DEVELOPMENT OF REAL-TIME IOT-BASED ENVIRONMENTAL MONITORING SYSTEM FOR AIR QUALITY

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UNIVERSITI SAINS MALAYSIA

2018

DEVELOPMENT OF REAL-TIME IOT-BASED ENVIRONMENTAL MONITORING SYSTEM FOR AIR QUALITY

by

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Thesis submitted in partial fulfilment of the requirements for the degree of Bachelor of Engineering (Mechatronics Engineering)

JUNE 2018

ACKNOWLEDGEMENT

First and foremost, I would like to express my deepest gratitude to my supervisor, Dr Zuraini binti Dahari for her guidance and supports throughout the completion of this project. She gave me advices and shared me her knowledge whenever I faced problems when executed the project. Without her guidance, this project could not be completed on time.

Furthermore, I would like to offer my sincere appreciation to lab staffs of School of Electrical and Electronic. They showed good intentions and proactive actions in helping me to find the components and equipment that I needed when I was doing the prototype of this project.

Last but not least, I would like to convey my special thanks to all my family and friends who helped and supported me throughout this project. The thoughtfulness and kind help is very much appreciated.

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LIST OF ABBREVIATIONS

IoT	Internet of Things
LPG	Liquefied Petroleum Gas
AQI	Air Quality Index
VOC	Volatile Organic Compound
SMS	Short Message Service
PEMS	Personal Environmental Monitoring System
WEMS	Wearable Environmental Monitoring System
BLE	Bluetooth Low Energy
LCD	Liquid-crystal Display
AODV	Ad Hoc On Demand Distance Vector
GPS	Global Positioning System
UART	Universal Asynchronous Receiver-Transmitter
MQTT	Message Queue Telemetry Transport
THz	Terahertz
FSS	Frequency Selective Surface
CSV	Coma Separated Value
RFID	Radio-Frequency Identification
WSNs	Wireless Sensor Networks
IIoT	Industrial Internet of Things
ppm	parts-per-million
PM	Particulate Matter

PAN	Peroxyacetyl Nitrate
TLV	Threshold Limit Value
NoSQL	Non-Structured Query Language
SQL	Structured Query Language
JSON	Javascript Object Notation
NTC	Negative Temperature Coefficient
IC	Integrated Circuit
GUI	Graphical User Interface
UI	User Interface

PEMBANGUNAN SISTEM PEMANTAUAN ALAM SEKITAR BERASASKAN OBJEK RANGKAIAN INTERNET UNTUK KUALITI UDARA

ABSTRAK

Pada masa kini, pemodenan telah meningkatkan gaya hidup manusia. Walau bagaimanapun, peningkatan krisis mengenai pencemaran udara banyak membawa masalah kepada kesihatan manusia dan alam sekitar seperti hujan asid, pemanasan global dan kemerosotan lapisan ozon. Pelepasan karbon monoksida dari kenderaan di jalan raya mengakibatkan manusia berasa pening dan letih serta mengalami sakit kepala Oleh itu, projek ini mencadangkan pembangunan sistem pemantauan alam sekitar Internet berasaskan objek rangkaian internet (IoT) untuk kualiti udara. Sistem pemantauan ini mengintegrasikan tiga sub-sistem yang terdiri daripada sistem penginderaan kualiti udara alam sekitar, sistem amaran pintar dan sistem pemantauan rangkaian. Sistem penginderaan kualiti udara alam sekitar menggunakan penderia gas untuk menentukan kepekatan karbon monoksida, gas petroleum cecair (LPG) dan asap dan penderia kelembapan dan suhu untuk mengukur suhu dan kelembapan persekitaran. Selain itu, sistem amaran pintar memberi amaran kepada orang di sekitar dengan mengaktifkan penggera dan memaparkan mesej amaran apabila kualiti alam sekitar adalah kurang baik. Di samping itu, sistem pemantauan rangkaian digunakan untuk memerhatikan pengukuran masa sebenar kualiti udara melalui aplikasi Android "AirProp" untuk banyak pengguna pada masa yang sama. Tambahan pula, kesan faktor seperti masa dan keadaan trafik pada suhu, kelembapan dan kepekatan gas pencemar juga disiasat. Pada akhir kajian ini, didapati bahawa sistem penggera dicetuskan apabila kepekatan

karbon monoksida melebihi 50 ppm. Selain itu, aplikasi Android membolehkan pengguna memantau pengukuran masa sebenar kualiti udara alam sekitar serta mengkaji semula data masa lalu pada tarikh tertentu melalui Wi-Fi. Data ini boleh dianalisis dan dimanfaatkan oleh kerajaan dan penyelidik untuk mengurangkan pencemaran udara. Trafik yang lebih sesak pada masa puncak adalah salah satu faktor penyumbang terbesar dalam kepekatan bahan pencemar udara yang tinggi. Purata kepekatan tertinggi karbon monoksida, LPG dan asap diperoleh di Kulim Hi-Tech Park pada waktu petang. Indeks Kualiti Udara (AQI) yang dikira berdasarkan kepekatan karbon monoksida adalah 50. Kualiti udara dianggap memuaskan dan tidak menyebabkan risiko kepada kesihatan manusia. Sebagai kesimpulan, sistem yang dicadangkan ini telah berjaya dibangunkan dengan penggunaan teknologi IoT.

