Identification and Visualization of Hazardous Gases Using IoT

Yashvin Munsadwala
Department of Computer Engineering
SCET, Surat, India - 395001
munsadwalayashwin@gmail.com

Pankti Joshi
Department of Computer Engineering
SCET, Surat, India - 395001
panktijoshi1996@gmail.com

Pranav Patel
Department of Computer Engineering
SCET, Surat, India - 395001
pranav.patel292@gmail.com

Keyur Rana
Department of Computer Engineering
SCET, Surat, India - 395001
keyur.rana@scet.ac.in

Abstract— **Air pollution is increasing exponentially because of natural and human causes. Adverse effects of air pollution are not only limited to human beings, flora and fauna but are extended to the historical monuments as well. Thus, air monitoring has become an imperative task for society. Atmospheric Air Surveil System (AASS) comprises of a portable model for the remote web-based monitoring of Carbon Monoxide (CO) and Carbon Dioxide (CO_2) gases in outdoor regions. The sensor mote (device) consists of a microcontroller, gas sensors and Global Positioning System (GPS). The calibrated sensor grid is used to measure the concentration of the gases from surrounding which are then processed using the microcontroller. The processed data from the motes are transmitted to the cloud via the Internet of Things (IoT). Using MQTT (Message Queuing Telemetry Transport) protocol these data are fed to the server after which, they are stored in the Data Acquisition (DAQ) unit. The dashboard is provided for the visualization of the stored data. Email notifications, activity log, Geographic Location Verification (GLV) and Device Authentication (DA) functionalities are provided. Also, the authorized user can control the whole device from a remote location. This system is tested for the scalability.**

Keywords—Air pollution, Environmental monitoring, Gas Detector, IoT, Microcontroller, MQTT protocol, Wireless communication

I. INTRODUCTION

In recent years, pollution has been the utmost concern worldwide. John Walke, the director of clean air program at Natural Resources Defense Council (NRDC), proclaims that the major air pollution source includes energy use and its production [01]. The rising urbanization and industrialization have led to a steep increase in both factors. The prime concern comes to air pollution as the toxicants that are released through the air alone exceed the total pollution caused by the hazardous substance of land and water together [02].

According to the World Health Organization (WHO), 91% of people reside at those locations where the level of air pollution exceeds the WHO guideline limit. Breathing in such a polluted environment decreases life expectancy by 1-2 years of an average human life [02]. Degradation in air quality is also responsible for the serious environmental concerns like acid rain, climatic fluctuations, eutrophication as well as global warming. The biotic life on earth is in direct contact with the air throughout their life, and some statistics depict that, in United States total annual damage caused to vegetation due to air pollution is around one to two billion dollars. Hence, there is an immediate need to monitor the presence of harmful toxicants in our surroundings for a healthy planet.

Furthermore, CO_2 is a major greenhouse gas. It has been observed that, for the last 50 years, CO_2 concentration ascended by 105 parts per million (ppm). It has led to an increase in the average temperature of the earth. According to the statistics released by scientists in June 2018, depicts that in recent years, the rate with which the Antarctic ice is depleting is three times faster as compared to that in 1991-2011 [03].

Additionally, CO is a major source from the exhaust of motor vehicles and about 70% of air pollution in major cities in China is from automobile exhaust. The CO gas particle gets tightly attached with the iron in the hemoglobin, which becomes difficult to detach then after. It also has a high detrimental effect on human health even when exposed to a minimal amount of CO for a long period.

This paper presents a portable gas detector for monitoring the concentration of CO and CO_2 in ambient air. Using IoT [04], one can effortlessly transfer data from the hardware device to the Internet and thus making it possible to monitor the concentration of gases from remote locations. AASS also has a significant mechanism for making amendments to the device. The sole purpose is to make air auditing more reliable and less tedious.

The basic flow of this paper is as follows. Section II provides the related work similar to AASS, Section III briefs about the proposed system and its architecture. Hardware components and its implementations are elaborated in section IV and section V respectively. After that, software implementations are epitomized in Section VI, and experimental results are discussed in Section VII. Lastly, we conclude the paper in Section VIII.

