DEVELOPMENT OF AN IOT ENVIRONMENTAL INFORMATION SYSTEM FOR USERS OF GPS-BASED PUBLIC TRANSPORT

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DEVELOPMENT OF AN IOT ENVIRONMENTAL INFORMATION SYSTEM FOR USERS OF GPS-BASED PUBLIC TRANSPORT

by

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LIST OF ABBREVIATIONS

API	Air Pollution Index
API	Application Programming Interface
BLE	Bluetooth Low Energy
CO	Carbon Dioxide
CSI	Camera Serial Interface
GPIO	General Purpose Input-Output
GPS	Global Position System
GSM	Global System for Mobile
GNSS	Global Navigation Satellite System
GUI	Graphical User Interface
HDMI	High-Definition Multimedia Interface
HTTP	Hypertext Transfer Protocol
I2C	Inter-Integrated Circuit
IoT	Internet-of-Things
IP	Internet Protocol
ITS	Intelligent Transport System
LoRa	Long Range
LPWAN	Low-Power Wide Area Network
M2M	Machine-to-Machine
M-ESB	Mobile Enterprise Sensor Bus
MQTT	Message Queuing Telemetry Transport
NMEA	National Marine Electronics Association
NFC	Near Field Communications
NO	Nitrogen Oxide
NO_2	Nitrogen Dioxide
PCB	Printed Circuit Board
PM	Particulate Matter

PPM	Parts per Million
PT	Public Transport
SoC	System on Chip
SQL	Structured Query Language
SPI	Serial Peripheral Interface
UART	Universal Asynchronous Receiver-Transmitter
USB	Universal Serial Bus
UV	Ultra-Violet
VOC	Volatile Organic Compound
V2I	Vehicle to Infrastructure
WPAN	Wireless Personal Area Network

PEMBANGUNAN SISTEM MAKLUMAT ALAM SEKITAR IOT UNTUK PENGGUNA PENGANGKUTAN AWAM BERASASKAN GPS

ABSTRAK

Internet-of-Things (IoT) membawa potensi pembangunan untuk mengubah komuniti kepada "Smart City" dengan ide menggabungkan pengumpulan data dan perkongsian perkhidmatan. Ia membawa banyak faedah termasuk merendahkan tahap pencemaran, ramalan cuaca masa nyata, meningkatkan trafik, membina kecekapan tenaga, dan kualiti kehidupan yang lebih baik untuk warganegara pada masa depan. Kerja penyelidikan ini mencadangkan platform pengesanan alam sekitar mudah alih untuk pengumpulan maklumat bandar dan pemantauan keadaan dengan membekalkan data kepada sistem pengkomputeran awan. Untuk membangunkan sistem ini, sensor kualiti udara, sensor suhu dan kelembapan dan modul geolokasi direkabentuk dan dihubungkan dengan Raspberry Pi 3. Selepas itu, parameter alam sekitar dikumpulkan, disimpan dalam pangkalan data tempatan PhpMyadmin dan dimuat naik ke pangkalan data awan ThingSpeak secara masa nyata. Kemudian, data tersebut diproses dan divisualisasikan secara grafik untuk menganalisis dan memantau data selanjutnya. Ujian medan prototaip telah dilakukan untuk menyiasat perlaksanaan kerja yang betul. Sistem yang dibangunkan menggunakan penginderaan statik konvensional dan penginderaan mudah alih baru. Didapati bahawa terdapat perbezaan 6.93% di antara kaedah penderiaan statik dan mudah alih, yang agak kecil. Secara keseluruhan, pembangunan sistem maklumat alam sekitar IoT dengan menggunakan penderiaan mudah alih adalah satu kejayaan dan dapat memudahkan penderiaan alam sekitar dan pemantauan.

DEVELOPMENT OF AN IOT ENVIRONMENTAL INFORMATION SYSTEM FOR USERS OF GPS-BASED PUBLIC TRANSPORT

ABSTRACT

The Internet-of-Things (IoT) brings a development potential to transform the communities into Smart Cities with the idea of incorporating data collection and services sharing. It brings a lot of benefits including lowering levels of pollution, real-time weather forecasting, improving traffic, building up energy efficiency, and a better overall quality of life for the future citizen. This research work proposes a mobile environmental sensing platform for city information collection and condition monitoring by feeding the data to a cloud computing system. To develop the system, the air quality sensor, temperature and humidity sensors and geolocation module are designed and interfaced with a Raspberry Pi 3. After that, environmental parameters are collected, stored in PhpMyadmin local database and uploaded to ThingSpeak cloud database in real-time. Then, the data are pre-processed and visualized graphically for further data analyses and monitoring. A prototype field test has been carried out to investigate proper working of the developed system using the conventional static sensing and new mobile sensing. It is found that there is a 6.93% difference between the static and mobile sensing method, which is rather small. Overall, the development of the IoT environmental information system by using mobile sensing has been a success and able to facilitate environmental sensing and monitoring.

CHAPTER ONE

INTRODUCTION

1.1 Background

Nowadays, public transport (PT) in Malaysia has become the most commonly used and affordable transport vehicle in any rural and urban regions globally. For instance, public buses and trains are being used and carry thousands of passengers to certain destinations from morning till night every day. Gradually, there is a trend that cities and the transport are getting smarter [1], where smart indicates that a device is active, digital, networked, able to operate to some extent autonomously, is reconfigurable and has local control of the resources it needs such as energy and data storage [2]. In this context, three basic design schemes for smart devices and services have been proposed. These include smart devices (including smart mobiles), smart environments (embedded with smart devices) and smart interaction between multiple devices [2]. Therefore, a road vehicle can be both a complex smart mobile device and a smart environment supporting smart interaction between the multiple devices embedded in it. A variety of data can be collected from these vehicles streaming in real-time through a wide-area GSM network or uploaded periodically to infrastructure (V2I) network via local area networks at bus stops and stations, as part of a wider system known as Intelligent Transport System (ITS).

