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COLLEGE OF SCIENCE AND TECHNOLOGY

IoT-Based Air Quality Monitoring System in Public Transport: A Case of Rwanda

By

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College of Science and Technology

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A dissertation submitted in partial fulfilment of the requirements for the degree of

MASTER IN INTERNET OF THINGS (EMBEDDED COMPUTING SYSTEM)

In College of Science and Technology

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January 2021

Student Declaration

I declare that this Dissertation contains my own work except where specifically acknowledged.

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Bonifide Certificate

This is to certify that the project entitled "IoT-Based Air Quality Monitoring System in Public Transport: A Case of Rwanda" is a record of original work done by Halima Mohamed with registration number 219013563 in partial fulfilment of the requirement for the award of masters of sciences in Internet of Things in College of Science and Technology, University of Rwanda, Academic year 2018/2019.

This work has been submitted under the guidance of Dr. Eric Umuhoza and Dr. Alexander Ngenzi.

Dr. Eric Umuhoza

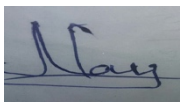


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Abstract

The majority of the population in low-and middle-income countries uses mainly public transport in day to day activities. For instance, in Kigali (Rwanda) public buses are the main means of transport since they are affordable compared to other transport means such as private cars, motorbikes, and cabs. Those buses are often overcrowded with more than 60 passengers each and this may lead to transfer of communicable diseases such tuberculosis and other respiratory diseases and also causes fatigue. These diseases cannot be known and avoided unless there is a monitoring system in place to identify the pollution in air causing these communicable diseases.

This research is intended to develop an IoT-based air quality monitoring system, the Internet of Things is used to monitor air quality in public transport by the use of environmental sensors and low cost microcontroller to collect data and send it to an open source-Internet of things cloud platform for analysis, storage and visualizations.

The methodology used in this study is experimental where prototype is developed to collect the data and secondary data from existing studies and reports on air quality is used to make decision.

The system incorporates different sensors to measure air quality variables such as carbon dioxide, carbon monoxide, temperature and humidity and transmits data to the Web server via Wi-Fi for storage, analysis, and data visualization for decision makers. The data was further analyzed using other tools such as Grafana and Microsoft excel.

The expected results from the study are a customized dashboard showing real time values of variables collected using prototype developed in a graph.

Abbreviations

IoT: Internet of Things

MQTT: Message queuing telemetry transport

TTN: The thing network

IAQ: Indoor air quality

REMA: Rwanda Environment Management Authority

Ppm: Particle Per Millions

EPA: Environment Protection Agency

CO: Carbon monoxide

CO2: Carbon dioxide

NO2: Nitrogen dioxide

PM: Particulate Matters

WHO: World Health Organization

VOC: Volatile Organic Compound

IDE: Integrated Development Environment

SDGs: Sustainable Development Goals

WSN: Wireless Sensor Network

AQI: Air Quality Index

ARIMA: Auto-Regressive Integrated Moving Average

AWS: Amazon Web Service

GPS: Global Positioning System

COVID: 19-Coronavirus disease 2019

RURA: Rwanda Utilities Regulatory Authority

ML: Machine Learning

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Chapter 1: Introduction

1.1 Background

Indoor Air Quality involves the purity of air conditioning in a confined environment such as buildings, offices, homes, classrooms and shopping malls. Air is polluted by harmful substances such as Particulate Matter, Sulphur dioxide, Oxides of Nitrogen, Carbon monoxide and other harmful gases that are emitted from industrialization, urbanization and vehicles. Air pollution affects the general population slowly in a way that it does not get detected easily. According to World Health Organization (WHO) Global Ambient Air Quality research done in 2016 [1], population in low- and middle- income cities are the most impacted. In fact, 98% of cities in low- and middle-income countries with more than 100,000 inhabitants do not meet WHO Air Quality guidelines [1].

As air quality declines, the risk of stroke, heart disease, lung cancer, and chronic and acute respiratory diseases.

