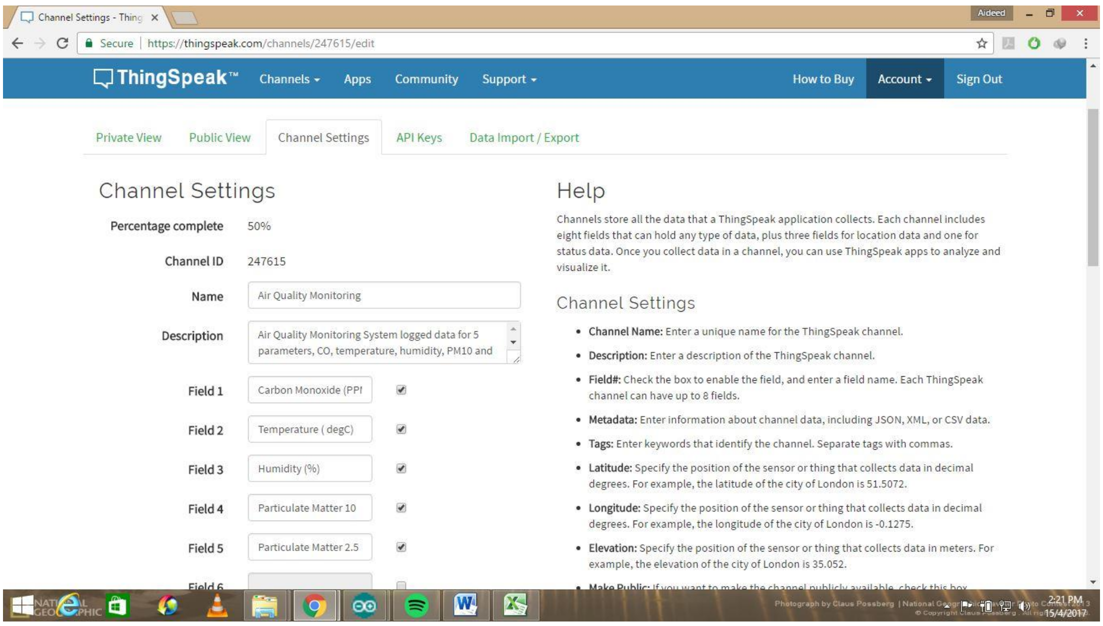


Figure 21. Type of Data on Channel Settings

The five types of pollutants measured set into respective field via one channel. The channel ID used in the Arduino program to ensure each of data correctly transmitted to the cloud.

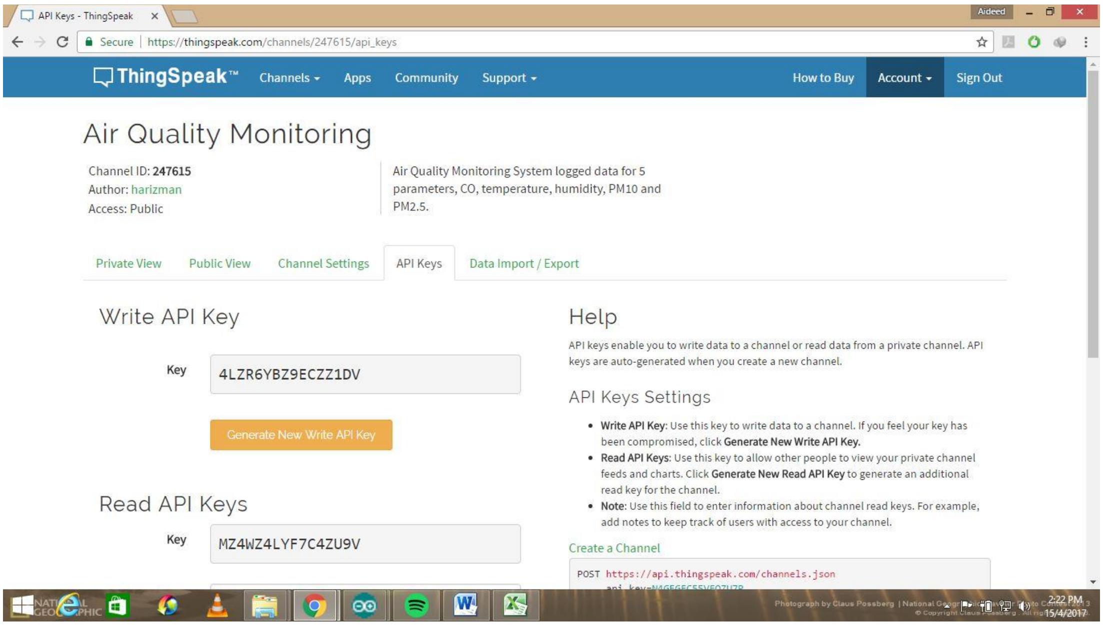


Figure 22. API Key for Uploading Data

The API key need to be including in the Arduino program to get permission to upload or received the data to the cloud channel.

3.6 Project Timeline

A project completion planning is necessary to make sure that the project progress in on track. A Key Milestone table have been developed to list out the highlighted milestone and expected completion. Through the completion of the milestone, a Gantt chart represents the amount of task has been done as a record of the achievement on this project. The Table below summarize the Project Key Milestone and Project Gantt Chart for this project.

Table 6. Project Key Milestone

No.	Major Milestone	Estimated Completion Date
1	Study of Project Background	September 30th 2016
2	Literature Review	October 7th 2016
3	Project Prototype System	October 9th 2016
4	Gathering Components Information	October 18th 2016
5	Hardware Selection	October 22th 2016
6	Circuit Integration	November 20th 2016
7	Preliminary Results	December 11th 2016
8	System Calibration	January 16th 2017
9	Data Collection	March 5th 2017
10	Poster Completion	March 21st 2017
11	Device Packaging	March 21st 2017
12	Dissertation & Technical Report Completion	April 17th 2017

PROJECT GANTT CHART

Table 7. FYP 1 Project Gantt Chart

ACTIVITIES	**WEEK**													
	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Project Identification														
Discussion with Supervisors on Project Title														
Securing Final Year Project Title														
Project Extended Proposal Completion														
Drafting Report														
Material Gathering & Proposal Writing														
Proposal Review with Supervisor														
Extended Proposal Submission														
Project Viva Preparation														
Data Gathering for Viva														
Viva Execution														
Interim Report Completion														
Report Writing & Review														
Report Turnitin Check														
Interim Report Submission														

Legend Completed Not Completed

Table 8. FYP 2 Project Gantt Chart

ACTIVITIES	WEEK													
	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Progress Report														
Progress Report Review														
Progress Report Submission														
Pre-SEDEX														
Designing Poster & Review														
Device Packaging & Review														
Final Documentation														
Final Report Completion & Review														
Technical Report Completion & Review														
Project Final Viva														
Slides Design and Review														
Final Report & Technical Paper Submission														
Project Final Viva														
Final Report Hard Cover Submission														

Legend Completed Not Completed

CHAPTER 4

RESULTS AND DISCUSSIONS

The integrated prototype has been used to monitor the air quality at University Teknologi PETRONAS, Tronoh, Perak, Malaysia for 5 weeks straight from January 22nd 2017 to February 26th 2017. The data acquired plotted to 4 different graphs by weeks representing the measurement of CO concentration, Temperature, Humidity and PM_{10}. $PM_{2.5}$ monitoring data acquired after IoT implementation on the device.

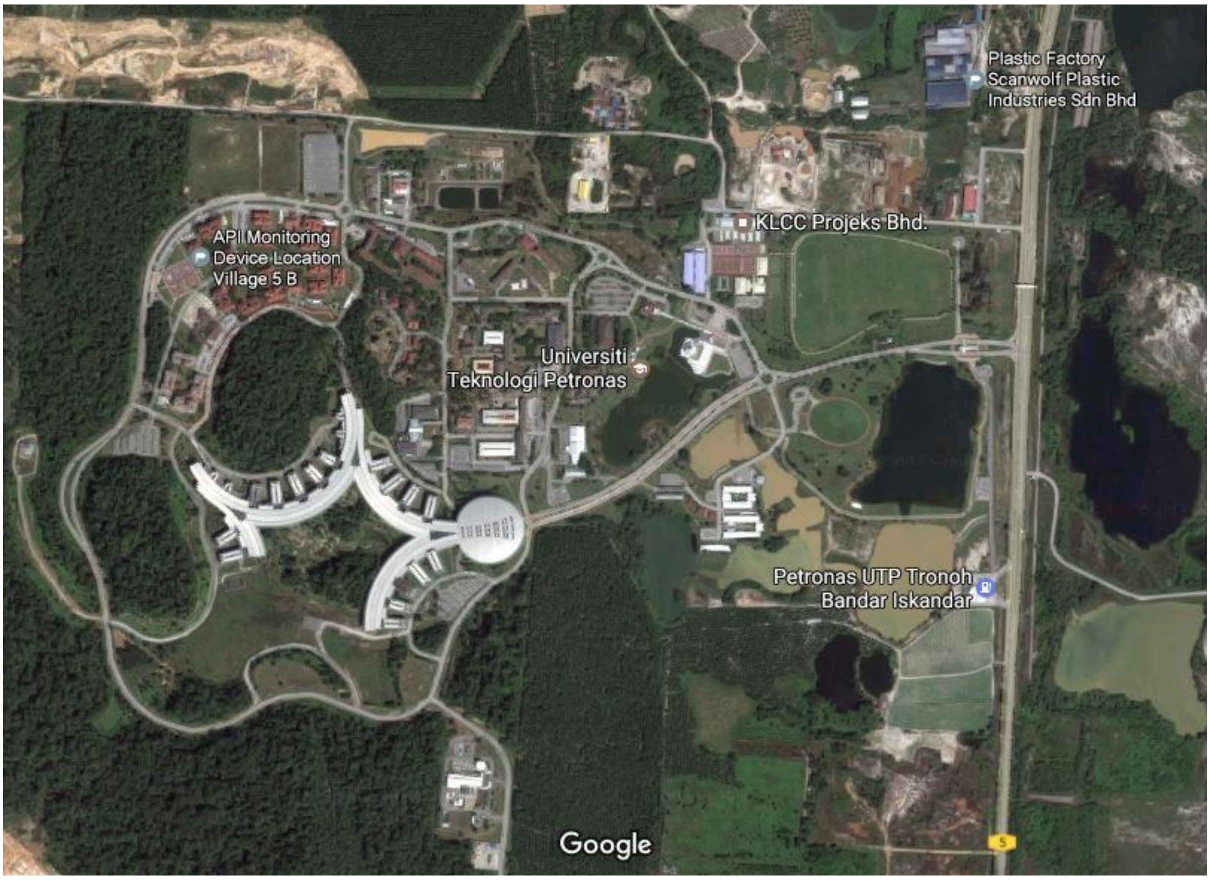


Figure 23. API Monitoring Location [28]