II. RELATED WORK

The prevailing method for monitoring gases consists of monitoring vans and monitoring stations which are quite expensive and requires more space due to the large size of machines. Also, the person responsible for auditing is adversely affected as one needs to go physically at the location or needs to stay within the vicinity for monitoring and get exposed to continuous contact of toxins at the monitoring site. It has been observed that the air inside a static closed bodied vehicle (car, van) at a site is up to ten times more harmful as compared to the air outside the vehicle, as the polluted air penetrates inside it [05]. More human intervention has a high chance of data manipulation. Resource consumption and operating cost in terms of power supply and the presence of only skilled persons to manage

978-1-7281-1253-4/19/$31.00 © 2019 IEEE

complex apparatus is high. It becomes difficult to make amendments in the system. Surveillance at crowded areas, indoor locations or remote areas becomes challenging.

Kiran Patil V. et al. [06] proposed the real-time detection of greenhouse gases - CO_2, CO, Methane (CH_4) and Nitrous Oxide (N_2O) which is done using sensors. Ethernet shield and XBee are connected with Arduino UNO microcontroller, and the data is transferred using IoT to ThingSpeak cloud. This information was depicted in various graphical forms and represented on the website. The system notifies the authorized person using the SMS facility. In this system, it is possible that the same device may be encountered at multiple proximate locations. Irrespective to the accurate location, the data may be entered into the location picture (map).

Fauzy Satrio Wibowo et al. [07] mentioned that CO and temperature sensors would detect the respective parameters which are connected to Arduino Mega microcontroller. Wi-Fi module is also connected to Arduino that will send data to the web server. It will acknowledge the receipt of data. It provides data logging, exporting data function and a buzzer mechanism for hardware in case the value rises above the threshold value. Data authentication is done using the API code. Data will not be published on a web server in case incorrect API code is given.

The system proposed by Neeraj Khera et al. [08], measures the real-time monitoring concentration of CO and CO_2 gases. The acquired data is shown on display affixed on the roadside. Using the LabVIEW software which is serially communicated to the Arduino UNO and data from LabVIEW is stored in the hard disk.

Ravi Kishore Kodali and his co-worker [09], proposed a system using micro-controller (Esp8266 NodeMCU) with a built-in Wi-Fi module, which is connected to the sharp dust sensors and CO sensor (publisher). Using MQTT protocol [10] the subscriber can retrieve the pollution content through mobile application and web page. Activity log facility is maintained in this system.

In the proposed work, we designed a system with additional functionalities like Over-The-Air (OTA) firmware update, mail alerts, Geographic Location Verification (GLV) and Device Authentication.

Table I depicts a comparison of systems mentioned above conducted by various authors and the innovations in our system (AASS).

TABLE I COMPARISION OF AASS WITH OTHER SYSTEMS

System	Alert	Cloud	OTA	Log	Export	GLV	DA	Repres-entation
AASS	✓	✓	✓	✓	✓	✓	✓	✓
[06]	✓	✓	✕	✕	✕	✕	✕	✓
[07]	✓	✕	✕	✓	✓	✕	✓	✓
[08]	✓	✕	✕	✕	✕	✕	✕	✓
[09]	✕	✓	✕	✓	✕	✕	✕	✓

III. PROPOSE SYSTEM

AASS is proposed for continuous real-time monitoring of the concentration of gases. The concentration of gases is measured and sent securely to the cloud. It is then published over the server using the MQTT protocol. Then, this data will be stored in the DAQ unit. The targeted data will be plotted on the website using various graphical representations. The main functionalities include DA, GLV and OTA update. Device Authentication is to ensure that the data is from the registered sensor motes. GLV guarantees that the readings are from the correct deployed location. In case the readings are from the non-authenticated device, or if the device is not deployed at the required location, then no readings are considered. OTA is to remotely update the code in the non-volatile memory of microcontroller using IoT. Without OTA update, it was tedious to even make small amendments in the firmware as one needed to retrieve the whole device from the deployed location, reprogram it and then redeploy it. Scalability is also tested for this system.