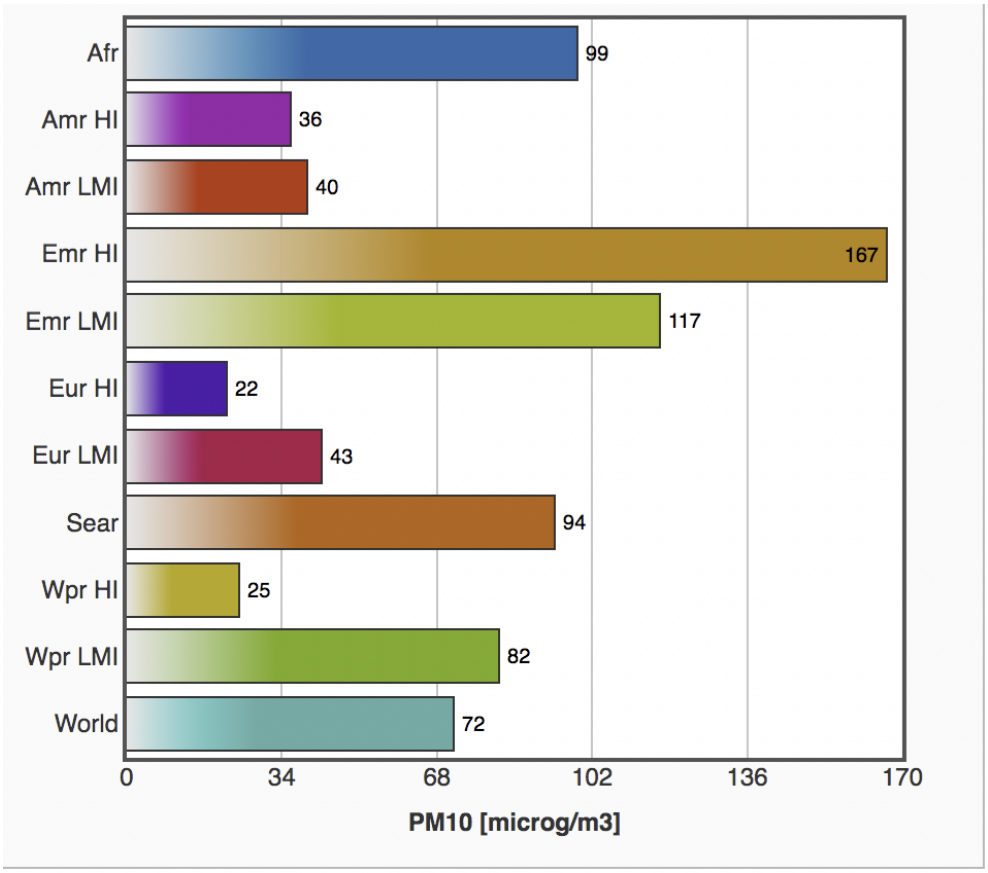


Figure 1.1: Particular Matter (PM10) levels by region, for the last available year in the period 2008-2016 (WHO)

Indoor air pollution can occur from a huge variety of sources such as fuel combustion, products for household cleaning, excess moisture and inadequate ventilation can increase indoor pollutant levels by not bringing in enough outdoor air to dilute emission from indoor sources. It can aggravate, irritate, and in some cases, cause serious harm [2]. Monitoring the quality of air requires measuring the concentration of several pollutants, such as carbon monoxide (CO), Sulphur dioxide (SO2), nitrogen dioxide (NO2), ozone (O3) and Volatile Organic Compounds (VOCs) [3].

It is often difficult for air conditioning managers who control ventilation inside buildings to obtain real-time indoor air quality (IAQ) data, and hence resort to over-ventilation to ensure safe levels of pollutants in their buildings. Air quality in a confined place inhabited by humans is not always pure due to decreased oxygen level and increased CO2 and also increased indoor temperature and humidity which can affect human effect due to poor ventilation or inflow of outdoor air. This can be monitored using Internet of things technology and necessary action is taken by the authority concerned to curb this.

