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

Worldey Gurut[1], Herman Wahid[1*], Dirman Hanafi Burhanuddin[2], Elmy Johana Mohamad[2]

[1] School of Electrical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81300 UTM Skudai, Johor, Malaysia.
[2] Instrumentation and Sensing Technology (InSeT) Research Group, Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

Corresponding author* email: herman@utm.my
Accepted 1 November 2021, available online December 2021

ABSTRACT

The most crucial factors that affecting the health and quality of life of people who live in urban area is the air pollution. In a country with a rapid development economy, such as Malaysia, air pollution one of the highest risks for this country to get involved in this problem. Furthermore, the presence of dust and particulate matter in the air affecting not only humans, animals and plants but also make the efficiency of solar panels in power generations will drop. In addition, the existing air quality monitoring system are mostly dependent on fixed power supply which makes the system less flexible and most of it are not mobile system which making the information difficult to be accessed by the user or public. In this work, a flexible and online monitoring system is proposed for monitoring and measuring the levels of some harmful gases such as CO_2, CO, SO_2, O_3 as well as other environmental parameters which are dust, temperature and humidity. Data is collected by using low cost MQ-series sensors that will send the data to the microcontroller (Arduino UNO), which represent the hardware part of this project as well as the solar tracker and others components. This microcontroller will be using WiFi module, ESP8266-01, a WiFi transceiver which will be connected to the available hotspots to allows the data to be send to the cloud by using an open source Internet of Things (IoT) platform known as ThingSpeak, which is the software part for this project. A solar tracker is added to make the system independent and more flexible. The solar panel will be used to power up the system as well as to recharge the battery at day time. The complete system will later be tested to get expected outcome. In the long term, this system is expected to help the community by providing the data of the surrounding air quality.

Keywords: IoT, Arduino, Air Quality Monitoring, Solar Tracker, solar power source

1. Introduction

Air pollution has become a major problem to nowadays society [1-3]. Many countries around the globe facing this problem almost every year or even every month. This air pollution is usually caused by people, emissions from cars, planes, factories and aerosol cans. This pollution brings a wide range of health effects to people that being exposed to it [4-5]. Health problem such as pneumonia, bronchitis and nausea often caused by air pollution. Global warming and acid rain which is harmful to environment also mainly caused by air pollution [5]. Based on World Health

Organization (WHO) research, increasing in urban air pollution index higher the risk for cardiovascular and respiratory disease and cancer.

Classical methods to analysis the problem is no longer suitable due to its complexity, unstable operation, large size and high cost. By using IOT and others inexpensive sensors, the system will be more flexible and low cost. Adding a solar tracker provides higher efficiency and flexibility [1]. In order to prevent people from being exposed to the pollution, a real-time monitoring system should be installed near the most affected areas. Using the new technologies such as Internet of Things (IoT) allows the residents to get the information faster and easier just by using their smartphone [2]. Many open source IoT platform such as ThingSpeak provide a real-time data analysis in term of graphical and digital representation which is easy to understand.

To make the system portable, energy harvesting by using solar panel can be implemented. This method not only makes the system flexible but also eco-friendly. By adding solar tracker, the energy harvested from the solar panel can be increased up to 15% compare to a solar system without a solar tracker [1].

This work will propose an air quality monitoring to address the aforementioned issues above. It uses IoT technology to collect the monitoring data and operated by using rechargeable battery and also a solar panel (which also used to charge the battery). Solar tracking system which utilizes LDR sensors will increase the energy harvested from the solar panel. Besides, the device uses inexpensive MQ series sensors to detect different gases for air quality data monitoring.

2. Background study

Nayyar et. al [4] has reviewed the semiconductor- type sensors and also suggest the suitable sensors for the detection. Most analysts utilized semiconductor-type gas sensor because of further extent of affectability, proficiency and can recognize various gases and are completely utilitarian in high temperature, reactivity, high moistness and others more terrible conditions. Semiconductor gas sensors are electrical conductivity sensors. The sensing layer of the sensor change when in contact with gas. This gas will respond with the outside parts of the sensors in a reversible reaction. The chemical composition properties of the sensors allow them to detect all sorts of reactive gases. This type of sensors also widely used for air pollution monitoring to detect gases like Carbon Monoxide (CO), Nitrogen Oxide (NO_2) and any others harmful gases. Gas sensors is usually consisting of two part which is receptor and transducer, as depicted in Figure 1. One of the recommended sensors are MQ series sensors which is low cost and easy to use.