A. System Architecture

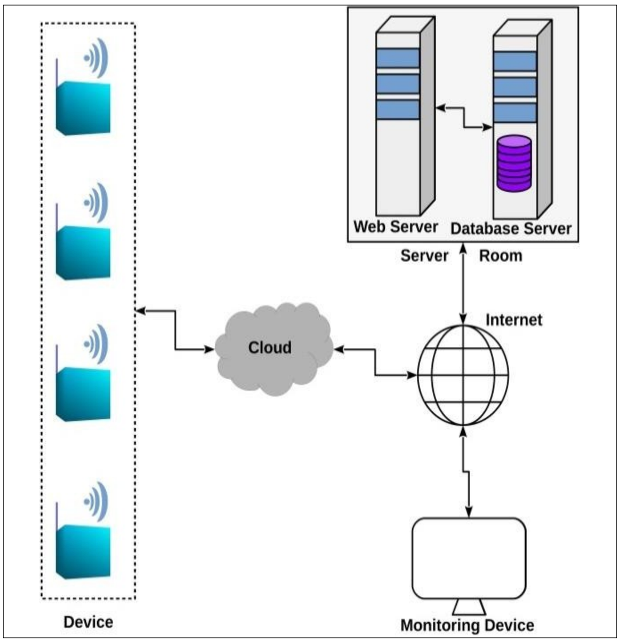


Fig. 1 Architecture of AASS

Fig. 1 depicts the architecture of the system. In the proposed system, the device consists of a microcontroller, calibrated gas sensors and GPS. The data obtained by the sensor mote is transmitted to the cloud. Data transmission between the cloud and the server is based on the MQTT protocol. Computer with the dedicated program (server) is responsible for storing and processing the data obtained from the cloud. The processed data is then illustrated in various graphical representations on a monitoring device.

IV. HARDWARE COMPONENTS

In this section, we have discussed various hardware components, which are used in our proposed system.

A. Microcontroller

Particle Photon [11] uses STM32F205RG [12] high performance ARM Cortex-M3 MCU. This microcontroller provides a fully integrated secure IoT platform which connects software and hardware to the Internet. The OTA firmware update is also possible.

B. Gas Sensors

The MQ series gas sensors are used namely MQ07 [13] and MQ135 [14] for sensing the CO and CO_2 respectively. The sensor must be calibrated to get accurate readings.

C. GPS Module

The antenna of the GPS module will receive the signals from the satellite and process them to get the coordinates of the location where the GPS module is placed. The GPS module that is used in the proposed system is NEO-6M [15]. The horizontal position accuracy of this module is about 2.5 meters.

V. HARDWARE IMPLEMENTATION

The hardware model is required to sense the gas concentration from the ambient atmosphere which is an essential part of the proposed system. This section comprises of working principle of gas sensors, calibration of gas sensors and verification of the integrated circuit.

A. Working Principle of Gas Sensor

The surface resistivity (R_s) of gas sensors changes when there is a variation in the concentration of gas [13].

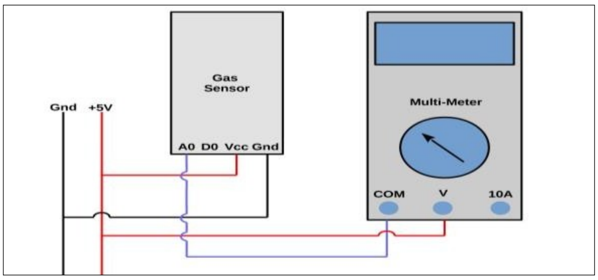
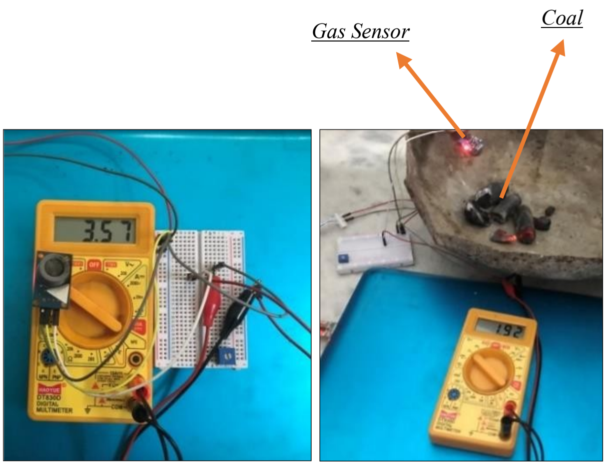


Fig. 2 Circuit to check voltage fluctuations when exposed to gases

According to Ohm's law, voltage and resistance are directly proportional to each other. Hence, change in resistance would change the voltage value. It has been practically verified by a simple circuit as shown in Fig. 2 using gas sensors and multi-meter connected in across.