Over the years, the smart vehicle development is being in better control and vehicle sensing and sharing data with remote diagnostic services. Over the last decade, researchers have investigated that PT bus can be applied to form a wide area mobile sensor which it moves around road surfaces and physical environment spaces and be able to monitor the environment. In this case, the public bus could monitor the region of the road network and air quality.

One of the issues related to developing cities is air pollution, people who are living in a big city such as Kuala Lumpur, Jakarta, Bangkok and Hong Kong are likely to be exposed to more polluted air than people living in small cities [3]. Since it has a great relationship with health and safety that could lead to breathing related illnesses [4], it is crucial to monitor the air quality of the states, so that the clean air policies are checked and updated to adhere. Also, a low air quality can incur an economic cost. The total economic value of the atmosphere was to be at least between 100 and 1000 time the Gross World Product [5].

The current advancement in the fields of technology and economy having a significant impact on the environment, and have led to serious concerns regarding pollution and climate change [6]. In the report released in 2014, the Intergovernmental Panel on Climate Change confirms that human activities are having an unequivocal and continuously increasing influence on the climate system, with recent changes that are unprecedented over decades to millennia [7]. Environmental monitoring represents a fundamental instrument for gathering relevant information in the city.

In the aspect of the air quality monitoring, where and how to deploy the environmental sensors, a system is proposed to separate into fixed, versus mobile or vehicle-mounted module respectively. Normally, the environmental sensors such as CO, NO and NO_2, temperature, humidity, illumination, UV radiations, wind direction, wind speed, air pressure, and altitude are likely to be deployed as fixed sensors [8]. Thus, the air pollution monitoring and forecasting services can be linked to the sensors via data analysis.

In spite of that, the coverage induced by static sensors is very limited and also costly to deploy all the sensors in every state. Therefore, researchers deployed mobile sensors embedded in cars or buses to collect data for road traffic condition and also the air quality monitoring. To some extent, a smart mobile environmental sensing has several benefits over a fixed smart environmental sensing. One of the benefits is the wide coverage of environmental sensing. It is also cheaper to deploy and maintain the system. Another one is the costly sensors are always left attended, where it packed in a transport for internal protection.

In addition, it has the flexibility and scalability in designing multi-use service infrastructure [9]. For example, put additional buses and sensors to increase coverage. The maintenance of sensors can be reduced as it can be done at bus station instead of sending technicians to the different fixed sensor areas. Furthermore, an appropriate bus route can create a city map with air quality distribution diagram.

The development of a smart public transport for the Internet of Things (IoT), where three smart design patterns, smart devices, smart environments and smart interaction are mingled together. The smart public transport acts as a mobile environmental sensing which is embedded with multiple sensors to collect the physical environment and display on a map interface for monitoring data easily. The collected data from the sensors will upload to a cloud server via a wireless network for post-processing. On the other hand, the implementation of the mobile sensors is normally done by the private company which could monopolize the use of the collected data. When other companies or government administration departments want to acquire some related information, they have to deploy their own system or else sharing the information with the provider by paying for the services. This kind of integrated model drives new environmental business and services [10].

A research study the development of environmental sensing for smart city have been done considerably in the past and it is still growing vigorously. Environmental monitoring is essential in smart cities for controlling air pollution levels in crowded urban areas in a collaborative, inexpensive, distributed and accurate manner. Moreover, it has to be noted that the impacts are more prominent in the urban areas with millions of citizens, which is called megacities. The core of the concept behind the Smart City is the integration of the physical world with the virtual world. To some extent, it provides additional capabilities such as automatic behavior and environmental sensing to common objects, to capture and to analyze the data from the real world to assure a better operation of the virtual one [11].

1.2 Motivation and Problem Statement

Environmental sensing has recently gained attention for use in air quality monitoring based on the environmental parameters such as temperature, humidity, the concentration of gases (CO_2, CO, NO_2 etc). Air quality monitoring can be a very challenging task in an urban area because the environmental parameters are sensitive to various factors such as weather, natural disaster and human factor. Numerous schemes have been proposed for environmental monitoring over the past few years. Based on the past discussion, the main problems of current environmental sensing techniques can be summarized as follows:

1. The effectiveness of a moving vehicle to collect the surrounding environmental parameters. Lohani and Acharya [12]
2. The accuracy of a smart mobile vehicle to show a real-time information. Cruz, et al. [13]
3. The capability of the system to convert raw data into human-readable information by showing the level of air quality. Kang and Hwang [14]

1.3 Project Objectives

The overall aim of this project is to develop a real-time tracking and environmental sensing system for city information collection in order to monitor the traffic and air quality in the urban environment. To achieve this, the objectives to be accomplished are as listed below:

1. To develop an information acquisition module in terms of geolocation and air quality condition for data communication.
2. To develop a cloud-based data module in terms of geolocation and air quality condition with a cloud server.
3. To integrate the modules in objectives 1 and 2 and validate their working performance.