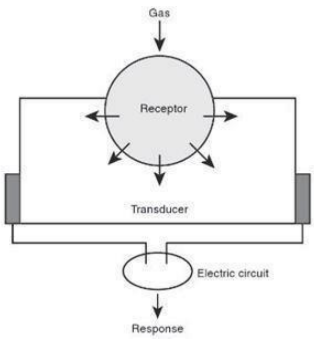

Figure 1. Gas sensor: Receptor and Transducer [4]

Xu and He made survey on the benefits of using IoT in the industry [2]. One of the foundational of IoT is RFID technology which is commonly used in industry until now. Another basic innovation for IOT is the wireless sensor networks (WFNs which uses interconnected intelligent sensors that has been used to detect and observing. The applications incorporate natural, medical services, industrial and traffic checking. Figure 2 shows others technologies those are associated with IoT [6].

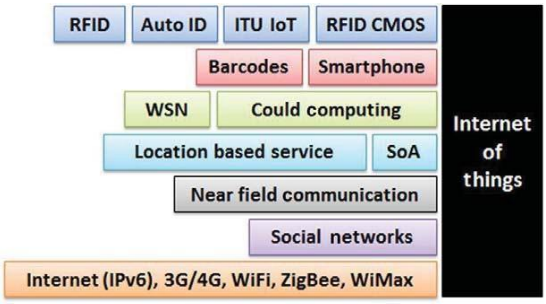

Figure 2. Technologies associated with IoT [6]

Sirsikar and Karemore reviewed on some technologies which are used to monitor the air quality and the effectiveness of these technologies [3]. Previously, the air contamination checking is done through automated tomography technique which generate a two-dimensional guide of toxin focus. Another method of monitoring air quality is by utilizing on the wed GPRS sensors cluster. The system is consisting of a single-chip microcontroller and a contamination server which has a top of the line individual application server with a web network. The wireless sensor is the best application to monitor air quality due to its low cost, easy to setup, and provide a real time pollutant data.

In another work, Devarakonda et. al proposed real-time air quality monitoring through mobile sensing [7]. They recommended the vehicular-principally based versatile technique for estimating fine-grained air quality continuously. Two cost-effective information cultivating models are proposed, and to be attached to public transportation and an individual detecting gadget. The first sensing model was built and to be installed on public transportation that has constant and good routes along the roads. The second sensing model is attached to personal cars and will be connected using Bluetooth to the smartphone. The system overview is illustrated in Figure 3. The weakness of this type of monitoring system is the devices still need to use external power supply and only a few people can access to the sensors data. Other examples of IoT based air quality monitoring system can be found in [8-10].

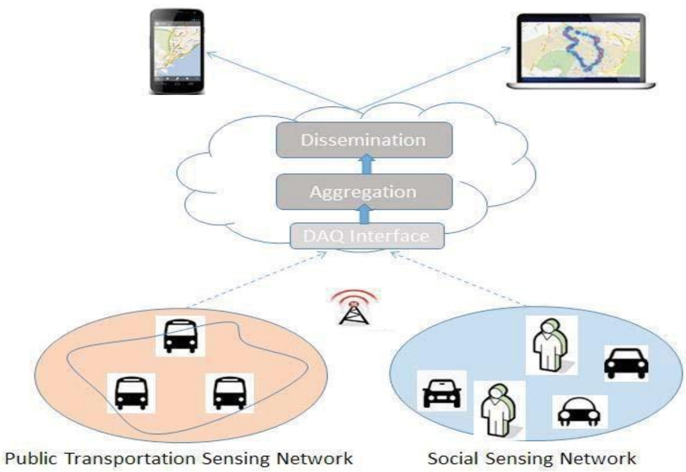

Figure 3. The system overview of air quality monitoring through mobile sensing [7]

3. Methodology

3.1 Overview of the Proposed System

The block diagram in Figure 4 shows how the flow of the system works starting from the sensors to the microcontroller and lastly to the users. The sensors will send the data to the microcontroller and the microcontroller will send the information wirelessly through the WiFi module to the cloud using ThingSpeak as the IoT platform. Lastly, the information will be send to users by displaying the information using smartphone or laptop.