4.1 CO Concentration Monitoring Results

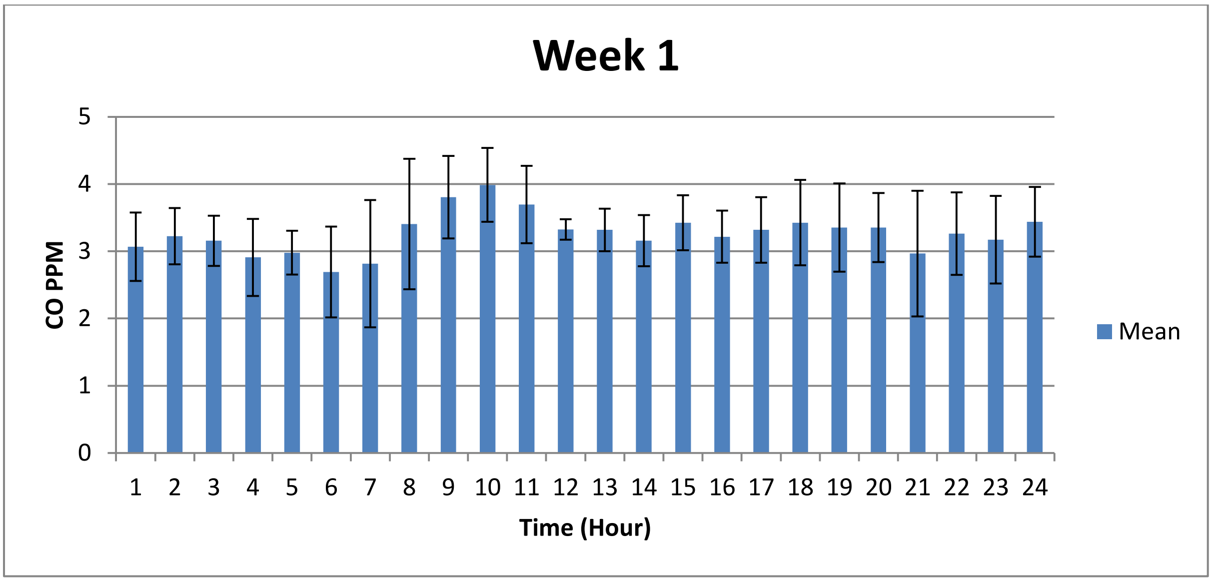


Figure 24. CO Concentration versus Time Week 1

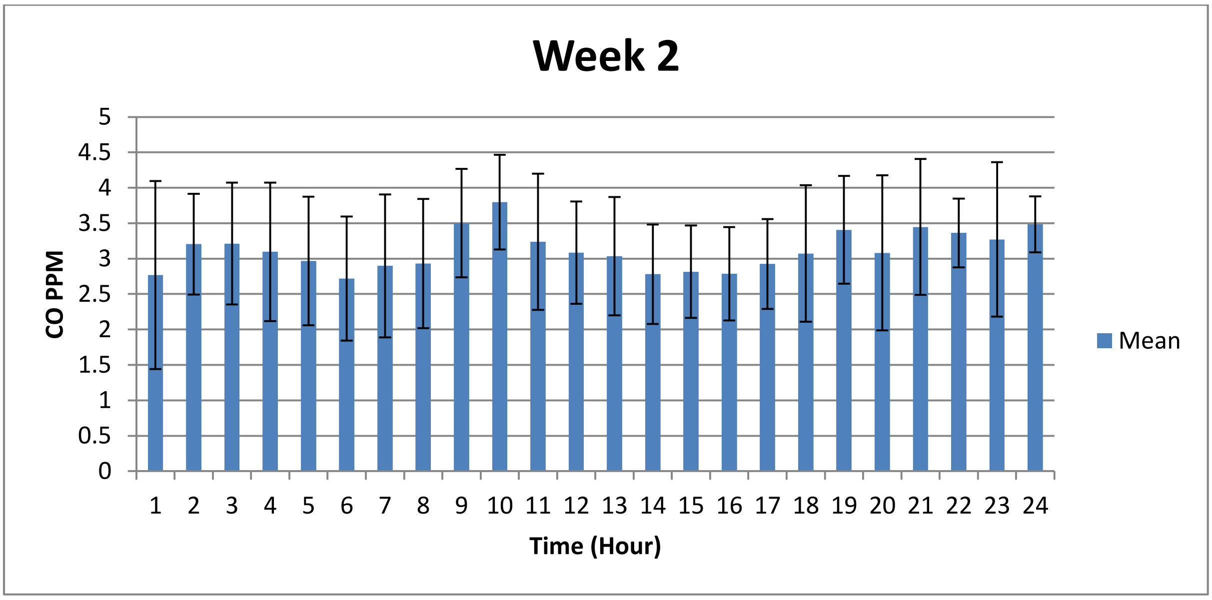


Figure 25. CO Concentration versus Time Week 2

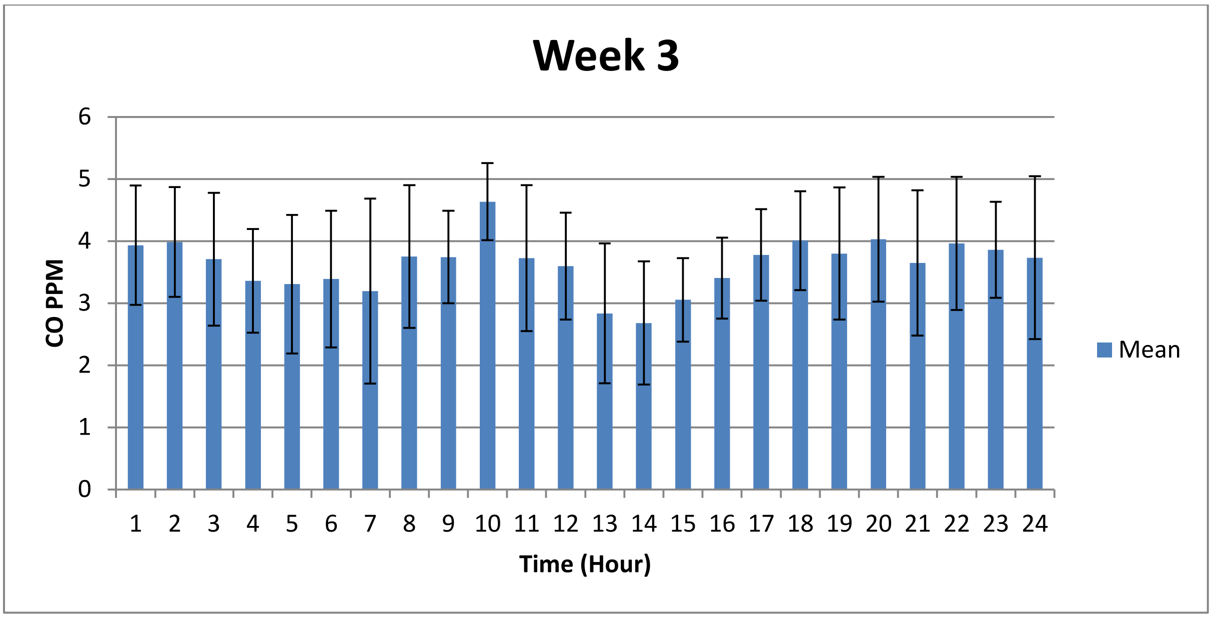


Figure 26. CO Concentration versus Time Week 3

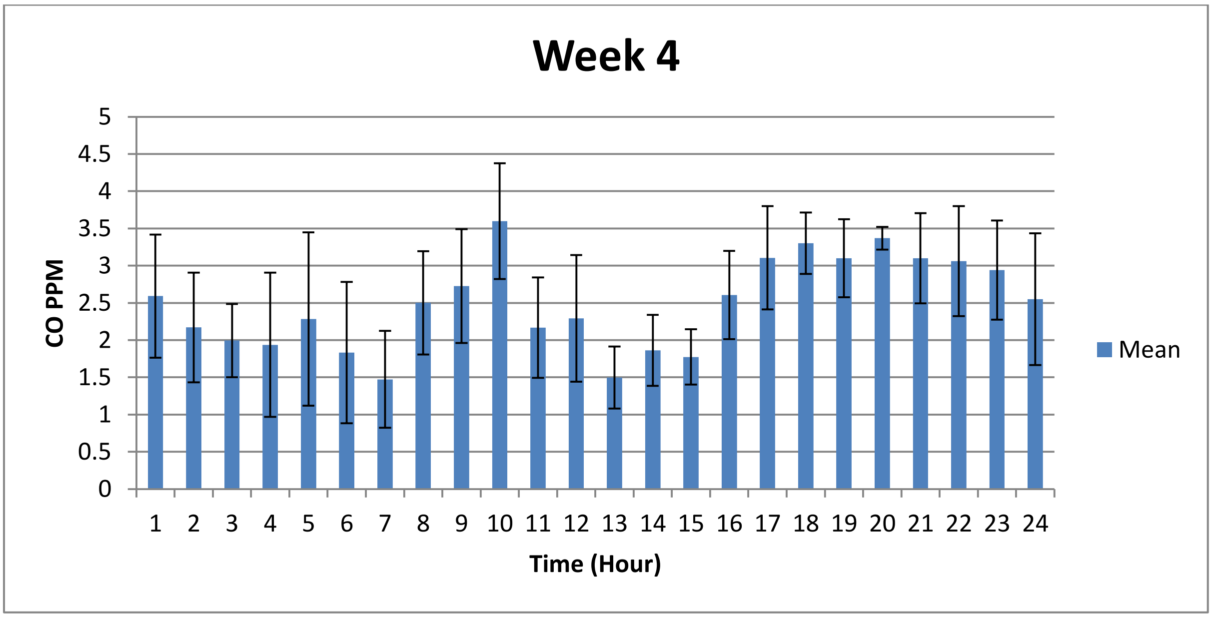


Figure 27. CO Concentration versus Time Week 4

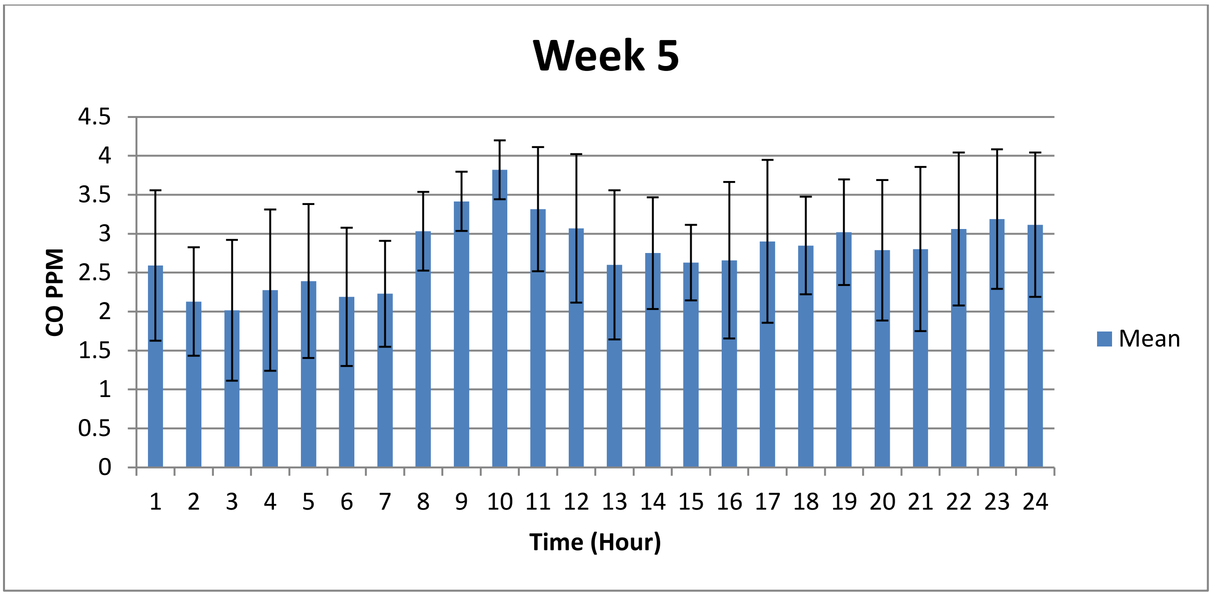


Figure 28. CO Concentration versus Time Week 5

Figure 24 until Figure 28 above shows 5 weeks of CO concentration monitoring. Each of the figures shows the CO concentration by mean of 7 days in the week for each hour. It is shown that for all of figures, there are similarities of trends which indicates the stabilities and consistency of sensor performance. The overall results show decrement from 0100 hour until 0600 hour and start to increase until the peak hour. This trend suspected due to the peak working hours. The peak hours for CO concentration measured highest at 1000 hour. The result from 1100 to 1500 hour shows significant decrement. One of the possible reason is the CO contain in the air reduced as the human working activities decreasing. There was a significant increase from 1500 until 1800 and fluctuations observed from 1800 until 0000 hour.

Of all 5 weeks of results, result on week 4 gives a little difference in terms of CO concentration level and more significant trend changes. Overall standard deviation computed shows that the highest was recorded at 0100 hour in week 2 with 1.3273 and the lowest at 2000 hour in week 4 with 0.1514. The discrepancies of CO concentration levels observed influenced by the weather conditions, human activities, wind directions and its sources.

4.1.1 Fogging Effect towards CO Concentration Measurement

In the event of fogging at the monitoring area, a significant change of CO concentration observed. The results of CO concentration monitored with the effect of nearby fogging activities plotted in the Figure 29.

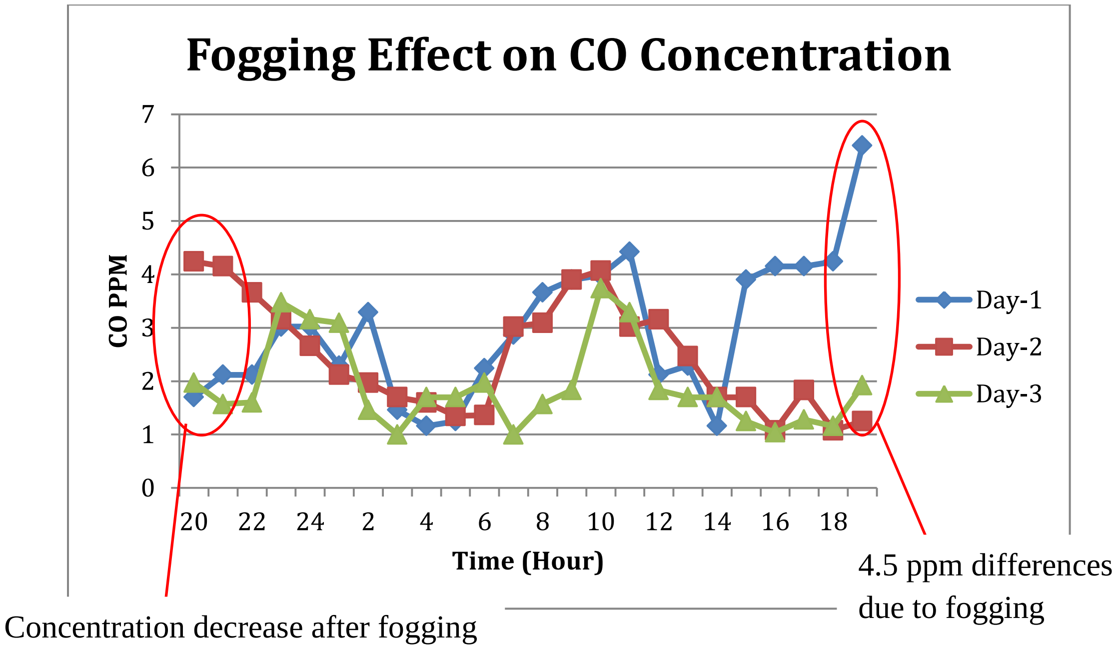


Figure 29. 72 Hours of CO Concentration Monitoring

The CO concentration observed for 3 days and the data plotted for 24-hours timeline Based on the Figure 17 above, Day-1, Day-2 and Day-3 have similarity of data trends except from the 1500-hour to 1900-hour on Day-1 and 2000-hour to 2200-hour on Day-2. From 1900-hour on Day-1, fogging started near the monitoring area. The sensor detects about 4.5 ppm differences (Day-2 and Day-3) due to the fogging. The sensor then continues the detection where the CO ppm concentration decreased from 4.3 ppm to 3.2 ppm before returning the normal for Day-2. This shows that the CO sensor is able to function consistently even with 3 consecutive days of monitoring.