1.4 Project Scopes

This project is focusing on improving city information collection and monitors the urban environment with environmental remote sensing. By the implementation of environmental sensors in the GPS-based public transport, it could be showing a real-time information about geolocation, climate and surrounding conditions along the specified routes. Therefore, it can be done by uploading the data to a cloud server and processing data analysis come out with useful information. As the appropriate usage of remote sensing data and information, it would help to understand the dynamics of the urban environment which may contribute to policy and urban management. However, there are some constraints that the proposed system is limited to. They are as listed below:

1. There are various types of wireless communication technologies that can be used in the system including Wireless networking (Wi-Fi), Bluetooth, ZigBee or LoRa

wireless technology. In this project, Wi-Fi 802.11 technology will be applied to the proposed system.

2. The implementation of mobile environmental sensors can greatly increase the coverage of the air quality distribution in the city. However, the proposed system will use one designated model for developing a highly accurate mobile environmental sensing technique. It will be covered on the air quality and traffic condition only for the development of smart transportation.
3. The device to control the environmental sensors and upload to a server will be a system-on-chip computer, Raspberry Pi 3 model B and will not apply on other microcontroller boards after comparing with the previous research.

1.5 Thesis Outline

This report consists of a total of five chapters which describe how the project is implemented. The first chapter is the introduction of the research topic which is the mobile environmental sensing on public transport. This chapter describes the background and application of environmental sensing and the reliability of a smart city concept. On top of that, this chapter also explains the problem statement of a development of mobile environmental sensing which emphasized the limitation of the previous research. Therefore, the project objectives and project scopes are presented in the detailed description.

Chapter two is the literature review of the environmental sensing and its implementation for city information collection. This chapter is stated by explaining a variety of ways to collect environmental data. Also, it goes on with the classification of previous environmental sensing methods to gather the information. After that, some significant environmental sensing methods are explained and stated in terms of advantages and disadvantages.

Chapter three describes the methodology of the proposed mobile environmental sensing. This chapter presents the overall flow of the proposed mobile environmental sensing and each process is briefly explained. In addition, each process of the scheme is described in detail.

Chapter four presents the results obtained from the proposed mobile environmental sensing system. This chapter states the comparison of the proposed system with some of the previous environmental sensing system by using the distribution of data collection. Then, the difference of the results is analyzed and explained in a logical manner.

Chapter five composes of the conclusion and future research that could be done for the developed mobile environmental sensing system. The summary and evaluation of the proposed mobile environmental sensing system are presented to conclude the project achievement. Moreover, the potential further research and recommendation on improving the proposed mobile environmental sensing system are briefly described.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In the recent years, the implementation of environmental sensors have been carried out in various ways, each of the approaches applied has its own superiorities and drawbacks. To develop a better environmental sensing approach, the previous relevant approaches are examined and compared on both sides.

In advance of justifying the previous approaches applied in the environmental sensing, a basic understanding of the environmental sensing must be understood. The idea of the environmental sensing will be briefed in section 2.2, followed by a variety of approaches used in the implementation of the smart city with environmental sensing will be discussed in section 2.3. Then, the difference between the relevant approaches in terms of superiorities and drawbacks will be summarized in section 2.4.

2.2 Background of Environmental Sensing

Environmental sensing can be defined as to place the environment parameters into a framework that enables our ability to measure, model, and map its features using remote sensing technology to gain intelligence. Also, the purpose of the environmental sensing is to manage the environment effectively and be able to have the optimum decision making based on the measurement and representation of earth surface characteristics that support the information requirements [15]. Therefore, environmental conditions can have a great impact on human well-being, comfort, and productivity.

To consummate a Smart City with fully capable of monitoring surrounding environment and improving the services of the infrastructure, These insignificant but crucial environmental parameters such as temperature, humidity, carbon dioxide concentration, particulate matter (PM2.5) and volatile organic compounds (VOCs) are essentially required to collect and analyze for solving the environmental issue earlier. Undoubtedly, environmental sensing exploits another possibility to generate smart devices for improving human well-being and enhance the energy efficiency of a variety of applications [16]. For example, there are various kinds of services such as healthcare, work environment measurement or tourism service could be provided as well. Also, research and development of the Internet of Thing (IoT) are growing rapidly. With IoT, everything can be connected to the Internet. Environmental sensors also become smaller, and able to transmit measured data through the network. These sensors can deploy on a large scale with low cost and controlled by using the latest Cloud services.

2.3 Internet of Things Protocols in the Infrastructure Layer

In the last few years, the Internet of Things (IoT) has become one of the most challenging research topics and it is still the hot topic offering a broad way of novel solutions for Smart Cities. Behind this concept, it involves a vast variety of domains such as healthcare, safety and security, industrial control, intelligent transportation systems, home-based solutions and environmental monitoring. Therefore, the implementation of the sensors scheme must deal with IoT protocols in order to stay connected with the Internet and interacts with each other in promoting sustainability and a better life quality. The major characteristics of the IoT are that they are constrained devices such as small sensors, indicating they have restricted processing, storage capacity, restricted battery, restricted communication characteristics (e.g. Low Bandwidth, Low Data Rate, Low Coverage)[11].

At present, IoT has several communication technologies that can be applied to create a network. As it relates to wireless communication field, a brief analysis of the possible wireless technologies for IoT are as listed:

(i) 5G network is the fifth generation cellular network architecture, designed to support great amounts of data, high speed, configurability for new emerging technologies such as the Internet of Things [17]. Currently, it is in the first phase, where new standards and services will be defined, but soon it shall become the default cellular network technology.

(ii) LoRa is a LPWAN (Low-Power Wide Area Network) technology designed to optimize different key aspects such as communication range, battery lifetime, and costs, supporting thousands of devices forward to several fields including metering, sensing, and machine-to-machine (M2M) communications [18].

