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COLLEGE OF SCIENCE AND TECHNOLOGY

AFRICAN CENTER OF EXCELLENCE IN INTERNET OF THINGS

IoT Based Air Quality Monitoring in Public Buses

Case study: Kigali City - Rwanda

A dissertation submitted in partial fulfilment of the requirements for the award of masters of science degree in internet of things -Wireless Intelligent sensor Network

Submitted by:

Name: Joas HAKIZIMANA (Ref:221000192)

OCTOBER, 2023



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DECLARATION

I Joas HAKIZIMANA, Master's student from African Center of Excellence in internet of things, at University of Rwanda. I declare that this research thesis is my own original work and it has never been presented before anywhere in the world.

Joas HAKIZIMANA

Ref: 222100192

Signed:

Date:/...../.....

BONAFIDE CERTIFICATE

This is to certify that the project work entitled **IoT Based Air Quality Monitoring in Public Buses** is a record of the original Work done by **Joas HAKIZIMANA** registration number is 221000192. It is in partial fulfilment of the requirement for the award of MSc with honours in Wireless Intelligent Sensor Network (WISENET) at the Africa Centre of Excellence in Internet of Things (ACEIoT) College of Science And Technology at University of Rwanda during academic year 2020-2022

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ABSTRACT

Ambient indoor air quality is crucial to human well-being, especially in densely populated areas. In developing countries such as Rwanda, which heavily rely on public transportation, mainly buses for affordability and accessibility, the increasing demand for buses often leads to overcrowding, resulting in poor air quality within these vehicles. This can cause respiratory problems among passengers. This research focuses on creating an Internet of Things (IoT)-based air quality monitoring system for public buses, the system uses environmental sensors and cost-effective micro-controllers to collect real-time data, which are then sent to an open source IoT cloud platform for analysis and secure storage. Various sensors measure key air quality parameters such as PM2.5, CO₂, CO, temperature, and humidity. Data transmission to a web server is facilitated by GSM technology, allowing for seamless data storage and in-depth analysis to support decision making. The study proposes a prototype that presents a custom dashboard for the real-time display of air quality data.

Keywords: *Internet of Things, Air Quality Monitoring, Cellular Sensor Nodes, ATmega328P, PM 2.5 Sensor*

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LIST OF ABBREVIATIONS

WHO: World Health Organisation

VOC: Volatile Organic Compound

IDE: Integrated Development Environment

SDGs: Sustainable Development Goals

Ppm: Particle per million

EPA: Environment Protection Agency

CO: Carbon monoxide

CO₂: Carbon dioxide

NO₂: Nitrogen dioxide

DHT11: Digital Temperature and Humidity Sensor

GSM: Global System for Mobile Communication

PM: Particulate Matters

WSN: Wireless Sensor Network

AQI: Air Quality Index

ARIMA: Auto-Regressive Integrated Moving Average

AWS: Amazon Web Service

GPS: Global Positioning System

KBS: Kigali Bus Services

RURA: Rwanda Utilities Regulatory Authority

ML: Machine Learning

IoT: Internet of Things

MQTT: Message Queuing Telemetry Transport

TTN: The thing network

IAQ: Indoor Air Quality

REMA: Rwanda Environment Management Authority

SPDT: Single Pole Double Throw

AVR: Advanced Virtual RISC

CHAPTER I: INTRODUCTION

1.1 Background

According to [1], air pollution is the presence of gases in the air that are dangerous to the health of humans and other living beings. Various air pollutants such as gases, particles and biological molecules. The air pollutant gases are nitrogen dioxide (NO₂), carbon monoxide (CO), ozone (O₃) and sulfur dioxide (SO₂) [2]. Among particles, PM_{2.5} and PM₁₀ refer to atmospheric particles that can cause many respiratory diseases such as asthma [2].

Air pollution poses a threat to public health and causes many diseases, including stroke, heart disease, lung cancer, chronic obstructive pulmonary disease and respiratory infections, as well as temporary ailments such as sneezing and coughing, eye irritation, headaches and dizziness [1]. According to the WHO press report in 2014 [8], poor air quality is considered the world's greatest environmental health risk. About 87% of global deaths occur in low- and middle-income countries, with over three million premature deaths attributed to poor air quality. Of the three million premature deaths, 211,000 (or 7%) occurred in sub-Saharan Africa. Rwanda has joined the rest of the world in celebrating the first International Clean Air Day for Blue Skies. The day calls on all of us, from governments and the private sector to civil society and individuals, to reduce air pollution and transform the way we live, work, move and power our economies [3].

Rwanda recognizes that air pollution poses a serious threat to our health and our environment in both urban and rural areas of the country. The World Health Organization estimates that the combined effects of outdoor and household air pollution result in approximately seven million premature deaths each year, largely due to increased mortality from stroke, heart disease, lung disease, lung cancer and acute respiratory infections [3].

The impact of the Air pollution can also be felt in Rwanda. In 2012, more than 2,200 deaths were attributed to air pollution. Between 2012 and 2015, hospitalizations for acute respiratory infections in health centres across the country nearly doubled to more than 3.3 million.

Figure 1 shows the number of deaths caused by particulate matter compared to other diseases in Rwanda

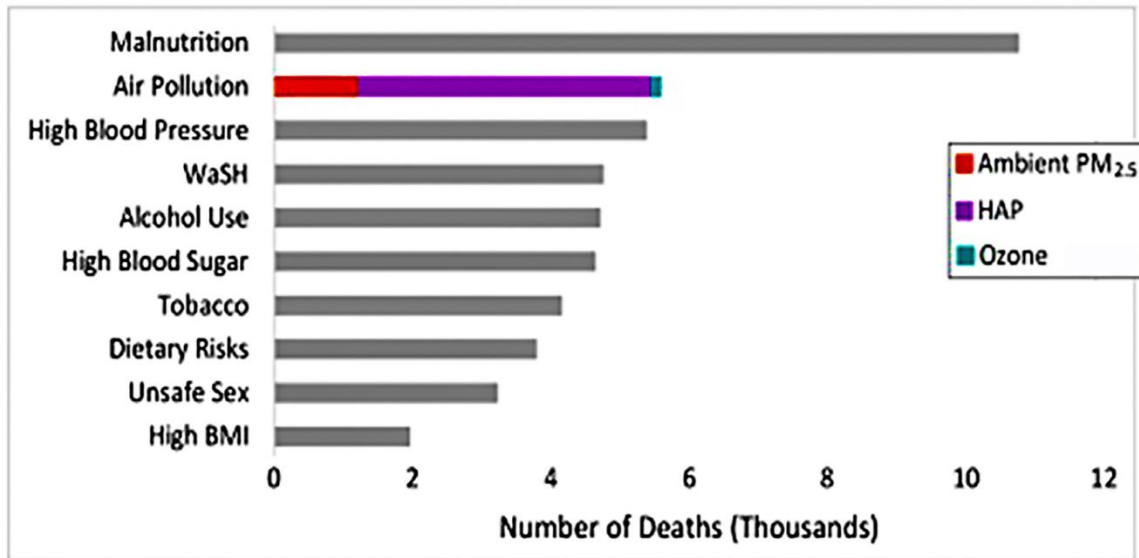


Figure 1: Deaths caused by Particulate Matter (PM_{2.5}) in 2017

Source: REMA, "Rwanda Compendium of Environment Rwanda Environment Statistics Compendium," no. February, 2019.

Indoor air pollution may arise from a wide range of origins, such as the combustion of fuel, household cleaning agents, excessive moisture, and insufficient ventilation. The lack of outdoor air circulation to dilute the emissions from indoor sources can lead to an increase in indoor pollutant levels. This could potentially exacerbate existing conditions, cause irritation, and, in severe cases, result in significant harm [4]. The monitoring of air quality necessitates the assessment of various pollutants, including carbon monoxide (CO), sulphur dioxide (SO₂), nitrogen dioxide (NO₂), ozone (O₃), and volatile organic compounds (VOCs) [3].

It is frequently challenging for individuals tasked with overseeing air conditioning systems and managing the airflow within buildings to acquire real-time data on indoor air quality (IAQ). Consequently, they often rely on excessive ventilation in order to ensure that pollutant levels within their buildings remain at safe levels. The air quality within enclosed spaces that are inhabited by humans is not always pristine, primarily due to reduced oxygen levels and heightened concentrations of CO₂. Additionally, increased indoor temperatures and humidity levels can adversely impact human well-being, particularly in instances of inadequate ventilation or the influx of outdoor air. An effective means of monitoring these conditions involves the utilisation of Internet of Things (IoT) technology, which allows for the continuous evaluation of IAQ. In the event that suboptimal conditions are detected, the relevant authorities can take appropriate measures to rectify the situation.

Figure 2 shows the World Health Organisation (WHO) report in 2016, showing how household air pollution significantly contributes to mortality rates worldwide, where the highest number is in Africa and Southeast Asia.

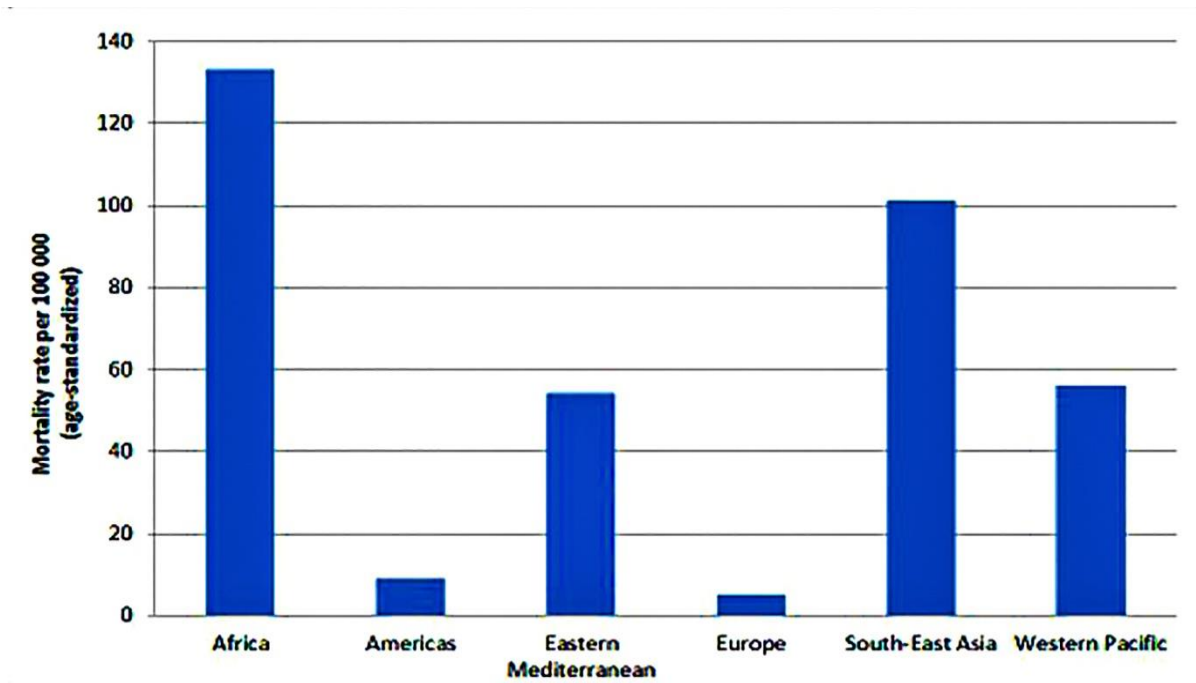


Figure 2: Mortality rate as a result of household air quality (WHO 2016)

Source: WHO (2016). Ambient Air Pollution: A global assessment of exposure and burden of disease

In 2016, the World Health Organisation (WHO) projected that household air pollution was accountable for the loss of lives of approximately 3.8 million individuals worldwide on an annual basis. The primary cause of this mortality is the inhalation of minute particulate matter (PM_{2.5}) and the contact with other contaminants released from domestic origins, such as the combustion of solid fuels employed for cooking and heating purposes.

Household air pollution has a significant impact on individuals, particularly those residing in low and middle-income nations, where traditional methods of cooking and heating are prevalent. The combustion of solid fuels, such as wood, coal, or biomass, in open fires or rudimentary stoves, emits substantial quantities of contaminants into the indoor environment. These contaminants encompass PM_{2.5}, carbon monoxide (CO), nitrogen dioxide (NO₂), sulphur dioxide (SO₂), and volatile organic compounds (VOCs).

Exposure to aforementioned pollutants can give rise to diverse health complications, including respiratory infections, chronic obstructive pulmonary disease (COPD), lung cancer, and cardiovascular disease. Women and children are particularly susceptible to these health risks owing to their long exposure during domestic undertakings.

To reduce the fatality rate instigated by indoor air pollution, it is imperative to confront the fundamental factors and execute efficacious interventions.