4.2 Temperature Monitoring Results

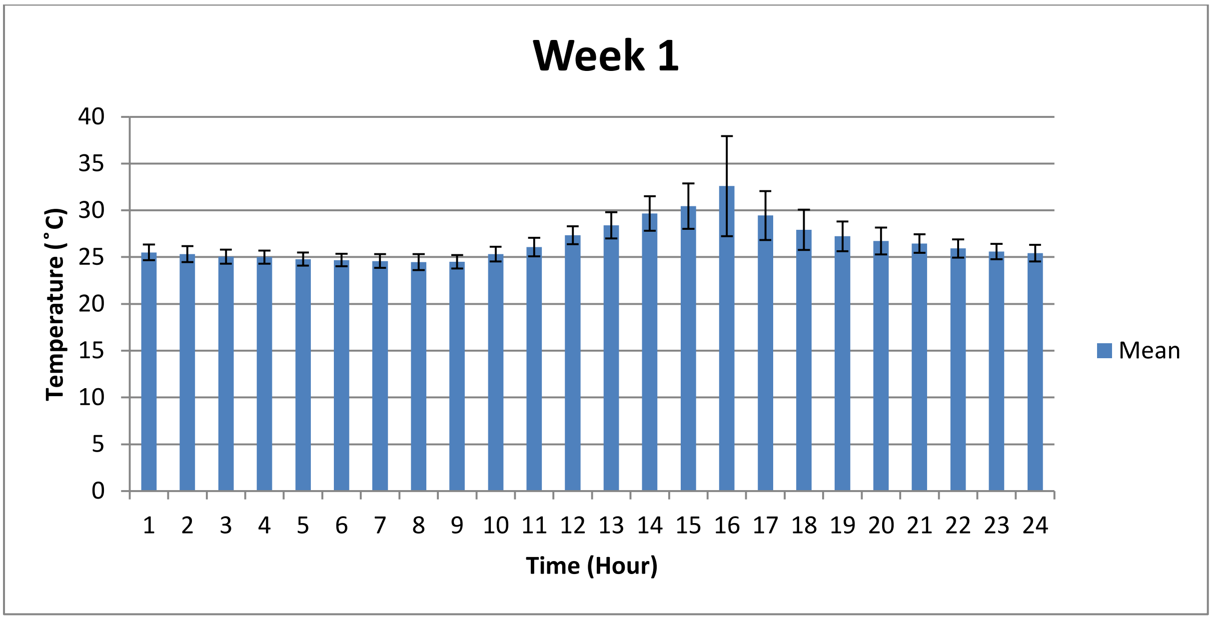


Figure 30. Temperature versus Time Week 1

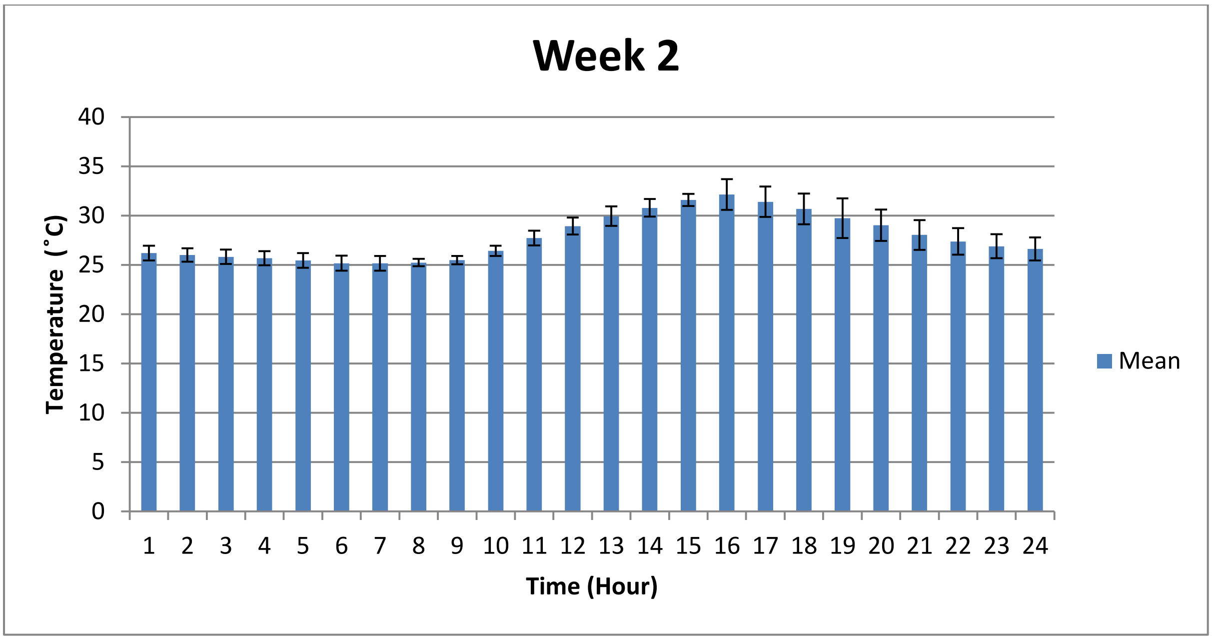


Figure 31. Temperature versus Time Week 2

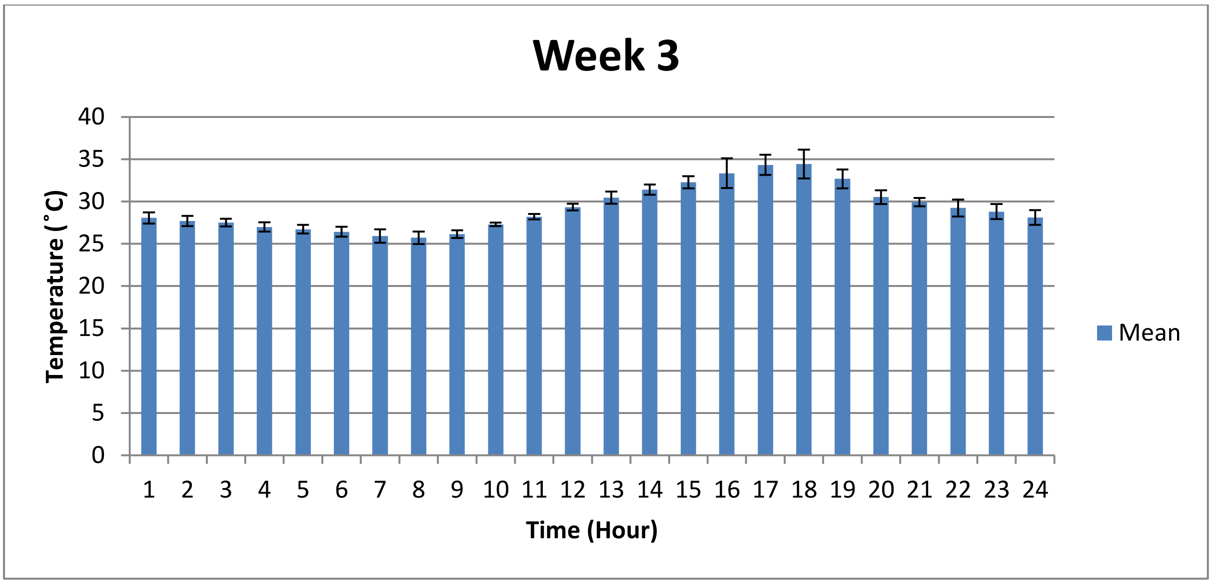


Figure 32. Temperature versus Time Week 3

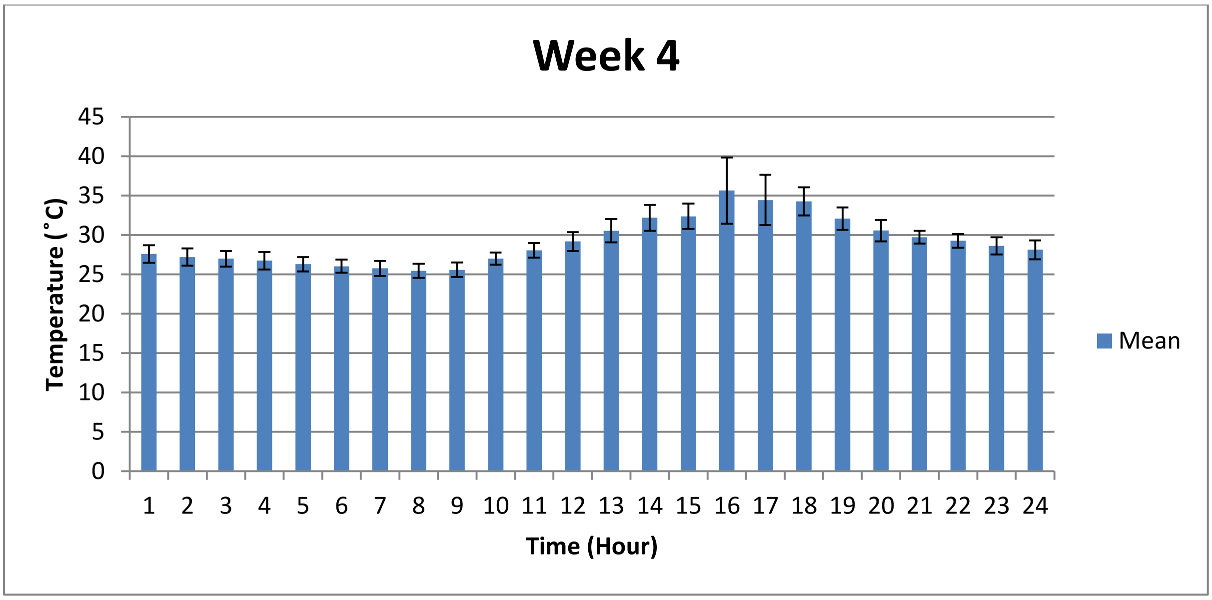


Figure 33. Temperature versus Time Week 4

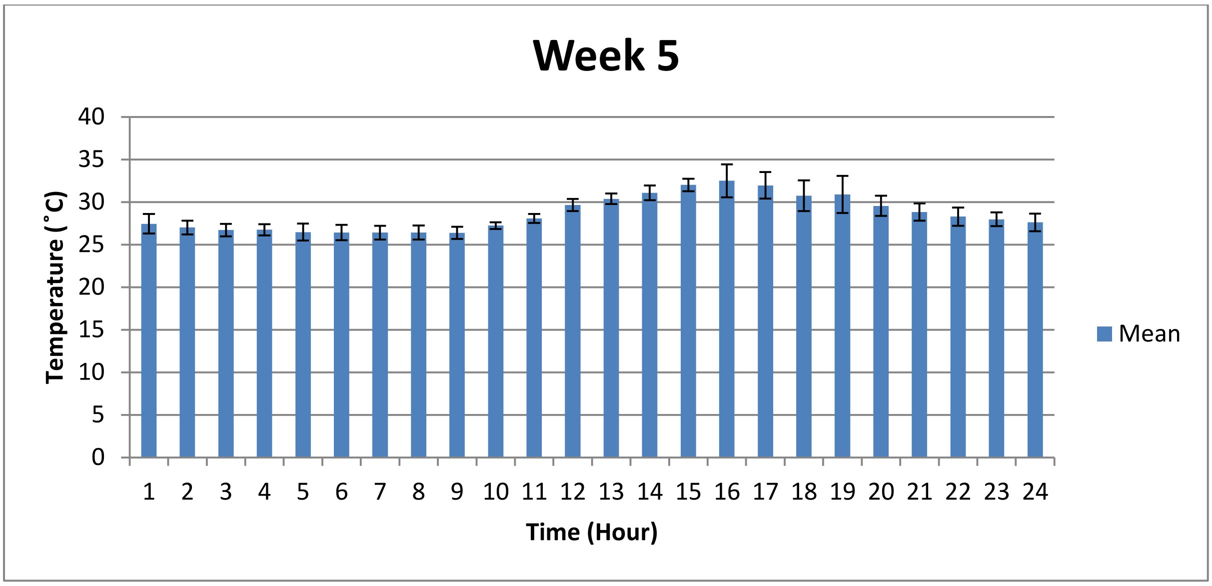


Figure 34. Temperature versus Time Week 5

Figure 30 until Figure 34 above shows 5 weeks of temperature monitoring. Each of the figures shows the temperature reading by mean of 7 days in the week for each hour. Based on the results above, there is a significant uniformity of trends between each of the 5 weeks. Generally, from 0100 hour, a decrement observed until 0800 hour. The temperature starts to increase from 0900 hour until its peak hour where the highest temperature recorded everyday which is at 1600 hour. This highest temperature recorded at 1600 hour because direct sunlight towards the API monitoring device happens at that hour. Subsequently, decrement observed from 1700 until 0000 hour.

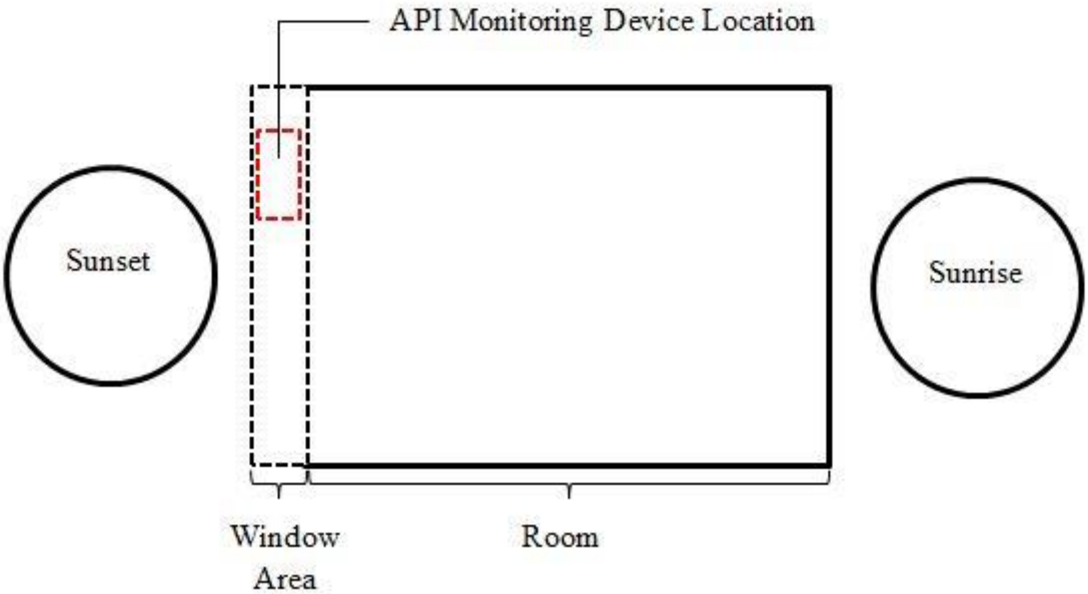


Figure 35. API Monitoring Device Location

Overall, the temperature readings give a very small standard deviation which the highest is 5.346 and the lowest is 0.2035. However, almost all of the data for each hour has standard deviation of below 1.00.