(iii) ZigBee is based on the IEEE 802.15.4 standard, and it was designed for Wireless Sensor Networks. The main characteristics are small size and low power consumption. Normally, the transmission range can vary from 10 to 100m, depend on its output power [19].

(iv) Wi-Fi is based on the IEEE 802.11 standard, and it was designed for Wireless Local Area Networks. Currently, the 802.11n version is the most widespread option and this technology operates in the 2.4GHz or in the 5GHz band. The transmission range for standard interfaces is around 100m [20].

(v) Bluetooth Low Energy (BLE) or Bluetooth Smart, also known as Bluetooth 4.0. The main advantage is that it uses ultra-low power compared with previous versions.

Undoubtedly, it becomes one of the best options for IoT application nowadays [21]. The coverage range is around ten meters similar to the previous Bluetooth specifications.

2.4 Overview of Available Hardware for IoT

Nowadays, the appearance of various embedded prototyping platform, that is Raspberry Pi or Arduino, which are complemented by a large number of compatible electronic components, paved by the way for the creation of diverse applications related to IoT [22]. On top of that, it can have different development options including different types of sensors and various communication interfaces while it is specifically centralized on the environmental monitoring requirements.

Commercially, there are several companies that provide small and powerful boards along with a large variety of electronic components for personalizing them according to user requirements. To develop air quality data acquisition, specialized pollution sensors must be connected to a microcontroller or microcomputer through a digital or analog port. Besides, the microcontroller or microcomputer must be connected to a communication module through a UART interface or USB port in the communication work.

Despite the lightweight processing constraints, there are several options available for embedded systems acting as a critical role in the sensor design. A brief analysis of the available microcontroller and microcomputer are as listed:

(i) Raspberry Pi is one of the most popular microcomputers worldwide. It is a low-cost and a small-sized computer that allows the connection of standard PC peripherals including a monitor, a keyboard, and a mouse. It was designed to explore computing, and it supports different Operating Systems: Raspbian, which is based on Debian, and also Ubuntu Mate or Windows 10 IoT Core, thereby allowing the use of several programming languages. In addition, all Raspberry Pi versions benefit from several input/output ports operating at 5 Volts, thus being ideal for all sorts of IoT projects [23]. Figure 2.1 shows the generations of Raspberry Pi models. Each board has the LEDs light to indicate the power supply. It contains HDMI port, CSI camera connector, Ethernet port, four USB ports and forty GPIO headers. The latest board, Raspberry Pi 3, it also supports wireless internet out of the box, with built-in Wi-Fi and Bluetooth. Moreover, it is powered by a smartphone processor capable of performing ten times faster than that of the Raspberry Pi and around fifty percent better than that of the Raspberry Pi 2.

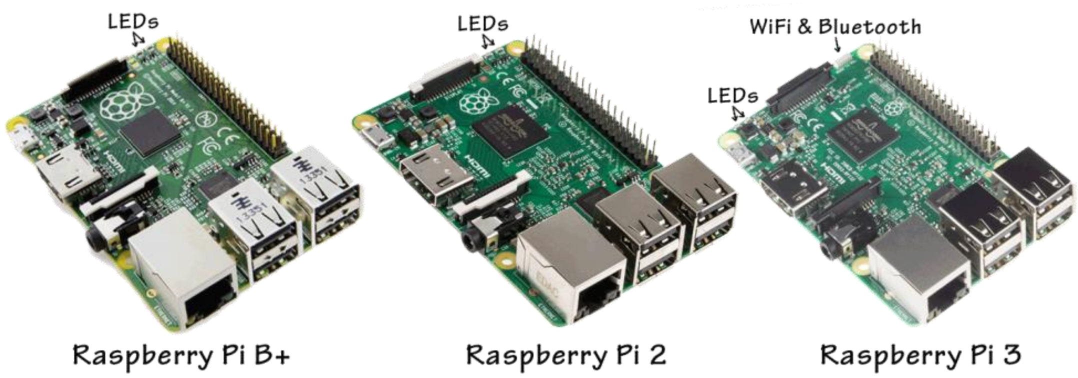

Figure 2.1 Generation of Raspberry Pi models

(ii) BeagleBone is a small computer running a Linux Operating System called Angstrom, and it is supporting various software distributions such as Android or Ubuntu. It has a USB port for connecting distinct peripherals, along with an HDMI port for the video connection, allowing to use it as a regular computer and design for IoT project [24]. It has two 46 pin headers which operate at 3.3V, allowing the connection of the different digital or analog devices like sensors or actuators. Figure 2.2 shows the BeagleBone Black board.

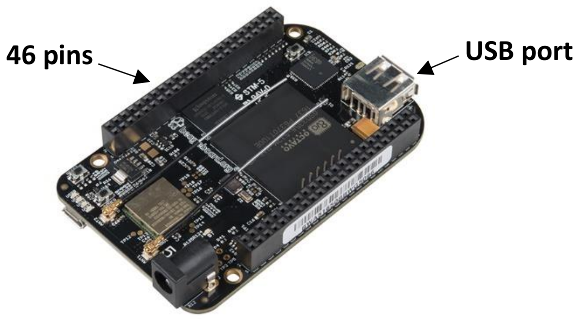

Figure 2.2 BeagleBone Black

(iii) Intel Galileo is a powerful open-source computer developed by Intel. It is designed for IoT applications and targeted towards both prototypes and commercial solutions with performance constraints. It integrates both Wi-Fi and Bluetooth 4.0 interfaces. Figure 2.3 shows the Intel Galileo board. It supports HDMI, could be powered by micro USB and contain thirty-two GPIO pin headers.