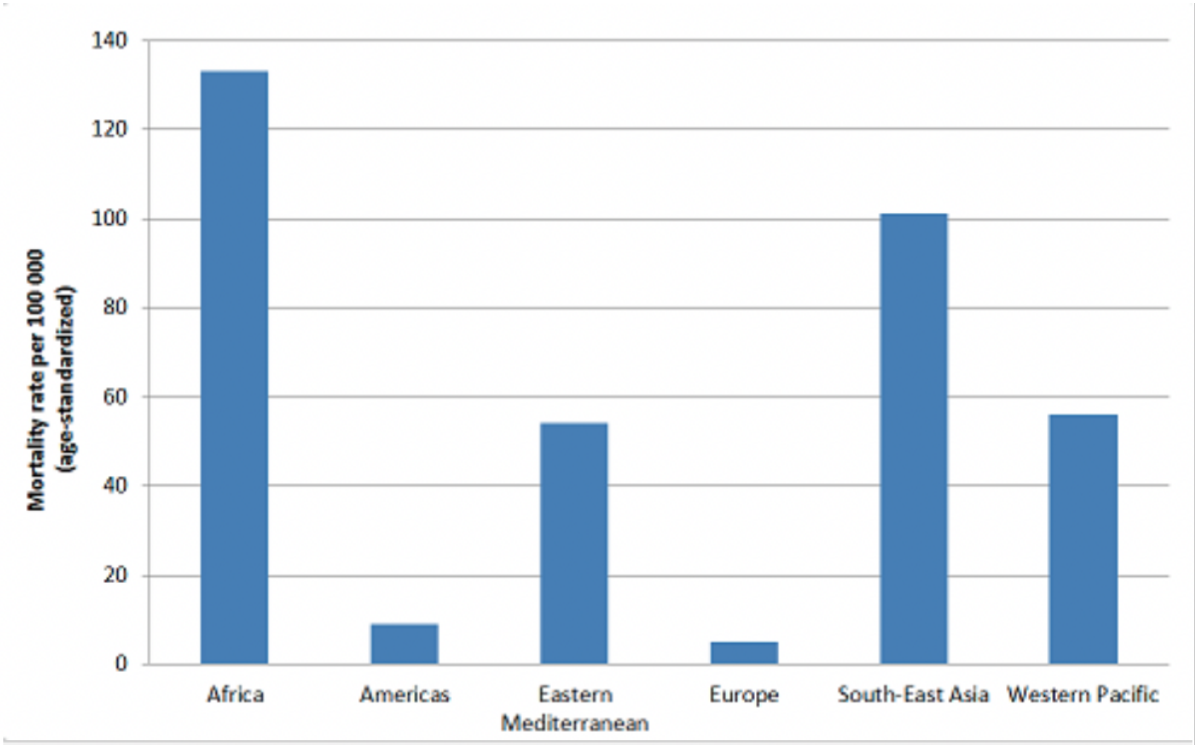


Figure 1.2: Mortality rate as a result of household air quality (WHO 2016)

Several related works to curb both indoor and outdoor air pollution have been proposed and also systems implemented mostly in India and West countries, in all research work the modern technology of the Internet of Things is used with other cloud based applications.

Currently most of the organization and governmental institutions in charge of the environment are focusing on air pollution monitoring caused by human activities, gas emission from industrial centres and vehicles. Rwanda has a policy framework governing air pollution caused by various factors and it also makes use of the WHO policy on air quality [4].

There are different approaches to monitor air quality which have improved on how air pollution is monitored and the research data are used by different people to identify the gap and also to learn about the conditions of different areas in relation to air quality.

The existing approaches have covered different areas of air pollution management but they are limited to monitoring air quality in outdoor and indoor environments. With the different pandemics going on, monitoring air quality in public transport is very important in this case to control the spread of diseases by using the data obtained. Air quality in public transport is different in that people are confined in that environment for a few minutes or hours on transit depending on the distance to their destination and the existing approach will not be suitable in this scenario.

The proposed IoT-based air quality monitoring system in public transport will address this problem by collecting air quality data using sensors installed in buses and transmitting the data to cloud for analysis and quick response, this system will also give alert signals for proper ventilation. The data can be used by authorities concerned to make future decisions to improve on the current situation identified and the results will give greater understanding on air quality in public transportation.