DEVELOPMENT OF REAL-TIME IOT-BASED ENVIRONMENTAL MONITORING SYSTEM FOR AIR QUALITY

ABSTRACT

Nowadays, modernization has improved the lifestyle of human. However, the crisis regarding air pollution has been increased which brings a lot of problems to human health and environment such as acid rain, global warming and the deterioration of the ozone layer. The emission of carbon monoxide from the vehicle on road makes people feel dizzy and tired and gives them headaches Thus, this project proposes the development of real-time Internet of Things (IoT)-based environmental monitoring system for air quality. This monitoring system integrates three sub-systems which consists of environmental air quality sensing system, smart alerting system and real-time monitoring system. The environmental air quality sensing system utilizes a gas sensor to determine the concentration of carbon monoxide, liquefied petroleum gas (LPG) and smoke and a humidity and temperature sensor to measure the temperature and humidity of environment. Then, the smart alerting system warns the surrounding people by activating the alarm and displaying the warning message when the air quality of environment is poor. In addition, the real-time monitoring system is used to observe the real-time measurement of air quality via an Android application "AirProp" for many users at the same time. Moreover, the effects of factors such as time and traffic condition on the temperature, humidity and concentration of pollutant gases are also investigated. At the end of this research, it is found that the alarm system is triggered when the concentration of carbon monoxide exceeds 50 ppm. Besides that, the Android application enables users to monitor the real-time measurement of environmental air quality as well as

review the past data on a specific date via Wi-Fi. These data can be analyzed and leveraged by governments and researchers to mitigate air pollution. Heavier traffic during peak hour periods is one of the greatest contributing factors in higher concentrations of air pollutants. The highest average concentration of carbon monoxide, LPG and smoke is obtained at Kulim Hi-Tech Park in the evening. The Air Quality Index (AQI) that calculated based on the concentration of carbon monoxide is 50. The air quality is considered satisfactory and causes no risk on healthy of human. In conclusion, the proposed system has been successfully developed with the technology of IoT.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Air pollution refers to a phenomenon where there are release of pollutants such as hazardous chemical gases into air that are harmful to human health. Nowadays, crisis related to air pollution is getting serious which cause a lot of troubles to human health and environment. Some of the common air pollutants are carbon monoxide, nitrogen dioxide, ozone and sulfur dioxide. In terms of human health, these pollutants cause higher risk for asthma, respiratory diseases, circulatory system diseases [1], high incidents of heart problem, damage of immune system and others. Moreover, some of the pollutant gases such as photochemical smog is released under sunlight which will make the victims feel unwell in eyes, throat and extremities and even disturb the consciousness of the victims [2]. On the other hand, these pollutants also cause a lot of problem to environment such as global warming, melting of polar ice caps, increase of sea level, acid rain and others.

The increment in number of vehicles such as cars and motorcycles on major road is a drastic problem in most developing and developed cities[3]. These cities are facing problems such as increasing road congestion and high traffic volume which act as indicator of atmospheric air pollution. These problems increase the vehicular emissions, which are the major source of air pollutants, such as carbon monoxide and volatile organic compound (VOC). VOCs are organic compounds such as benzene, gasoline or natural gas that may have short-term long-term adverse health effects. As a result, the ambient air quality of environment is degraded.

Some precaution or proactive actions must be taken to reduce and prevent the air pollution from getting more serious. Thus, the air quality is determined based on the estimation of some essential and indicative parameters [4]. Air temperature, radiation, activity level, air flow, humidity and presence of carbon monoxide are the important parameters that are needed to be determined [5]. These measurement and data are very essential and vital in helping the governments and researchers to figure out the factors that cause the air pollutions and reduce the air pollutions.

A survey on various air pollution monitoring systems has been carried out in 2017 [6]. Some of the monitoring systems are IoT, Kernel Models Technique [7] which describes the architecture of a product unit network and evolutionary learning algorithm and mobile system which is reliable measurement system. Besides that, an air pollution monitoring system using LabVIEW that display real time data acquisition and monitoring system on LabVIEW interface [8] also reviewed. These monitoring systems have their own advantages and issues. For example, with IoT application, all the network of the devices can be connected to the same cloud server for collecting and sharing the data [9]. Therefore, a project entitled of development of real-time IoT-based environmental monitoring system for air quality is proposed and developed to monitor the real-time measurement of environmental air quality.

1.2 Problem Statements

Road congestion and high traffic volume are also dominant problems that cause air pollution due to large amount traffic emissions are produced. These traffic emissions are the major source of pollutant gases such as carbon monoxide and VOC. A research on pollution emission inventory along a major traffic route within Ibadan Metropolis, southwestern Nigeria was carried out to investigate the impact of high traffic volume on air quality [3].

The air quality parameter such as carbon monoxide, nitrogen dioxide, ammonia, sulphur dioxide, and hydrogen sulphide were measured at eight sampling point. The data was collected monthly for four months in morning peak, off peak, and evening peak hours [3]. A constant monitoring of vehicular emissions is needed to figure out the major causes in the increase of traffic emissions and prevent possible air pollution.

Many researches on air pollution monitoring system also have been conducted to observe the condition and level of environmental air quality. A research on design of air quality meter and pollution detector is carried out by A. Mukhopadhyay and his group in 2017 [10]. However, this work has some limitations such as only one device can be connected to the system to view the data through the display device because Bluetooth is used as the communication channel. Wi-Fi communication channel will be more suitable to replace the Bluetooth in this situation to display the data for many devices.

Another research on air monitoring system based on space-borne terahertz radiometer conducted by R. You, Z. Lu, Q. Hou and T. Jiang in 2017 [11]. By observing the absorption peak, the identity of the pollution gases such as carbon monoxide, particulate matter, sulfur dioxide, ammonia and hydrogen sulfide can be defined because different pollution gases have different absorption peak. However, this monitoring system does not have a systematic networking monitoring which can view the real-time data by using mobile application via Wi-Fi.

In addition, Arnab Kumar Saha and his group proposed a research on a Raspberry Pi controlled cloud-based air and sound pollution monitoring system with temperature and humidity sensing in 2018 [12]. This work used an IoT-based method to monitor the AQI and Noise Density of an area. It also used Anomaly Notification Module to alerts the user by sending an email and SMS when the condition of environment is unhealthy. However, there may be some people are failed to check the SMS and email due to the reasons that they do not have electronic devices or the device is not available. In short, this system does not have an alarm such as buzzer to be activated to give warning to the people around the area.