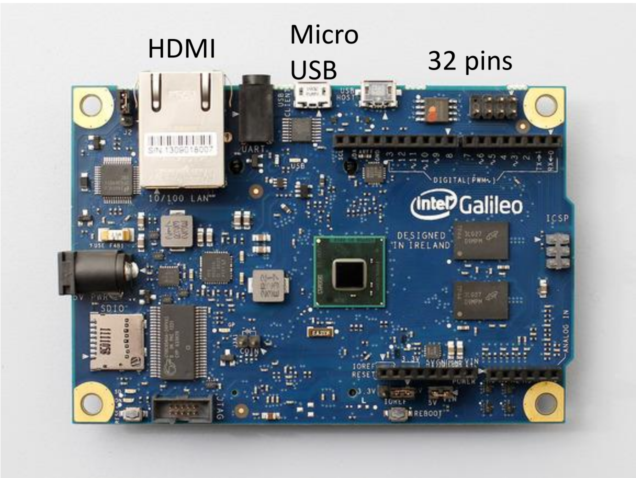

Figure 2.3 Intel Galileo

(iv) Pycom is a microcontroller based on the ESP32 chip with 24 GPIO pins, two UART, one SPI and one I2C port, using a firmware based on micropython. It can access wireless communication technologies such as Wi-Fi, BLE, LoRa, and SigFox. Also, it can integrate an SD card by using an expansion board. Figure 2.4 shows the Pycom module.

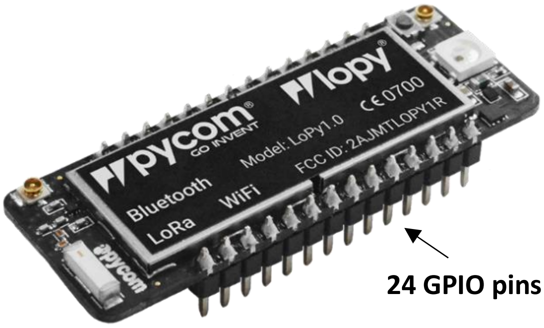

Figure 2.4 Pycom

(v) Arduino is an open-source prototyping platform characterized by easy-to-use software and hardware. It also has several digital and analog input-output pins (GPIO pins) to connect sensors, actuators or complementary boards, allowing to design a variety of IoT solutions [25]. On the other hand, Arduino has its own programming language based on Wiring, and its own Arduino Software based on Processing. Overall, it has a central microcontroller and USB port for programming and power supply. Figure 2.5 shows the Arduino Uno and Arduino Nano boards.

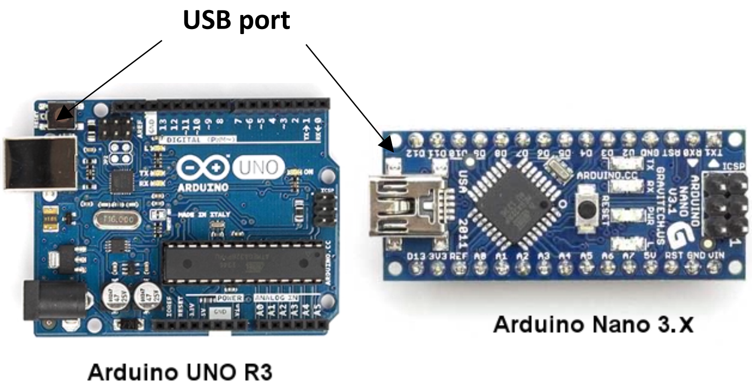

Figure 2.5 Arduino boards

In this paper, Raspberry Pi 3 model B will be implemented into the project to control, collect, and upload data to the Cloud service. It is the most flexible and scalable and yet cheaper among other available hardware for IoT project.

2.5 Cloud Services for IoT Platform

The Internet is changing, it is not only run by humans, but also a bunch of devices that are starting to take over the Internet. These devices are not controlled by people and do not send messages to people either. Basically, they talk to other machines simply known as “Things”. These devices started to connect to the Internet, a place to send, store, and process all kind of the information is needed. Logically, a personal in-house system is not practical for such enormous information to handle as it requires highly cost of maintaining, upgrading, and securing a system. Instead, plenty of cloud services rise in response to the proper time and conditions.

Each cloud service has its own advantages and disadvantages. Here is an overview of some IoT solutions to get an idea of what is on offer at the moment below:

(i) Amazon Web Services IoT Platform claims to be able to support billions of devices and trillions of interactions between them. Figure 2.6 shows the structural level of the Amazon web services IoT platform. However, Amazon charges the messages to be sent or received. It has a software development kit (SDK) to help developer build applications to run on this IoT platform. Overall, Amazon has the comprehensive service of the cloud provider but it can be quite expensive.