This research will give the background information on air quality with statistics, brief description of related work, methodology used, system analysis and design, data collection and analysis, system validation and testing, conclusion and future recommendations.

1.2 Problem Statement

The majority of African population uses public transport, mainly buses, in their daily activities within and outside the cities. Most of those buses have the capacity of carrying about 50 passengers or more depending on the country's policy. Unfortunately, most of these buses do not have a stable air quality monitoring system and this is critical because polluted air can lead to various diseases such as coronary heart, tuberculosis and asthma [2].

Few works [5] [6] [7] [8]attempting to address air quality monitoring in outdoor and indoor environment exist but do not cover the case of air quality monitoring in public buses. I believe that an internet of things based solution can advance the state of the art in this field.

This research will design and implement an air quality monitoring system in public transport in Kigali, Rwanda. The system will be able to automatically identify and examine the impurities, check against the accepted threshold in the Air Quality index and inform the authority for further actions. It will also include an alert subsystem for in-place actions like opening windows etc. The proposed solution will help the government of Rwanda in achieving its smart city vision which includes the reduction of air pollution.

The proposed system can also contribute in achievement of Sustainable Development Goals (SDGs) [6]: (i) Goal 3, good health and well-being since air quality related diseases are among the deadly disease the proposed system will reduce on the risks involved with air quality; (ii) Goal 11, sustainable cities and communities because the proposed system will enhance monitoring of pollution from environmental gases which affects human health; and (iii) Goal 13, climate change as the proposed system will help in detection of air quality gases which has negative effect of the climate and rain pattern.

The Covid-19 pandemic has brought health and economic crisis worldwide, but from the perspective of sustainable environment lockdown is very healthy but not a sustainable solution to control air pollution.

1.3 Objectives

The general objective of this research is to develop an IoT based air quality monitoring system to manage the air quality in public transport. The specific objectives are:

a) To design and implement an air quality monitoring system, this involves assembling of the hardware devices used and configuration of the hardware using Arduino IDE.

b) To design and implement a web-based application to store, analyze and visualize the data obtained by the gas sensors, it involves setting up a web application to connect with hardware devices.

c) To determine the quality of air in public transport and effect on human health.

1.4 Research Questions

1. How can current technology be used to monitor air quality in public transport?

2. How the air quality data collected in public buses will be analyzed and visualized?
3. How harmful is air quality in public transportation and what are the benefits of using the Internet of Things to monitor air quality?

1.5 Significance of the Study

1. This research will contribute to the existing pool of knowledge, many research has been done but none focuses on air quality in public buses, this study will be focusing on aspect of public buses and it will give researchers in academia and health sectors access to data. The authority concerned with air quality monitoring can make use of the data in decision making in terms of precautions or formulation of guidelines to be adhered to.
2. The system developed will enable passengers and bus companies to take precautions of having proper ventilation and protective gears.
3. The results can be used by relevant authority to implement safety measures or regulations for air quality
4. The system will contribute in achievement of Sustainable Development Goals (SDGs): (i) Goal 3, good health and well-being since air quality related diseases are among the deadly disease the proposed system will reduce on the risks involved with air quality; (ii) Goal 11, sustainable cities and communities because the system will enhance monitoring of pollution from environmental gases which affects human health; and (iii) Goal 13, climate change as the system will help in detection of air quality gases such as carbon monoxide and carbon dioxide which has negative effect of the climate and rain pattern.

1.6 Scope of the Study

This research focuses on collecting air quality data in public buses in Kigali City. The study consists of using environmental sensors integrated with other hardware and application platform to monitor air quality. The study does not cover air quality in buses outside Kigali City and it is limited to four variables (CO, CO2, temperature and humidity).

1.7 Motivation of the Study

For someone who uses public transport in day-to-day life, one encounters different challenges such as overcrowded bus and poor supply of air. Many people spend few minutes or hours on

transit; therefore, conducive environment is needed for larger population of people in the continent using public buses as main means of transport.