(a) *(b)*

Fig. 3 Voltage variation of sensor when kept (a) Under normal condition (b) Above burning coal

The voltage reading obtained when the circuit is kept under normal room condition is 3.57V, while the reading drops to 1.92V when sensor is kept over burning coal. This experiment is shown in Fig. 3 (a) and (b).

B. Calibration of the Gas Sensors

MQ series gas sensor is sensitive to more than one type of gas. To obtain accurate readings, the gas sensors must be made sensitive to one particular gas, and thus there is a need to calibrate the sensors.

While calibrating the MQ07 gas sensor for CO gas, we have considered the value of R_L as 10kΩ from the datasheet, since R_L value varies for different gases.

As the readings from MQ series gas sensors are in the non-standard unit, there is a need to convert them into the standard unit that is ppm [16] using (1).

$$ppm = 10^{\frac{\log(y) - b}{m}} \quad (1)$$

where,

ppm	Gas concentration in ppm
Y	The ration of R_s to R_0
R_s	Sensor resistance at various concentration of gases
R_0	Constant resistance at 100 ppm CO in clean air
b	Value of y-intercept
m	The slope of the line

So, we need to find the values of m, b and Y to solve (1). By considering the lines as linear in sensitivity characteristic curve defined in the datasheet [13] and a logarithmic scale, select any two coordinate points to find the slope m of particular gas which has to be calibrated. To find the value of b: consider any one point (x, y) on the line and use the coordinates in the (2).

$$b = log(y) - m \times log(x) \quad (2)$$

V_{CC} is the voltage supply to the sensor and V_{RL} is a voltage drop when the gases pass through the sensors. To find the value of R_S, we have the following (3).

$$R_S = \frac{V_{cc} \times R_L}{V_{RL}} - R_l$$

From the sensitivity characteristic curve, we observed that the line of air is constant k for all the values. To compute R_0 in fresh air one needs to use (4).

$$R_0 = \frac{R_S}{k} \quad (4)$$

V_{RL} can be computed using (5). Where V_{CC} is 5.0 volt, and 4095 is photon's in-built ADC value (12 bit).

$$V_{rl} = \frac{\text{Analog Value} \times V_{cc}}{4095} \quad (5)$$

After calculating all the unknown parameters, we can retrieve the gas concentration in ppm using (1). The values calculated for the calibration of MQ07 gas sensor in our case for R_0, m, b is 1.32, -0.6567 and 1.3134 respectively. Similarly, we have a calibrated MQ135 gas sensor for CO_2 as well [20].

C. Circuit Diagram of Typical Device

The circuit diagram of one of the typical device of the proposed system is shown in Fig. 4.

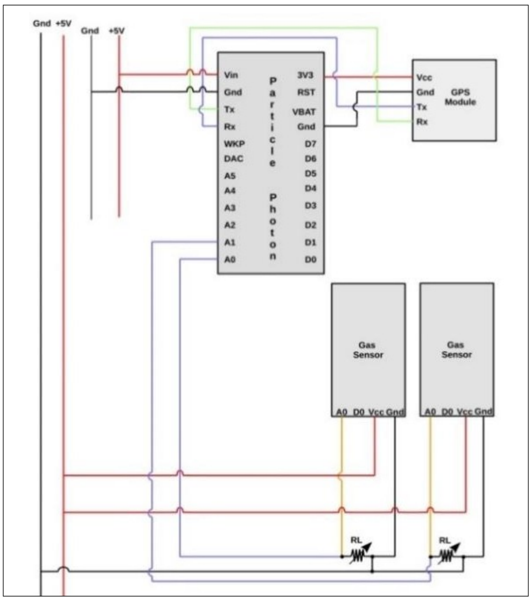


Fig. 4 Hardware integration of the typical device

Here, the individual power supply is required for the particle photon and gas sensors. The analog pin of gas sensors is connected to a potentiometer (R_L). From here, the pin is connected to any of the available analog pins of a photon (in Fig. 4, it is A0 and A1). GPS is connected to the R_x and T_x pin of a photon in cross connection. V_{CC} and ground pin of GPS is electrically connected to photon's "3V3" pin and ground respectively.