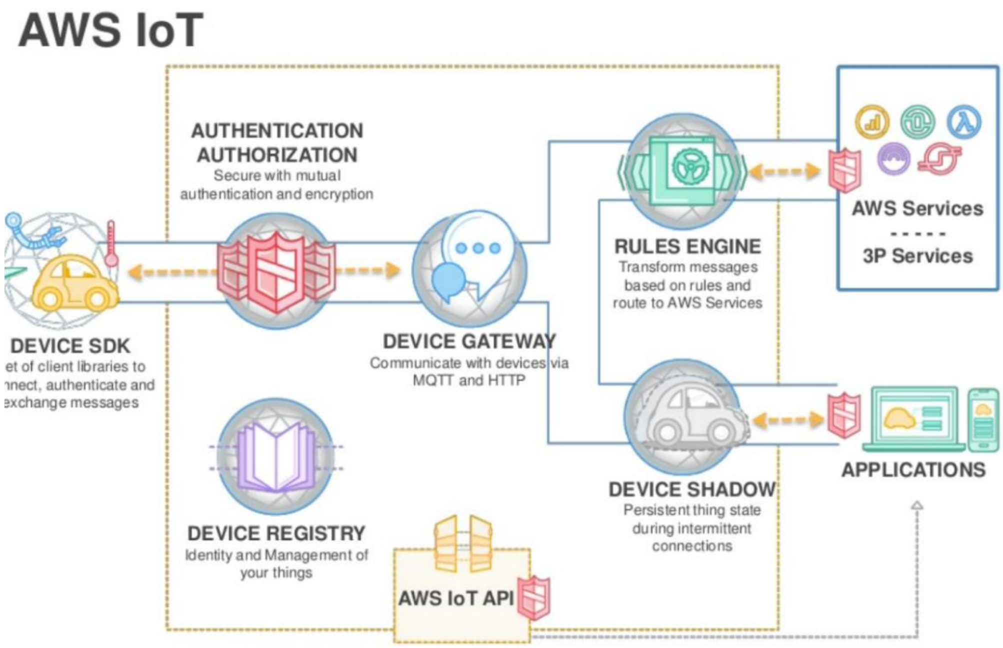

Figure 2.6 Amazon web services IoT platform

(ii) Microsoft Azure IoT Hub have cloud storage, machine learning, and IoT services, and also developed their own operating system for IoT devices. Normally, 8000 messages per unit per day is free of charge. Figure 2.7 shows the structural level of the Microsoft Azure IoT services. It provides flexible, scalable and economical IoT platform to the customers as well as to the software engineers.

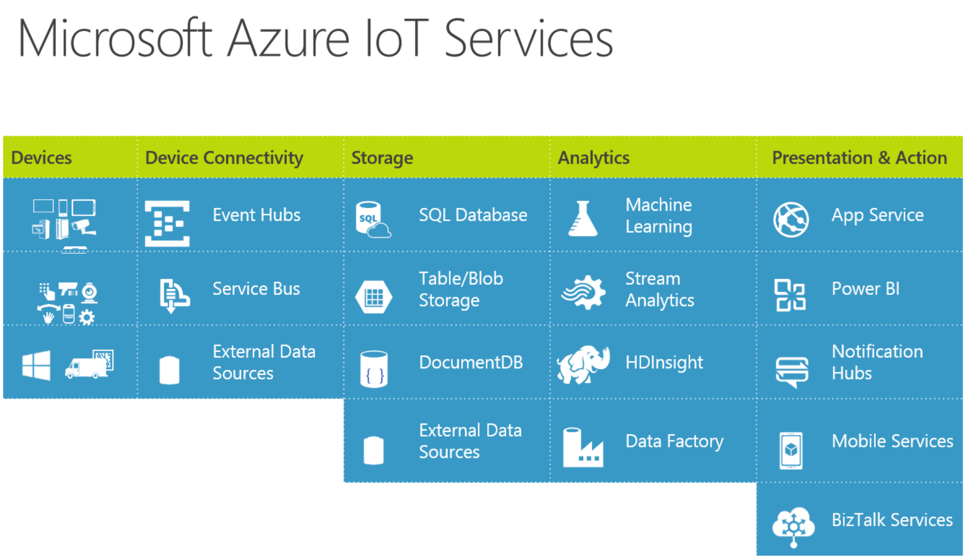

Figure 2.7 Microsoft Azure IoT platform

(iii) Google Cloud Platform is a huge platform to build IoT initiatives, taking advantage of Google's heritage of web-scale processing, analytics, and machine intelligence. Figure 2.8 shows the main products of the Google Cloud Platform. They are mainly making things easy and quick start-up for the business. The pricing on Google Cloud is done on a per-minute basis. In addition, Google has its own IoT operating system for Android system.

Figure 2.8 Google Cloud Platform

(iv) ThingSpeak is an open source Internet of Things application and Application Programming Interface (API) to store and retrieve data from the device using the HTTP protocol or MQTT protocol via the Internet. It enables the creation of sensor devices logging applications, location tracking applications, and a social network of Things with updating status and trigger specific action on devices. On the other hand, ThingSpeak integrated support from the numerical computing software MATLAB, allowing users to analyze and visualize the collected data by using MATLAB. Figure 2.9 shows the relation between ThingSpeak, smart devices, and MATLAB. Also, it provides user-friendly services and suitable for anyone to start-up their IoT application easily.