1.8 Organization of the Document

The remainder of this document is organized as follows: Chapter 1 introduction, comprises of background, problem statement, objectives, research questions, significance and scope of the study; Chapter 2 gives the breakdown of related work; Chapter 3 Methodology, presents the general introduction, descriptions of components and platform used; Chapter 4 Implementation, comprises experiment setup, circuit diagram of prototype, configuration and deployment of the prototype; Chapter 5 Results and discussion, presents the analysis of collected data, visualization and interpretation of results; and Chapter 6 concludes the document by presenting the recommendations drawn from this study.

Chapter 2: Literature Review

There are several works related to air quality monitoring and some air quality monitoring systems have been developed. This section reports on the ones closest to my research. Those works can be grouped into three categories: Outdoor (Section 2.1), Indoor (Section 2.2) air monitoring and air quality statistics in Rwanda (Section 2.3).

2.1 Outdoor Air Quality Monitoring

This category is further subdivided into mobile application-based and cloud server-based approaches.

2.1.1 Mobile Application-based Approaches

In [7] an IoT mobile-air pollution monitoring system (IoT-Mobair) is developed. Involves the detection of concentration of CO, CO2, and Methane (CH4) in the area of interest using gas sensors, Arduino Uno microcontroller and ESP8266 for Wi-Fi module. The sensed data is transmitted to Ubidots cloud platform for storage. The users can access this information on IoT-Mobair mobile applications using their Android devices. The application allows users to check the quality of air of a specific route by using google map to set destination.

Real-time AQI monitoring system: An economical approach using wireless sensor network (WSN) is developed where child sensor nodes collect pollutant data and send it to the central hub termed as parent node. Central hub gathers data from child nodes, calculates AQI of the data and also acts as a gateway to the cloud which is Firebase [8]. Firebase analyses and stores all the data received and the real-time data are then forwarded to custom mobile applications (Android and IOS platforms) over the internet where end users can easily access pollution data from anyway [8].

2.1.2 Cloud Based (MQTT, Web Server app)

Outdoor Air Quality Monitor Using MQTT on Smart Campus Network. This system consists of sensor nodes, broker and web-based server. The variables measured are Oxygen (O2), Carbon monoxide (CO), Carbon dioxide (CO2) and Nitrogen hydroxide (NH3). The sensed data are sent to the broker connected via private Wi-Fi every 5minutes delay then sent to a local web server which displays the measurement graph at sensor nodes. The gas sensor MQ811 consumes more power compared to MQ7 as it uses a heater as the internal part of the sensor [9].

In [10] Smart air quality monitoring system with LoRaWAN has been proposed. A machine learning model (a python implementation of Auto-Regressive Integrated Moving Average, ARIMA) is used to give expected values of air quality parameters based on the input datasets. The sensed data are transmitted to LoRaWAN gateway which forwards the data to the Things Network (TTN) server. TTN server acts as both MQTT broker and publisher when transferring data from TTN server to database, the subscriber application in cloud server subscribes to the data in TTN server. A time series InfluxDB database is used and Grafana is used to allow users to acquire data with a user-friendly interface.

In [11] an IoT based low cost air pollution monitoring system has been proposed. It is composed of a perception layer (sensing layer), network layer and application/presentation layer. In the sensing layer, a low power microcontroller that is Nucleo is used with MQ7 and MQ135 gas sensors to detect CO, CO2 and NH3 gases. Low cost ESP8266 serial- Wi-Fi module is used to transmit sensed data to a central server in a base station which is Raspberry pi 3 used as a gateway (Network layer). Application layer consists of Raspberry pi 3 micro-computer which handles data transmission using TCP server implemented, data storage using MangoDB installed and also works as a web server for data visualization and a web page is implemented using MEAN stack.

The work reported in [12] is the one closest to my study because it studies the air quality in public buses using wireless sensors. Sensor nodes are installed in buses and sink nodes installed on the streets where there is a road junction. The sensor node collects environmental data and transfers the processed data to sink nodes nearby, the sink node aggregates the received data and sends them to the cloud using the long- range radio method. The sink node removes redundancy due to overlapping [12].