4.3 Humidity Monitoring Results

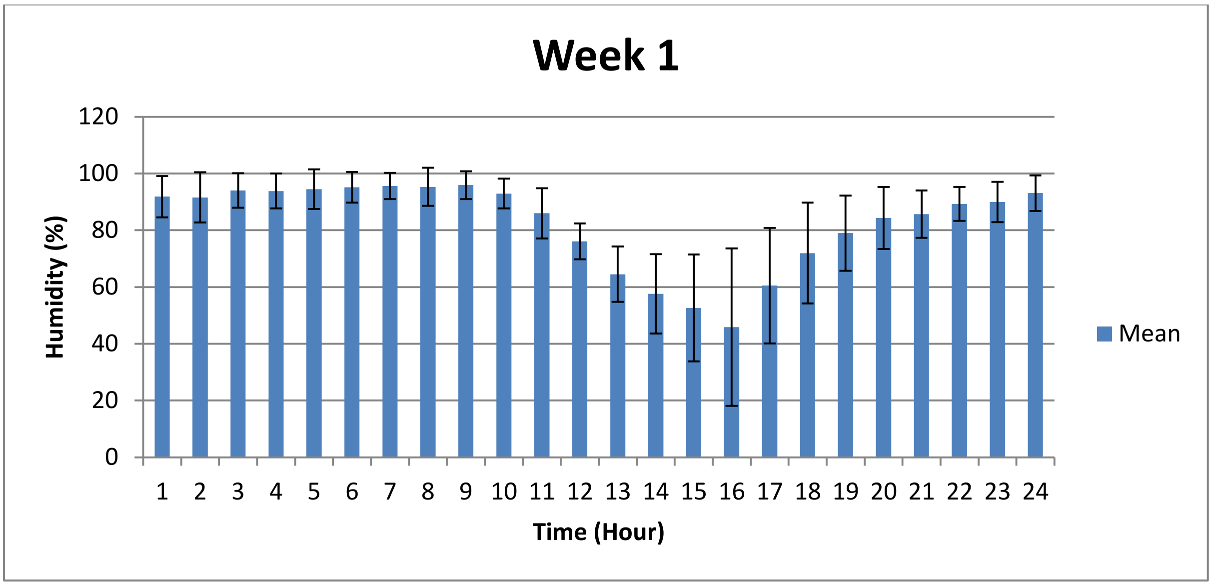


Figure 36. Humidity versus Time Week 1

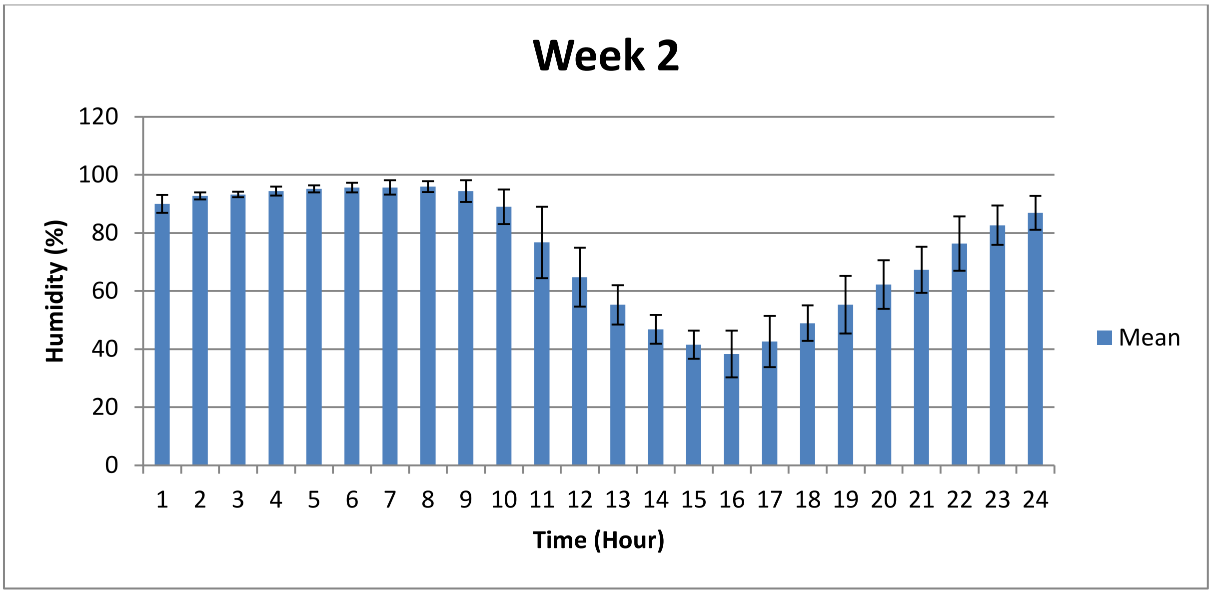


Figure 37. Humidity versus Time Week 2

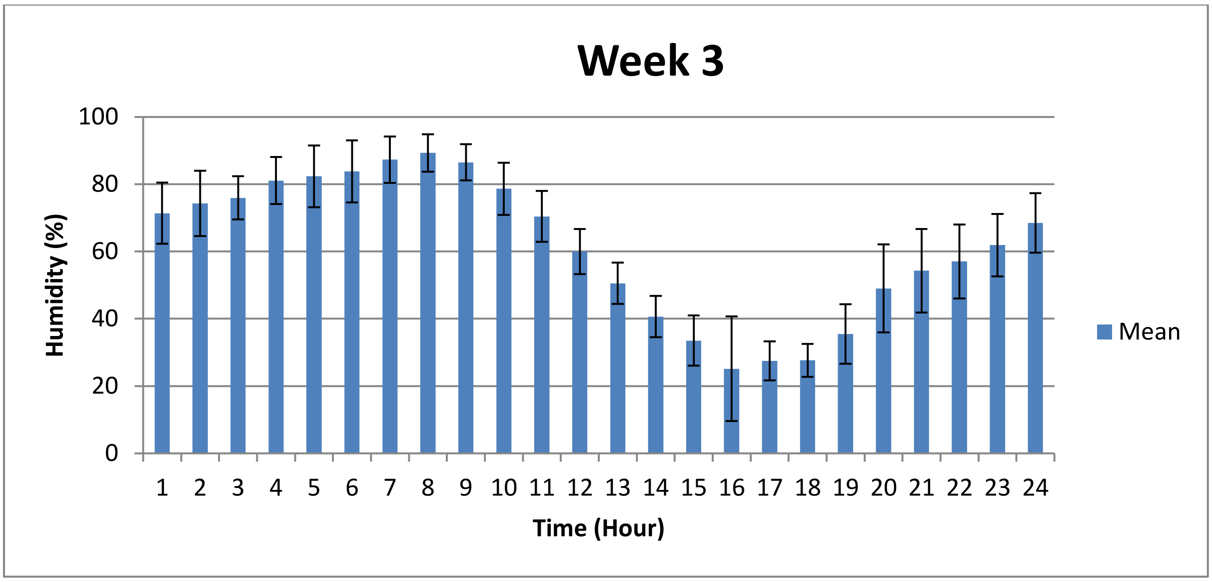


Figure 38. Humidity versus Time Week 3

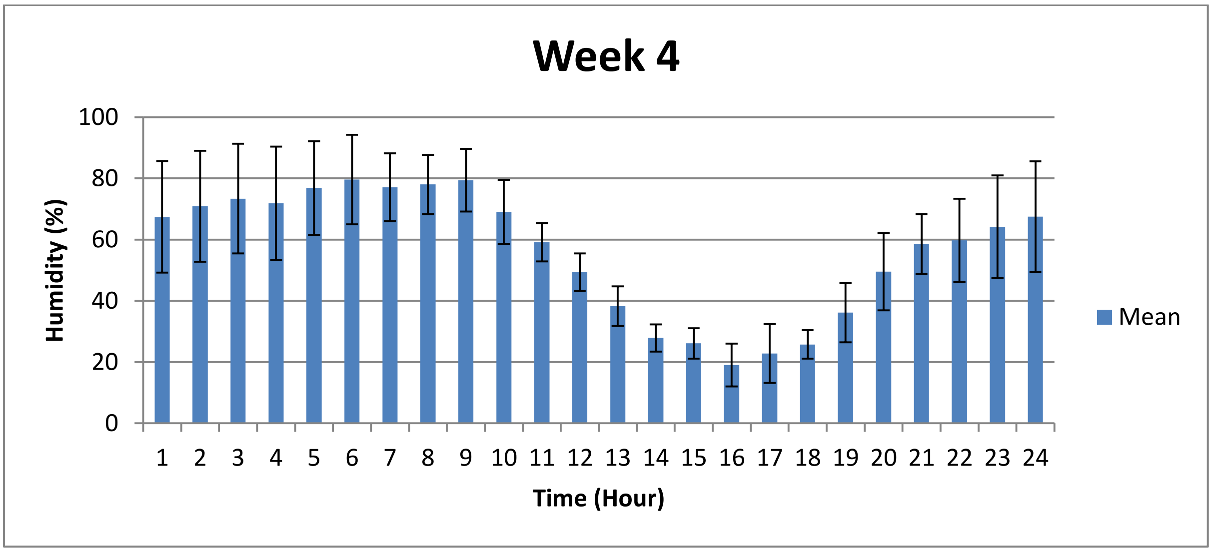


Figure 39. Humidity versus Time Week 4

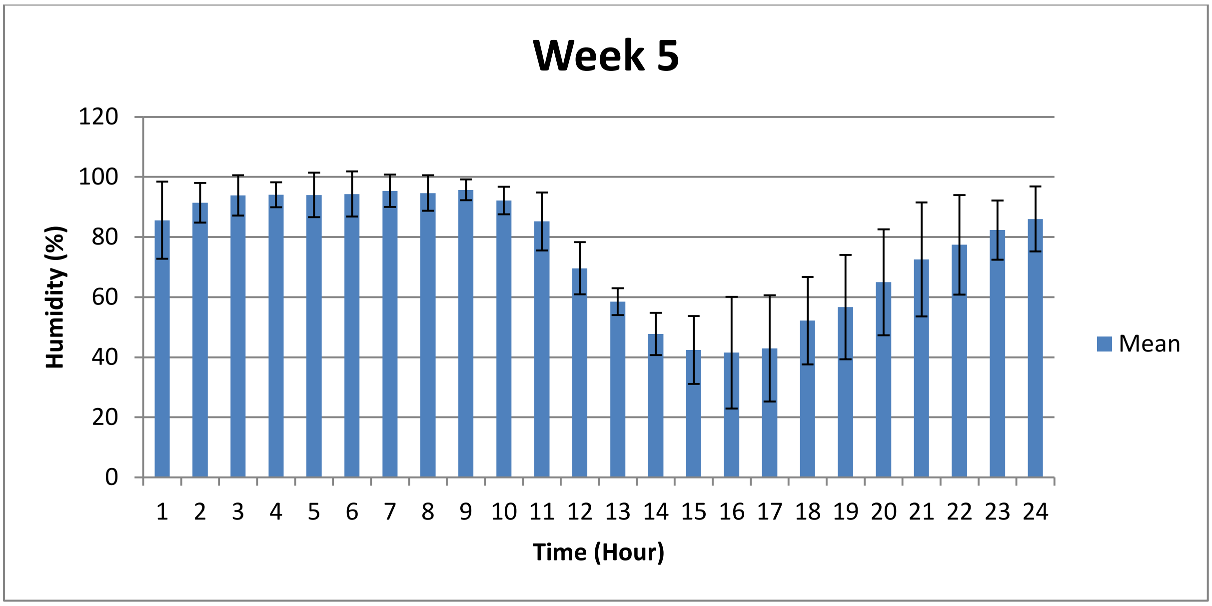


Figure 40. Humidity versus Time Week 5

Figure 36 until Figure 40 above shows 5 weeks of humidity monitoring. Each of the figures shows the temperature reading by mean of 7 days in the week for each hour. They have inverse relationship between each other. From 0100 hour until 0800 hour, increment on humidity observed and the peak hour recorded at 0800. There is significant decrement from 0900 hour to 1600 hour and the lowest humidity recorded is at 1600 every day. Subsequently, the humidity changes with increment from 1700 until 0000 hour.

Generally, the humidity results are somehow correlated with the temperature results obtained. The humidity and temperature have inverse relationship with each other. This clearly can be seen where the peak hour of humidity corresponds to the lowest temperature recorded which is at 0800 hour. On the other hand, the lowest humidity recorded corresponds to the peak hour of temperature which at 1600 hour. Similar to the temperature results, humidity results are affected by the changes of weather.

4.4 PM_{10} Monitoring Results

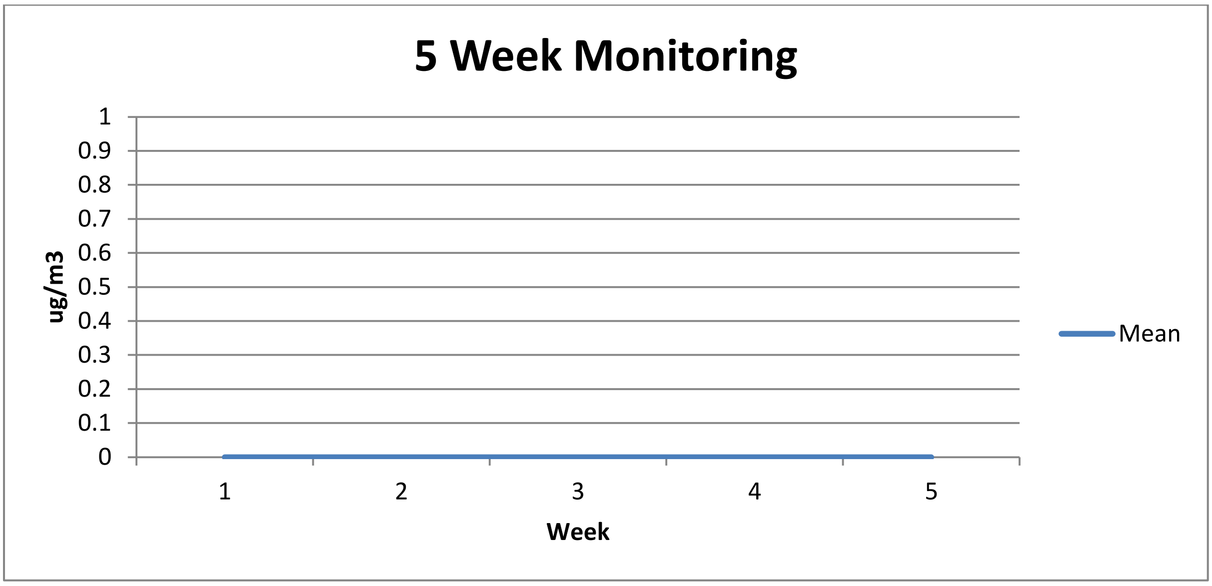


Figure 41. PM_{10} versus Time

Figure 41 shows 5 weeks of PM_{10} monitoring. For all weeks, the PM_{10} result shows that there is no PM measured because of the location factor where the monitoring location does not have many industrial activities. Furthermore, the sensor also has less sensitivity and required a significant change of environment to ensure its detection.

4.4.1 Burning effect towards PM_{10} Sensor Detection

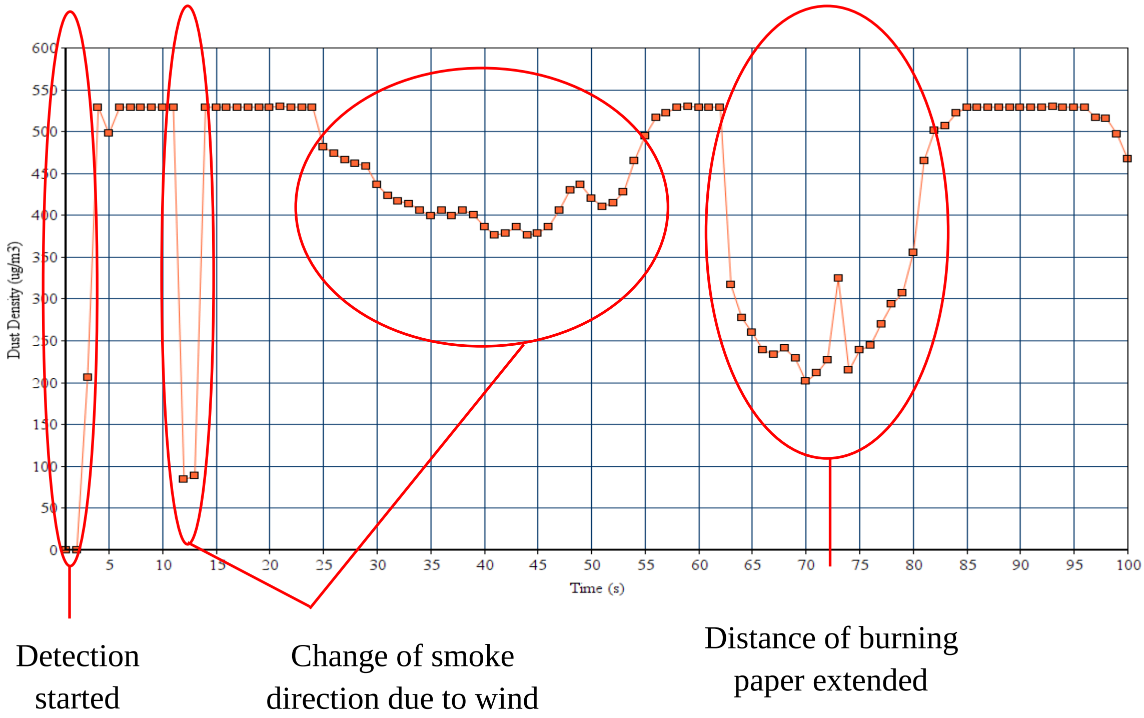


Figure 42. PM_{10} Smoke Monitoring Near Burning Paper

Since there is no detection on PM_{10} sensor through the 5 weeks monitoring, investigation was taken to expose the PM_{10} sensor towards the effect of burning. To do this, a paper was burnt and the PM10 sensor exposed near to the smoke. On the Figure 39 above, the SHARP GP2Y1010AU0F PM_{10} sensor started to reacts and detects the presents of smoke at the 3-second. The burning papers placed about 1 meter from the PM_{10} sensor and the fluctuation of data obtained from 12-second to 62-second. This is expected due to the different smoke direction towards the PM_{10} sensor due to the wind. From 63-seconds to 84-seconds, the distance between PM_{10} sensor and burning paper extended and the data decreased. When the burning paper directed near to the measurement chamber of PM_{10} sensor, the constant results of maximum detection obtained from 85-second to 95-second. Thus, it is known that the range of PM_{10} sensor is between 0μg/m^3 to 530μg/m^3 and it is tally with the datasheet given. It can be conclude that the PM_{10} sensor detection is working and functioning but required direct trigger or high degree of exposure for a stable detection.

4.5 API Monitoring Device Output Display

Figure 43. API Monitoring Device LCD Output

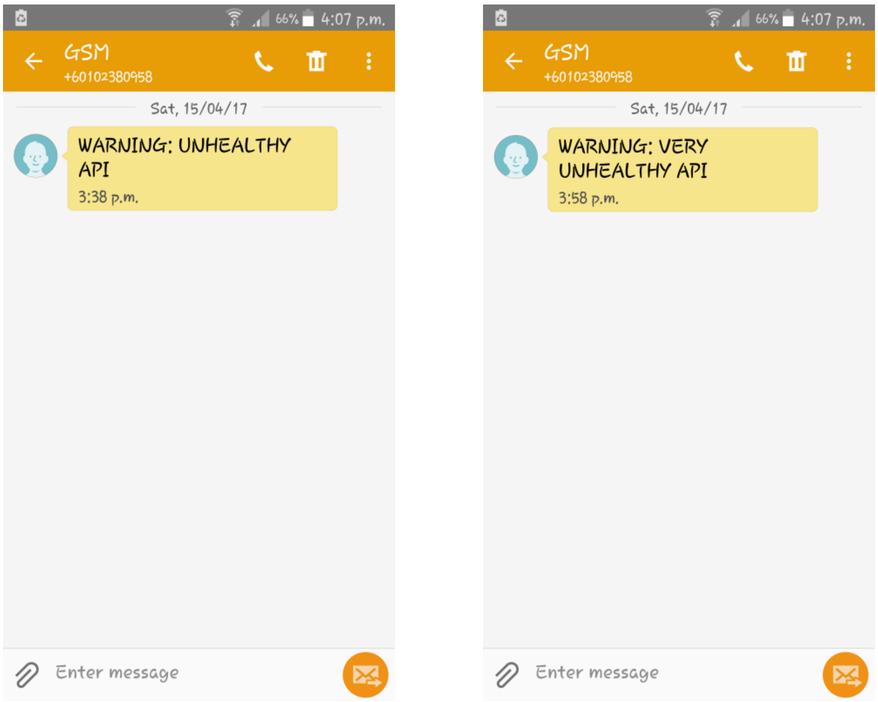


Figure 44. API Monitoring Device Text Message

Figure 44 shows the example of SMS notifications of warning when the API status reached Unhealthy, Very Unhealthy and Hazardous.