In short, the factors such as traffic volume that cause air pollution and limitations of these monitoring systems are being considered and improved in this research. Thus, a real time IoT-based environmental monitoring system for air quality is developed to monitor real-time measurement of air quality of the environment. The collected data can be leveraged by governments and researchers to mitigate air pollution. Moreover, it arises community's awareness and engagement toward air pollution [13].

1.3 Objectives

There are three objectives needed to be achieved to complete the project.

i. To design an environmental air quality sensing system with alarm and warning indicator which can determine the temperature, humidity and concentration of pollutant gases.

ii. To develop an Android application which can monitor the real-time measurements of temperature, humidity and concentration of pollutant gases via Wi-Fi.

iii. To investigate the effect of factors such as time and traffic condition on the temperature, humidity and concentration of pollutant gases.

1.4 Research Scope

This research will only focus on determining the concentration of carbon monoxide, LPG and smoke. Other pollutant gases such as ammonia, nitrogen oxide and ozone will not be detected by the system. An alarm will be only triggered if and only if the concentration of carbon monoxide exceeded a threshold value. Besides that, the weather information such as temperature and humidity of the environment will be determined. An Android application will be also developed for only Android users to monitor the real-time measurements of temperature, humidity and concentration of pollutant gases via Wi-Fi. The effect of factors such as time and traffic condition on the temperature, humidity and concentration of pollutant gases will be investigated. The data collection only will be carried out at USM EE school parking lot and Kulim Hi-Tech Park in the morning, afternoon, evening and night.

1.5 Thesis Structure

This thesis consists of five chapters which are organized as below:

Chapter 1 discusses the introduction of the study which includes research background, motivation, objectives and the scope of the research.

Chapter 2 reviews some researches about the air pollution monitoring systems that conducted by the previous researchers. The IoT technology, characteristics about semiconductor gas sensors, cloud database and the factors that cause air pollution are also discussed in this chapter.

Chapter 3 describes the methodology that has been carried out to design the overall system. The overall flow and experimental procedure are discussed in this chapter.

Chapter 4 presents the results that obtained from this research. The results are analyzed and discussed detailed in this chapter.

Chapter 5 concludes all the works regarding to the research. The research contribution and future improvements also have been stated in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses on the literature review of the proposed researches of various air pollution monitoring systems that developed by the previous researchers. The IoT technologies, the gas sensor that used to detect the pollutant gases, the cloud database that used to store the collected data and the factors of air pollutants are also described and explained in this chapter. Lastly, the summary of all the researches that related to this project is included.

2.2 Air Pollution Monitoring System

Air pollution monitoring system is used to monitor the air quality of the environment so that some proactive and effective actions can be taken to prevent and reduce the air pollution. There are various air pollution detector systems that were designed and developed by the researchers.

In 2015, Hyuntae Cho published a paper about Personal Environmental Monitoring System (PEMS) and a Wearable Environmental Monitoring System (WEMS) to detect air pollution [14]. PEMS is a stationary device which can be used to detect hazardous gases in indoor environment such as home, office or factory. WEMS is wearable device which can used be measure outdoor environment. Both systems have internet connection to allow transmission of data to users. PEMS sends the data of the sensor to cloud and receives useful data from cloud or other PEMS through Wi-Fi. Besides that, it can use other communication channel such as Bluetooth Low Energy (BLE) or ZigBee [15] to replace Wi-Fi due to more energy and cost are needed by using Wi-Fi based platform [16].

PEMS shows the indoor air quality status through a 3.5 inches Liquid-crystal Display (LCD) display with a capacitive touch panel. Figure 2.1 (a) shows the concept of the PEMS. On the other hand, WEMS sends the data of the sensor to smartphones or other PEMS's via BLE. Then, the cloud service collects all the information from PEMS's for further process. Besides that, cloud service also provides further information to clients by processing the data from Big Data sources. The WEMS has dual processors which function differently. One processor is used to record users' daily activity and the other processor is used to measure the outdoor air pollution as well as the temperature and humidity. One of the advantages of WEMS is that it automatically synchronized with the smartphone when paring with a smartphone. Figure 2.1 (b) shows the concept of the WEMS.

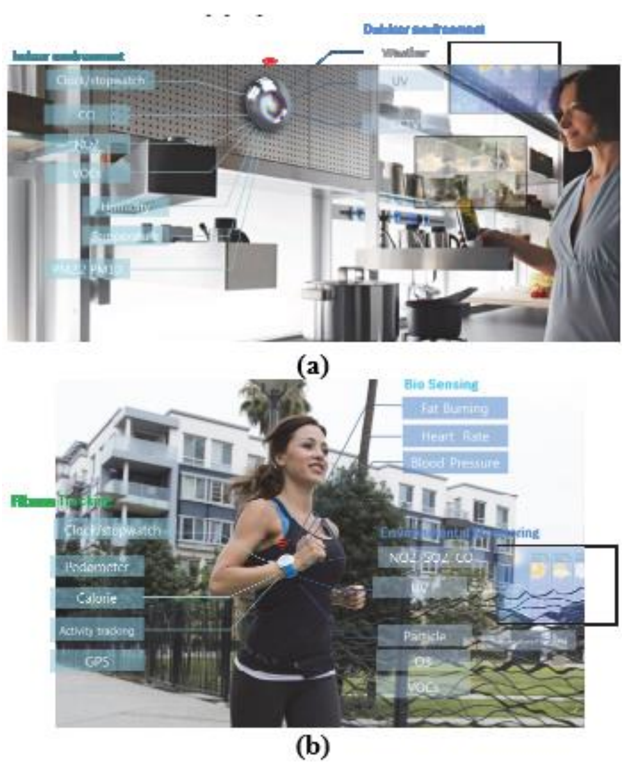

Figure 2.1: (a) Concept of PEMS. (b) Concept of WEMS [14].