This encompasses the promotion of the utilisation of more environmentally friendly and efficacious methodologies for cooking and heating, such as enhanced cook stoves and less polluting fuels. The availability of electricity and the accessibility of clean energy sources can also yield a notable decrease in reliance upon solid fuels.

Also, it is imperative to engage in public awareness and education initiatives, and behaviour change programs in order to impart knowledge to individuals regarding the health risks associated with household air pollution and to encourage the adoption of healthier practices. Collaborative efforts involving governmental bodies, non-governmental organisations, and international entities are indispensable for the enforcement of policies, provision of financial backing, and ensuring the widespread acceptance of clean cooking and heating alternatives.

By addressing the issue of household air pollution and enhancing the quality of indoor air, it is feasible to reduce the mortality rate and enhance the overall health and well-being of people, particularly in regions deeply impacted by these concerns.

Numerous interconnected studies have suggested ways to control air pollution, and likewise, systems have been implemented primarily in India and developed countries. In all research endeavours, the modern technology of the Internet of Things is employed in conjunction with other cloud-based applications. At present, the majority of organizations and government institutions responsible for the environment concentrate on monitoring air pollution stemming from human activities, emissions of gases from industrial centres, and vehicles. Rwanda possesses a policy framework that governs air pollution originating from various factors and also adopts the World Health Organization's policy on air quality. [4].

There exist various methodologies for the monitoring of air quality that have enhanced the manner in which air pollution is monitored. Furthermore, diverse individuals utilize research data to discern the discrepancy and gain knowledge regarding the environmental conditions of different regions in relation to air quality.

Prior approaches have encompassed a range of aspects pertaining to the management of air pollution. However, these approaches have been restricted to the monitoring of air quality in both outdoor and indoor settings. Considering the occurrence of various pandemics, it

becomes crucial to monitor air quality in public transportation in order to effectively control the dissemination of diseases through the utilization of acquired data.

The distinction lies in that air quality within public transportation, wherein individuals are confined in this particular environment for a brief duration, ranging from a few minutes to several hours, contingent upon the distance to their intended destination. Consequently, the current methodology is rendered unsuitable for this particular scenario.

To tackle this issue, a proposed Internet of Things (IoT)-based air quality monitoring system has been put forth. This system aims to address the aforementioned problem by employing sensors installed in buses that gather air quality data. The data is subsequently transmitted to the cloud for analysis and prompt action. Additionally, this system will also emit alert signals to ensure proper ventilation.

The data can be employed by the relevant authorities in order to formulate forthcoming decisions for the purpose of enhancing the present predicament that has been identified. Consequently, the outcomes will yield a more profound comprehension pertaining to the air quality within the realm of public transportation.

This investigation will furnish foundational knowledge regarding the air quality, inclusive of statistical data, a concise depiction of the relevant research, the employed methodology, an evaluation of the system, as well as its design, the collection and analysis of the data, the validation and testing of the system, the ultimate conclusion, and suggestions for future undertakings.

1.2 Problem Statement

This study aims to address the challenges of implementing IoT-based air quality monitoring in public buses, including the lack of real-time data, technical implementation obstacles, ensuring data accuracy, and making air quality information accessible to passengers and authorities."

Public buses can be considered enclosed spaces wherein the air quality can be compromised due to the presence of various pollutants. These pollutants may include particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NO₂), sulphur dioxide (SO₂), volatile

organic compounds (VOCs), and other harmful gases. Prolonged exposure to these pollutants can cause respiratory problems, allergies, and other adverse health effects.

In the majority of developing countries, such as Rwanda, the primary mode of transportation for low-income individuals, including students, is public transport, particularly buses, within cities or urban areas and even between provinces. During peak periods (morning and evening), a significant number of these buses exceed their intended passenger capacity, leading to overcrowding. Those who are unable to secure a seat are accustomed to standing in very close proximity to one another until they reach their destination.

Aside from a few instances of ventilation in these buses, the overcrowding conditions present challenges for passengers in terms of respiration, primarily attributable to the fluctuating air quality that occurs as the buses travel and accommodate more passengers. The absence of reliable air quality and thermal comfort monitoring systems further compounds the issue, making it arduous for passengers, drivers, and traffic officials to ascertain the air quality within a vehicle and effectively manage the number of passengers at any given time.

This results in a range of respiratory illnesses, such as asthma, coronary heart disease, and tuberculosis. Additionally, individuals may experience temporary symptoms such as headache, cough, heart attack, and difficulty breathing due to unfavourable thermal comfort conditions.

Numerous scholars, including those identified as [1][2][3][7][8], have endeavoured to tackle the matter of monitoring indoor air quality. However, their studies do not encompass settings such as public areas that involve mobility, particularly buses. Moreover, the majority of existing solutions fail to prioritize the prediction of air quality as the number of passengers increases. Additionally, these solutions do not offer any information to drivers regarding the state of air quality prior to embarking on a trip or long journey.

The air quality within public buses is continuously monitored in real-time by the system. It collects data on various contaminants, including particulate matter, carbon dioxide, and detrimental gases. This provides accurate and up-to-date information regarding the conditions of air quality.

By means of monitoring the air quality in public buses, the system aids in safeguarding the well-being of passengers and operators with the bus. It facilitates the early detection of

elevated pollution levels and activates alerts or notifications when the air quality surpasses acceptable thresholds. This empowers individuals to undertake necessary precautions, such as wearing masks or adjusting ventilation, in order to reduce exposure to pollutants.

Integrating IoT-based air quality monitoring systems in buses aligns with Rwanda's vision of developing smart cities. The implementation signifies the government's commitment to using technology and data-driven solutions to improve the quality of life of its citizens. The act of monitoring air quality within public buses not only aids in bolstering the overall sustainability and accountability of cities, but also fosters a cleaner and healthier environment for residents.

The proposed system has the potential to contribute to the attainment of the Sustainable Development Goals (SDG) [9]:

(i) Goal 3, which focuses on promoting good health and well-being. This is because diseases related to air quality pose a significant threat to human health. By mitigating the risks associated with air quality, the proposed system can help improve overall well-being.

(ii) Goal 11, which aims to foster sustainable cities and communities. The proposed system can aid in monitoring the pollution of environmental gases that have detrimental effects on human health. This monitoring capability can contribute to the creation of healthier and more sustainable urban environments.

(iii) Goal 13, climate change, as the proposed system will help identify air quality gases that have adverse impacts on the climate and precipitation patterns. By detecting and addressing these harmful gases, the proposed system can play a role in combating climate change and its associated challenges.

1.3 Objectives

The general objective of this research is to develop an IoT-based air quality monitoring system to control air quality in public buses.

Specific objectives are as follow:

- a) Real-time monitoring of air quality to enable early detection of elevated levels of pollutants that may pose a health risk to passengers and drivers.

Addressing these issues quickly by introducing measures such as improving ventilation systems or introducing alternative routes in heavily polluted areas can ensure the health and safety of people travelling on public buses.

- b) To design a system for monitoring air quality, which will involve the assembly of the necessary hardware and its configuration using the Arduino IDE.
- c) To create a prototype of an IoT device that can collect data and transmit it to the cloud.

1.4 Research Questions

- a) How can IoT-based air quality monitoring systems be effectively implemented in public buses to collect real-time data on pollutants such as PM2.5, CO2, and harmful gases?
- b) What are the key factors that influence air quality inside public buses, and how do these factors vary between different routes and times of day?
- c) What is the effectiveness of IoT-based air quality monitoring in public buses in improving public health outcomes and reducing the exposure of passengers and drivers to harmful pollutants?

1.5 Significance of the study

The city of Kigali, like many urban areas, confronts challenges pertaining to air pollution arising from factors such as the discharge of emissions from vehicles, industrial activities, and the progression of urban development. The focus of this research lies in the monitoring of air quality within public buses, which serve as a significant mode of transportation within the city. By providing an IoT-based monitoring system, this study contributes to the identification and mitigation of the incoming air pollution within a crucial mode of transportation.

The developed system will facilitate passengers and bus operators to adopt precautionary measures by ensuring adequate ventilation and employing protective equipment.

The outcomes of the study can be employed by pertinent authorities to implement safety measures or regulations aimed at improving air quality.

1.6 Organisation of the study

Chapter One: Introduction This is an introductory chapter. It describes the background of the study, the problem statement, the objectives of the study, the scope of the study, the significance of the study and the organisation of the study.

Chapter Two: The review of the literature. This chapter clarifies the work done by the other researchers on IoT-based air quality monitoring in public buses.

Chapter Three: The research methodology, This chapter clearly shows the methodology followed to address the identified problems.

Chapter Four: The configuration and deployment: This chapter shows the prototype, corresponding to the data dashboard, serial monitor, plotter monitor, and how the connectivity is done.

Chapter Five: Results and Discussion This chapter shows the results of the prototype.

Chapter Six: Conclusion and recommendation This chapter gives the conclusion of the study and recommendations for future researchers.

1.7 Scope of the Study

The study on IoT-based air quality monitoring in public buses in Kigali city, involves the implementation of IoT-based air quality monitoring systems in public buses. The aim of the study is to collect real-time data on air quality such as PM2.5, CO2, humidity, temperature and harmful gases in buses. Data collected will be subjected to analysis in order to evaluate the levels of air quality, identify pollution hotspots, and comprehend the various factors that influence air quality. Furthermore, this investigation will assess the effectiveness of the IoT-based monitoring system in enhancing public health outcomes and facilitating decision-making processes for the management of air quality in the city of Kigali.

1.8 Motivation of the study

The motivation for conducting a study on IoT-based air quality monitoring in public buses can be derived from several factors. Here are some potential motivations for such a study:

- **Health and well-being:** Poor air quality can have detrimental effects on the health and well-being of people, especially those who spend a lot of time in enclosed spaces such as public buses. Monitoring air quality in buses allows for a better understanding of the pollutants present and their potential impact on the health of passengers and drivers.
- **Occupational Safety:** Bus drivers spend a considerable amount of time operating vehicles, often exposed to pollutants related to traffic.
- Monitoring air quality in buses can help identify occupational safety concerns for drivers and provide insight into improving their working conditions.
- **Passenger Comfort:** Air quality directly affects passenger comfort and satisfaction. Monitoring and maintaining good air quality in buses can improve the overall passenger experience, making public transport more attractive and encouraging its use.
- **Data-Driven Decision Making:** IoT-based air quality monitoring in public buses provides real-time data on pollutant levels, which can be used for data-driven decision making. The insights gained from the collected data can inform policy changes, route optimisation, maintenance strategies, and the implementation of targeted interventions to improve air quality.

In general, the motivation for conducting a study on IoT-based air quality monitoring in public buses revolves around the goal of improving public health, reducing environmental impact, ensuring occupational safety, complying with regulations, improving passenger comfort, and making informed decisions to optimise public transportation systems.

CHAPTER II: LITERATURE REVIEW

There exist numerous studies pertaining to the monitoring of air quality, and various air quality monitoring systems have been developed. In this section, the focus will be on reviewing those works that are most closely aligned with my own research.

Saha et al. [34] put forth a real-time system for monitoring air quality that utilizes sensor nodes, sink nodes, and a cloud storage infrastructure. Sensor nodes are specifically designed to gather, process, and consolidate the air quality index data. These sensor nodes are installed on public transportation buses to collect data as they traverse through different regions within the city.

Once the data is collected by the sensor nodes, it undergoes processing and aggregation. When a bus approaches a sink node, the sensor node proceeds to transmit the accumulated data to the sink node. The sink nodes are strategically positioned at road intersections, enabling them to not only acquire, process, and aggregate data from the sensor nodes but also from other sink nodes in close proximity. Consequently, this facilitates the establishment of a mesh network that utilizes a long-range radio frequency band for communication between the sink nodes.

By utilizing the nodes within the mesh network, the sink node effectively transmits the acquired data to a central collection point. Subsequently, the data is uploaded to cloud storage to undergo further processing and analysis. One notable advantage of this system lies in its expansive coverage of the city, as the sensor nodes are strategically deployed on buses throughout the urban landscape.

Huang Kuo-Kun and colleagues [35] present an innovative and portable air pollution monitoring system that leverages Internet of Things (IoT) technology to deliver precise and timely information regarding air quality. The authors expound upon the system's conception and execution, which encompasses the integration of diverse sensors for pollutant measurement, wireless data transmission, and a web-based user interface for data visualization.

The authors engage in a comprehensive analysis of the selection and amalgamation of sensors for the measurement of prevalent air pollutants, including carbon monoxide (CO), sulphur dioxide (SO₂), nitrogen dioxide (NO₂), and particulate matter (PM).

They underscore the significance of sensor calibration in order to secure accurate measurements while addressing the obstacles entailed in sensor selection and calibration.

The system based on the Internet of Things (IoT) facilitates the transmission of data in real-time from sensors to a central server, where the data is processed and analyzed. The authors involve the utilization of wireless communication technologies, such as Wi-Fi and GPRS, to ensure uninterrupted data transmission even in mobile environments.