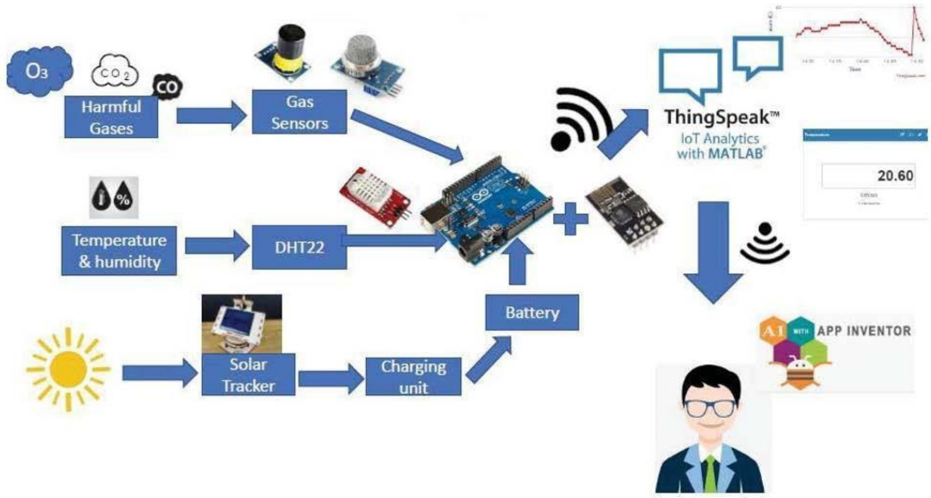

Figure 4. Block diagram of the system

3.2 Solar Charging Method for Powering the System

The method to charge both Li-ion battery and the power bank is different. For the batteries, the 9 V output from the solar panel is step down to 5 V by using a 5 V voltage regulator circuit. The 5 V output from the regulator circuit then connected to 5V input of the battery charger controller before the output port of it connected to the two batteries which in parallel connection. Figure 5 below shows the overall connection for the batteries charging method.

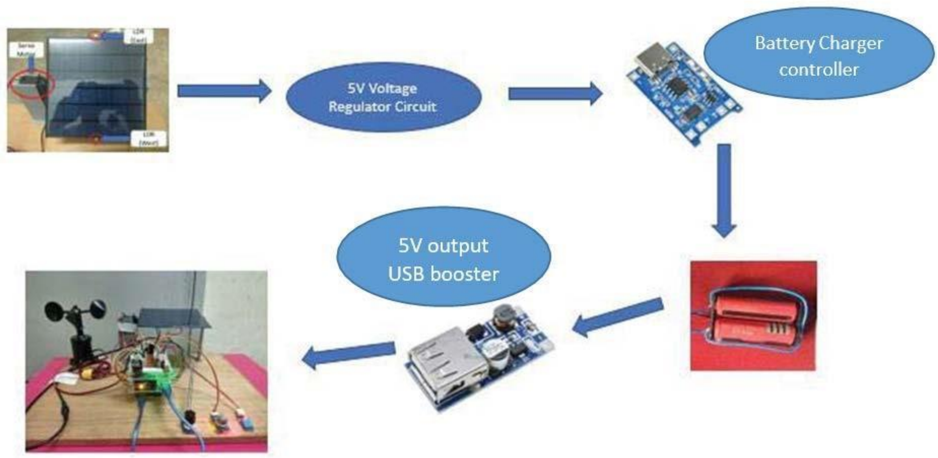

Figure 5. Solar Charging Method for Li-ion Batteries

For the power bank, the only different is, the USB booster with 5 V output is connected to the output of the charger controller to step up the 4 V to 5 V before charging the power bank since the power bank need 5 V input to charge it. Figure 6 shows how the connection is done.