4.6 Monitoring Results on ThingSpeak Website

The integration of Yun Shield Wi-Fi and Ethernet module in the system introduce the IoT concept to the device. Hence, data can be accessed publicly and the results trend can be reviewed easily. ThingSpeak cloud storage and website used to presenting the data efficiently. The data on the cloud can be export publicly in excel format.

4.6.1 CO Monitoring Results

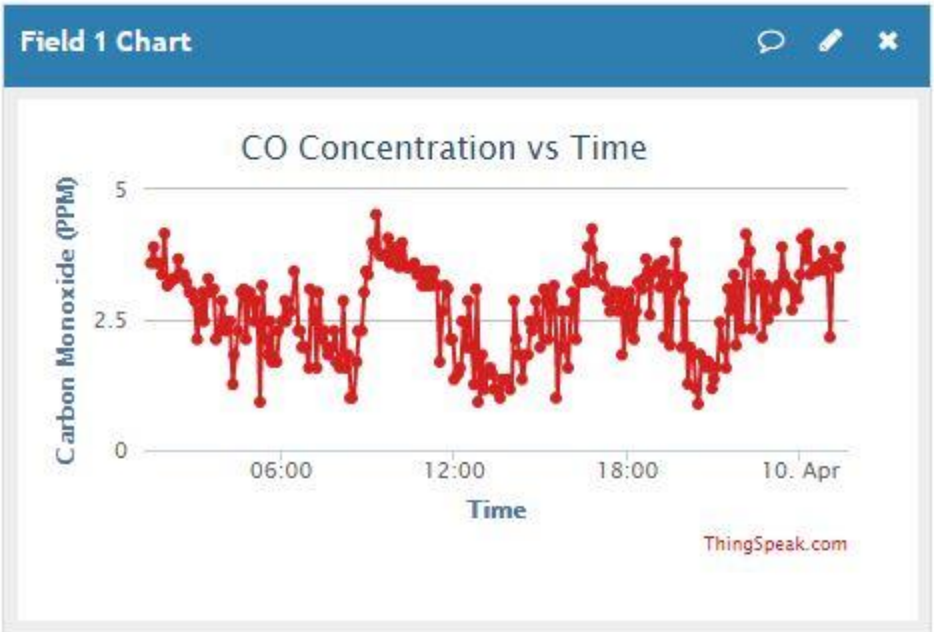


Figure 45. Example of CO Monitoring Result

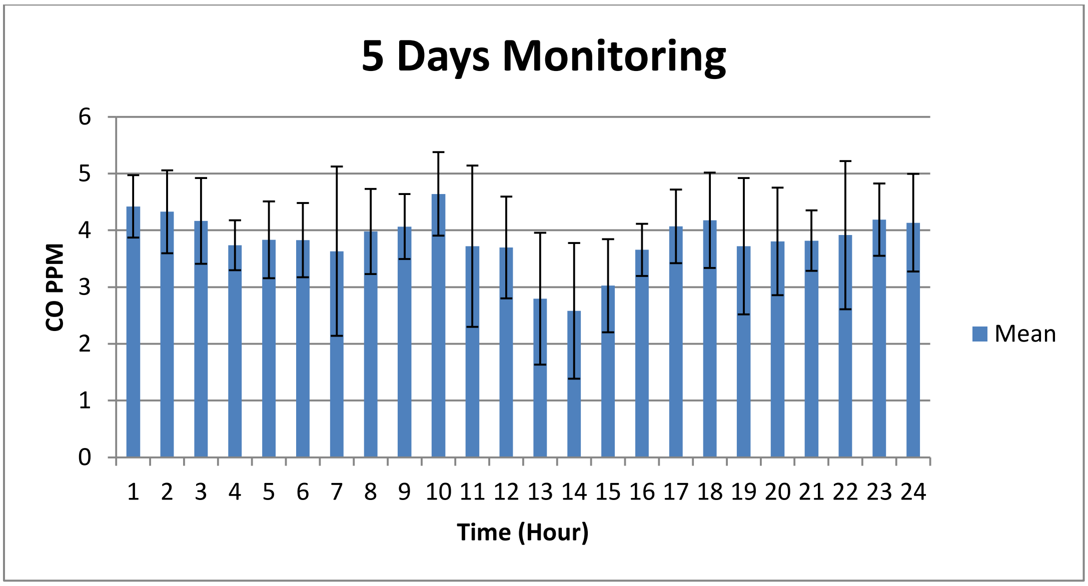


Figure 46. 5 Days CO Monitoring Exported from ThingSpeak

Based on the Figure 45, the data trend shown quite similar to the 5 week monitoring. This 1 day monitoring result obtained from ThingSpeak website have not much difference of trend to the 5 days monitoring results considering it is plotted by mean values for 5 days. As the sampling time is more frequent, the deviation as shown in the 5 days monitoring can also be seen from this trend. Human activities and wind is the possible external interference towards this result.

4.6.2 Temperature Monitoring Results

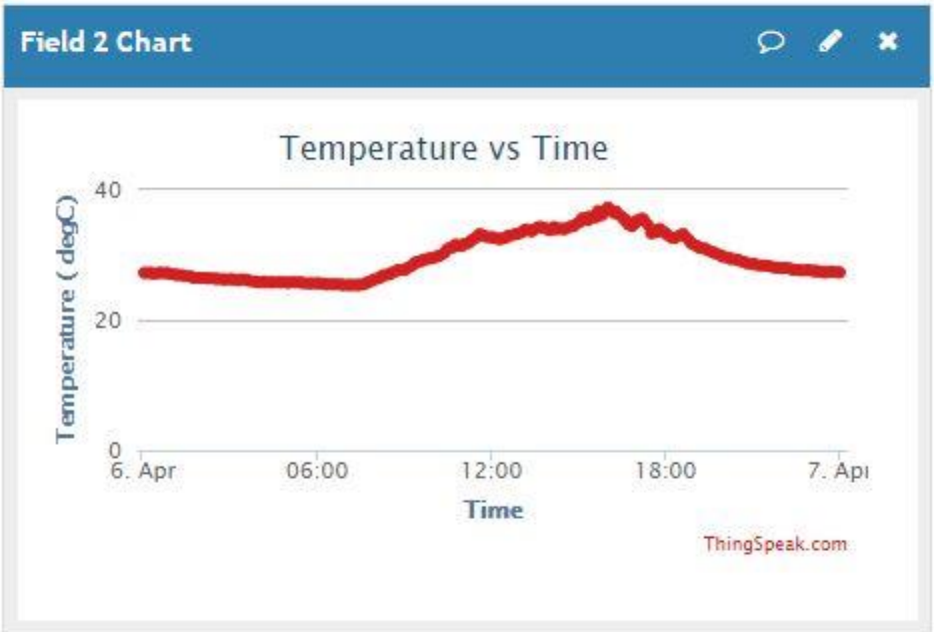


Figure 47. Example of Temperature Monitoring Results

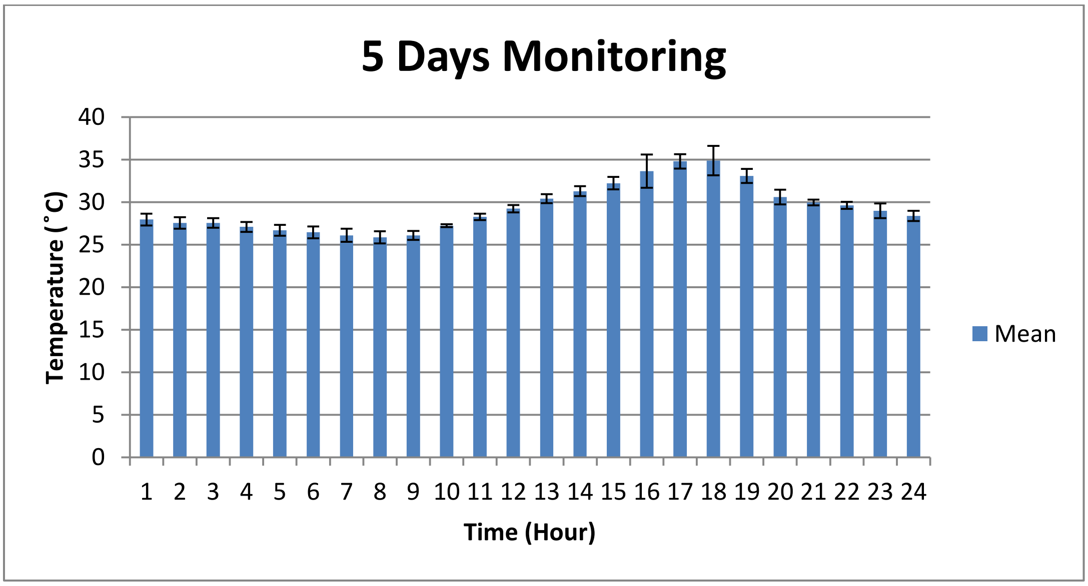


Figure 48. 5 Days Temperature Monitoring Exported from ThingSpeak

Based on the Figure 47, the highest peak hours of temperature monitored around 1600-hour. The results plotted has same trend as the 5 days of temperature monitoring.

4.6.3 Humidity Monitoring Results

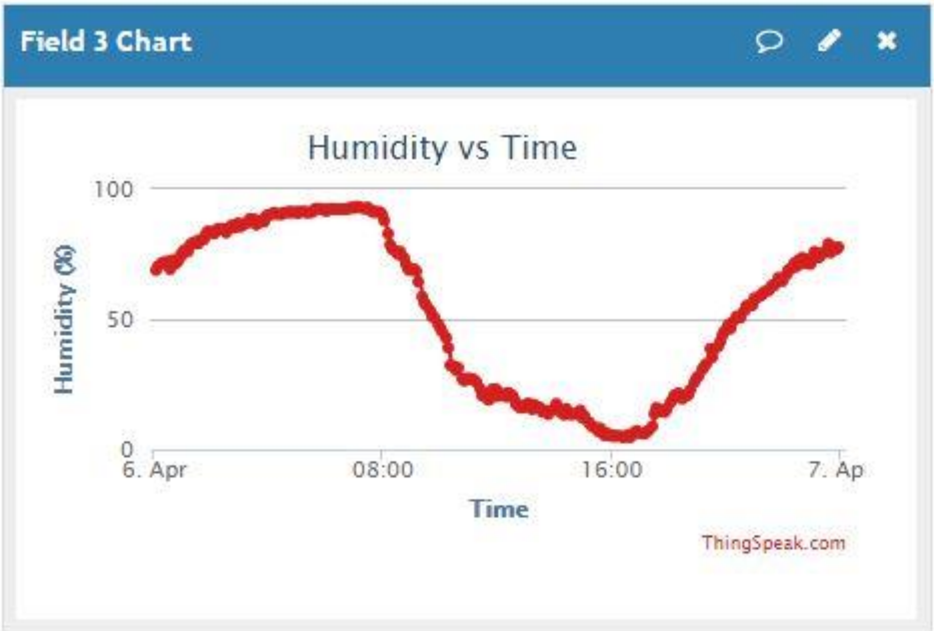


Figure 49. Example of Humidity Monitoring Results

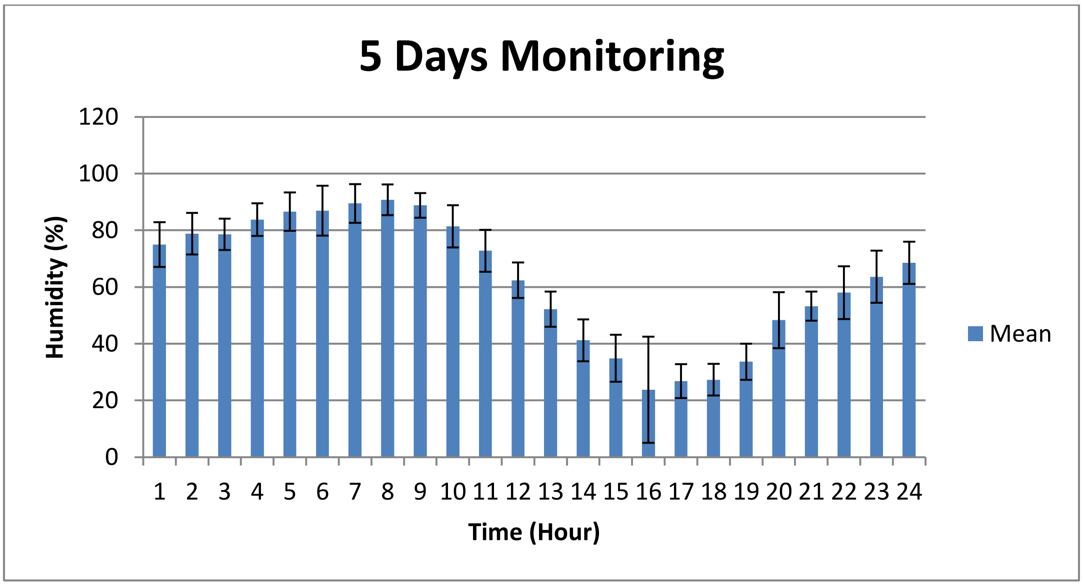


Figure 50. 5 Days Humidity Monitoring Exported from ThingSpeak

Based on the Figure 49, the lowest peak hours of humidity monitored around 1600-hour. The results plotted has same trend as the 5 days of humidity monitoring.

4.6.4 PM_{10} Monitoring Results

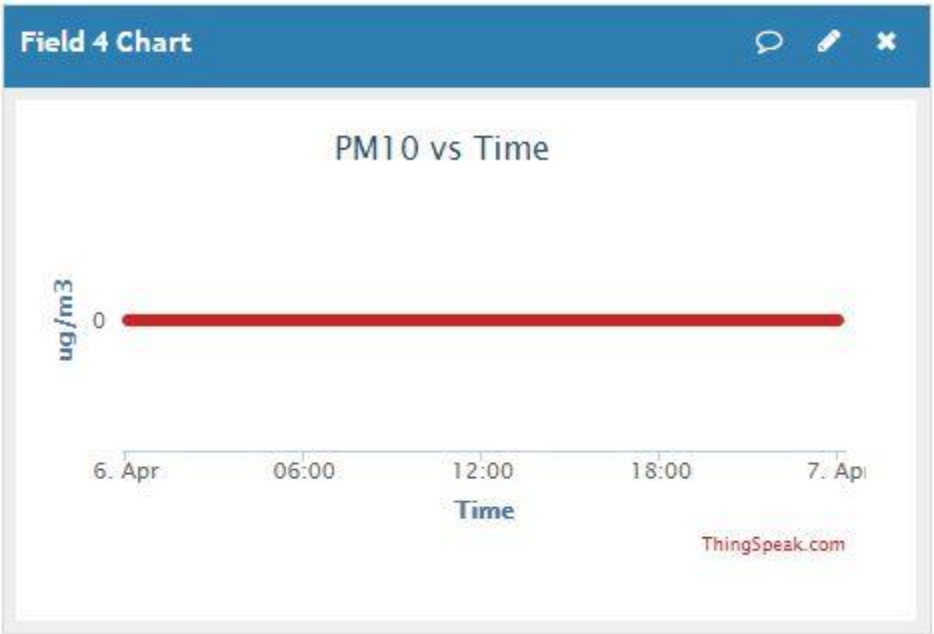


Figure 51. Example of PM_{10} Monitoring Results

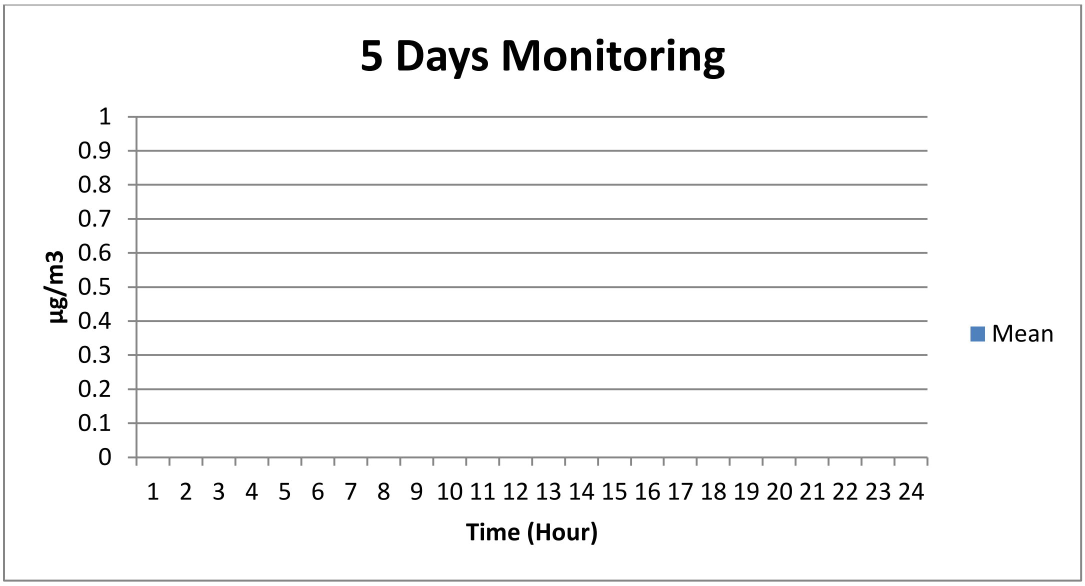


Figure 52. 5 Days PM_{10} Monitoring Exported from ThingSpeak

Based on the figures above, the PM10 still did not get results same as the previous 5 week monitoring.