A user interface, accessed through the web, has been developed to visualize data on air quality. This interface allows users to remotely access the data in real-time. The graphical representations provided by the interface enable users to easily interpret and analyse the levels of air pollutants.

The authors highlight the portability of the system, making it suitable for various applications including urban air quality monitoring, personal exposure assessment, and environmental research. They discuss the benefits of using portable devices that can be deployed in different locations to complete air quality monitoring.

The real-time system, developed by Sun et al. [36], has the primary objective of monitoring air quality. This system is composed of sensor nodes, mobile nodes, gateway nodes, and a monitoring centre.

The sensor nodes, which are immobile, are situated in fixed locations and are equipped with several sensors, including the DSM501A sensor for PM2.5 measurement, the MQ-131 sensor for ozone measurement, the MG811 sensor for CO2 measurement, and the DHT11 sensor for temperature and humidity measurement.

These nodes acquire air pollution data by utilizing sensors. The mobile nodes possess an embedded gateway node as well as a GPS module. They traverse along a designated and specific route that connects the sensor nodes. Upon reaching the position of a particular sensor node, a mobile node collects the data from said sensor node and transmits it directly to the monitoring centre.

The gateway nodes receive data from the sensor nodes through the utilization of Zigbee modules, which function as the medium of communication or communication protocol

between the sensor and the gateway nodes. In addition, each gateway node is equipped with a GSM module to transmit the accumulated data to the central monitoring facility. Furthermore, the gateway nodes are powered by batteries and possess solar power modules to recharge their energy storage.

The central monitoring facility acts as the central hub for the reception, storage, and retrieval of data. It acquires data from the gateway nodes, archives them for subsequent analysis, and provides the means to access the compiled air quality information.

Sensor nodes measure various air pollutants, while mobile nodes help calibrate the readings by collecting data directly from the sensor nodes at the point of convergence. The gateway nodes play a crucial role in facilitating effective communication between the sensor nodes and the central monitoring unit, thereby ensuring the seamless transmission of data in real-time.

To enable local communication, the system employs Zigbee modules, while remote data transmission is achieved through the utilization of GSM modules. Furthermore, the system incorporates GPS modules to accurately track the movements of the mobile nodes. In addition, the integration of solar power modules into the gateway nodes significantly enhances the energy efficiency of the overall system.

Shirai et al. [37] implemented an air quality monitoring system by installing sensors and gateways in garbage trucks. Each vehicle was equipped with a gateway and a variety of sensors, including GP2Y1010AU0F for dust measurement, DN7C3JA001 for PM2.5 measurement, PS2 for pollen measurement, SHT71 for temperature and humidity measurement, G5842 for UV measurement, BH171FVC for luminance measurement, TGS2602 for CO measurement, MICS-2614 for O3 measurement, MICS-2714 for NO2 measurement and a GPS receiver for location information. The collected data was transmitted to the gateway, which then sent it to a remote server via cellular networks.

The system consisted of two software components: a control centre and a mobile application. Both the Control Centre and the mobile application communicated with the remote server and presented the collected data in graphical form. The mobile application allowed citizens to assess the air quality in their specific location, while the system operator used the Control Centre to present data and control sensor nodes. The system operator had the ability to remotely update the sensor node programme to make adjustments such as changing the

sampling rate of a sensor. This was achieved by uploading a new programme to the server, from which the gateways received and deployed the updated programme to the sensor nodes.

2.1. Related work

Air pollution remains a significant global issue, necessitating inventive and innovative approaches for monitoring and managing its detrimental impact on public health and the environment. The integration of Internet of Things (IoT) technology has emerged as a feasible solution to combat air quality challenges in recent years. This section provides an in-depth review of the existing literature in the field of IoT-based air quality monitoring, with particular attention given to its implementation in public bus systems.

This study Iot-Based Air Quality Monitoring in Public Buses is an extension of a study done by ABDULRAHMAN Halima Mohamed in 2021[38].

Iot-Based Air Quality Monitoring in Public Buses, serves as an expansion of a previous study conducted by ABDULRAHMAN Halima Mohamed [38], which explored the subject of "Iot-Based Air Quality Monitoring System in Public Transport."

Halima [38], conducted a study in 2021 that effectively demonstrated the efficacy of an Internet of Things (IoT)-based air quality monitoring system that was implemented on public buses within the city of Kigali. The research findings unveiled notable fluctuations in pollutant concentrations across diverse bus routes and time periods throughout the day. Only three sensors, namely DHT11, MQ135, and MQ7, were utilized to monitor the air quality within the buses. However, the collection of data within the bus environment encountered a significant obstacle due to the outbreak of the Covid-19 pandemic, of which responsive measures imposed the mandatory wearing of masks and the implementation of reduced capacity on public buses. Consequently, this position rendered the acquisition of reliable results problematic. Consequently, Halima recommended that the study be repeated once normal conditions are restored [38].

2.2. Gaps

The absence of a PM_{2.5} sensor in Project 1 can be regarded as a deficiency when compared to Project 2. The inclusion of a PM_{2.5} sensor in Project 2 is a significant improvement that

allows for the measurement of fine particulate matter, which carries considerable implications for human health.

The lack of the ability to display results on a LCD screen in Project 1, can also be seen as another gap in its implementation. In Project 2, the system is equipped with the capability to transmit warning messages to the driver through SMS, which represents a proactive approach to alerting drivers about potential air quality issues. This particular feature enhances the usability of the system and ensures that prompt action can be taken to address any concerns regarding air quality levels.

In order to enhance the efficiency of air quality monitoring in public buses that utilize Internet of Things (IoT) technology and overcome the limitations of existing solutions, several technologies employed in this study have been implemented. Sophisticated sensors for monitoring air quality have been deployed to furnish accurate and real-time measurements of diverse pollutants, including the sensor for particulate matter (PM_{2.5}).

Additionally, an automated system has been devised to notify drivers or decision-makers through the transmission of SMS messages directly to their mobile devices.

2.3. Air Quality Case Statistics in Rwanda

According to the press report published by the World Health Organisation (WHO) in 2014, the world's largest environmental health risk is considered to be poor air quality. It is observed that approximately 87% of global deaths are reported in low- and middle-income countries, with over three million untimely deaths attributable to the adverse air quality. Out of these three million premature deaths, a total of 211,000, accounting for 7%, were documented to have occurred specifically in Sub-Saharan Africa.

As documented by the WHO in their 2016 report [5], the country of Rwanda experienced a total of 2227 deaths as a result of air pollution. Acute respiratory issues and stroke were identified as the leading causes behind these fatalities.

Figure 3. Shows the impact of air quality mortality in Rwanda, according to the WHO report [5], 940 died from stroke, 738 respiratory diseases, 496 died from heart diseases, 34 chronic obstructive pulmonary diseases and 19 died by lung cancer.

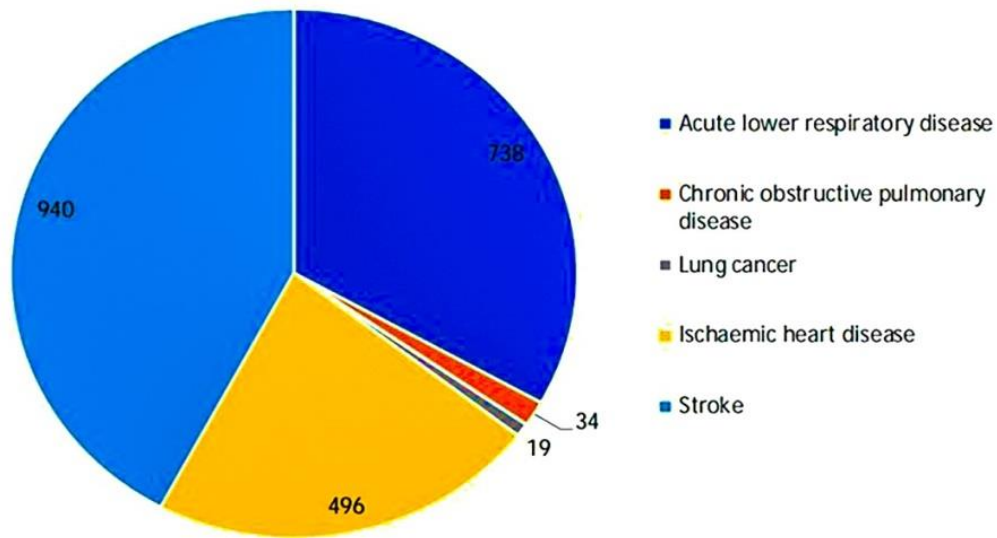


Figure 3: Impact of Air Quality on Mortality in Rwanda

Source: REMA, "Determination of Future Trends and Development of a National Air Quality Control Strategy," no. January, p. 176, 2018

The development of air quality policies and guidelines will benefit the Rwandan health sector to reduce premature deaths. Regulations on vehicle gas emissions and air pollution limit standards implemented by REMA may improve air quality [18].

The key pollutants that concern Rwanda are:

- Nitrogen oxides (including oxides of nitrogen (NO_x) and nitrogen dioxide (NO₂))
- Sulphur dioxide (SO₂)
- Particulate matter (PM₁₀) and 2.5 microns (PM_{2.5})
- Ozone (O₃)
- Carbon monoxide (CO)

According to the REMA report [19] on the inventory of sources of air pollution, no specific sector emerges as the primary contributor to air pollution in Rwanda. This is due to the fact that air pollution levels are contingent upon various sources of pollution, such as proximity to roads and the emissions produced by vehicles. It is worth highlighting that vehicle emissions constitute the largest contributor to the decline in air quality. Additionally, domestic cooking stoves also play a pivotal role in polluting residential areas. While emissions from industrial

centres or power plants remain at elevated levels, their impact is relatively minor, as these facilities are situated in sparsely populated residential regions.

The composition of the air we breathe encompasses a diverse range of gases and other particles. The quality of the air is determined by the concentration of pollutants, including sulphur and carbon oxides. In order to inform residents, government agencies and environmentalists utilize the air quality index (AQI) as a means of ascertaining whether the air is contaminated or not.

Countries have different ways of calculating AQI; for example, the United States uses four pollutants (ozone, particulate matter, sulphur dioxide and carbon monoxide) to calculate air quality with an index scale of 0 to 500 [20].

CHAPTER III: METHODOLOGY

In this study, our focus is on the gathering of data pertaining to the monitoring of air quality in public buses, utilizing the Internet of Things (IoT) framework. The research design employed a quantitative methodology, relying exclusively on sensor data to gauge key air pollutants. Meticulous selection and deployment of sensors such as PM2.5, DHT11, MQ135, and GSM were carried out within the buses to continuously evaluate air quality parameters. The collected data were instantaneously transmitted to Thingspeak, a central cloud-based platform that facilitates the ongoing monitoring and storage of air quality data. Consistent calibration and validation of the sensors were undertaken to ensure the accuracy and dependability of the data. Ethical considerations were adhered to, guaranteeing the privacy and confidentiality of the participants. The methodology duly acknowledges limitations, including potential external factors that may impact air quality measurements. By implementing this approach to data collection and utilizing the capabilities of Thingspeak, the primary objective of the study is to contribute to the comprehension of air pollution levels in public buses, thereby paving the way for future interventions aimed at enhancing air quality and the commuting experience.

MQ135 is an air quality sensor used to detect carbon dioxide, DHT11 sensor for detecting temperature and humidity, gas sensors are connected to the arduino through a micro controller chip, ATmega328p has only one analogue pin, and other digital sensors such as DHT11, are connected directly. The data collected are sent to the ThinkSpeak IO cloud through a GSM module. The ThinkSpeak platform analyses and visualises processed data in the dashboard and also stores the data in the cloud.

Figure 4 illustrates a simplified diagram of the proposed system. The central control node of our system is the ATmega328P micro controller. Various sensors are used to detect different environmental parameters, including particulate matter, carbon monoxide, carbon dioxide, temperature, and humidity. Sensed data are continuously transmitted from the GSM to the cloud over the Internet due to its reliable network connectivity.