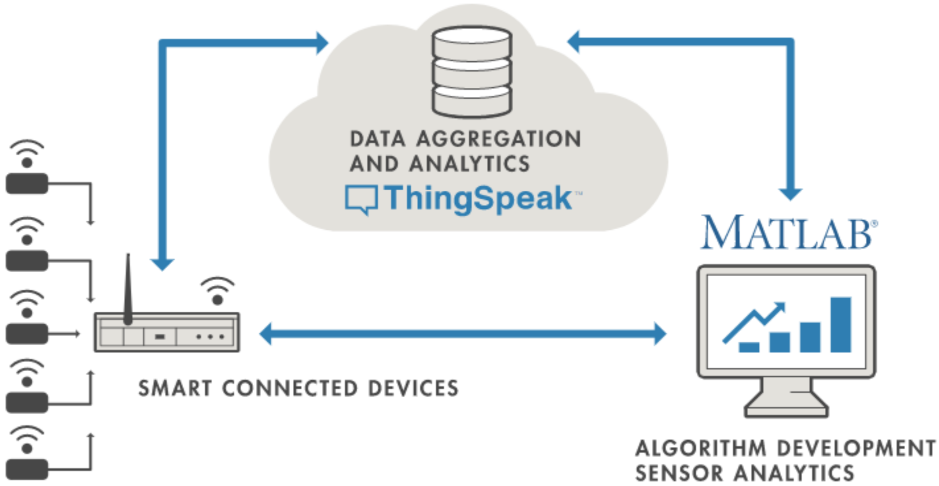

Figure 2.9 ThingSpeak IoT platform

In this study, ThingSpeak will be applied in the project. It provides easy configuration and able to visualize the collected data graphically. Also, it can monitor a real-time data visually on web-service which is more convenient to create an IoT project.

2.6 Static Environmental Sensing Design Schemes

Several of environmental sensors were installed nearby a city park in Gandhinagar, Gujarat, India [26]. In Figure 2.10, it shows the architecture of IoT sensing and environmental monitoring system. These sensors act as a transmitter node (TX node) and a 16-bit microcontroller (PIC24F16KA102) connected with USB dongle acts a receiver node (RX node), with extremely low power technology and consumes nanowatts of power. The data collected from the TX node is transmitted to the RX node via wireless communication. Then, the data received at the RX node is transmitted to the laptop via USB interface. After that, the laptop processes the data and illustrates it as graphically and recorded in an excel sheet through a Graphical User Interface (GUI), which is designed by LabVIEW. Finally, the processed data is uploaded to a MySQL database on an Internet server and be able to transfer data to the Android-based smartphone, thereby enabling IoT based applications.

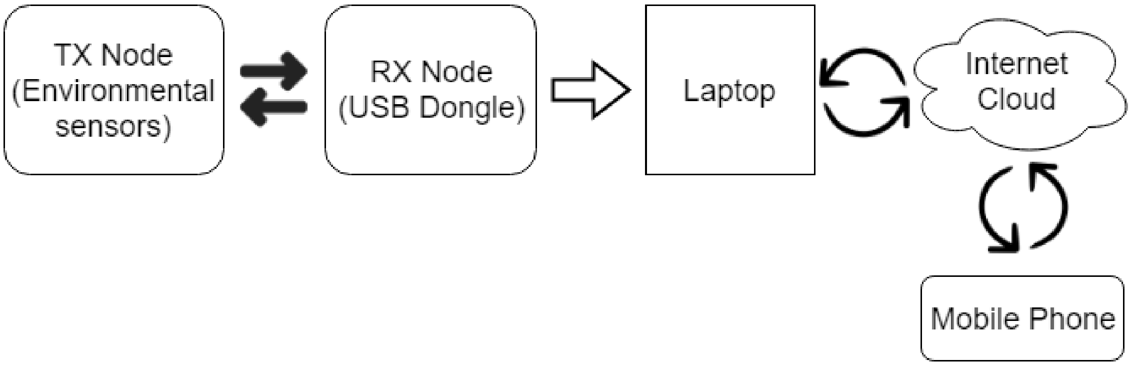

Figure 2.10 The architecture of the IoT enabled sensing and monitoring system

Overall, the proposed system for monitoring temperature, humidity and CO_2 has been implemented successfully and validated at various places in the city. Besides the environmental sensors, the sensor node has a low power consumption of 4.99mW. In addition, the predicted network lifetime can be improved by increasing the sleep time of the microcontroller in order to reduce the power consumption significantly. The quantification of the time along with current consumption of this system provides an intuitive way to deploy the sensor nodes based on the available power.

In 2018, Abdulrahman Abdullah Alkandari and Samer Moein have done another approach by using a small single-board computer, Raspberry Pi [27]. It is economically and yet affordable compared with other microcontrollers. Also, it is able to provide the accurate readings that can be analyzed and manipulated or even sending a warning signal via various of ways such as sending email and SMS alarm to depend on the requirements and conditions. The paper was focusing on monitoring a few harmful gases which are Nitrogen Dioxide (NO_2), Carbon Monoxide (CO) and other gases. In this project, Raspberry Pi was used because it is relatively cheaper, easier to program, a pocket-sized computer and capable of controlling a certain number of sensors. After installing the hardware and software, the environmental parameters were collected in the computer and were uploaded into an excel sheet. All the environmental parameters were able to measure and identify the hazardous level in terms of air quality. Besides, the programming used was in Python, which is an open source and has the possibilities to expand into different measurements and experiments. However, the coverage of the environmental sensors are limited to a certain range and the cost to deploy the system into a city is higher than expected.

Besides the environmental sensing from air quality, the public transport users should be interested in obtaining timely information while a bus reaches a bus-stop on route or whether the bus is delayed or not. An embedded sensor on the public transport will process GPS longitude and latitude information to provide the users with highly accurate automated messages about bus arrival at bus-stops. On the other schema, IEEE 802.15.4 based beacons were installed at both bus-stops and onboard buses, it calculates the position in relation to a roadside beacon in order to estimate the bus arrival time.