D. Circuit Verification for Device

The integrated hardware must be checked to see whether it is functioning properly. It is verified using the changes in the sensor readings for the two obvious cases illustrated below.

1) Preheating the gas sensors – This is done by giving the normal power supply to the sensors for about 12-48 hours, which makes the sensor coil more sensitive and thus one can get more reliable sensor readings [10].

2) Blowing air directly to the sensors – The sensors can sense the gases in a better way if air is blown directly to the sensor inlet using air blower.

Four instances were created in terms of a combination of the above-mentioned cases as shown in Table II.

TABLE II CONDITIONS BUILT WITH THE COMBINATION OF PREHEAT AND BLOWER FOR CIRCUIT VERIFICATION

Condition	Preheat	Blower
I	✗	✗
II	✓	✗
III	✗	✓
IV	✓	✓

The following graph was plotted for the conditions mentioned above.

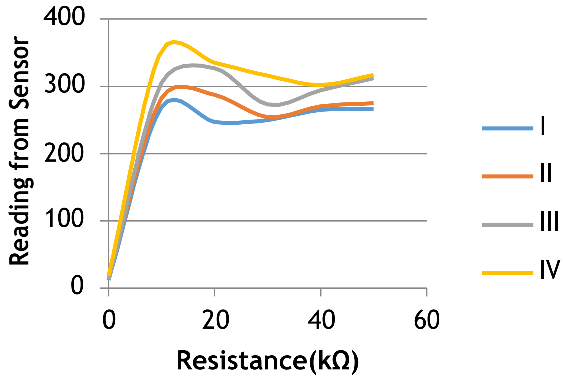


Fig. 5 Changes in readings under various built conditions

From the graph in Fig. 5, it can be inferred that the preheated gas sensors and with a blower (condition IV from Fig. 5) have significantly greater gas concentration.

VI. SOFTWARE IMPLEMENTATION

Interfacing AASS to the dashboard, which facilitates the user to monitor as well as retrieve the desired past information of the concentration of gases. A server program is made in NodeJS whereas MongoDB is used as the DAQ. The framework used in NodeJS includes express, node mailer, mongoose, body-parser, ejs, express-session and particle-API-js. Google API is used to create charts and maps. The dashboard shows the processed data in a meaningful format that is easy to understand.

A. Forms

Forms enable the authorized person to make a new entry in DAQ via the dashboard. There are mainly two forms namely gas and device. To add new gas to the system, primarily one needs to integrate the calibrated gas sensors with a microcontroller and secondly, map this entry with the system using gas form. Device form has considerable attributes namely latitude, longitude and device id. The latitude and longitude (coordinates) signify the exact location where the device needs to be deployed, which is used for GLV. The device id is used for DA. Also, to change the location of the device (to use it at a different site) facility is provided. It is configured through device form.

B. Device Authentication (DA)

Authentication of the device is done by verifying the device id of the deployed device and id present in the DAQ. The sensed data will only be considered and stored in DAQ if it comes from the authenticated device.

C. Geographic Location Verification (GLV)

The coordinates entered in device form is verified with the obtained GPS coordinates of the deployed device. If both the coordinates match, then the data is considered valid and stored in DAQ, else the data is discarded. In the proposed system, the values of latitude and longitude are considered up to four decimal places for fault tolerance. Table III shows four different cases of our experiment where data are considered legitimate only if GPS location obtained from the deployed device and location in the DAQ match up to four decimal places. When the data are discarded more than 100 times, then notification is sent to the authorized person so that precautionary steps can be taken.

TABLE III CONSIDERATIONS OF DATA BASED ON GEOGRAPHIC LOCATION VERIFICATION IN AASS

GPS Location		Location from DAQ		Data considered
Latitude	***Longitude***	***Latitude***	***Longitude***	
21.72341	72.12567	21.72345	72.12565	YES
21.56763	72.78654	21.56765	72.78345	NO
21.67341	72.67843	21.43212	78.78906	NO
21.23678	72.45311	21.23672	72.45314	YES

D. OTA firmware update

The main functionality of the OTA firmware update in the system includes i) Signalling device, ii) Updating device and iii) *Un-claim* device. The scalable nature of the system allows many devices to be deployed together. To identify a particular device from the set of devices at the place of deployment, signaling functionality is used. It has two phases, start and stop. While making the signaling functions of the device as a start, it will change the color of the inbuilt LED of the photon. It will ensure that one would not pick the incorrect device while deploying. The functionalities as mentioned above are illustrated in Fig. 6.