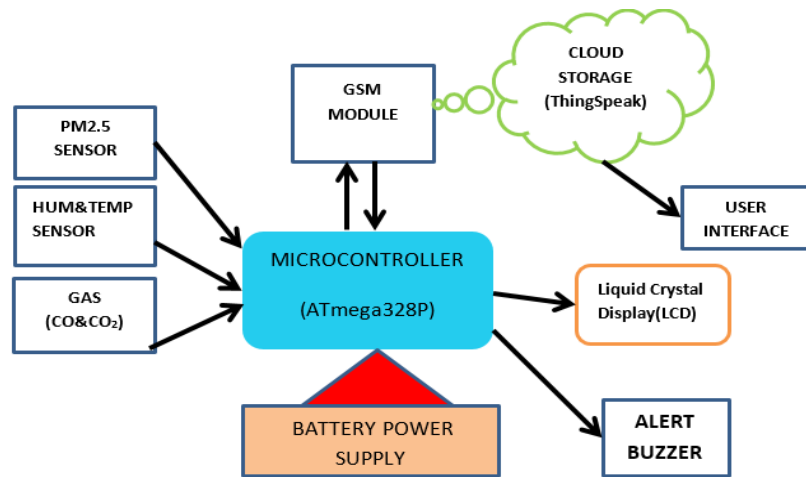


Figure 4: High-level sensing block diagram

3.1 Sensing Layer

The sensing unit consists of 3 sensors: MQ135, PM2.5, and DHT11

3.1.1 MQ135

The MQ-135 is a gas sensor used for air quality control and is suitable for detecting NH₃, NO_x, alcohol, benzene, smoke, CO₂, etc. The sensitive material of the MQ-135 gas sensor, which has a lower conductivity in clean air. When the target combustible gas exists, the sensor conductivity increases along with the gas concentration increasing.

Using a simple electric circuit, convert the change in conductivity to correspond to the output signal of the gas concentration [21]. The MQ135 gas sensor has high sensitivity to ammonia, sulphur, and benzene steam, and is also sensitive to smoke and other harmful gases. It is low cost and is suitable for different applications.

These gas sensors have 4 pins: VCC, GND, DO (Digital Output) and AO (Analogue Output) [22]. The MQ135 analogue output is between 0-5V, while the ATmega328P analogue pin can only read between 0 and 3.3V. Therefore, a voltage reduction is needed. In this project, a voltage divider with two resistors is used.

Figure 5 shows the MQ135 gas sensor widely used to detect and measure various air pollutants. It is commonly used in applications related to air quality monitoring, indoor air pollution detection, and environmental monitoring.



Figure 5: MQ135 gas sensor

3.1.2 Particulate Matter Sensor (PM2.5)

The figure below shows PM2.5 sensors designed to measure the concentration of particulate matter that is 2.5 micrometres or smaller in diameter in the air. These sensors are typically used in air quality monitors to provide real-time data on the level of PM2.5 particles in the air.



Figure 6: PM2.5 Sensor

The functionality of a PM2.5 sensor is based on the principle of light scattering. When light passes through a sample of air containing particles, some of the light is scattered by the particles. The amount of light that is scattered is proportional to the number and size of particles in the air. PM2.5 sensors use this principle to measure the concentration of PM2.5 particles in the air.

The sensor typically consists of a light source that shines a beam of light onto a sample of air and a detector that measures the amount of light scattered by the particles in the air.

The sensor may also include a fan or pump to draw air through the sensor and a filter to remove larger particles that could interfere with PM2.5 particle measurement.

PM2.5 sensors can be designed using a variety of technologies, including optical, electrochemical, and gravimetric methods. Optical sensors are the most common and use a light source and a detector to measure the amount of light scattered by particles in the air. Electrochemical sensors use a chemical reaction to detect the presence of PM2.5 particles, while gravimetric sensors use a filter to collect particles from the air, which can then be weighed to determine the concentration of PM2.5 particles.

Only an electron microscope can spot PM2.5 particles because they are so tiny, measuring 5 microns in diameter or less. Dust, soot, dirt, smoke, and liquid droplets are examples of particles known as particulate matter (PM) that are present in the air.

PM2.5 is a particulate matter that is one of the most dangerous pollutants to the human body. As a result of their small size, the particles can penetrate deep into the lungs. Over a longer period of time, they can cause lung diseases such as bronchitis or asthma and even contribute to cardiovascular disease [8].

The PM 2.5 sensor detects and counts particles by means of light scattering: when air flows through the detection chamber, particles pass a laser beam, which is scattered on the particles. The scattered light is received by a diode and converted into an electrical signal that is used to calculate the particle concentration [8]. In this project, The PM2.5 sensors was used to measure particle concentration in air.

3.1.3 DHT11 SENSOR

Figure 7 shows that the DHT11 sensor consists of a small module with a built-in temperature and humidity sensor. It has three main pins: VCC (power supply), data and ground (GND). The sensor operates at low voltage, typically 3-5V, making it compatible with microcontrollers and other electronic devices.



Figure 7: DHT11 sensor

The DHT11 is a widely used digital temperature and humidity sensor. It is a low-cost sensor that provides basic functionality for measuring temperature and relative humidity. Here are some key points about DHT11:

- **Measurement range:** DHT11 can measure the temperature in the range of 0 ° C to 50°C (32°F to 122°F) with an accuracy of $\pm 2^{\circ}\text{C}$. For relative humidity, it can be measured in the range of 20% to 80% with an accuracy of $\pm 5\%$.
- **Output:** The sensor provides a digital output signal that can be easily read by microcontrollers or other digital devices. It uses a single-wire serial interface to transmit data.
- **Operating Voltage:** The DHT11 operates in a voltage range of 3.3V to 5V, which makes it compatible with a wide range of microcontrollers and development boards.
- **Low power consumption:** The sensor is designed to operate with low power consumption, making it suitable for battery-powered applications.
- **Sampling Rate:** The DHT11 takes measurements at a relatively slower rate than other sensors. It can provide a new set of temperature and humidity data every 2 seconds.
- **Sensor calibration:** The DHT11 is factory calibrated, which means it is calibrated from the manufacturer. However, it does not have provisions for user calibration.
- **Limitations:** Although DHT11 is cost-effective and easy to use, it has some limitations. It has lower accuracy and a narrower measurement range compared to more advanced sensors. It is also less suitable for applications that require high precision or operate in extreme environmental conditions.

The sensor can measure the temperature from 0 ° C to 50 ° C and the humidity from 20% to 90% with an accuracy of $\pm 1^{\circ}\text{C}$ and $\pm 1\%$. So, if you are looking to measure in this range, this sensor might be the right choice for you [23].

3.1.4 ATmega 328P microchip

The ATmega328P is a high performance but low power 8-bit AVR microcontroller that can execute 131 strong instructions in a single clock cycle. As a processor, it is frequently found in Arduino boards such as the Fio and Uno.

Figure 8 shows the ATmega328 microchip used to interface with various sensors, including air quality sensors such as PM2.5, CO2, or gas sensors. It can collect data from these sensors and convert analogue signals into digital data for further processing and analysis.

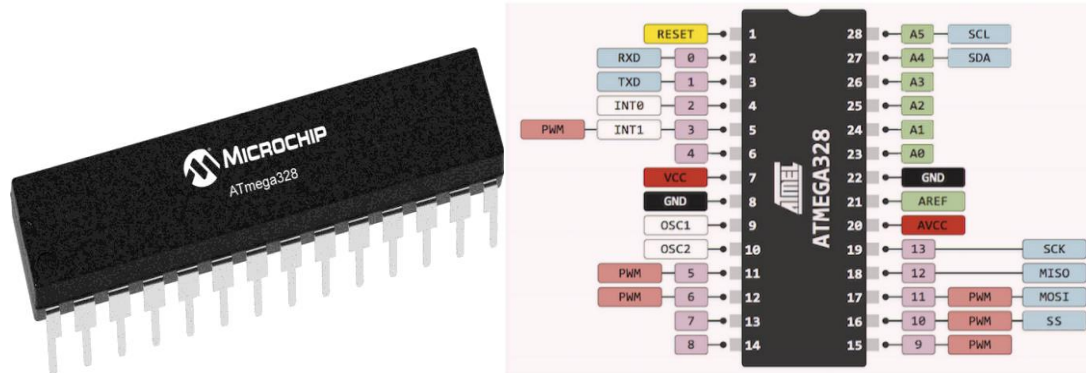


Figure 8: ATmega 328 microchip and pin I/O

The ATmega328 microchip, a member of the AVR microcontroller family, can play an important role in IoT-based air quality monitoring in public buses. Here are some key roles for the ATmega328 microchip in this context.

- a) **Data Acquisition:** The ATmega328 microchip can be used to interface with various sensors, including air quality sensors such as PM2.5, CO2 or gas sensors. It can collect data from these sensors and convert analogue signals into digital data for further processing and analysis.
- b) **Processing and Control:** The ATmega328 microchip has a powerful processing capability and can handle real-time data processing tasks. It can perform computations, apply algorithms, and execute control logic based on the collected sensor data. This allows data analysis, decision-making, and control on board the air quality monitoring system.
- c) **Connectivity:** The ATmega328 microchip can be integrated with wireless communication modules, such as Wi-Fi or Bluetooth, enabling connectivity with other devices or a central monitoring system. It can facilitate data transmission from the air quality monitoring system to a cloud platform or a central server for remote monitoring and analysis.
- d) **Memory and storage:** The ATmega328 microchip has built-in Flash memory for programme storage and SRAM for data storage. It can store sensor readings, configuration settings, and other relevant data locally. This enables the microchip to

maintain a record of air quality measurements and provide historical data for analysis or troubleshooting purposes.

- e) **User interface:** The ATmega328 microchip can be used to interface with user interface components such as LCD displays, buttons, or touch screens. It can process user input and provide feedback on the system's status or display real-time air quality information to passengers or bus operators.
- f) **Power Management:** The ATmega328 microchip has power saving features and can be programmed to operate in low power modes. This is crucial for IoT-based applications in public buses, where power efficiency is essential to preserve battery life or reduce power consumption.
- g) **Integration and expansion:** The ATmega328 microchip is highly versatile and can be easily integrated with other components or sensors according to the specific requirements of the air quality monitoring system. Supports various communication protocols and interfaces, allowing seamless integration with different sensors, modules, or peripheral devices.

CHAPTER IV: CONFIGURATION AND DEPLOYMENT

This chapter explains how sensors and other components are connected to Arduino microcontroller to get accurate data. The system has a power backup of batteries that are supposed to be activated by the switch. The system is used to collect data from sensors on public buses and monitor them on LCD, this information can be used by passengers to decide whether to use the bus or not.

The circuit diagram for an IoT-based air quality monitoring system in public buses consists of several components that work together to measure and transmit air quality data. Here is an explanation of the key components and their functions:

- a. **Air Quality Sensors:** The circuit includes air quality sensors, an MQ135 sensor for gas detection, and a dedicated PM2.5 sensor. The PM2.5 sensor is specifically designed to measure fine particulate matter in the air and provides a digital or analogue output corresponding to the PM2.5 concentration.
- b. **Microcontroller:** A microcontroller, such as an Arduino board, serves as the central processing unit. It interfaces with air quality sensors, including the PM2.5 sensor, to collect data. The microcontroller processes the sensor output and controls the overall functionality of the system.
- c. **Communication Module:** A communication module, such as a GSM or IoT module, facilitates the connection between the monitoring system and a remote server or cloud platform. It enables the transmission of air quality data, including PM2.5 readings, through a wireless network such as GPRS, 3G or 4G.
- d. **Power supply:** The circuit requires a stable power supply, which can be provided by a battery or connected to the bus electrical system. Voltage regulators or power management components may be included to ensure that the sensors and microcontrollers receive the necessary power levels.
- e. **Display unit:** A display unit, such as an LCD or LED display, can be incorporated to show real-time air quality information, including PM2.5 concentrations. This allows passengers and bus operators to monitor air quality levels inside the bus.
- f. **Wiring and Interconnections:** The components of the circuit are connected using appropriate wiring and interconnections. This includes connecting the air quality sensors, including the PM2.5 sensor, to the microcontroller. The communication module and the display unit are also interconnected according to the circuit design.

Figure 9 shows that the circuit diagram provides a visual representation of how components are connected and work together. It illustrates the interconnections, pin assignments, and power flow between the components.

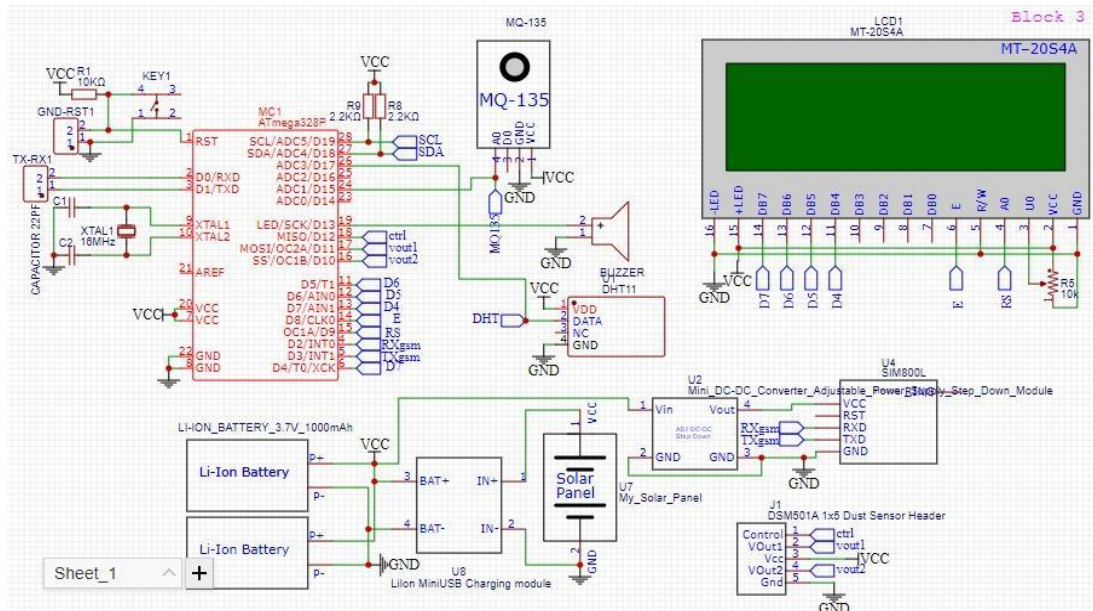


Figure 9: Circuit diagram

Figure 10 shows that the project title displayed on the LCD delays 5 seconds to display the next screen that contains real-time monitored sensor data.