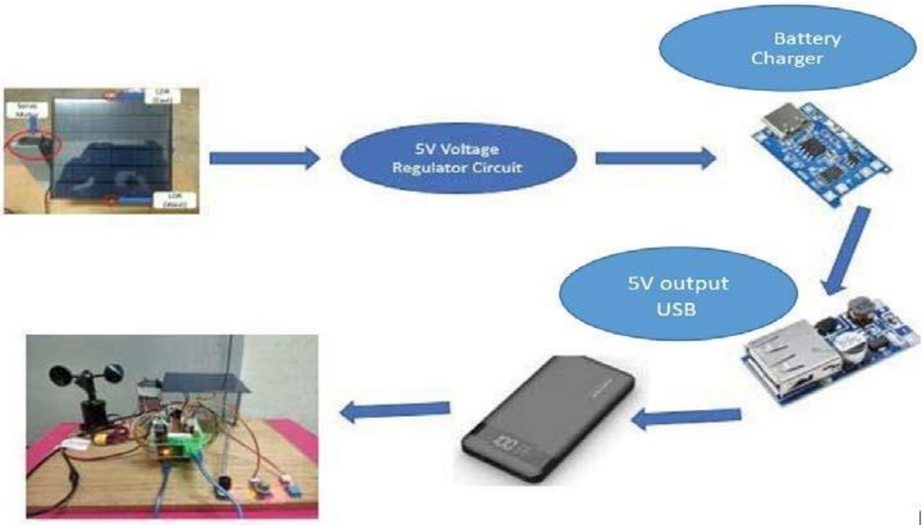

Figure 6. Solar Charging Method for Power Bank

3.3 The Single Axis Solar Tracker

Since this project is consisting of a solar charging method, the single axis solar tracker is designed as well to increase the energy harvested from the sunlight to power and charge the batteries. This solar tracker uses two Light Dependent Resistors (LDR), which each of it are represent east and west direction. A servo motor is used to move the panel when there is a different of light intensity detected by the LDRs. Two resistors is used to make a simple voltage divider circuit and connected to the ground. The different of light intensity will affect the resistance of the LDR, the voltage divider is used to detect the voltage sent to the Arduino analogue pin and lastly the servo will move to the direction which has higher light intensity. The servo only stops when the different or the error between the two analogue input is below the threshold value given. Figure 7 shows the overall connection of the tracker and the Arduino.

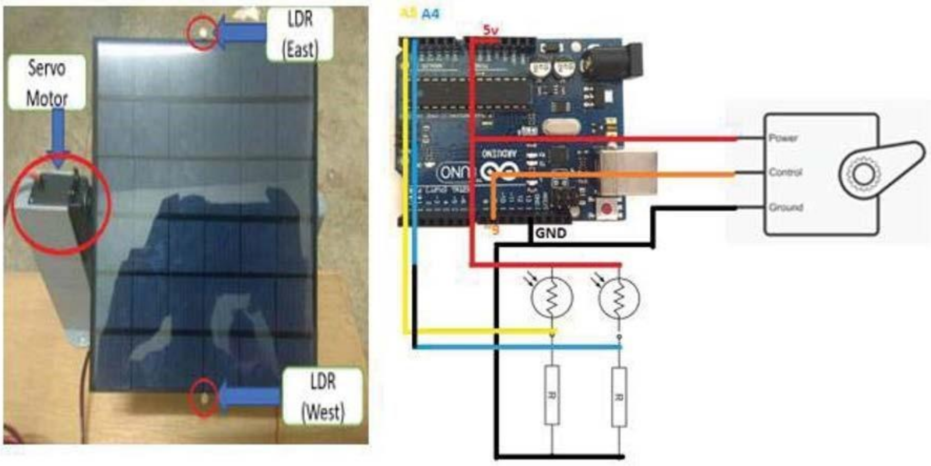

Figure 7. The solar tracker and connection to the Arduino

3.4 The Internet of Things (IoT) and Smartphone App

This project uses ThingSpeak as an open source IoT platform. ThingSpeak is used to display the data from the sensor in cloud. This project also used open source application inventor known as MIT App Inventor. The combination of both open source platforms allowed users or public to view the data from the monitoring system. It is very user friendly since the user just need to install the app on their smartphone and they can view the current air quality from the system easily as long as they have an active internet connection. Figure 8 and Figure 9 show the ThingSpeak view and also the MIT App Inventor, respectively.

Figure 8. ThingSpeak view (Graphical and Numerical)

Figure 9. MIT Apps Inventor

3.5 The System Prototype

To test the functionality of the project, all the component including the sensors are assembled before the experiment start. Figure 10 below shows the full setup of the project.