Fig. 6 Provided interface for OTA firmware update

Another feature is updating the firmware using .bin file type extension from remote locations to a selected device. When the device has some fault, which is irrecoverable, then one should un-claim the device to remove it completely from the system. These features can be performed by authenticated users only.

E. Activity Log

All the main activities that are performed on the dashboard are maintained in a file, which can be downloaded for further references.

F. E-Mail Notification

The authorized person is notified using an email if the device is not connected to the Internet. After every 120 seconds, there is a mechanism which checks if the deployed device is connected to the network. An email notification is sent in case the device could not find Internet connection until 600 seconds or when the average gases concentration rises above threshold level for certain period of time interval.

G. Virtual Device

In our system, we have integrated two sensors for CO and CO_2. As mentioned earlier, a device which comprises of the gas sensor, GPS module and a microcontroller will fetch gases from the ambient atmosphere. It is stored in the DAQ for further processing. We have made such two devices to place at two different locations. However, to check the scalability of the system, we need some devices. As it was not feasible to create up to 50 such devices due to the limitation of funding, we have created virtual devices to simulate the gas readings. Such virtual device behaves similarly to the physical device in terms of sending data. After all, we aimed to check the behavior of the system when there are number of devices sending data at a time.

VII. RESULTS

According to the filters selected by the user, different types of visualizations are made on the dashboard. Real-time data representation is done using Gauges and tabular format. Gauges show the aggregated concentration of gases present in the system. History of the data is shown in tabular format and can be downloaded for future analysis. One of the graphical forms of representation is depicted in Fig. 7.

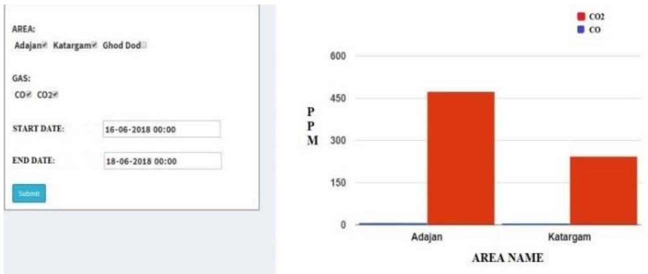


Fig. 7 One of the representations of past data based on different filters selected

Maps (Fig. 8) depict past average data collected from the device location using a color-coded marker. In case the value exceeds the threshold then the marker is in red else green, which gives the idea of the concentration of air pollutants at a different location. The threshold value can differ based on topography and the type of gases.

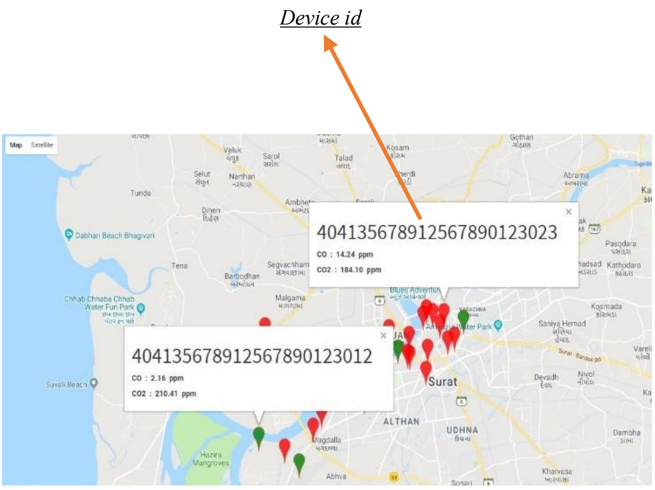


Fig. 8 Representation of data using map according to device

VIII. CONCLUSION

AASS has been successfully able to monitor the concentration of CO and CO_2 gas in the atmosphere near the residential area. The overall system is portable, cost-effective, scalable, reliable, secure, compact and easy to update from a remote location. A web-based dashboard is created which facilitates the user to analyze data from the devices which are deployed at the targeted location. The system can handle a large amount of data from the verified devices. The system can be used near the industrial location by just “plug and fetch”. This system can be further extended to mobile applications too.