Figure 10: Project title displayed on the LCD

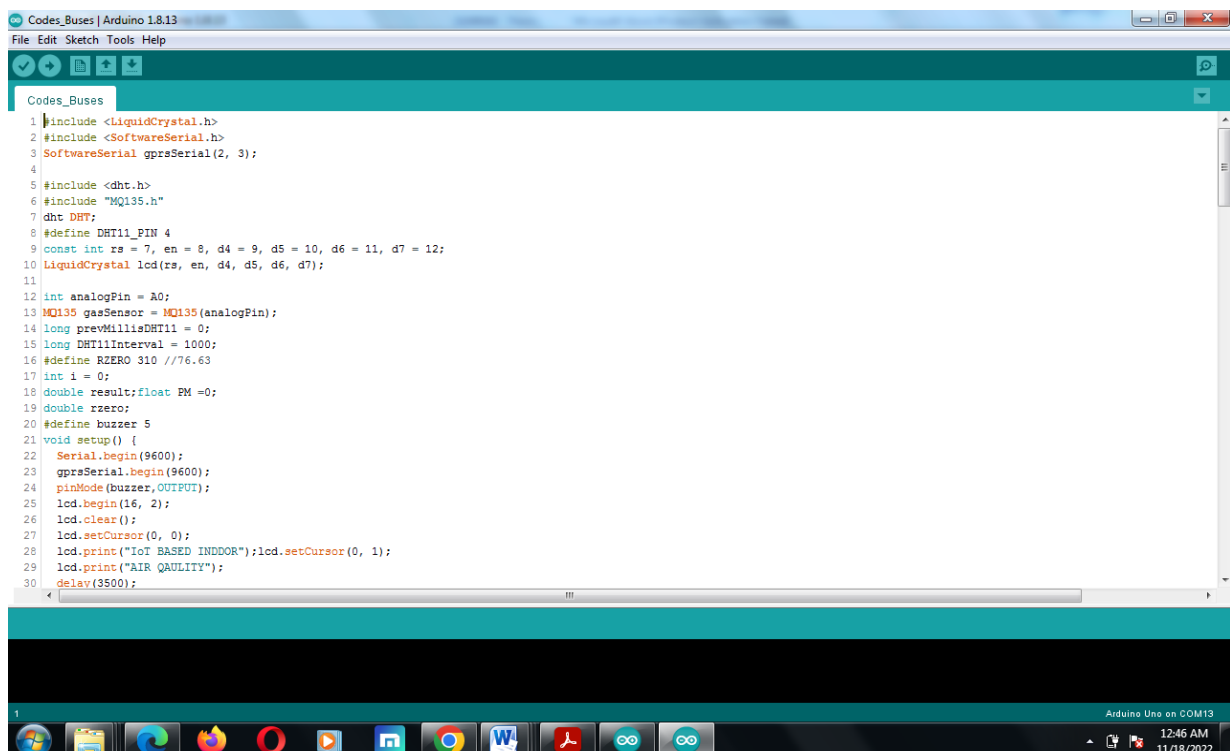
4.1. Components Configurations

Arduino IDE is an open-source electronic prototyping platform that allows users to create and interact with electronic objects.

This text editor uses C and C++ programming language to allow the system to interact with connected sensors or peripherals, all configuration and setting of threshold is done in this text editor by creating codes and uploading them to a microcontroller.

One of the significant advantages of the Arduino IDE is its platform independence, enabling it to run on various operating systems such as Windows, Linux, and MacOS. The IDE incorporates several key features, including a text console, a message area, and a toolbar with common functions.

Figure 11 shows that the Arduino IDE is a platform-independent software tool that serves as the foundation for Arduino hardware projects. Programmers, project development professionals, and researchers are highly regarded for developing a wide range of Arduino projects using different sensors.



```
1 #include <LiquidCrystal.h>
2 #include <SoftwareSerial.h>
3 SoftwareSerial gprsSerial(2, 3);
4
5 #include <dht.h>
6 #include "MQ135.h"
7 dht DHT;
8 #define DHT11_PIN 4
9 const int rs = 7, en = 8, d4 = 9, d5 = 10, d6 = 11, d7 = 12;
10 LiquidCrystal lcd(rs, en, d4, d5, d6, d7);
11
12 int analogPin = A0;
13 MQ135 gasSensor = MQ135(analogPin);
14 long prevWillisDHT11 = 0;
15 long DHT11Interval = 1000;
16 #define RZERO 310 //76.63
17 int i = 0;
18 double result;float EM =0;
19 double rzero;
20 #define buzzer 5
21 void setup() {
22   Serial.begin(9600);
23   gprsSerial.begin(9600);
24   pinMode(buzzer, OUTPUT);
25   lcd.begin(16, 2);
26   lcd.clear();
27   lcd.setCursor(0, 0);
28   lcd.print("IoT BASED INDDOR");lcd.setCursor(0, 1);
29   lcd.print("AIR QAULTY");
30   delay(3500);
```

Figure 11: Arduino IDE text editor

Figure 12 shows the system power supply consisting of an internal lithium battery of 3.7v and TP4045 charging module with an SPDT switch to turn the system on or off with other components connected to PCB (Printed Circuit Board)



Figure 12: Power supply

This system is made up of different input and output (I/O) components, input components are those components used to read data and spread those data to the system to be executed by a microcontroller, then a microcontroller uses output components to show what is executed.

The microcontroller used is atmega328p which has 14 digital pins and 6 analogue pins, its operating voltage is 1,8V - 5.5V and all components connected to a controller use the same operating voltage range.

DHT11 which is used as an input component to sense temperature and humidity, the data pin is connected to digital pin 4 (D4) of a microcontroller MQ135 that inputs analogue data of carbon dioxide from public transportation buses to the microcontroller, and uses an analogue pin connected on A0 (Analogue 0 of a microcontroller).

Figure13 shows In general, the meaning of the wire colours of PM2.5 sensors.

1. **Red:** Power supply or VCC connection.
2. **Black:** Ground or GND connection.
3. **Yellow:** Connection of data or signals.



Figure 13: PM2.5 sensor

Table 1: PM2.5 Sensor Pins

Red wire	5V
Black wire	GND
Yellow wire	Data

Table 1 shows that the red wire provides power to the sensor, the black wire connects to the ground, and the white or yellow wire carries the data or signals from the sensor.

Based on international standards of indoor air quality, this sensor has been code calibrated to know the level of particles in the air, and then we set the threshold in five parts. Once the dust sensor (PM2.5) is connected, we will have different messages on the display based on the detected data. Therefore, when the particle concentration is less than $1000\mu\text{g}/\text{m}^3$ the clean message will be printed. Similarly, when the concentration of particles is between $1000\mu\text{g}/\text{m}^3$ and $10000\mu\text{g}/\text{m}^3$ then the Good message will be printed. If the concentration is between $10000\mu\text{g}/\text{m}^3$ and $20000\mu\text{g}/\text{m}^3$ then the Acceptable message will be printed. If the concentration is between $20000\mu\text{g}/\text{m}^3$ and $50000\mu\text{g}/\text{m}^3$ then the heavy message will be printed. And if the concentration of particles is greater than $50000\mu\text{g}/\text{m}^3$ then the Hazard message will be printed.

Table 2: PM2.5 Threshold

From 0 ←————→ 1000	Clean
From 1000 ←————→ 10000	Good
From 10000 ←————→ 20000	Acceptable
From 20000 ←————→ 50000	Heavy
From 50000 ←————→ Above	Hazard

Table3 shows the calibrations of the pm2.5 sensor and that will be displayed on the LCD when the collection is clean, good, acceptable, heavy or dangerous.

As output devices used in this system, LCD (liquid crystal display) to display processed data and a buzzer connected to D5 (digital pin 5 of a microcontroller) beeps frequently due to the threshold set.

Figure 14 shows T=27 ,H=26 ,CO₂=0, PM2.5="Clean" where T stands for temperature in degrees Celsius, H stands for humidity measured in percentage and C02 stands for carbon dioxide measured in ppm(parts per million)



Figure 14: Display data readings on an LCD

The GSM SIM800L module provides various functionalities for GSM/GPRS communication and data transmission.

The SIM800L module enables communication over GSM networks (Global System for Mobile Communications) networks, allowing devices to connect to cellular networks for voice

and data transmission. It supports 2G connectivity, including technologies such as GPRS (General Packet Radio Service) and EDGE (Enhanced Data Rates for GSM Evolution)

The module supports SMS (Short Message Service) functionality, allowing devices to send and receive SMS messages. You can use AT commands to send SMS messages, read incoming messages, and manage SMS storage.

The SIM800L module enables GPRS data transfer, allowing devices to establish Internet connectivity over the cellular network.

Supports the TCP/IP and UDP protocols for data transmission. You can send and receive data packets, which makes it suitable for IoT applications that require remote monitoring, control, or data exchange.

Figure 15 shows the GSM used to connect air quality monitoring devices to the Internet and help send sms to the driver's phone to take measures based on the level or data received.

The SIM800L module has a slot for a SIM card, which is required for authentication and access to the GSM network. The SIM card stores the subscriber information and allows the module to connect to the network.



Figure 15: GSM SIM800L Module

When data are sent to Thingspeak, it follows a numerical format for explanation. Thingspeak is an IoT platform that allows users to collect, analyse, and visualise sensor data. Here is a breakdown of the numerical explanation when sending data to Thingspeak:

- a. **Channel ID:** Each Thingspeak channel is assigned a unique channel ID. It is a numerical value that identifies the specific channel to which the data is being sent. Channel ID helps Thingspeak route the data to the correct channel for storage and processing.
- b. **Field Values:** Thingspeak channels are divided into fields where data can be stored. Each field has a numeric index that starts from Field1 to field N, where N represents the total number of fields in the channel. Field values are numerical measurements or data points that correspond to specific sensor readings or variables that are being monitored.
- c. **Timestamp:** Along with the field values, a timestamp is associated with each data entry. The timestamp represents the date and time the data were recorded or sent to Thingspeak. It helps to organise the data chronologically and enables time-based analysis and visualisation.
- d. **API key:** To authorise data submission, an API key is required. It serves as a unique identifier and authentication mechanism for the sender. The API key ensures that only authorised entities can post data to the specific Thingspeak channel.

Figure 16 shows that the data collected by sensors is sent to cloud using GPRS communication as the IoT devices use the Thingspeak dashboard to monitor and visualise the data in graphs and numerical so that when you need the data in case of backup or data inspection, the dashboard provides a way to generate and download a CSV file that contains the recorded data.