4.6.5 $PM_{2.5}$ Monitoring Results

Figure 53. Example of $PM_{2.5}$ Monitoring Result

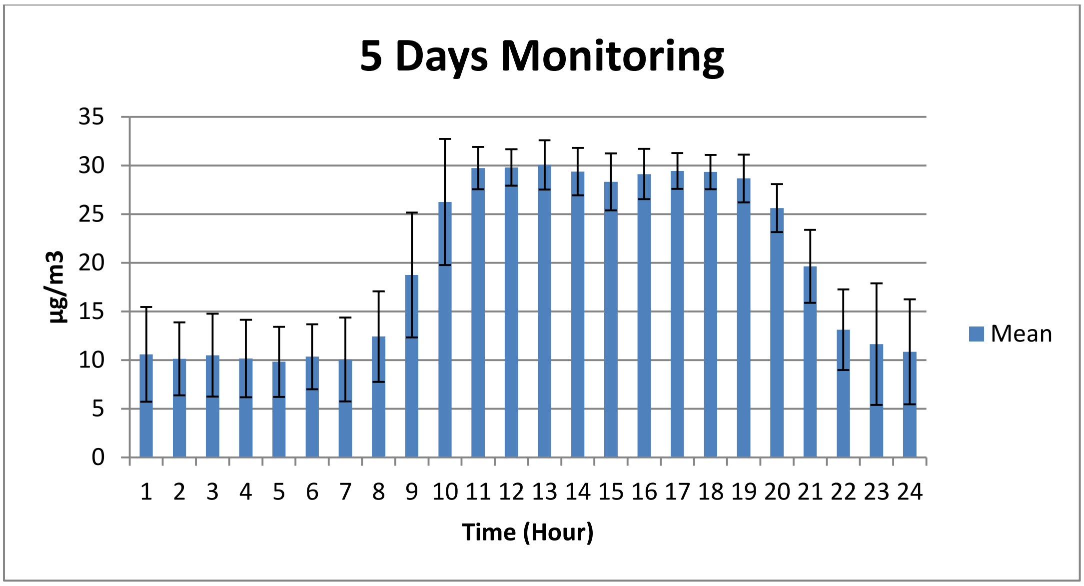


Figure 54. 5 Days PM2.5 Monitoring Exported from ThingSpeak

Based on the figures above, the trends of the 5 days $PM_{2.5}$ have been exported into excel and analysed by the mean values. The sensitivity of $PM_{2.5}$ can detect the changes more clearly. This shows that $PM_{2.5}$ is important to be added in the system.

4.7 Total Cost of Implemented System

Based on the implemented system, the total cost of the components used calculated. The total cost analysis divided into 2 parts which are the API monitoring device equipped with GSM for SMS emergency alert and IoT monitoring concept.

4.7.1 Total Cost for API Monitoring Device with GSM

Table 9. Total Cost for API Monitoring Device with GSM

Item	Cost (RM)	Quantity	Total Cost (RM)
Arduino Uno R3	45.00	1	45.00
GSM900A Module	62.00	1	62.00
LCD Keypad Shield	18.00	1	18.00
GP2Y1010AU0F PM_{10} Sensor	25.00	1	25.00
DN7C3CA006 $PM_{2.5}$ Sensor	107.34	1	107.34
TGS2600 CO Sensor	29.68	1	29.68
DHT22 Sensor	22.50	1	22.50
4cm x 4cm DC Brushless Fan	6.50	2	13.00
			322.52

4.7.2 Total Cost for API Monitoring Device with IoT Implementation

Table 10. Total Cost for API Monitoring Device with IoT Implementation

Item	Cost	Quantity	Total Cost
Arduino Uno R3	45.00	1	45.00
Yun Shield Ethernet and Wi-Fi Module	230.00	1	230.00
GP2Y1010AU0F PM_{10} Sensor	25.00	1	25.00
DN7C3CA006 $PM_{2.5}$ Sensor	107.34	1	107.34
TGS2600 CO Sensor	29.68	1	29.68
DHT22 Sensor	22.50	1	22.50
4cm x 4cm DC Brushless Fan	6.50	2	13.00
			472.52

Based on the total cost analysed, it is found that IoT implementation towards API monitoring system is consuming slightly higher cost than GSM-based implemented system. However, both of the system has low total cost of development.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In brief, the focus of his project is to develop a portable, affordable and dependable prototype for real time air quality monitoring. The necessity of knowing the level or condition of the quality of the air we breathe in our surroundings is very crucial in order to keep our good health condition. There were some reviews of literature made which describing the designs proposed and actual prototype developed by respective authors. Based on the reviews made, there are strong rationale to develop and improvise the current air quality monitoring system to be flexible in terms of location and time.

Of all the reviews made on the existing models, it is revealed that a monitoring system that covering the specification of portable, affordable and dependable yet to be developed until now. The project proposal to implement a portable system that have reasonable type of pollutant to measure, dust pollutant measurement for haze incident and providing real time information via short message service (SMS) yet inexpensive is considered to be an improvement from the models developed. Thus, this prototype will be easily to be use by the people in their daily life for multipurpose reason. The proposed system will be able to solve Malaysians concern on the delay announcement and measuring the $PM_{2.5}$ haze in Malaysia considering the Malaysia new API system will be only available in 2020.

The $PM_{2.5}$ measurement is very essential to give clearer dust pollutants condition to ensure healthy life environment. The prototype developed successfully monitor for API in UTP for 5 weeks. The GSM equipped gives real time notifications during Unhealthy, Very Unhealthy and Hazardous API states. This prototype will be easily to be use by the people and institution such as schools and universities in daily life for multipurpose reason.

5.2 Recommendation

It is recommended to calibrate the sensor with industrial gas concentration control system to further ensuring the system accuracy. Moreover, as the implementation of wireless connection to the device is possible which follow the IoT trend, this project have strong potential to enhance its features to be a portable IoT device which have capabilities of sending SMS or emergency call alert to the users by using high speed cellular network shield replacing the Yun Shield. At the moment, the system using the external power source to power ups the system. As a part of improvement, embedded power circuitry can be developed to sustain the system. A user-friendly application also possible to be developed which compatible with various devices.

REFERENCES

[1] Mabahwi N. A., Leh O. L. H. and Omar D. (2015). Urban Air Quality and Human Health Effects in Selangor, Malaysia. Procedia – Social and Behavioral Science. 170(1), 282-291.

[2] Impact Haze of Health. Retrieved on November 21st, 2016, from https://www.moh.gov.sg/content/moh_web/home/pressRoom/Current_Issues/2014/haze/faq--impact-of-haze-on-health0.html

[3] United States Environment Protection Agency, (2013). Air Quality Index A Guide to Air Quality & Your Health. United States: Environmental Protection Agency.

[4] Wong T. W., Tam W. W. S., Lau A. K. H., Ng S. K. W., Yu I. T. S., Wong A. H. S. & Yeung D. (2012). A Study of Air Pollution Index Reporting System. Hong Kong: The Chinese University of Hong Kong.

[5] Ling O. H. L., Ting K. H., Shaharuddin A., Kadaruddin A. & Yaakob M. J. (2010). Urban Growth and Air Quality in Kuala Lumpur City, Malaysia. *International Journal of Thai Society of Higher Education Institutes on The Environment, 3*(2), 123-128.

[6] Department of Environment Malaysia, (2000). A Guide to Air Pollutant Index (API) in Malaysia 4th Edition. Malaysia: ASMA Sdn. Bhd.

[7] Air Pollution Index of Malaysia. Retrieved on September 24th , 2016, from http://apims.doe.gov.my/v2/

[8] Last Minute Notice to Close Schools Irks Malaysians. Retrieved on September 30th, 2016, from http://www.thestar.com.my/news/nation/2015/09/16/lastminute-notice-to-close-schools-irks-malaysians/

[9] Metal Oxide Semiconductor Operating Principle. Retrieved on October 17th, 2016, from http://www.figaro.co.jp/en/technicalinfo/principle/mos-type.html

[10] Dust Sensor Detection Operating Principle. Retrieved on October 17th, 2016, from https://itp.nyu.edu/archive/physcomp-spring2014/sensors/Reports/GP2Y1010AU.html

[11] Ruslan N. (2015). Air Pollution Index Real Time Monitoring System. Malaysia: Universiti Tun Hussein Onn.

[12] AEA Technology Plc (2006). A Guide for Local Authorities Purchasing Air Quality Monitoring Equipment 2nd Edition. United Kingdom: AEA Technology Plc.

[13] Liu J. H. et al. (2012). An Air Quality Monitoring System for Urban Areas Based on the Technology of Wireless Sensor Network. *International Journal on Smart Sensing and Intelligent Systems*, *5*(1), 191-214.

[14] Suyuti A. et al. (2012). Microcontroller ATMEGA8535 based design of Carbon Monoxide Gas Detector. ***International Journals of Engineering and Science, 12*(4), 71-80.**

[15] Edward O. O. (2014). A Microcontroller Based Data Acquisition System for Industrial Air Pollution Concentration Measurement in Nigeria. *Journal of Multidisciplinary Engineering Science and Technology*, *1*(3), 19-24.

[16] Witte T. F. (2014). Development of An Indoor Air Quality Monitoring System based on a Microcontroller. Finland: Helsinki Metropolia University of Applied Sciences.

[17] Shariff S. S. (2015). Real Time Air Quality Reporting System. Malaysia: Universiti Tun Hussein Onn.

[18] G. B. Fioccola, R. Sommese, I. Tufano, R. Canonico and G. Ventre, "Polluino: An efficient cloud-based management of IoT devices for air quality monitoring," *2016 IEEE 2nd International Forum on Research and Technologies for Society and Industry Leveraging a better tomorrow (RTSI)*, Bologna, 2016, pp. 1-6.

[19] J. Dutta, F. Gazi, S. Roy and C. Chowdhury, "AirSense: Opportunistic crowd-sensing based air quality monitoring system for smart city," *2016 IEEE SENSORS*, Orlando, FL, 2016, pp. 1-3.

[20] S. Jangid and S. Sharma, "An embedded system model for air quality monitoring," *2016 3rd International Conference on Computing for Sustainable Global Development (INDIACom)*, New Delhi, 2016, pp. 3003-3008.

[21] Revised AQI Breakpoints. Retrieved on December 4th, 2016, from http://aqicn.org/faq/2013-09-09/revised-pm25-aqi-breakpoints/

[22] FIGARO USA INC, "TGS 2600 for Detection of Air Contaminants" TGS 2600 Datasheet, January 2005. [Revised on December 2016].

[23] SHARP Corporation, "$PM_{2.5}$ Sensor Module" DN7C3CA006 Datasheet, September 2014. [Revised on December 2016].

[24] SHARP Corporation, "Compact Optical Dust Sensor" GP2Y1010AU0F Datasheet, December 2006. [Revised on December 2016].

[25] Adafruit Industries LLC, "Digital Relative Humidity & Temperature Sensor AM2302/DHT22". [Revised on February 2017].

[26] GSM Module Specifications. Retrieved on December 5th, 2016 from http://www.mybotic.com.my/webshaper/store/viewProd.asp?pkProductItem=1783

[27] Hoegg U. R. (1972). Cigarette Smoke in Closed Spaces. Environmental Health Perspectives 2: 117-128.

[28] Universiti Teknologi PETRONAS Google Maps. Retrieved March 2, 2017 from https://www.google.com.my/maps/@4.3816948,100.972529,2653m/data=!3m1!1e3?hl=en

[29] Arduino UNO Specifications. Retrieved on December 5th, 2016 from https://www.arduino.cc/en/main/arduinoBoardUno

APPENDICES

FIGARO **PRODUCT INFORMATION**

TGS 2600 - for the detection of Air Contaminants

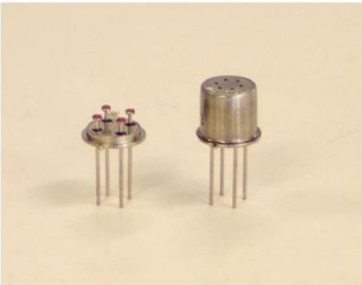
Features:

* Low power consumption
* High sensitivity to gaseous air contaminants
* Long life and low cost
* Uses simple electrical circuit
* Small size

Applications:

* Air cleaners
* Ventilation control
* Air quality monitors

The sensing element is comprised of a metal oxide semiconductor layer formed on an alumina substrate of a sensing chip together with an integrated heater. In the presence of a detectable gas, the sensor's conductivity increases depending on the gas concentration in the air. A simple electrical circuit can convert the change in conductivity to an output signal which corresponds to the gas concentration.



The **TGS 2600** has high sensitivity to low concentrations of gaseous air contaminants such as hydrogen and carbon monoxide which exist in cigarette smoke. The sensor can detect hydrogen at a level of several ppm. Figaro also offers a microprocessor (FIC02667) which contains special software for handling the sensor's signal for appliance control applications.

Due to miniaturization of the sensing chip, TGS 2600 requires a heater current of only 42mA and the device is housed in a standard TO-5 package.

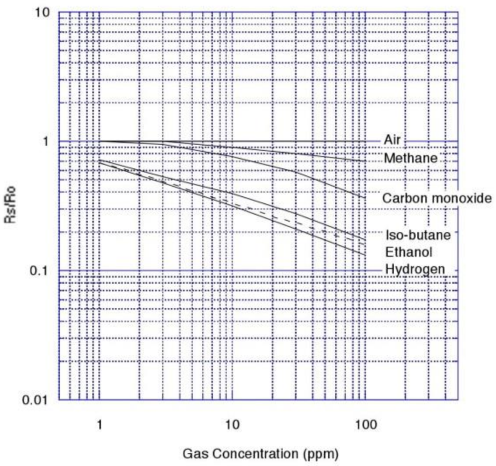
The figure below represents typical sensitivity characteristics, all data having been gathered at standard test conditions (see reverse side of this sheet). The Y-axis is indicated as sensor resistance ratio (Rs/Ro) which is defined as follows:

Rs = Sensor resistance in displayed gases at various concentrations
Ro = Sensor resistance in fresh air

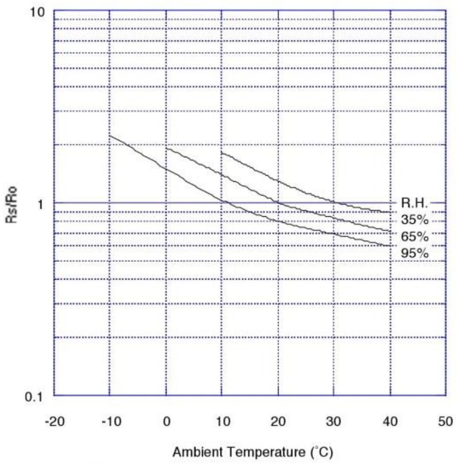
The figure below represents typical temperature and humidity dependency characteristics. Again, the Y-axis is indicated as sensor resistance ratio (Rs/Ro), defined as follows:

Rs = Sensor resistance in fresh air at various temperatures/humidities
Ro = Sensor resistance in fresh air at 20°C and 65% R.H.