REFERENCES

[1]. J. Walke, “Air Pollution: Everything You Need to Know”. [Online]. Available: https://www.nrdc.org/stories/air-pollution-everything-you-need-know [Accessed: Jun. 14, 2018].

[2]. Home Air Quality Guide, “36 Air Pollution Facts And Heath Statistics”. [Online]. Available: https://homeairguides.com/air-quality/25-air-pollution-facts-and-health-statistics/ [Accessed: Jun. 14, 2018].

[3]. “Mass balance of the Antarctic Ice Sheet from 1992 to 2017”, Nature vol. 558, p. 219-222, Jun. 01,2018, [Title]. Available: https://doi.org/10.1038/s41586-018-0179-y [Accessed: Jun. 16,2018].

[4]. A.Iera, C.Floerkemeier, J. Mitsugi and G. Morabito, “The Internet of things,” IEEE Wireless Commun. Vol. 17, no. 6, pp. 8-9, Dec. 2010.

[5]. A. Kimberell & Co., “In-Car Air Pollution The Hidden Thread to Automobile Drivers,” [Executive Summary] A report to International Center For Technology Assessment, no. 4, Jul. 2000.

[6]. K. Patil, Kiran B. N and R. Srinath, “INTERNET OF THINGS FOR GREENHOUSE GAS DETECTION SYSTEM,” IJRET, vol. 03, pp. 3053-3055, May. 2016.

[7]. F. S. Wibowo, F. Alqodri, N. Lathifah, S. Sendari, D. Lestari, A. N. Handayani, Y. Rahmawati, A. Lestari, C. Kusumahadi and C. U. Kusmahadi, “Developing Portable Instrument Based on Internet of Things for Air Quality Information System,” in International Conference on Signals and Systems (ICSigSys), May 2017.

[8]. N. Khera, P. Sharma, D. Shukala and I. G. Dar, “Development of Web-Based Gas Monitoring System Using LabVIEW”, in Recent Developments in Control, Automation & Power Engineering (RDCAPE), Oct. 2018.

[9]. R. K. Kodali and B. S. Sarjerao, “MQTT based Air Quality Monitoring,” in IEEE Region 10 Humanitarian Technology Conference (R10-HTC), Dec. 2017.

[10]. HiveMQ Team, “MQTT Essentials Part 3: Client, Broker and Connection Establishment”, Jan. 2015. [Online]. Available: https://www.hivemq.com/blog/mqtt-essentials-part-3-client-broker-connection-establishment/ [Accessed: Jan. 17, 2018].

[11]. Datasheet Particle Photon. [Online]. Available: https://docs.particle.io/datasheets/photon-(wifi)/photon-datasheet/ [Accessed: Jun. 17, 2018].

[12]. Datasheet STM32F205RG. [Online]. Available: http://www.st.com/content/ccc/resource/technical/document/datasheet/bc/21/42/43/b0/f3/4d/d3/CD00237391.pdf/files/CD00237391.pdf/jcr:content/translations/en.CD00237391.pdf [Accessed: Jun. 15, 2018].

[13]. Winson Toxic Gas Manual for MQ07 Gas Sensor. [Online]. Available: https://cdn.sparkfun.com/datasheets/Sensors/Biometric/MQ-7%20Ver1.3%20-%20Manual.pdf [Accessed: Jun. 17, 2018].

[14]. Datasheet MQ135. [Online]. Available: https://www.olimex.com/Products/Components/Sensors/SNS-MQ135/resources/SNS-MQ135.pdf [Accessed: Jun. 17,2018].

[15]. Ublox NEO-6 GPS Datasheet. [Online]. Available:https://www.ublox.com/sites/default/files/products/documents/NEO-6_DataSheet_(GPS.G6-HW-09005).pdf [Accessed: Jun. 17, 2018].

[16]. “Measuring PPM from MQ Gas Sensor using Arduino (MQ-137 Ammonia)”. [Online]. Available: https://circuitdigest.com/microcontrollerprojects/arduino-mq137-ammonia-sensor [Accessed: Jun. 17, 2018].

[17]. D. Wang, C. Jiang, Y. Dan, “Design of air quality monitoring system based on the Internet of things,” in 10th International Conference on Software, Knowledge, Information Management & Application (SKIMA), Dec. 2016.