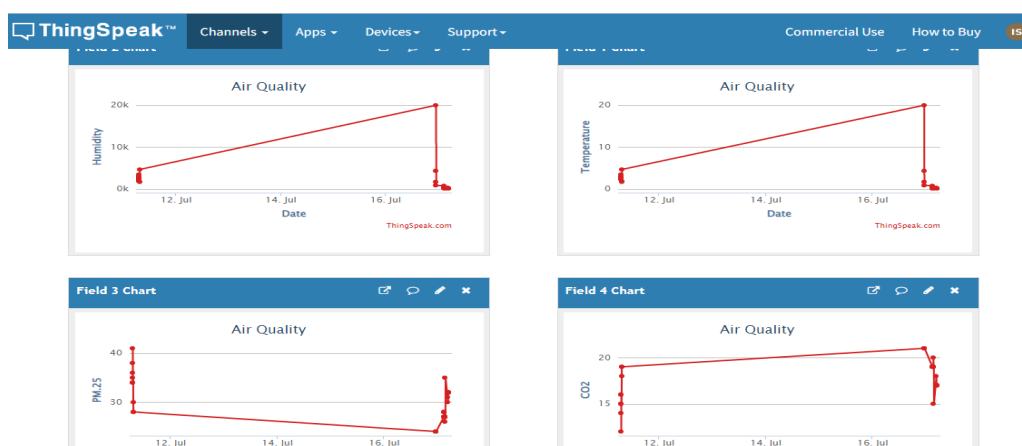


Figure 16: Visualisation of data in Thingspeak dashboard in graphs

The figure below describes the data sent to Thingspeak channel, which is assigned a unique channel ID. It is a numerical value that identifies the specific channel to which the data are sent. For this figure $PM_{2.5}=0.62\mu/g$, $CO_2=419ppm$, Temperature = $26^{\circ}C$, Humidity = 25%

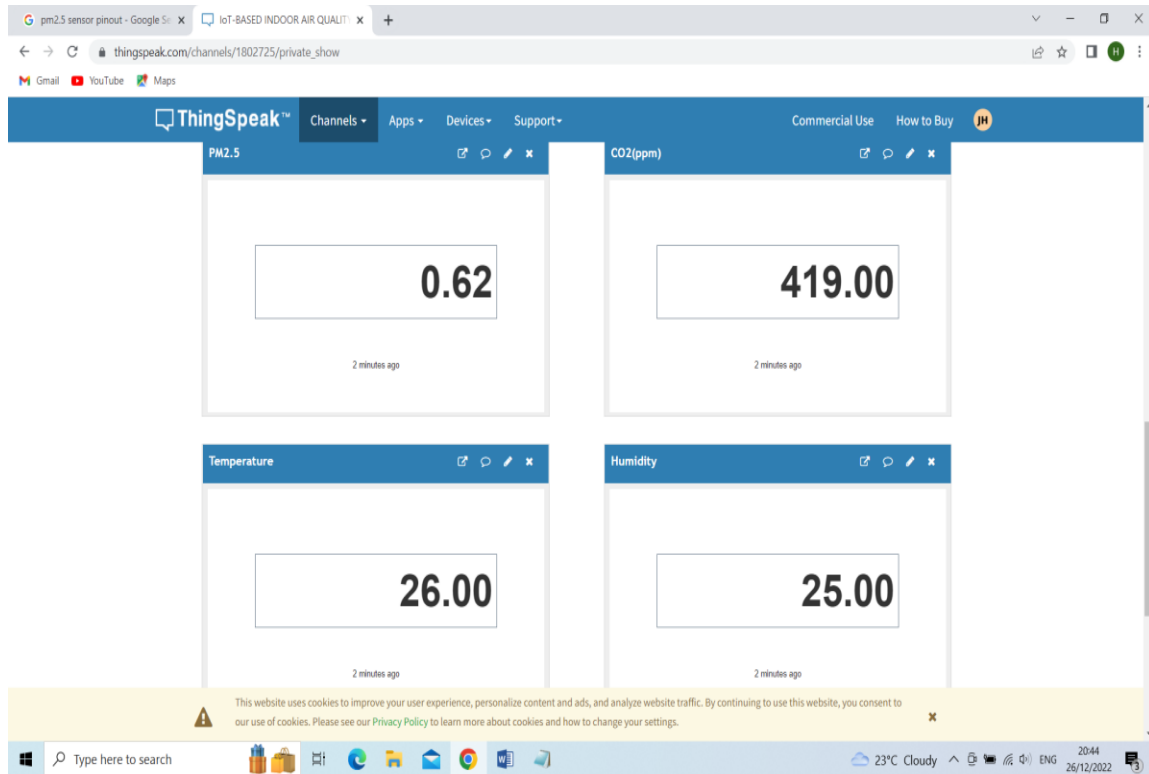






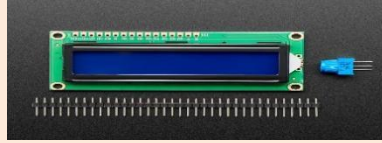
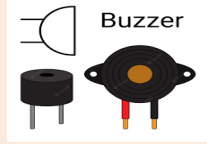


Figure 17: Data Visualisation in Thingspeak Dashboard in Numeric

4.2. Components Used and Their Role

Table 4 shows all components and their roles used to improve air quality on public buses.

Table 3: Components Used Components and Their Roles

COMPONENT	Role in the System
	<p>PM2.5 sensors are designed to measure the concentration of particulate matter that is 2.5 micrometres or smaller in diameter in the air. These sensors are typically used in air quality monitors to provide real-time data on the level of PM2.5 particles in the air.</p>

	<p>The ATmega328 microchip can be used to interface with various sensors, including air quality sensors such as PM2.5, CO2 or gas sensors. It can collect data from these sensors and convert analogue signals into digital data for further processing and analysis.</p>
	<p>The DHT11 is a widely used digital temperature and humidity sensor. It is a low-cost sensor that provides basic functionality for measuring temperature and relative humidity.</p>
	<p>The MQ135 sensor plays a critical role in detecting and measuring gas concentrations to assess air quality in public buses. Its real-time monitoring capabilities, alert notifications, and integration with data logging systems contribute to creating a healthier and more sustainable environment for passengers and bus operators.</p>
	<p>The LCD in IoT-based air quality monitoring systems in public buses serves as a vital component for displaying real-time air quality data, alert notifications, historical trends, and system status. It improves passenger awareness, promotes proactive measures to address air pollution, and supports informed decision making for a healthier environment within public transportation.</p>
	<p>A buzzer is an electronic device that produces a buzzing or beeping sound. It is commonly used in this project to provide audible alerts, notifications, or alarms.</p>
	<p>Batteries provide the necessary power to operate these devices, enabling them to continuously monitor air quality within public buses.</p>
	<p>PCBs provide a platform for mounting various electronic components such as buzzer, capacitors, microcontroller, sensors, and lcd, and more. These components are soldered onto the PCB, creating a solid electrical and mechanical connection.</p>



Wires or jumpers are used to bridge the necessary connections between components, enabling them to work together as intended.

4.2 Deployment

The deployment of IoT-based air quality monitoring in public buses offers numerous advantages. First, it enables the collection of comprehensive and high-resolution data on pollutant concentrations, helping to identify pollution hotspots and areas of concern.

Secondly, it provides an opportunity to assess the effectiveness of existing pollution control measures and to evaluate the impact of transportation policies on air quality. Additionally, IoT-based systems can improve public awareness by providing real-time air quality information to passengers and relevant stakeholders.

The data collected by the monitoring system can be used to identify areas where air quality is poor and implement measures to improve it, such as changing the ventilation system or reducing the idle time of the bus. It can also be used to alert passengers and drivers to potential health risks and help them take appropriate measures to protect themselves, such as wearing masks or opening windows.

At this stage, the system's prototype is currently being implemented and evaluated on a public transportation bus in order to assess the quality of air being inhaled by passengers. Through the utilization of an LCD, any passenger, driver, or verification team member can access and analyse the data collected by the sensor on the IoT dashboard. Furthermore, they will also receive an SMS notification once the threshold reaches its peak.

Figure 18 exhibits an air quality monitoring device that has been installed and securely positioned within the bus itself. This device serves the purpose of monitoring and transmitting various parameters, such as PM2.5, CO₂, temperature, and humidity. It has been strategically placed in the middle of the bus to facilitate ease of manipulation and control.



Figure 18: Air Quality Monitoring Prototype Testing on Public Bus

4.3 Challenges faced

Various buses may possess diverse power supply arrangements. Certain buses may possess dissimilar voltage levels or incompatible power sockets, resulting in the arduous task of establishing consistent connectivity and powering of IoT devices. Modifying the monitoring system to operate seamlessly with a myriad of power supply configurations can pose a technical obstacle.

Certain members of the transportation enterprise's management exhibit a lack of comprehension regarding the significance of this project, relying solely on business calculations.

CHAPTER V: RESULTS AND DISCUSSION

5.1. Introduction

This study endeavours to investigate and examine the outcomes derived from an Internet of Things (IoT)-based air quality monitoring system implemented in public buses. Through assessment of the gathered data, this research strives to ascertain trends and patterns, as well as spatial and temporal variations in the levels of pollutants, and potential strategies for mitigating their impact. Additionally, the study aims to evaluate the effectiveness and dependability of the IoT-based monitoring system, and to discuss its implications for public health, transportation policies, and urban planning.

In Sections 1 and Section 2 we will discuss previous work and the comparison of the result obtained by Halima in his study on air quality monitoring in public transport and the results obtained by Joas' study on air quality monitoring in public buses.

5.2. Section one

This section presents a comparative analysis of two research projects that have focused on monitoring air quality in public transportation using Internet of Things (IoT) technology. The projects being examined are "IoT-based air quality monitoring system in public transport" and its extension, the "IoT-based air quality monitoring system in public buses".

The main purpose of this comparison is to assess the effectiveness of IoT-based air quality monitoring in enhancing the understanding of the exposure of commuters to air pollutants during their journeys. Furthermore, our aim is to investigate potential disparities in air quality levels across different modes of public transport.

5.2.1 Objectives for both projects

Project 1, entitled "IoT Based Air Quality Monitoring System in Public Transport," aimed to implement an air quality monitoring system in public transport utilizing the Internet of Things technology. The purpose of this project was to evaluate and enhance the air quality encountered by passengers during their journeys.

Project 2, denoted as "IoT-based Air Quality Monitoring in Public Buses," shared an analogous objective with Project 1. However, Project 1 encountered impediments in data collection due to the COVID-19 pandemic, which had a significant impact on the operations and accessibility of public transport.

5.2.2. Methodology - Project 1 (IoT Based Air Quality Monitoring System in Public Transport):

- a) **Sensor Selection:** For Project 1, three different sensors were chosen to measure key air quality parameters. The DHT11 sensor was used to monitor temperature and humidity levels inside public transport vehicles, providing context for air quality data. The MQ135 sensor was selected to measure the concentration of carbon dioxide (CO₂) in the air, which are common indoor

air pollutants. Furthermore, the MQ7 sensor was used to detect levels of carbon monoxide (CO), a harmful gas emitted from combustion sources.

- b) **Micro controller:** The ESP8266 micro controller is used to interface with the sensors and collect data from them.

5.2.3. Methodology - Project 2 ("IoT Based Air Quality Monitoring in Public Buses"):

- a) **Sensor Selection:** For Project 2, a subset of sensors was chosen to target specific air quality parameters relevant to buses. The MQ135 sensor, also used in Project 1, measured CO₂ concentrations in the air. In addition, the PM2.5 sensor was deployed to monitor fine particulate matter, a crucial component of air pollution, and the DHT11 sensor for temperature and humidity.
- b) **Micro controller:** The ATmega328p micro controller is used to interface with the sensors and collect data from them.
- c) **Data Collection and Analysis:** The IoT-based air quality monitoring system was installed inside the buses to continuously collect data during regular bus operations. Data analysis focused specifically on understanding the levels of pollutants inside buses and how they changed over different routes.

5.2.4. Findings

In both projects, IoT-based air quality monitoring systems were installed in public buses to measure various air pollutants and environmental parameters. The data collected from the sensors (MQ7, MQ135, DHT11 and PM2.5) and the respective measurements recorded are as follows:

5.2.5. Project 1

Sensors used:

- a) MQ7 Sensor: Measures carbon monoxide (CO) concentrations in the air.
- b) MQ135 Sensor: Measures nitrogen dioxide (CO₂) concentrations in the atmosphere.
- c) DHT11 Sensor: Records temperature and humidity levels inside public buses.

5.2.6. Data collected:

- a) CO Concentrations: The MQ7 sensor provides real-time data on carbon monoxide levels in parts per million (ppm).
- b) CO₂ concentrations: The MQ135 sensor offers real-time data on carbon dioxide levels in ppm.
- c) Temperature: The DHT11 sensor records temperature in degrees Celsius (°C) inside public buses.
- d) Humidity: The DHT11 sensor measures the relative humidity (%) inside the buses.

5.2.7. Data analysis

In Project 1, the ESP8266 microcontroller was responsible for processing the collected data and transmitting it to a central server through Wi-Fi connectivity. The microcontroller conducted a real-time data analysis to calculate CO and CO₂ concentrations, CO₂ concentrations, as well as temperature and humidity levels.

5.2.8. Project 2: Sensors used:

- a) MQ135 Sensor: Measures carbon dioxide (CO₂) concentrations in the air.
- b) DHT11 Sensor: Records temperature and humidity levels inside public buses.
- c) PM2.5 Sensor: Measures particulate matter (PM) concentrations with a diameter of 2.5 micrometres or smaller.

5.2.9. Data collected:

- a) CO₂ concentrations: The MQ135 sensor provides real-time data on carbon dioxide levels in ppm.
- b) Temperature: The DHT11 sensor records temperature in degrees Celsius (°C) inside public buses.
- c) Humidity: The DHT11 sensor measures the relative humidity (%) inside the buses.
- d) PM2.5 Concentrations: The PM2.5 sensor offers real-time data on fine particulate matter levels in micrograms per cubic metre ($\mu\text{g}/\text{m}^3$).

5.2.10. Data analysis

In the context of Project 2, the utilization of the ATmega 328 microcontroller facilitated the process of analysing and transmitting data. The microcontroller diligently processed the data acquired from the sensors and effectively conducted real-time computations to ascertain the levels of carbon dioxide, temperature, humidity, and PM2.5 concentrations.