2.7 Mobile Environmental Sensing Schemes

In 2016, a new research proposed a solution, that is the implementation of a transportation bus as a Mobile Enterprise Sensor Bus (M-ESB) service in China [28]. It was designed mainly for two requirements which are monitoring the urban physical environment and monitoring road conditions. Also, it was integrating both physical environmental parameters and road condition monitoring. Then it applied a data exchange interface to feed the data into cloud computing system. In short, the idea of M-ESB combined the air quality monitoring and traffic flow detection together in an extensible way. Due to the mobility of the public transport, the coverage of the environmental sensing is greatly enlarged. Therefore, those sensed data on different routes can be combined in time and geolocation to form a wide area sensor grid which shares those data with a remote database. Plus, the sensor data can be shared with subscribed users to fulfill their requirements and interests. Consequently, the public transport embedded with sensors become a mobile enterprise bus.

The idea of the M-ESB is composed of the following sub-systems which are an onboard information-collection network (containing the sensors local area network and sensors access node including memory storage for data and a CPU), embedded gateways to upload the sensor data to the IP backbone network, and a remote data cloud. To this extent, the onboard bus subsystem contains two main functional modules which are the environmental monitoring module and a gateway for data transmission. It is using a Wi-Fi link to transmit the sensing data to an IP backbone network. If the Wi-Fi link is not accessible as well as the data is sensitive to time, the data can be transmitted to the backbone network through a cellular network with a charge. After all, the proposed system M-ESB can achieve both environmental monitoring and road condition detection using onboard Sensor Networks (SNs). In addition, it provides another market-place in management field for the bus company to sell sensing data to those people who are interesting to do further data processing. However, there are some limitations to the proposed system, that it requires a higher cost for the System on Chip (SoC), CC2530 and a limit number of sensors to be controlled.

In 2016, Yi Gao et al. have done another approach by using a microcontroller to monitor air quality based on mobile sensing [29]. Mosaic was built as a low-cost mobile sensing system for urban air quality monitoring. The idea was to deploy the air quality sensors to city buses in order to increase the system coverage. Then Mosaic-Nodes was developed and attached to buses carefully with the tuned airflow-disturbances design.

This novel system addresses the lack of coverage and scalability problem and it has been redesign and improved. After running the test of the prototype, the design able to achieve higher coverage while keeping the low-cost feature unaffected. In addition, the inference accuracy greatly depends on the model used and the model used in this paper was Gaussian inference model. The result also showed that the system is able to monitor urban air quality. Overall, this constructive design achieved a better coverage and low-cost compared with conventional static sensing.

2.8 Chapter Summary

Environmental sensing is generally a processing step in measuring the environmental parameters and convert it into a human-readable information. There are many on-going types of research and projects that transforming the sensors data into a variety of IoT-based services. In this project, many kinds of the scheme have been proposed for the development of an IoT environmental monitoring. It has several considerations such as scalability, flexibility, power consumption and cost to utilize the project feature and its specification.

The conventional approach to the environmental monitoring is using the fixed roadside sensors placed at several areas to form a bigger coverage of air quality distribution in a city. In this proposed solution, it has a high accuracy of measuring gases levels and able to provide a clear air quality report through the Wireless Sensor Network. Nevertheless, this has some limitations due to several constraints. By using this proposed solution, it will have the limited coverage because of the installation fee. It will be costly to scale up the design to monitor a whole city. Also, it has an appreciate cost for maintenance of the sensors, as it requires to dispatch a professional technician to certain spots to maintain the quality of the system at regular intervals. Therefore, the limited monitoring coverage has restricted the accuracy of the overall monitoring in the urban area.

On the other hand, a deployed environmental sensors installed in the transportation such as private cars, taxis or public buses to collect physical environmental data has more advantages compared with the static sensors system [13]. Firstly, this kind of schema can be used to collect the environmental data over a bigger region. As it tends to be a more economical way to implement and maintain. Secondly, the sensors not only mounted on the vehicle but it also covered by the vehicles to protect its hardware part and leads to a long-lasting cycle life of the devices. Thirdly, it has the most critical characteristics which are the flexibility and scalability in designing such multi-purpose service infrastructures. In addition, the maintenance of the sensors device can be reduced as it can be carried out in a rendezvous place such as a bus station. There is no need to send the technicians into different fixed sensors sites. Also, if an appropriate routing is planned wisely, a detailed map of the air quality of the city can be visualized clearly. This chapter has presented several design schemes that used in environmental sensing for Smart City. On top of that, the optimum design scheme to be used in environmental sensing remains unrevealed. Nevertheless, the implementation of mobile sensors in the transportation has many priorities and the least drawbacks to access the environmental parameters compared with the fixed sensors scheme. Therefore, a more reasonable scheme of mobile sensor embedded in transportation that is capable of determining the traffic and air quality condition to be used for Smart City with environmental sensing in using an optimum design scheme is required.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter presents a study aimed at investigating the requirements, design, and implementation of mobile environmental sensing on public transport. The research is done in six sections. In section 3.2, a proposed workflow is briefed below. The process of requirement analysis and hardware selection are discussed in sections 3.3 and 3.4. In section 3.5, the development of information acquisition module is explained. In section 3.6, the development of real-time sensing data module is explained in detail. In section 3.7, the development of data storage module is presented. Lastly, the prototype building and testing methods are explained in section 3.8.

3.2 Proposed Work Flow

The overall system is composed of three sub-modules which are information acquisition module, real-time sensing data module, and data management module. Figure 3.1 shows the flow of the overall methodology of this study. At the beginning of this study, the requirements for the proposed scheme must be considered first. Then, the circuit design and system design are carried out after the requirement analysis. In the information acquisition module, it is to develop a subsystem that is to collect the environment parameters from the environment sensors and interfaced by the single-board computer. In the real-time sensing data module, it is to develop a subsystem that is to update the environment parameters to a database consistently by using a programming language. In the data storage module, it is to develop a subsystem that is to store the