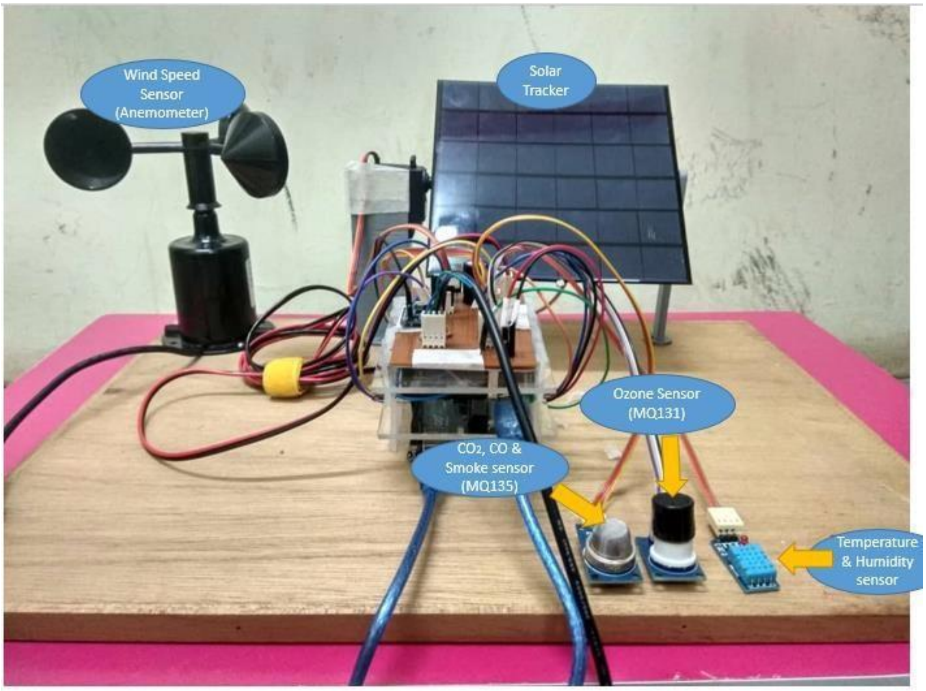

Figure 10. Full system assembly

4. Results and Discussion

The project testing is included the monitoring the air quality and the power management. All the reading in term of voltage was measured by using a portable multimeter. Only calibration using sensors library was conducted done using the Arduino IDE programmer.

4.1 Voltage Consumption of Li-ion Batteries and Power Bank

To make sure that the system can run for a certain period of time, a voltage consumption of the system was recorded in every 5 minutes for 45 minutes by using different types of power source which is the batteries and the power bank. For this experiment, the solar charger was disconnected from the system, by doing this, we can consider that the system is running at night time or at the time when there is no sunlight. All the data obtained was recorded and the voltage consumption by using the two different power source is calculated, as listed in Table 1.

Table 1. Voltage Consumption when using Li-ion Battery

Time (minutes)	Battery Voltage (V)
0	4.20
5	2.15
10	4.10
15	4.04
20	3.99
25	3.94
30	3.89
35	3.83
40	3.78
45	3.73

From the Table 1, the average voltage consumption of the battery per one minute over the experiment time was identified as 0.01 V/min. Next, the time for the battery to completely discharged is calculated. Note that the Li-ion battery fully charged at 4.20 V and discharged at 3.00 V. With this information, we can calculate the time for the battery to completely discharged for about 120 min (2 hours). From the calculation, we can conclude that the battery can only last for two hours to power up the system when there is no solar energy available.

For the power bank, the data taken is extended for one hour to get the accurate power consumption of it. Same as the battery, the solar charger is also disconnected from the system. The data once again recorded as in Table 2 and the calculation is done to obtain the voltage consumption of the system when using the power bank in one minute. The voltage consumption in one minute was identified as 0.13%/min. Assuming that we want the power bank voltage at least 5% before the solar charging is available, hence t = 100 - (0.13 x t) * 5 = 730.77 min. From the calculation we can conclude that the power bank can last about 12 hours without the solar charging. Therefore, by considering the case in Malaysia, the sunlight is only available for 12 hours from 6.30 am to 6.30 pm and the night time is also 12 hours form 6.30 pm to 6.30 am. Conclusion can be made that, the power bank is the most suitable power supply for the project based on the experimental results obtained.

Table 2. Voltage Consumption when using Power Bank

Time (minutes)	Power Bank Voltage (%)
0	69%
5	68%
10	68%
15	67%
20	67%
25	65%
30	65%
35	64%
40	64%
45	63%
50	63%
55	62%
60	61%

4.2 Charging Rate of Li-ion Batteries and Power Bank

The charging rate for both power supply is important as we need to make sure that the system can run at night with a fully charged power supply. For this experiment, the solar charger is connected to the system as shown in the methodology part. Charging rate for both power supply is recorded and analyzed. The data taken for both power supply is every five minutes for 45 minutes. The average charging rate for one minute and time to fully charged the power supply was identified as 0.011 V/min.