The integration of the PM2.5 sensor in Project 2 yielded a noteworthy enhancement to the air quality monitoring system by furnishing supplementary information regarding fine particulate matter. Significantly, this data is of paramount importance in evaluating the health ramifications of air pollution, given that PM2.5 particles have the ability to permeate deeply into the respiratory system and induce severe health complications.

The most significant distinction between the aforementioned projects lies in the outcome of the data collection assignments. Despite the challenges encountered by Project 1 attributable to the COVID-19 pandemic, which resulted in the inability to collect data pertaining to various modes of public transportation [38], Project 2 experienced less adverse effects and successfully gathered data within the limited and confined scope of buses..

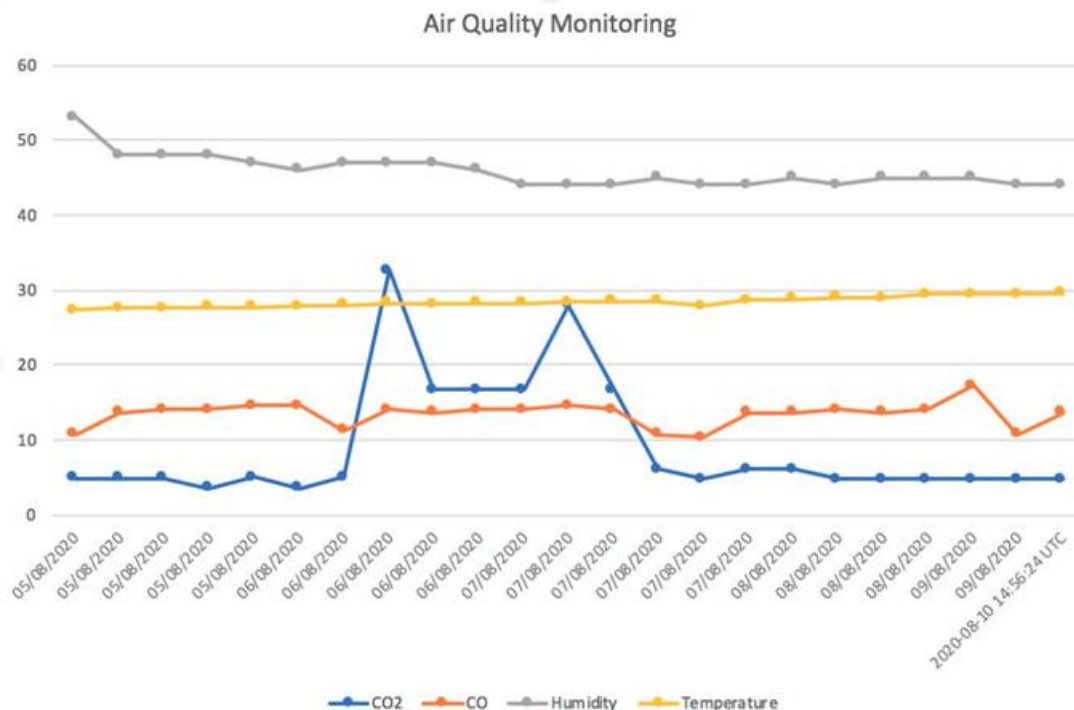


Figure 19: Data collected in 10 days for Project 1

Data collected for both projects exhibit differences, with only two sensors (MQ135 and DHT11) being common between the two studies. Based on data depicted in the figures below reveals that the levels of CO₂, temperature, and humidity within the bus fleet that operated during the Covid-19 pandemic remained within normal parameters, with an approximate passenger count of 30 individuals.

However, upon analysing the data from the buses that resumed full operations after the Covid-19 pandemic, it becomes evident that the levels recorded by the sensors, particularly for CO₂ and temperature, exhibited a notable increase or decrease in correlation to the number of passengers present on board. The average number of passengers observed within these buses was approximately 70 individuals.

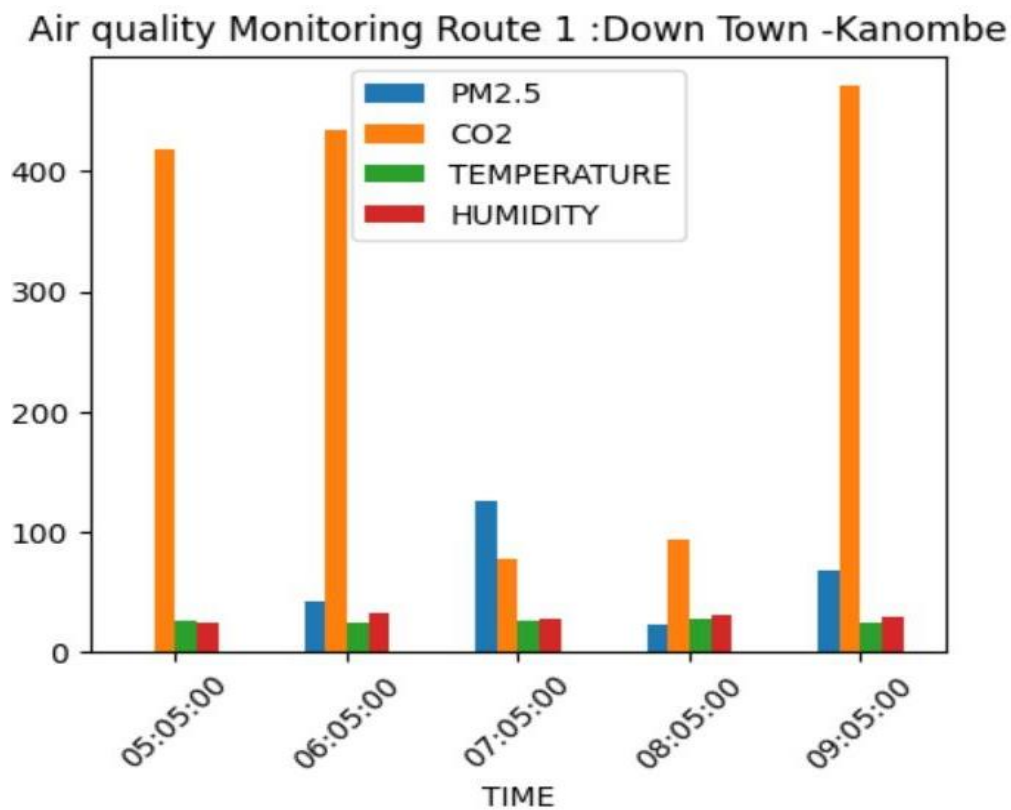


Figure 20: Data collected in 5 hours for Project 2

5.3. Section 2 Data results and discussion on Project Two

5.3.1 Introduction

Project 2, with its focus on the monitoring of air quality within public buses, exemplifies the capacity to adapt to dynamic circumstances and refine research objectives. The selection of sensors employed in the second project, which includes the incorporation of PM_{2.5} sensors, had the potential to enhance the accuracy and relevance of the data collected.

The Internet of Things (IoT)-based system designated for monitoring air quality facilitates the real-time assessment of pollutant levels. In the event that measured concentrations surpass predetermined thresholds or if substandard air quality conditions are detected, automated notifications or alerts are dispatched to bus operators, maintenance personnel, or other concerned parties. These notifications incite timely measures to alleviate the repercussions of subpar air quality on the health and well-being of passengers.

5.3.2 Experiment test 1

The data obtained from the journey taken from downtown to Kanombe, known as route 1, was transferred to the cloud via thingspeak and subsequently exhibited on the thingspeak dashboard. The measurement device remained operational and recorded data on 14 May 2023 during the time period ranging from 5:00 pm to 9:00 pm.

Figure 19 illustrates the graphical representation of the data collected by an air quality monitoring device positioned within the bus operating on route one. During this particular stage, the bus accommodated approximately 80 passengers. Although the level of CO₂ detected was elevated, it did not surpass the predetermined threshold of 1000ppm, which is the limit value established for a 5-hour duration of operation.

Air quality Monitoring Route 1 :Down Town -Kanombe

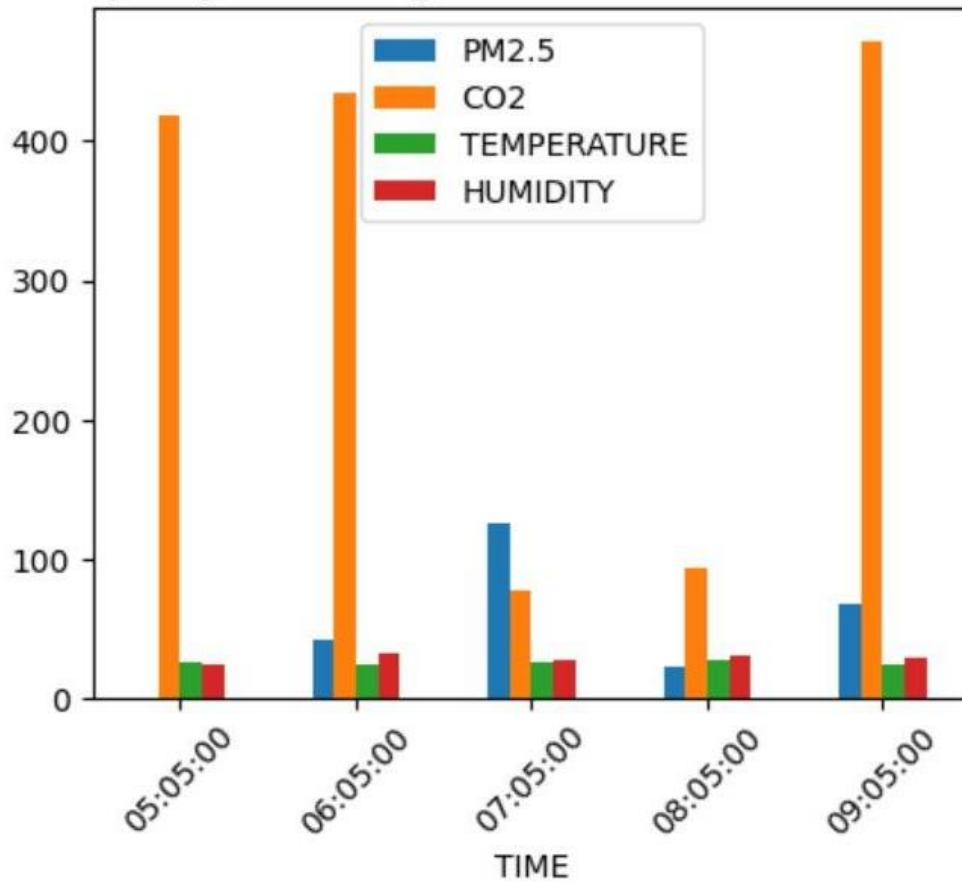


Figure 21: : Level of data collected on route one with air quality monitoring device

Figure 22 depicts the empirical evidence gathered on Route 1 and presented on the Thingspeak Dashboard in numerical format. The vehicle accommodated approximately 80 individuals, with all windows being ajar due to the prevailing sunset conditions. The measurement of particulate matter (PM2.5) stood at $0.62\mu\text{g}/\text{m}^3$, signifying a favourable level of pollution. Conversely, the concentration of carbon dioxide (CO2) amounted to 419 ppm (Parts per Million), whereby an escalation in CO2 levels was observed during periods of pronounced congestion or traffic congestion. The ambient temperature materialized at 26°C , accompanied by a humidity reading of 25%.

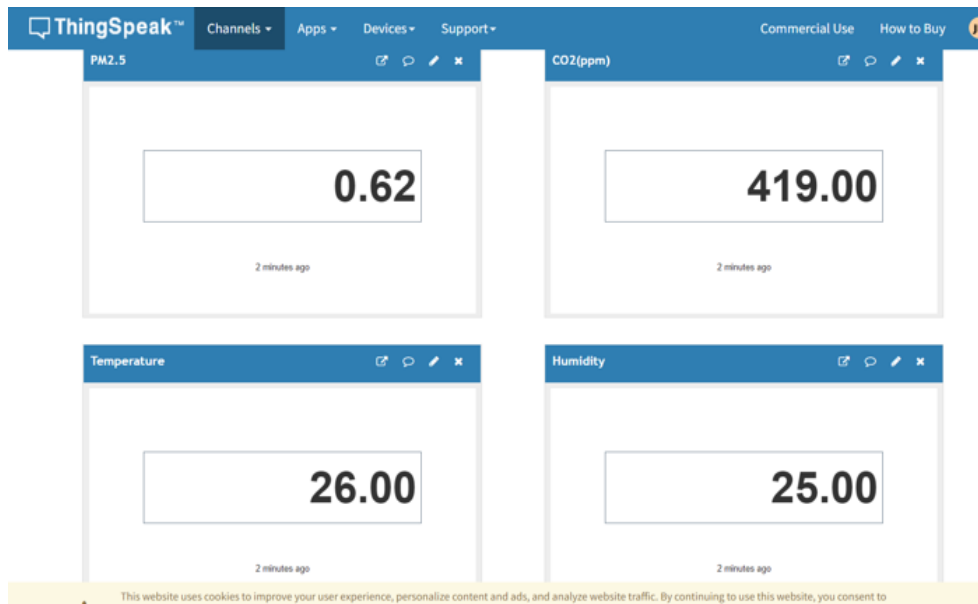


Figure 22: Thingspeak dashboard in numerical data collected by devices

5.3.3 Experiment Test 2

Figure 23 depicts the data that was gathered during the course of route two and subsequently exhibited on the display of air quality monitoring devices in the form of a numerical and graphical Excel file. In this particular instance, the bus accommodated approximately 70 individuals, with certain windows being open while others remained closed. The monitoring device was actively engaged in conducting measurements on Sunday, 7 May 2023, commencing from 2 pm and concluding at 5 pm. It is worth noting that the interior of the bus was excessively warm, as indicated by the reading displayed on the air quality monitoring device, which registered a temperature of 30 °C.