This research states that the network topology that established by PEMS and WEMS is based on Ad Hoc On Demand Distance Vector (AODV). AODV is a routing protocol that designed for wireless and mobile sensor network based on ZigBee radio. Figure 2.2 shows the conceptual overview of the environmental monitoring system and the network platform of the research of PEMS and WEMS. An application for cloud service will be implemented in future.

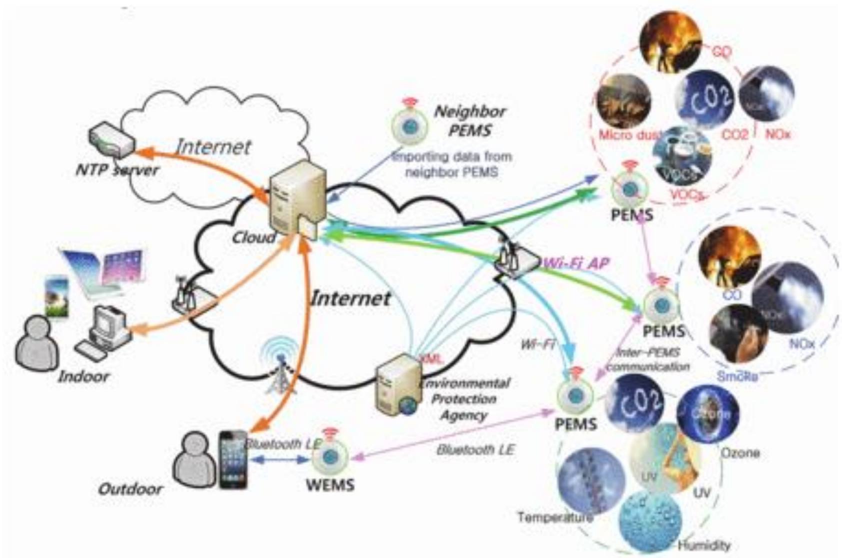

Figure 2.2: Conceptual overview of the environmental monitoring system and the network platform [14].

In 2016, Petr Brynda have proposed a comprehensive system of mobile sensor units to detect air pollution in urban areas [17]. This mobile sensor unit contains either electrochemical sensors or photoionization detector. The electrochemical sensors are small in size which have wide measuring range and low energy consumption but they do not last long with a lifetime at maximum of 1 to 2 years. On the other hand, the photoionization detectors are sensors that used to measure volatile organic compounds that release in contact with vehicle transportation. It has longer lifetime but the power consumption is high. The mobile sensor unit also implements a BLE [18] communication module to allow the communication between the sensor mobile node and a smartphone. A Pollution Gathering application is developed to process the data received from the mobile node via smartphone which has equipped with Global Positioning System (GPS) and internet data connection. The application sends the data with position and time to server and a website is developed for professional users, public authorities and citizens to view real-time air quality situation on a map. Figure 2.2 shows one of the mobile unit sensor.

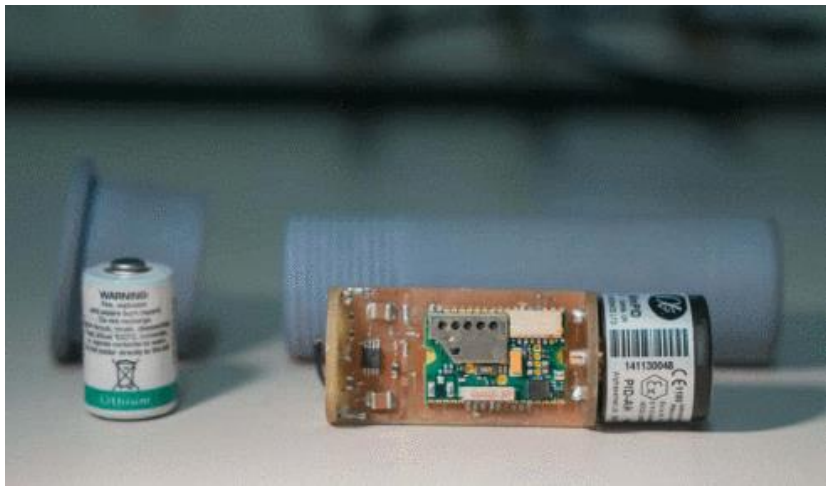

Figure 2.3: Mobile sensor unit [17].

Moreover, another research on multi-sensor system for environment regarding air and water quality monitoring has been conducted by M. Simić, G. M. Stojanović, L. Manjakkal and K. Zaraska in the same year [19]. In this research project, a low-cost, low-power and portable sensor system which is powered by battery with solar panel-based charger unit is developed to monitor the air quality and water quality of the environment. An ATmega128 controller is used in their research to receive all the sensor data such as air temperature and relative humidity from SHT11, volatile organic compounds from MQ-135, water temperature from LM35 and pH value from TiO_2-based thick film pH resistive sensor. They integrated the developed system with IBM Watson IoT Platform. They used Arduino Uno and Ethernet Shield boards through Universal Asynchronous Receiver-Transmitter (UART) communication interface to send the sensor data every 5 seconds to the IoT Foundation via Message Queue Telemetry Transport (MQTT) protocol. Figure 2.4 shows the air and water quality monitoring cloud-based system with IBM Watson IoT Platform. The users can view the real-time graph of parameter and sensor reading through the webpage of IBM Watson IoT platform. Low-power wireless data transmission from the measurement nodes to the central unit and expansion of more sensor into the multi-sensor network system are the future works of the researchers.