Table 3. Charging Rate for Li-ion Battery

Time(minutes)	Battery Voltage (V)
0	3.34
5	3.38
10	3.46
15	3.53
20	3.59
25	3.62
30	3.66
35	3.73
40	3.78

45	3.84

The charging rate experiment for the power bank is recorded in Table 4. Here, the average charging rate in one minute for the power bank was calculated as 0.60%/min. Thus, the total time to fully charge the power bank form zero percentage is calculated as t = 0 + (0.6 x t) * 100 = 166.67 min. It is concluded that the charging time took around two hours and 47 minutes to reach 100% battery percentage.

Table 4. Charging Rate for Power Bank

Time(minutes)	Battery Percentage (%)
0	54
5	57
10	60
15	63
20	65
25	68
30	71
35	74
40	77
45	80

4.3 Monitoring via ThingSpeak and Android App

The main purpose of this project is for monitoring the air quality by using Internet of Things (IoT) technology. An open source IoT platform known as ThingSpeak is used in this project, as well as the android apps creator which is MIT app Inventor, to make the monitoring purpose more user friendly. The data read from the gas sensors are in parts per million (PPM) unit. To know how safe is the air quality is, a Malaysia Ambient Air Quality Standard as in Table 5 is used as the reference.

Table 5. New Malaysia Ambient Air Quality Standard [11]

Pollutants	Averaging Time	Ambient Air Quality Standard		
		IT-1 (2015) µg/m³	IT-2 (2018) µg/m³	Standard (2020) µg/m³
Particulate Matter with the size of less than 10 micron (PM_{10})	1 Year	50	45	40
	24 Hour	150	120	100
Particulate Matter with the size of less than 2.5 micron ($PM_{2.5}$)	1 Year	35	25	15
	24 Hour	75	50	35
Sulfur Dioxide (SO_2)	1 Hour	350	300	250
	24 Hour	105	90	80
Nitrogen Dioxide (NO_2)	1 Hour	320	300	280
	24 Hour	75	75	70
Ground Level Ozone (O_3)	1 Hour	200	200	180
	8 Hour	120	120	100
*Carbon Monoxide (CO)	1 Hour	35	35	30
	8 Hour	10	10	10

*mg/m³

(Note that: $1ug/m^3=1x10^{-3}mg/m^3=1ppb=0.001ppm$)

The result from the ThingSpeak and the android app are both presented in graphical and numerical view. In the data provided, users can look at the sensors reading to know the air quality in their surrounding referring to the standard as in Table 5. The table also available in the android app for reference purposes. The IoT outputs appearance of the air quality data in desktop/laptop browser and in Android App are shown in Figure 11 and Figure 12, respectively. The system only provides three types of gas concentration which are Carbon Dioxide (CO_2), Carbon Monoxide (CO) and Ozone (O_3). Others gases such as Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2) as well as the Particulate Matter are not included in this project due to limit of sensors available and its cost.