The level of particulate matter (PM2.5) was recorded at 0.62 µg/m³, signifying a clean bus interior devoid of dust. The concentration of CO₂ was determined to be 152 ppm (Parts per Million), which falls within the expected normal range. However, it should be highlighted that the temperature reading of 30 °C is deemed unfavourable, as the standard threshold for the temperature sensor (DHT11) typically ranges from 0 °C to 25 °C. Furthermore, the humidity level was measured at 33%.

A common range for the normal threshold of a temperature sensor (DHT11) inside the bus could be between 18 °C and 25 °C. This range is generally considered comfortable for most

people and is commonly used as a reference for indoor climate control in various settings, including public transportation.

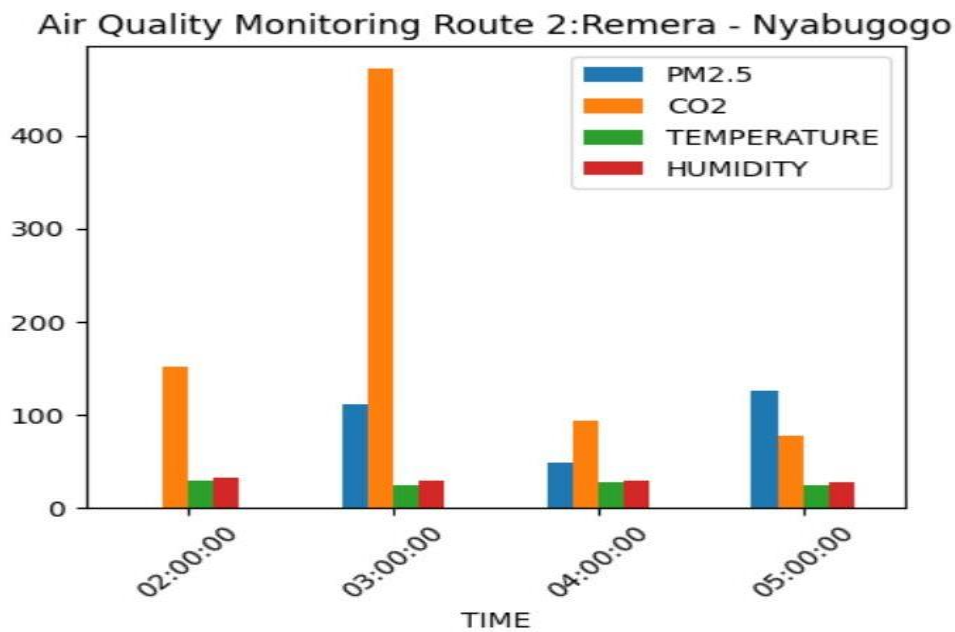


Figure 23: The level of air quality monitoring on route two



Figure 24: The level of data collected on route two with the device is then displayed on the device's screen

5.3.5 Warning messages

To enhance safety and promptly address elevated levels of pollutants, we integrated an alert system into the Internet of Things (IoT)-based setup. In cases where sensor data surpassed predetermined threshold values for specific pollutants, the system automatically initiated a cautionary message to the bus operator. This alert mechanism empowered the operator to promptly undertake appropriate measures, such as altering the route, adjusting air flow, or informing passengers, in order to mitigate potential health hazards associated with substandard air quality.

These messages can be presented as visual alerts, audible alarms, or textual notifications on the telephone, ensuring that the operator is promptly informed of the prevailing air quality conditions.

Figure 24 illustrates that upon receiving the warning message, the operator is able to undertake the suitable actions to alleviate air quality risks. This may encompass opening windows for ventilation, conducting bus cleaning, or altering the bus route, if feasible.

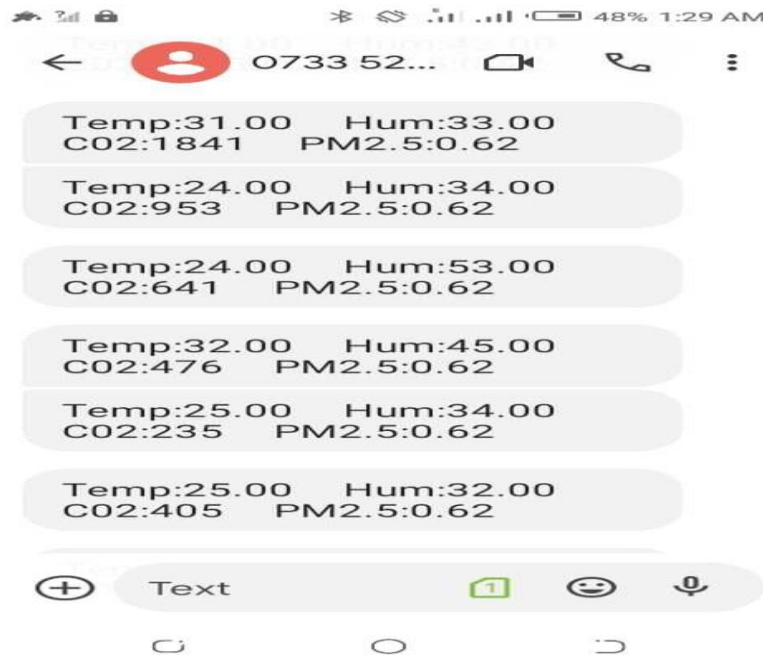


Figure 25: Warning messages received by the bus driver

Figure 25 shows a graph representing all data collected for a period of two months from 15 July up to 15 June 2023, CO₂ is higher than other parameters where humidity is low compared to temperature.

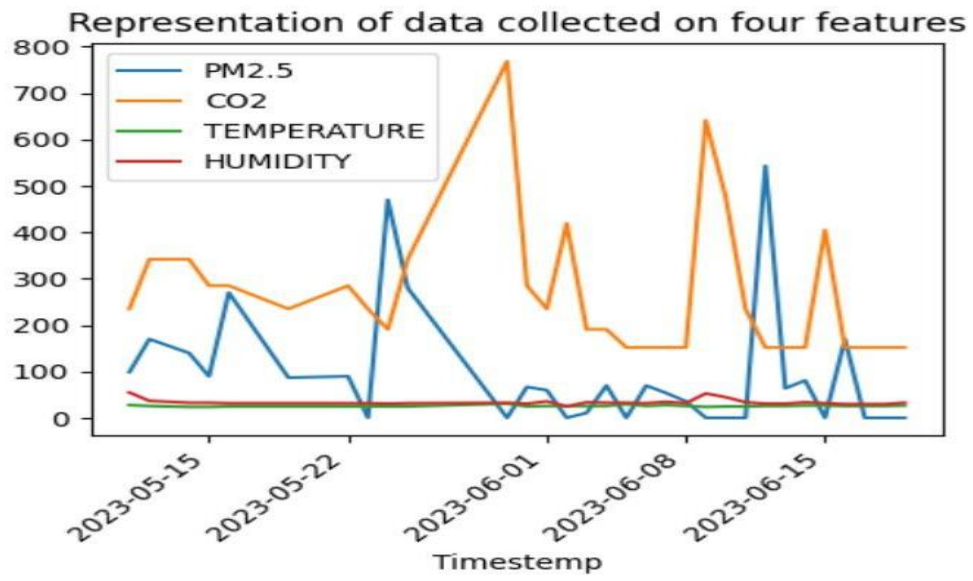


Figure 26: Representation of all data collected.

CHAPTER VI: CONCLUSION

In summary, the implementation of air quality monitoring systems based on the Internet of Things (IoT) in public buses brings forth noteworthy advantages concerning the well-being of passengers, the preservation of the environment, and the ability to perform preventive maintenance. By confronting the difficulties associated with this technology and harnessing its capabilities, it becomes plausible to establish more hygienic and healthier conditions within public transportation networks, thereby resulting in an enhanced overall state of air quality and welfare for the entire population.

6.1 Recommendation

As technological advancements progress and further research is conducted within this particular field, it is reasonable to anticipate additional innovations and enhancements. These may encompass the creation of more precise and dependable sensors, improved techniques for data analysis, and the integration of air quality monitoring systems with other initiatives related to smart cities.

Based on the data gathered during this inquiry, I would like to extend my recommendation to the Government of Rwanda, the Rwanda Utilities Regulatory Authority (RURA), and private transportation companies operating within Kigali city.

It is imperative that the government extends its support towards the installation of air quality monitoring devices in all buses operating in Kigali City. These devices should consistently measure and report levels of air pollutants, thereby furnishing real-time data that can be utilized to monitor the quality of air within buses.

During periods of high demand, buses become packed with a greater number of individuals on board. Consequently, the emission of carbon dioxide (CO₂) intensifies due to exhalation and the release of CO₂ into the atmosphere. Elevated concentrations of CO₂ can result in air that is stagnant or lacking freshness, potentially leading to discomfort or fatigue. We propose that RURA should establish regulations that limit the number of passengers based on bus occupancy levels and diligently adhere to the operational standards of the bus ventilation system on a daily basis.

In the case of private enterprises, it is imperative that buses undergo thorough cleaning both before and after each trip. This is especially crucial for those vehicles that traverse unpaved roads, as it aids in reducing the accumulation of airborne particles within the buses.

6.2 Future work

Researchers in the future ought to employ machine learning (ML) algorithms to derive valuable insights from the amassed air quality data. The creation of accessible mobile applications or web interfaces that afford real-time air quality information to commuters and enable them to furnish feedback or register air quality concerns would be a productive pursuit..

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APPENDICES

Appendix 1: Data collection letter from ACEIOT



UNIVERSITY of
RWANDA



Website: www.aceiot.ur.rw
Mail: aceiot@ur.rw

COLLEGE OF SCIENCE AND TECHNOLOGY

To: DIRECTOR...MANAGER...OF, KBS

Kigali, Rwanda

March 31st, 2023

Dear Sir/Madam,

Subject: Introductory letter for data collection, for ACEIoT Master's student,

Mr Hakizimana Joas

This is to introduce **Mr Hakizimana Joas** with reference number **22100192**, a master's student who is doing his research for master's thesis under the African Center of Excellence in Internet of Things (ACEIoT) established at the University of Rwanda (UR), College of Science and Technology (CST) in the program of Wireless Intelligent Sensor Network (WSN).

His research title is "IoT based Air Quality monitoring in public buses" The student needs to collect data related to his thesis from 02.10.2023 - 01.06.2023 for your esteemed Institution under your responsibility.

Your support with the needed information will be highly appreciated.

Dr. Damien HANYURWIMFURA

Ag. Director, ACEIoT

College of Science and Technology

University of Rwanda

Tel: 0787394447



Appendix 2: Letter requesting data collection permission from Kigali Bus Services(KBS)

Joas HAKIZIMANA

Kigali on 26th April 2023

University of Rwanda

College of science and technology

Master's student at Africa Center of Excellence in Internet of Things (ACEIoT)

Telephone: 0788522112

Email: hjoe50@gmail.com

To: Managing Director KBS



Re: Request Data Collection permission

Dear sir/Madam,

I'm Joas Hakizimana a master's student at university of Rwanda College of Science and Technology(CST), Africa centre of excellent in Internet of Things (ACEIoT)

I'm writing to request your assistance in collecting data for my research project.as part of my study, I'm interested in collecting information about **IoT-Based Air quality monitoring in Public Buses**, and I believe that your company has valuable insights that could greatly benefit my research.

I am hoping to gather data trough installing my device inside the bus which is small and simple to fix it (Device), and I would be grateful if your company could assist me in this process. specifically, I'm looking to collect data on air quality inside the public buses in Kigali, and I believe that your company has access to this information

If your company is willing and able to provide me with the necessary data, I would be happy to provide you with any further information you require about my research project.

Thank you for considering my request. i look forward to hearing back from you soon

Sincerely

Joas HAKIZIMANA

Master's student at University of Rwanda

College of science and technology