Sensitivity Characteristics:



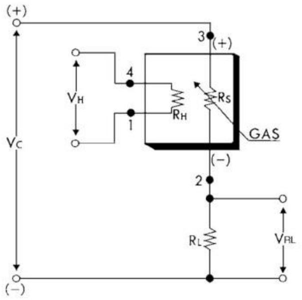
Temperature/Humidity Dependency:



IMPORTANT NOTE: OPERATING CONDITIONS IN WHICH FIGARO SENSORS ARE USED WILL VARY WITH EACH CUSTOMER'S SPECIFIC APPLICATIONS. FIGARO STRONGLY RECOMMENDS CONSULTING OUR TECHNICAL STAFF BEFORE DEPLOYING FIGARO SENSORS IN YOUR APPLICATION AND, IN PARTICULAR, WHEN CUSTOMER'S TARGET GASES ARE NOT LISTED HEREIN. FIGARO CANNOT ASSUME ANY RESPONSIBILITY FOR ANY USE OF ITS SENSORS IN A PRODUCT OR APPLICATION FOR WHICH SENSOR HAS NOT BEEN SPECIFICALLY TESTED BY FIGARO.

Basic Measuring Circuit:

The sensor requires two voltage inputs: heater voltage (V_H) and circuit voltage (V_C). The heater voltage (V_H) is applied to the integrated heater in order to maintain the sensing element at a specific temperature which is optimal for sensing. Circuit voltage (V_C) is applied to allow measurement of voltage (Vout) across a load resistor (R_L) which is connected in series with the sensor.
DC voltage is required for the circuit voltage since the sensor has a polarity. A common power supply circuit can be used for both V_C and V_H to fulfill the sensor's electrical requirements. The value of the load resistor (R_L) should be chosen to optimize the alarm threshold value, keeping power consumption (P_S) of the semiconductor below a limit of 15mW. Power consumption (P_S) will be highest when the value of Rs is equal to R_L on exposure to gas.



Specifications:

Model number			TGS 2600-B00	
Sensing element type			D1	
Standard package			TO-5 metal can	
Target gases			Air contaminants	
Typical detection range			1 ~ 30 ppm of H_2	
Standard circuit conditions	Heater voltage	V_H	5.0±0.2V DC/AC	
	Circuit voltage	V_C	5.0±0.2V DC	Ps ≤ 15mW
	Load resistance	R_L	Variable	0.45kΩ min.
Electrical characteristics under standard test conditions	Heater resistance	R_H	approx. 83Ω at room temp. (typical)	
	Heater current	I_H	42±4mA	
	Heater power consumption	P_H	210mW	V_H=5.0V DC
	Sensor resistance	Rs	10k~90kΩ in air	
	Sensitivity (change ratio of Rs)		0.3~0.6	Rs (10ppm of H_2) / Rs (air)
Standard test conditions	Test gas conditions		normal air at 20±2°C, 65±5%RH	
	Circuit conditions		V_C = 5.0±0.01V DC V_H = 5.0±0.05V DC	
	Conditioning period before test		7 days	

The value of power consumption (P_S) can be calculated by utilizing the following formula:

$$P_S = \frac{(V_C - Vout)^2}{R_S}$$

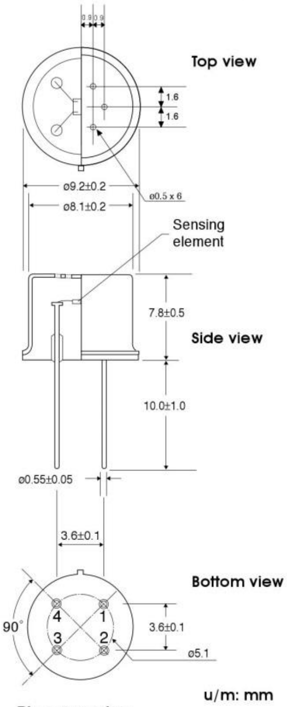
Sensor resistance (Rs) is calculated with a measured value of Vout by using the following formula:

$$R_S = \frac{V_C \times R_L}{Vout} - R_L$$

For information on warranty, please refer to Standard Terms and Conditions of Sale of Figaro USA Inc. All sensor characteristics shown in this brochure represent typical characteristics. Actual characteristics vary from sensor to sensor. The only characteristics warranted are those in the Specification table above.

REV: 01/05

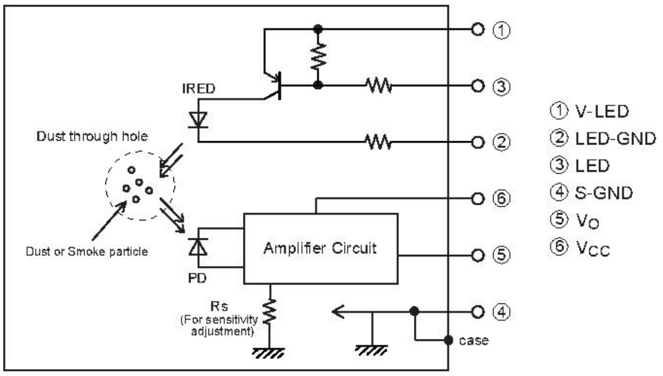
Structure and Dimensions:



Pin connection:
1: Heater
2: Sensor electrode (-)
3: Sensor electrode (+)
4: Heater

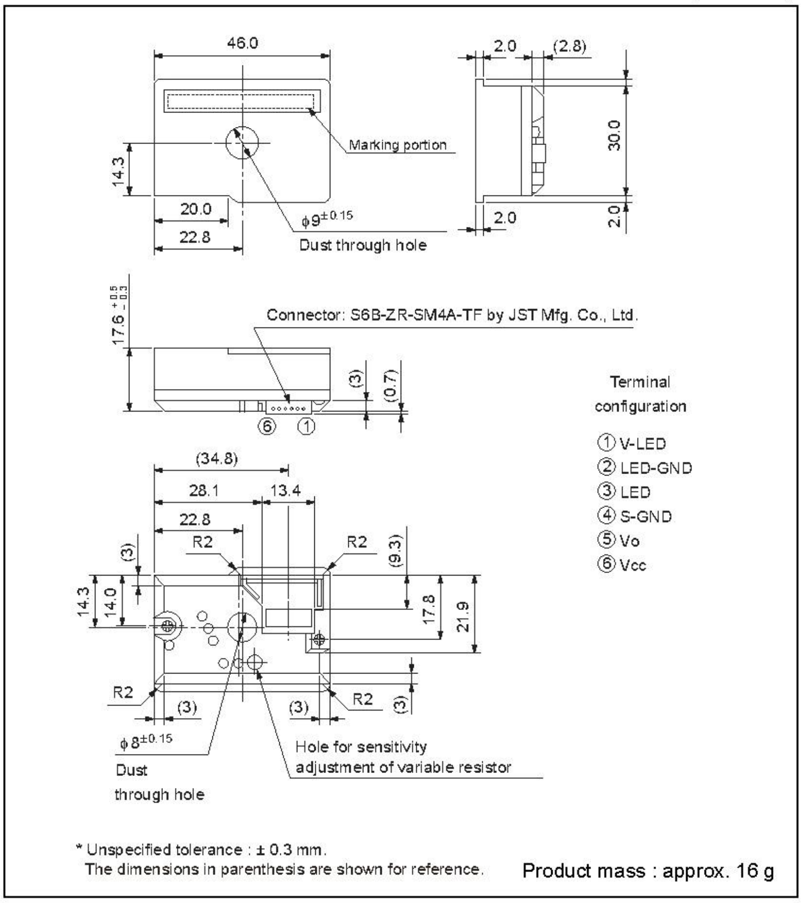
FIGARO USA, INC.
121 S. Wilke Rd. Suite 300
Arlington Heights, IL 60005
Phone: (847)-832-1701
Fax: (847)-832-1705
e-mail: figarousa@figarosensor.com

■ Internal schematic



■ Outline Dimensions

(Unit : mm)



■ Absolute Maximum Ratings

(T_a=25°C)

Parameter	Symbol	Rating	Unit
Supply voltage	V_{CC}	−0.3 to +7	V
*1 Input terminal voltage	V_{LED}	−0.3 to V_{CC}	V
Operating temperature	T_{opr}	−10 to +65	°C
Soldering temperature	T_{sol}	−20 to +80	°C

*1 Open drain drive input

■ Electro-optical Characteristics

(T_a=25°C, V_{CC}=5V)

Parameter	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Sensitivity	K	*1 *2 *3	0.35	0.5	0.65	V/(0.1mg/m³)
Output voltage at no dust	V_{OC}	*2 *3	0	0.9	1.5	V
Output voltage range	V_{OH}	*2 *3 R_L=4.7kΩ	3.4	–	–	V
LED terminal current	I_{LED}	*2 LED terminal voltage = 0	–	10	20	mA
Consumption current	I_{CC}	*2 R_L=∞	–	11	20	mA

*1 Sensitivity is specified by the amount of output voltage change when dust density changes by 0.1 mg/m³.
And the dust density for detection is a value of the density of cigarette (MILD SEVEN®) smoke measured by the digital dust monitor (P-5L2: manufactured by SHIBATA SCIENTIFIC TECHNOLOGY LTD.).
*2 Input condition is shown in Fig. 1
*3 Output sampling timing is shown in Fig. 2

■ Recommended input condition for LED input terminal

Parameter	Symbol	Value	Unit
Pulse Cycle	T	10 ± 1	ms
Pulse Width	P_W	0.32 ± 0.02	ms
Operating Supply voltage	V_{CC}	5 ± 0.5	V

Fig. 1 Input Condition for LED Input Terminal

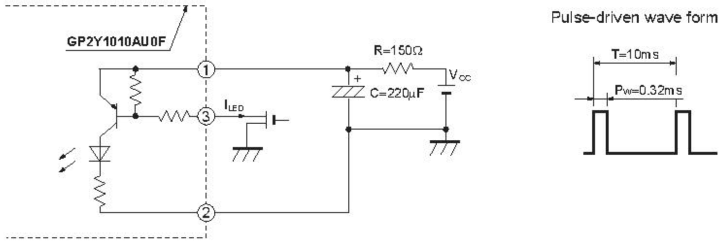


Fig. 2 Sampling Timing of Output Pulse

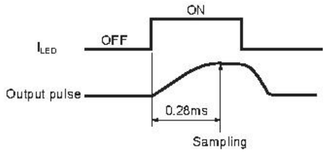
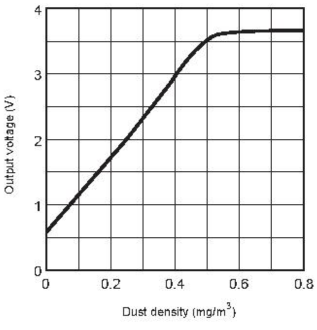


Fig. 3 Output Voltage vs. Dust Density



Remarks : Please be aware that all data in the graph are just for reference and are not for guarantee.

Aosong Electronics Co.,Ltd

Your specialist in innovating humidity & temperature sensors

1. Feature & Application:

* Full range temperature compensated * Relative humidity and temperature measurement
* Calibrated digital signal *Outstanding long-term stability *Extra components not needed
* Long transmission distance * Low power consumption *4 pins packaged and fully interchangeable

2. Description:

DHT22 output calibrated digital signal. It utilizes exclusive digital-signal-collecting-technique and humidity sensing technology, assuring its reliability and stability.Its sensing elements is connected with 8-bit single-chip computer.

Every sensor of this model is temperature compensated and calibrated in accurate calibration chamber and the calibration-coefficient is saved in type of programme in OTP memory, when the sensor is detecting, it will cite coefficient from memory.

Small size & low consumption & long transmission distance(20m) enable DHT22 to be suited in all kinds of harsh application occasions.

Single-row packaged with four pins, making the connection very convenient.

3. Technical Specification:

Model	DHT22
Power supply	3.3-6V DC
Output signal	digital signal via single-bus
Sensing element	Polymer capacitor
Operating range	humidity 0-100%RH; temperature -40~80Celsius
Accuracy	humidity +-2%RH(Max +-5%RH); temperature <+-0.5Celsius
Resolution or sensitivity	humidity 0.1%RH; temperature 0.1Celsius
Repeatability	humidity +-1%RH; temperature +-0.2Celsius
Humidity hysteresis	+-0.3%RH
Long-term Stability	+-0.5%RH/year
Sensing period	Average: 2s
Interchangeability	fully interchangeable
Dimensions	small size 14*18*5.5mm; big size 22*28*5mm

4. Dimensions: (unit----mm)

1) Small size dimensions: (unit----mm)

Thomas Liu (Business Manager)

Email: thomasliu198518@yahoo.com.cn

2．性能 (General characteristics)

2.1 絶対最大定格 (Absolute maximum ratings)

Item	Symbol	Specification	Unit	Note
電 源 電 圧 Supply voltage	Vcc	-0.3 ～ +7	V	センサ印加電圧 Sensor voltage
電 源 電 圧 Supply voltage	FAN Vcc	+5.7 Max.	V	ファン印加電圧 Fan voltage
入力端子電圧 Input terminal Voltage	VLED	-0.3 ～ Vcc	V	オープンドレイン駆動入力 Open-drain drive input

2.2 動作条件 (Operation condition)

-10 ℃ ～ +60 ℃ / 10%～90%RH(水蒸気圧6643Pa 以下) 結露しない事

(Water vapor pressure 6643Pa max.) (No Condensation)

2.3 保存条件 (Storage condition)

-20 ℃ ～ +70 ℃ / 10%～90%RH(水蒸気圧6643Pa 以下) 結露しない事

(Water vapor pressure 6643Pa max.) (No Condensation)

2.4 動作電圧 (Operating voltage) △1

Symbol	Specification	Unit	Note
Vcc	5 ± 0.25	V	センサ電圧 Sensor voltage
FAN VCC	5 ± 0.25	V	ファン電圧 Fan voltage

2.5 試験条件 (TEST condition)

Symbol	Specification	Unit	Note
Vcc	5 ± 0.1	V	センサ電圧 Sensor voltage
FAN VCC	5 ± 0.1	V	ファン電圧 Fan voltage
Ttest	25 ± 1	℃	周囲温度 Temperature
Htest	65 ± 10	%	相対湿度 Humidity

2.6 電気的光学特性 (Electrical and optical characteristics)

(特に指定の無い場合は2.5項の条件に従うこと)

(Of the designation when there is not it,

the follows obey a condition of Clause 2.5)