Figure 11. ThingSpeak View using Laptop/Desktop Browser

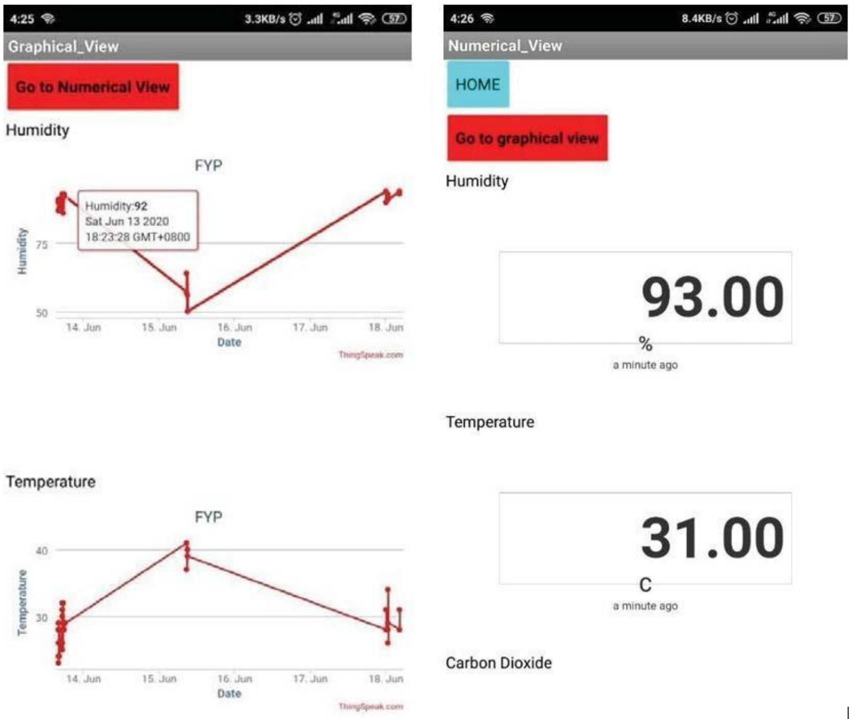

Figure 12. ThingSpeak View from Android App

5. Conclusion

As the conclusion, this work proposes an online real-time air quality monitoring system for the public usage. The solar tracking allows maximum power absorption from the sun rays. The collected information can be used by the government to alert the residence if there is a sudden change in air quality. The proposed device can also be implemented to a certain region which is often affected by the air pollution for example near the factories or industrial park. By utilizing the low-cost sensors and microcontroller, this proposed project is inexpensive in term of construction and maintenance.

The graphical and digital representation using ThingSpeak allows user to easily obtain the information.

Acknowledgment

This work is funded by the Ministry of Higher Education under FRGS, Registration Proposal No: FRGS/1/2020/ICT02/UTM/02/5 & UTM..

References

[1] J. Rizk, Y. Chaiko, "Solar Tracking System: More Efficient Use of Solar Panels," *World Academy of Science*, Engineering and Technology, 41, 2008.

[2] Li Da Xu, S, Wu He, Shancang Li, "Internet of Things in Industries: A Survey," *IEEE Transactions on Industrial Informatics*, vol. 10, no. 4, November 2014.

[3] Snehal Sirsikar, Priya Karemore, "Review Paper on Air Pollution Monitoring system," *International Journal of Advanced Research in Computer and Communication Engineering*, Vol. 4, Issue 1, January 2015.

[4] Anand Nayyar, Vikram Puri, Dac-Nhuong Le, "A Comprehensive Review of Semiconductor-type Gas Sensors for Environmental Monitoring," *Review of Computer Engineering Research*, 2016, 3(3): 55-64.

[5] Mark LI and Léo MALLAT, "Health impacts of air pollution," *Score Paper - Score: The Art and Science of Risk* Pg 12 – 21, July 2018.

[6] Keyur K Patel, Sunil M Patel, "Internet of Things-IOT: Definition, Characteristics, Architecture, Enabling Technologies, Application & Future Challenges," International Journal of Engineering Science and Computing (IJESC), DOI10.4010/2016.1482 ISSN 2321 3361, 2016.

[7] Srinivas Devarakonda, Parveen Sevusu, Hongzhang Liu, Ruilin Liu, Liviu Iftode, Badri Nath, "Real-time Air Quality Monitoring Through Mobile Sensing in Metropolitan Areas," *Urb Comp'13*, August 11–14, 2013, Chicago, Illinois, USA.

[8] Poonam Pal, Ritik Gupta, Sanjana Tiwari, Ashutosh Sharma, "Iot Based Air Pollution Monitoring System Using Arduino," *International Research Journal of Engineering and Technology (IRJET)*, vol. 4, October 2017.

[9] Gagan Parmar, Sagar Lakhani, Manju K. Chattopadhyay, "An IoT Based Low Cost Air Pollution Monitoring System," *Proceeding International conference on Recent Innovations is Signal Processing and Embedded Systems (RISE-2017),* 27-29 October, 2017.

[10] Chen Xiaojun1, Liu Xianpeng2, Xu Peng, "IOT-Based Air Pollution Monitoring and Forecasting System," Electro-Mechanical Department, Nantong campus of Jiangsu City Vocational College.NO.169, zhongyuanroad of ChongchuanDistrict, Nantong, Jiangsu Prov, China

[11] Jabatan Alam Sekitar (JAS), " New Malaysia Ambient Air Quality Standard," Retrieved from: http://www.doe.gov.my