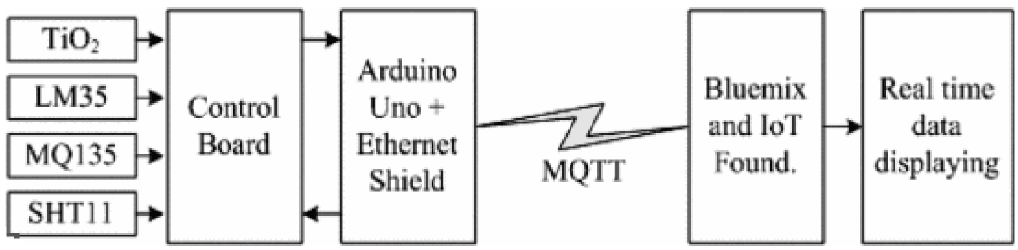

Figure 2.4: Air and water quality monitoring cloud-based system with IBM Watson IoT platform [19].

Furthermore, other than the previous researches, Arunava Mukhopadhyay and his research group have proposed a project on air quality meter and air pollution detector in 2017 [10]. In this project, an IoT technology via Bluetooth was applied to monitoring the environment. Arduino UNO R3 are used as the microcontroller to allow communication for it with the sensors. Gas sensors MQ2, MQ7 and MQ135 are used to detect smoke, carbon monoxide and ammonia gases while DHT11 is used to monitor the temperature and humidity of the environment. Piezo buzzer is activated when the air quality level is dangerous to health. Bluetooth module is used as the wireless communication device as it does not require internet connection. Besides that, Bluetooth module is cheap compared to Wi-Fi module and can transmit data effectively. The data from the sensors is then sent to a computer or smartphone for real-time monitoring. The limitation of this project is that the gathered data can be only sent to one device for real-time monitoring due to Bluetooth module is used. The limitation can be overcome by using a Wi-Fi module to replace the Bluetooth module so that many devices can be connected to this device simultaneously. The researcher state that the project can be further improved by adding three more gas sensors to increase the efficiency of this device.

In addition, a research on air monitoring system based on space-borne terahertz radiometer is proposed R. You, Z. Lu, Q. Hou and T. Jiang [11]. This is a high efficiency and low-cost air pollution monitoring system. Terahertz (THz) waves have the rotational energy states of polar molecules and large molecules due to their unique electromagnetic wave band. Polar molecule shows many rotational modes when interact strongly with THz waves. Besides that, due to the characteristic THz wave that can penetrate fog, gas and smoke, it is very helpful in remote sensing application [20]. In this research, at certain frequency, Space-borne THz radiometer is implemented to measure the THz radiation from the earth. Thus, by observing the absorption peak, the identity of the pollution gases can be defined because different pollution gases have different absorption peak. Reflector antennas with a Frequency Selective Surface (FSS), receivers, data processing units and power supply units are the main components inside a radiometer. Table 2.1 shows the absorptions peak of some of the common pollutant gases.

Table 2.1: Absorption peaks of common pollutant gases [11].

No.	Pollutant Gases	Absorption Peak (THz)
1	CO	0.346, 0.461, 0.576
2	SO_2	0.362, 0.456, 0.556, 0.662, 0.765, 0.858
3	PM2.5	3.36, 6.91
4	H_2S	0.74, 1, 1.29, 1.61
5	NH_3	0.575, 0.662, 0.825

Besides that, N. S. Desai and J. S. R. Alex have conducted a research on IoT-based air pollution monitoring and predictor system on Beagle bone black [21]. In this project, sensors such as MQ7, MQ11 and GPS module are implemented to detect the pollutant gases which are carbon dioxide and carbon monoxide level with GPS location. An embedded Beagle bone board is used to acquire data from sensors and send the sensed data to Azure Cloud Service. Machine learning provided by the Microsoft's Azure is used to train the module with the help of previous data so that the observations related to pollution metrics in future can be predicted. Moreover, Power BI is used to observe the real-time data from sensors which retrieved from beagle bone board. The data also is backed up to local database in the form of Coma Separated Value (CSV) and synchronized with the cloud data when there is internet connection. This is to prevent the situation when the data is unable to be uploaded to cloud if the internet connection is interrupted. Figure 2.5 shows the block diagram of the air pollution and predictor system on Beagle bone black. Other gases to detect nitrogen dioxide and Sulphur dioxide can be implemented for a future improvement.

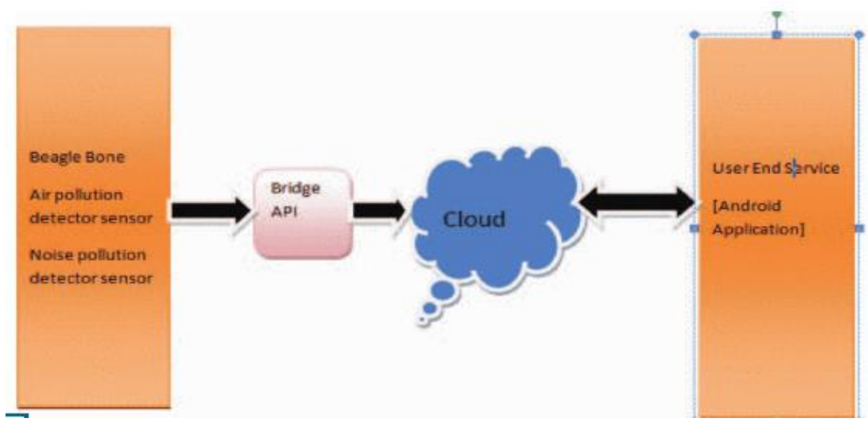

Figure 2.5: Block diagram of the air pollution and predictor system on Beagle Bone Black [21].