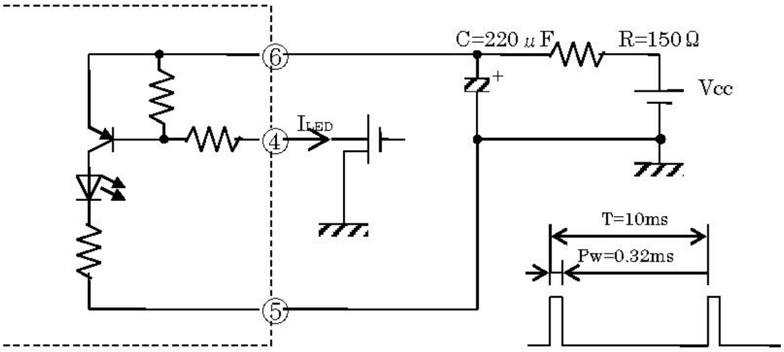
項目 Parameter	記号 Symbol	条件 Condition	MIN	TYP	MAX	単位 Unit
検出感度 Detection sensitivity	K	(注1)(注2) (注3)(注4) (Note 1)(Note 2) (Note 3)(Note 4)	0.85	1.0	1.15	V/ (100μg/m³)
無塵時出力電圧 Output voltage under dust-free condition	VOC	(注2)(注3)(注4) (Note 2)(Note 3) (Note 4)	—	1.0	1.7	V
出力電圧範囲 Output voltage rage	VOH	RL＝4.7KΩ (注2)(注3) (注4) (Note 2)(Note 3) (Note 4)(Note 5)	3.4	—	—	V
ＬＥＤ端子電流 LED terminal current	ILED	LED端子＝0V (注2)(注3) (Note 2)(Note 3)	—	10	20	mA
消費電流 Current consumption	ICC	RL＝∞ (注2)(注3) (Note 2)(Note 3)	—	11	20	mA
ファン電流 Fan current	Ifan			140		mA
温度係数 ⊿mV/℃	Ktemp	(注2)(注3) (注4) (Note 2) (Note 3) (Note 4)		6 1.5		mV/℃ (-10℃～40℃) mV/℃ (40℃～60℃)

(注1)・粉塵濃度は、デジタル粉塵計(柴田化学器械工業㈱製　P－5L2)を使用し、
たばこ（メビウス）の煙濃度を測定した値とする。
・検出感度Kは、粉塵濃度が100μg/m³変化した時の出力電圧変化量について規定するものである。

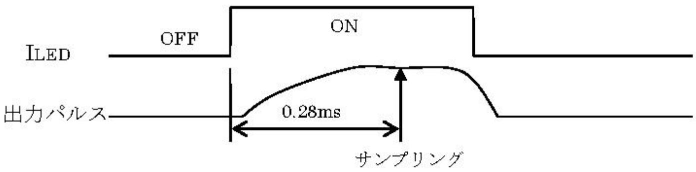
(Note 1)・The dust concentration is the value which measured the smoke density of MEVIUS using the digital dust indicator (P-5L2 from Sibata Scientific technology LTD.).
・The detection sensitivity is the change amount of the output voltage when the dust concentration changed 100μg/m³.

(注2) LED端子への入力条件(パルス駆動条件)
(Note 2) Input condition of the LED terminal (pulse driving condition).

(注3) 以下定数の C、R を接続
(Note 3) A capacitor and a resister as follows are mounted.



(注4) 出力パルスサンプリングタイミング
(Note4) Output pulse sampling timing



2.7 LED入力端子へのパルス入力範囲 (Pulse input range to LED input terminal)

項　目 Parameter	記号 Symbol	パルス入力範囲 Pulse input range	単位 Unit
パルス周期 Pulse period	T	10 ± 1	ms
パルス幅 Pulse width	Pw	0.32 ± 0.02	ms

2.8 PM2.5 測定範囲 (PM2.5 measurement range) △1

項　目 Parameter	記号 Symbol	仕様 Specification	単位 Unit
測定レンジ Measurement range	―	25 to 500	μg/m^3

PM2.5 測定レンジ は下記条件下での出力電圧を以下の変換式を用いて換算した時の値とする。

【測定条件】 25±1℃ 、Vcc＝5±0.1V
ハイプレシカ(SiO2) φ2.5μm のサンプルを $1m^3$ のボックス内で
噴霧し、60 秒後の測定値を換算

The measurement accuracy is the value which is converted the output voltage under the following condition using the following conversion formula.

Measurement condition: 25±1℃, Vcc=5±0.1V
Convert the measurement value after 60 seconds from spraying the samples of HIPRESICA (SiO2)φ2.5um in the $1m^3$ box.

当モジュールは光散乱方式を用いて、センサを通る大気中のほこりなどにLEDの光を照射し、その反射光を検出します。その反射光の大きさにより電圧が変化します。
そのため、電圧変化として出力する機器であり質量濃度(μg/m3)を計測する装置ではありません。
後述の変換式を用いて質量濃度に変換する為、精密な測定器としては使えません。
また大気中のほこりの種類、成分により出力電圧は変化します。

This module adopts a light scattering method. Our module irradiates atmospheric dust going along the sensor with light of the LED and detects the borrowed light. The voltage changes by reflected light.
This module is the device with respect to output voltage change as a particle volume concentration (μm/m3) of dusts in atmosphere, Not a device for measuring the mass concentration (μg/m3).
This module is not able to use a precision measuring apparatus, Because it is necessary to convert the mass concentration using the conversion formula described below.
and the conversion formula will be changed below will change by the type , components, mass distribution of the dust in atmosphere.

換算方法

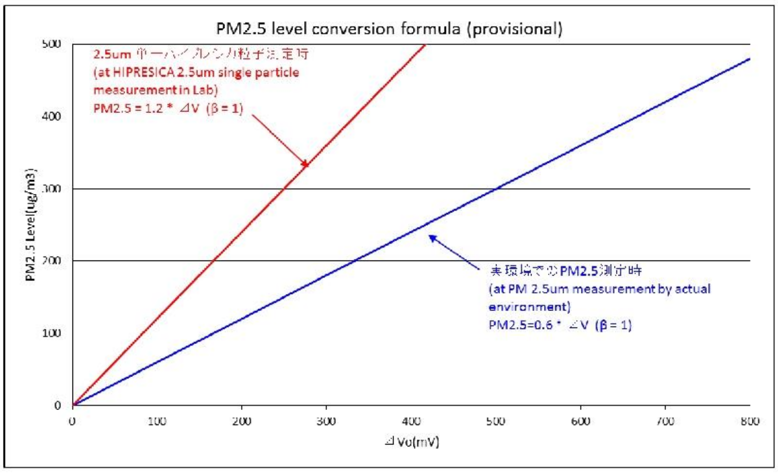
① ほこりの少ない環境下(例えばクリーンボックス)で基準電圧(Vs)を記憶する。
又はファンを止め数分経過後(ほこりが重力で落ち着いた状態)に基準電圧(Vs)を記憶する。
※出力電圧は、Vo 端子(2 番ピン)から取り出して下さい。
② ファンを回した状態で①の状態の出力電圧(Vo)と基準電圧との差を⊿電圧[mV] (Vo[mV] － Vs[mV])とすると下記換算式で PM2.5 濃度を概算する事が出来ます。

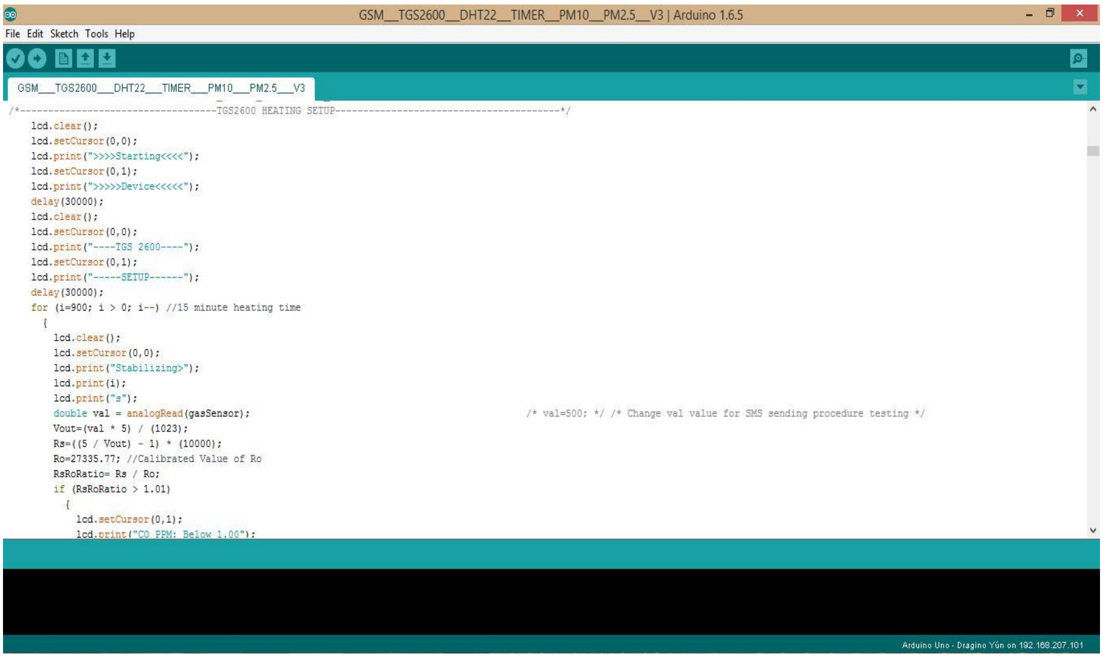
換算式：
PM2.5 濃度 (μg/m3) ＝ α × β × (Vo[mV] － Vs[mV])
※ 温度補正をしない場合の実環境での概算値
α ： 実環境における換算係数 （ ”0.6” を推奨 ）
(β ： 湿度係数〔h=湿度(%)〕)
〔 β ＝ {1-0.01467(h-50)} (h>50) 〕
〔 β ＝ 1 (h≦50) 〕

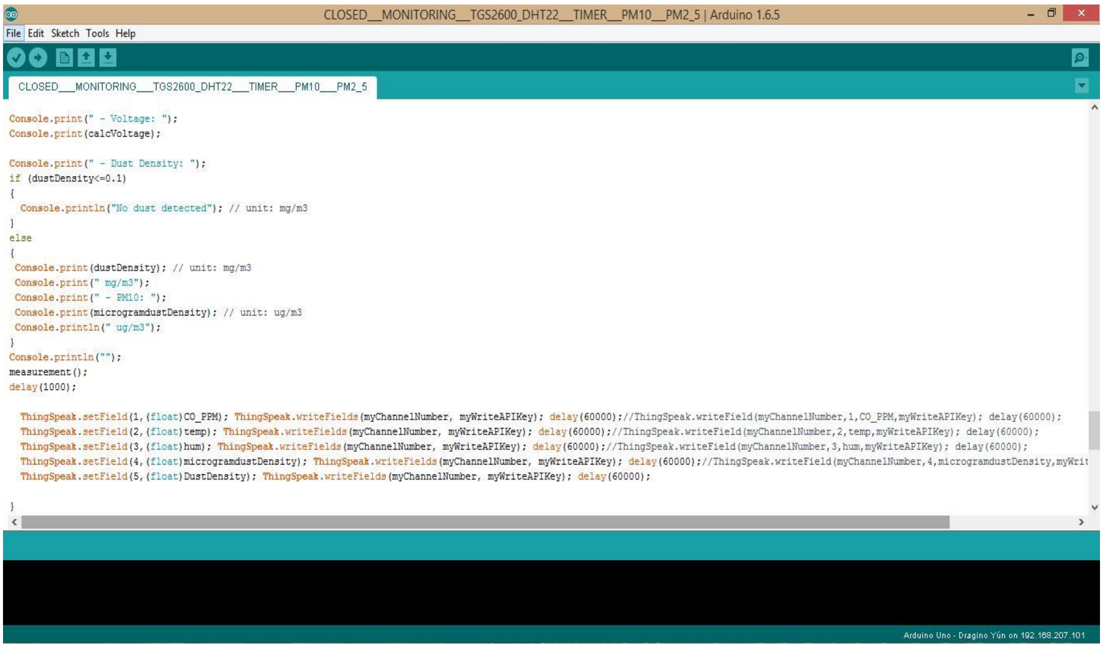
Conversion Formula

1. Store a reference voltage (Vs) in the environment with less dust (for example clean box etc).
or store a reference voltage (Vs) in the state that after a few minutes to stop the fan (state that dust fell by gravity).
Note. The output voltage is Vo terminal (pin 2)
2. In case that ⊿ voltage[mV] (Vo[mV] － Vs[mV]) is difference between the reference voltage(Vs) and the output voltage (Vo) when the fan turn on.
It is possible to approximate the PM2.5 level by use following conversion formula.

Conversion formula (draft):
PM2.5 level (μg/m3) ＝ α × β × (Vo[mV] － Vs[mV])
Note. Do not temperature correction, an estimates in actual environment.
α ： Conversion factor in the true environment
Recommendation ： 0.6
(β ： Humidity factor〔h=humidity(%)〕)
〔 β ＝ {1-0.01467(h-50)} (h>50) 〕
〔 β ＝ 1 (h≦50) 〕




GSM__TGS2600__DHT22__TIMER__PM10__PM2.5__V3 | Arduino 1.6.5
File Edit Sketch Tools Help
GSM__TGS2600__DHT22__TIMER__PM10__PM2.5__V3
/*----------------------------------TGS2600 HEATING SETUP---------------------------------------*/
lcd.clear();
lcd.setCursor(0,0);
lcd.print(">>>>Starting<<<<");
lcd.setCursor(0,1);
lcd.print(">>>>>Device<<<<<");
delay(30000);
lcd.clear();
lcd.setCursor(0,0);
lcd.print("----TGS 2600----");
lcd.setCursor(0,1);
lcd.print("-----SETUP------");
delay(30000);
for (i=900; i > 0; i--) //15 minute heating time
{
lcd.clear();
lcd.setCursor(0,0);
lcd.print("Stabilizing>");
lcd.print(i);
lcd.print("s");
double val = analogRead(gasSensor);
/* val=500; */ /* Change val value for SMS sending procedure testing */
Vout=(val * 5) / (1023);
Rs=((5 / Vout) - 1) * (10000);
Ro=27335.77; //Calibrated Value of Ro
RsRoRatio= Rs / Ro;
if (RsRoRatio > 1.01)
{
lcd.setCursor(0,1);
lcd.print("CO PPM: Below 1.00");
Arduino Uno - Dragino Yún on 192.168.207.101


CLOSED__MONITORING__TGS2600_DHT22__TIMER__PM10__PM2_5 | Arduino 1.6.5
File Edit Sketch Tools Help
CLOSED__MONITORING__TGS2600_DHT22__TIMER__PM10__PM2_5
Console.print(" - Voltage: ");
Console.print(calcVoltage);
Console.print(" - Dust Density: ");
if (dustDensity<=0.1)
{
Console.println("No dust detected"); // unit: mg/m3
}
else
{
Console.print(dustDensity); // unit: mg/m3
Console.print(" mg/m3");
Console.print(" - PM10: ");
Console.print(microgramdustDensity); // unit: ug/m3
Console.println(" ug/m3");
}
Console.println("");
measurement();
delay(1000);
ThingSpeak.setField(1,(float)CO_PPM); ThingSpeak.writeFields(myChannelNumber, myWriteAPIKey); delay(60000);//ThingSpeak.writeField(myChannelNumber,1,CO_PPM,myWriteAPIKey); delay(60000);
ThingSpeak.setField(2,(float)temp); ThingSpeak.writeFields(myChannelNumber, myWriteAPIKey); delay(60000);//ThingSpeak.writeField(myChannelNumber,2,temp,myWriteAPIKey); delay(60000);
ThingSpeak.setField(3,(float)hum); ThingSpeak.writeFields(myChannelNumber, myWriteAPIKey); delay(60000);//ThingSpeak.writeField(myChannelNumber,3,hum,myWriteAPIKey); delay(60000);
ThingSpeak.setField(4,(float)microgramdustDensity); ThingSpeak.writeFields(myChannelNumber, myWriteAPIKey); delay(60000);//ThingSpeak.writeField(myChannelNumber,4,microgramdustDensity,myWrit
ThingSpeak.setField(5,(float)DustDensity); ThingSpeak.writeFields(myChannelNumber, myWriteAPIKey); delay(60000);
}
Arduino Uno - Dragino Yún on 192.168.207.101