2.3 Internet of Things Technology

Internet of Things (IoT) is a network that connect all devices to the internet. The type of communication of IoT is machine-machine (M2M) which provides a great future for internet. IoT devices integrate sensing, computation and communication technique through the wireless network. This can distribute and facilitates the remote data collection and analysis. The IoT knowledge is very essential and useful in industrial systems such as smart grids [22], transport logistics [23], and smart cars [24] to manufacturing [25].

With the implementation of IoT, the smart electronic devices can be used for real-time alert, data transferring and archiving, trend analysis and forecasting[26]. IoT allow the exchange of important and useful information between devices by leveraging the technologies such as Radio-Frequency Identification (RFID) and Wireless Sensor Networks (WSNs). Basic automated action can be achieved in which the sensing data by sensors can be further process for decision making [27].

RFID is widely used due to its reduced size and cost. It is a transceiver microchip which have active and passive application [28]. It acts as active which continuously transmit the data signal while acts as passive which is triggered when it gets activated. Its data signal is transmitted to receiver by using radio frequency which the will be analyzed by the processor. WSN is a technology where the sensors can be bi-directional wirelessly connected to the network. The sensing node is built from several nodes which in a multi-hop way [29]. It has a Memory Unit which can used to save the sensed data for further processing.

The IoT technologies have many applications in many fields which can help to improve human's life such as smart traffic system, smart environment, smart home, smart hospitals, smart agriculture and smart retailing and supply-chain management. For example, in traffic system, an intelligent monitoring system can be implemented to identify the vehicle automatically and other traffic factors [30]. This can help to reduce the traffic congestion by providing a good traffic experience for traffic users. For environment, the occurrence of natural disaster such as fire, flood, earthquakes, tsunami can be predicted with the IoT environmental monitoring system. A proper monitoring of air pollution in the environment can also be developed.

Moreover, IoT technology also plays an important role in Industry 4.0. Industry 4.0 is next stage in the evolution on the control of manufacturing process in industry's production line [31]. Industry 4.0 is directly associated with organization of smart factories [32]. The resources can be managed more efficient and the production needs can be adapted more flexible. For example, Furthermore, Industrial IoT (IIoT) systems are able to locate and track items automatically [33]. This system also allows the exchange data from different workstations, suppliers, clients and front office. Moreover, information can be easily collected from all the different part of the value chain. These information or data can be analyzed with computerized machine which can help to increase the quality of products and decrease the production costs.

2.4 Characteristic of Gas Sensor

Gas sensors are widely used to monitor various gases including the pollutant and non-pollutant gases. Gas sensor can be categorized into many type such as semiconductor, solid electrolyte, electrochemical and catalytic [34]. Semiconductor-type gas sensors are widely used due to their high degree of sensitivity and efficiency. Besides that, these sensors also can detect various gases and functional normally even in environment of high temperature, reactivity and high humidity. The working principle of the gas sensor is that there is a metal oxide surface inside a semiconductor gas sensor. When there are gases come from the surrounding in contact with the metal oxide surface to undergo oxidation or reduction of the ion. The metal oxide layer absorbs or desorbs the gases to change the conductivity or resistivity of the gas sensor. This change has the significant linear and proportional relationship with the concentration of the gases. The calibration is necessary so that the sensed value of gas sensor is more accurate. However, the calibrations of the gas sensors are not consistent for all sensors all the time. Thus, individual calibration is needed for sensor to increase the accuracy of the sensor value. However, it increases the sensor costs including the resources and labour time.

The calibration of carbon monoxide with the change in resistivity of the gas sensor can be calculated as shown in Equation 2.1 [35].

$$\frac{R}{R_0} = 1 + A[CO] \tag{2.1}$$

Where R is the resistance exposure with gas. R_o is the baseline resistance, A is a constant sensitivity parameter and CO is carbon monoxide.

There are some limitations of semiconductor gas sensors. Different gases have different concentration part-per million (ppm). Semiconductor CO_2 gas sensors have the best performance in the range from 2000 to 10000 ppm. The best monitoring range for indoor air quality application is between 500ppm and 1000pm [35]. Therefore, the CO_2 gas sensors may not very suitable in this application.

A research on gas sensors for monitoring air pollution was carried by K. Soo in 2011 [36]. In this research, the major pollutants such as nitrogen oxide, carbon monoxide, carbon dioxide and volatile organic compounds and secondary pollutants such as particulate matter (PM), ozone and peroxyacetyl nitrate (PAN) were discussed. The major focus of the project is the environmental gas sensors. The environmental monitoring includes air, water and land and the classification of these applications is also defined. There are two type of the monitors which are fixed monitor and mobile monitor. For example, fixed monitor is used to observe the industrial emissions, car exhausts. Biochemicals, leaks and air quality while the mobile monitor is used as a gas alarm. Different gases have different environment standard concentration and threshold limit value (TLV) and the details of four important pollutant gases are shown in Table 2.2.

Table 2.2: Environmental standard concentration and threshold limit value for air pollution [36].

Pollutants	Concentration		
	Environmental	TLV	Request of sensors
CO_2	-	5000ppm	200-400ppm
CO	More than 35 ppm (1 h average)	50ppm	0.1-10ppm
SO_2	Less than 0.04 ppm (daily average)	2ppm	0-2ppm
NH_3	-	25ppm	-
O_3	Less than 0.06 ppm (1 h average)	0.1ppm	0-0.5ppm

In this particular research, the characteristics of carbon dioxide gas sensor are discussed. Most of the carbon dioxide gas sensor are made up by mixed oxide capacitors, solid electrolyte and polymers with carbonate solution [37]. Due to the reason of low-cost, high-sensitivity, high-selectivity and simple-element structure, solid electrolyte-type carbon dioxide sensors are widely used. Many researchers figured out that the carbon dioxide gas sensor can be upgraded with auxiliary phases in sensing electrodes, which is known as the binary carbonate systems. Better long-term stability, resistance to water vapor interruption and quick response time can be achieved by using this binary carbonate system [36]. Figure 2.6 shows the schematic diagram of a carbon dioxide gas sensor.

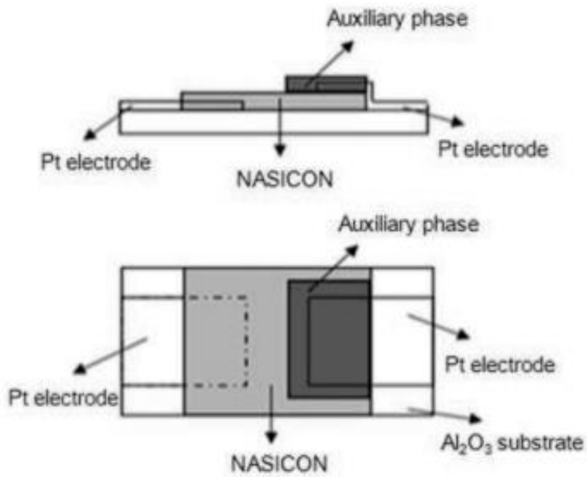

Figure 2.6: Schematic diagram of a carbon dioxide gas sensor [36].

2.5 Cloud Database

A cloud database is a database that used to store the data which can runs on a cloud computing platform. There are some features of the cloud computing such as Infrastructure, Platform and Software as a Service [38]. There are two type of databases that are frequent used by many users. These databases are relational database and Non-Structured Query Language (NoSQL) database. The details of these databases are discussed.

A relational database is a database that stores the data items in an organization of formally-described tables. It is also a well-established system used to store and query large amount of structured data. Structured Query Language (SQL) is used as the standard user and application program interface for the relational database. SQL can easily extract the required data from the pool of the database. Relational database is widely used as it is simple and easy to use. The data is easy to modify and extend by using the operation such as join, aggregation, addition, creation, retrieval and deletion [39].

NoSQL database is a non-relational database that used to manage unstructured data. This can be used to manage the non-uniform data. NoSQL database is high scalable, efficient, can store a large amount of data. There are three kind of data which are structured, semi-structured and unstructured data. It is very hard or difficult to store the semi-structured and unstructured data in a relational database as relational database requires the data in a systematic and uniform form. NoSQL has some advantages compared to SQL database such as it able to manage big data efficiently, handle various data with varied complexities and provide high velocity in storing and retrieving the data.

There are four major classification of a NoSQL database which are graph databases, key value stores, wide column stores, and document stores. Graph database used graph theory as the fundamental while key value store stores the data into two parts which are key and value. Column store stores the data in form of sections of columns of data whereas the document database stores the data in the form of complex structure as document such as Javascript Object Notation (JSON) [39].

In 2017, N. Jain conducted a research on the future of database services which is the cloud database [40]. He found that there are many challenges for researchers to improve the cloud server to achieve more efficient and effective task. First, the important factor that needed to be considered is security of the data in cloud. The data coding and decoding mechanism are developed to access the security. Second challenge is database deployment which involves the pre-installed and pre-configured cloud database. Third challenge is queries' optimization which consists of the researches on the effectiveness of Codd's query optimization in cloud databases. Finally, the last challenge is measuring cloud efficiency with the query optimization. A database resource algorithm is developed to improve the efficiency of the cloud and query optimization [40].

2.6 Factor of air pollutants

Road congestion and high traffic volume are the main factors that contribute to air pollution. In 2016, a research paper regarding the air pollution emission inventory along a major traffic route Ibadan Mertropolis, southwestern Nigeria was published to investigate the impact of high traffic on environmental air quality [3]. Eight locations with different traffic volume were selected for the air quality monitoring. The concentration of carbon monoxide, sulphur dioxide, nitrogen dioxide, hydrogen sulphide and ammonia are the air quality parameter that needed to collect monthly for four months in the morning, afternoon and evening. The data was collected twice in the morning (7:00-10:00am), afternoon (12:00-3:00 pm), evening (4:00-7:00pm) and night (12pm-1am) for each of the months between March and June 2013.

The traffic volume of trucks, cars and motorcycles were estimated by personal observation in the eight locations. At the end of the research, it was found that when the traffic volume especially the number of car was increased, the concentration of carbon monoxide also increased. The concentration of carbon monoxide achieved highest at 50.8 ppm during evening peak hours at location L-4. This location is characterized by high traffic congestion [3]. Figure 2.7 shows the relationships between traffic volumes (x10^2) and atmospheric CO (ppm) levels.

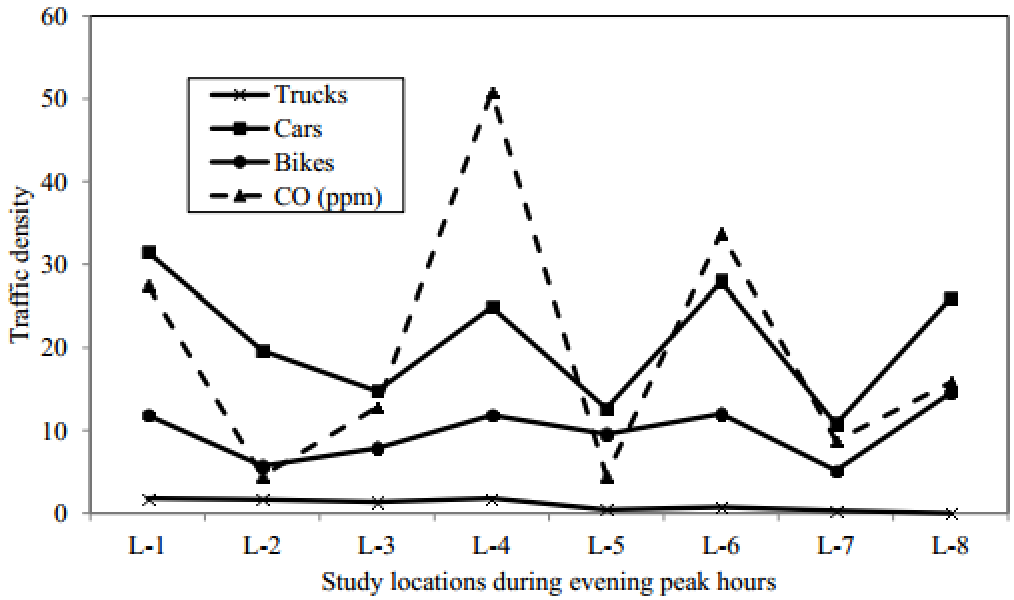

Figure 2.7: Relationships between traffic volumes ($x10^2$) and atmospheric CO (ppm) level [3].

In this study, the fact that high traffic density that lead to much higher concentrations of air pollutants was emphasized [3]. Besides that, cars were considered as the major source of the air pollution in this research. Carbon monoxide is the main pollutant emissions from the vehicle and its concentration was much higher during morning and evening peak hours.

2.7 Summary

A systematic environmental monitoring system for air quality can be developed in many ways depending on the purpose. Each air pollution monitoring system in the previous section has its own advantages and usages. The researches on the air pollution monitoring system which have been discussed in the previous section are summarized. Table 2.3 shows different air monitoring system proposed by different researchers.

Table 2.3: Air monitoring system proposed by different researchers.

Authors	Advantages	Limitations
Hyuntae Cho [14]	Both stationary and wearable devices which various functions with IoT concept are proposed.	Limited application for cloud service as cloud service is not fully ulitized.
P. Brynda, Z. Kosová and J. Kopřiva [17]	Real-time air quality situation can be viewed on a map from website.	Bluetooth Low Energy (BLE) is used as communication module which only allow limited distance data transmission.
M. Simić, G. M. Stojanović, L. Manjakkal and K. Zaraska [19]	Solar panel-based charging method is used to power the system.	Only some gases can be detected as limited gas sensors are used in the system
A. Mukhopadhyay, A. Sengupta, S. Paul, D. Saha, K. Shome, S. Roy [10]	Bluetooth module is used as the wireless communication device as it does not require internet connection.	The gathered data can be only sent to one device for real-time monitoring due to Bluetooth module is used.
R. You, Z. Lu, Q. Hou and T. Jiang [11]	Terahertz (THz) is used due too it unique electromagnetic wave band which can penetrate fog, gas and smoke.	The absorption peak must be known to identify the pollutant gases.
N. S. Desai and J. S. R. Alex p [21]	Machine learning is used to predict the observations related to pollution metrics in future.	Only certain gases can be detected due to only two gas sensors are implemented in the system.

The advantages and limitations of each air pollution monitoring system are studied and being considered in this project. For example, the limitations of research conducted by A. Mukhopadhyay and his team [10] which used the Bluetooth communication can be improved and modified by involving the technology of IoT. IoT with the application of Wi-Fi can provide real-time measurement of air quality for many users. Thus, the technology of IoT is investigated in this chapter. An environmental air quality sensing system with alarm and warning indicator which can determine the temperature, humidity and concentration of pollutant gases will be designed by utilizing a gas sensor, humidity and temperature sensor and buzzer. The sensed data will be sent to the database. Therefore, gas sensor and cloud database are the main components in an air pollution monitoring system. Some studies on the semiconductor gas sensor and NoSQL database are emphasized due to their advantages and functionality. An Android application which can monitor the real-time measurements of temperature, humidity and concentration of pollutant gases will be developed by connecting the application to database for data retrieval. The journal "Air pollution emission inventory along a major traffic route within Ibadan Metropolis, southwestern Nigeria" [3] was studied so that the factors of air pollution can be more familiarized. Lastly, the effect of factors such as time and traffic condition on the temperature, humidity and concentration of pollutant gases will be also investigated.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter presents and discusses methodology that used to achieve the objectives of the study. The overall project implementation flow, the component selection of the project and the development of prototype of the project are described and discussed. Besides that, the development of algorithm of the project, preliminary experiment on sensors with different factors and the performance testing under different conditions are also presented and explained. Moreover, the data collection in database, the development of Android application and the data retrieval and analysis of this study are described and discussed. Lastly, a summary of the methodology is included in this chapter.

3.2 Project Implementation Flow

In order to make sure the project can be completed smoothly, a flow chart about the project implementation is drawn out. Figure 3.1 shows the project implementation flow of the overall system. Initially, a gas sensor MQ2 and a humidity and temperature sensor, DHT11 were chosen to determine the concentration of carbon monoxide, smoke and LPG as well as the humidity and temperature of environment. The data sheets of both sensors which are attached in Appendix C were studied so that the characteristic of the sensors can be familiarized. After that, these sensors were connected to Raspberry Pi to develop the prototype of the project. The algorithm of the project was developed, and a Python script as shown in Appendix A was written to initiate the communication of hardware and software.

A preliminary experiment was carried out to determine the functionality of MQ2 in condition with and without the presence of carbon monoxide. Another preliminary experiment was also conducted to determine the functionality of DHT11 on temperature in outdoor and indoor and functionality of DHT11 on humidity in bathroom and kitchen.

Then, a performance testing of the environmental monitoring system for air quality was carried out under different conditions such as venue and time. A database was created to store all the collected data from sensors. In addition, an Android application was developed to view the real-time data of the sensors which retrieved from the database. Lastly, the collected data was retrieved and analyzed.