2.2 Indoor Air Quality Monitoring

Indoor air quality monitoring system with Fuzzy Logic control based on IoT is developed using CO2 sensor, PM10 sensor, Arduino and Raspberry pi 3 with exhaust fan which will automatically turn on/off depending with the threshold of CO2 and PM10 concentrations. The sensor data is sent by MQTT protocol to AWS IoT cloud server for monitoring purposes on the dashboard provided using Kibana in AWS cloud. The dashboard consists of AQI PM10, AQI CO2, real-time graph of CO2 and PM10 values. And also, users can access the dashboard from the browser of devices [13].

Another research is on Wireless Sensor Node for Indoor Air Quality Monitoring System which uses devices such MQ gas sensors, DH11 sensor and Arduino uno, LEDs display, micro SD card for data capturing, Wi-Fi module and power supply. Environmental data are collected and processed by sensor nodes which will drive the status of LEDs to either green indicating clean, yellow indicating moderate and red danger depending on the presence of pollutants in air. The processed data is broadcasted to the web interface and saved to an external SD card [14].

IAQ supervision systems using ZigBee Wireless Networks is another related work which detects presence of harmful substances in air such as CO, CO2 and Particle Matters (PM2.5) at specific temperature and humidity. The data collected by the sensor is transmitted to the computer terminal via XBee network. The Supervision system program compares the data received with the standard value from Environmental Protection Administration (EPA) and automatically operates the ventilation system if it exceeds the normal so as to refresh the air. Users are able to observe the current status using their handheld devices with internet connection and link to specific websites [5].

In research on "Development of an IoT-Based Indoor Air Quality Monitoring Platform", Smart Air is developed, the parameters measured by Smart Air are CO, CO2, VOC, dusts, temperature and humidity. The set of sensing devices to collect the data consisted of a laser dust sensor, CO sensor, CO2 sensor, VOC sensor and temperature and humidity sensor. Smart Air to collect accurate and reliable data from the indoor environment and transmit to the web server via LTE modem for analysis and visualization. The platform was designed with also LED strips to alert users and managers through the web server and mobile application when poor air quality is detected. Amazon Web Service (AWS) was used as a web server to analyze, visualize and present the data collected from smart air and also a web server provides a database to store data in the cloud and a mobile application was developed for end users to visualize air quality in real time [15].

A similar system developed is a wireless indoor air quality sensor for health management using IoT with focus on Asthma disease. The system collects air quality parameters using sensors such as CO, dust sensor, temperature and humidity sensor, and the sensed data is given as input to an Arduino microcontroller which is already programmed with the threshold values of different air quality. The microcontroller compares the received values with the threshold values and if the received value exceeds threshold value microcontroller gives indication to the user (holder of the device) and the caretaker who in this case is a medical practitioner through cloud based architecture [16].

Table 2.1: Summary of the Literature Reviewed and Their Gaps

S/N	AUTHORS	Description and Technique applied	Accomplishment	Gaps and Remarks
1	Pradityo et al. [6]	Use of Mamdani Fuzzy Logic in exhaust fan which automatically turn depending on gas threshold.	Automation	Detect limited variables Making it less reliable and not working in buses.
2	Tijani et al. [8]	Wireless Sensor Node to Monitor AQ and show status on LEDs.	Affordability and Simplified data presentation for to end users	Reliability but does not work on public transport.
3	Muladi et al. [12]	Use MQTT protocol to transmit Sensed data in campus environment to web server.	Simplified setup	High power usage by MG811 sensor
4	Saha et al. [15]	Sensor nodes installed in buses to collect environmental data and send data to sink nodes on the street which agg the data and transmit via long range ra cloud.	Sink node removes redundancy caused due to overlapping	Limited to regions covered by long range.
5	Parmar et al. [14]	IoT based low cost air quality monitoring MQ series sensors, ESP8266 and Raspberry pi which act as gateway, storage and web server for data visualization.	Cost effective	Not suitable for targeted environment.
6	Dhingra et al. [10]	IoT-Mobair, mobile application based collected data is transmitted to Ubidots storage via ESP9266 Wi-Fi module.	Mobility	Not suitable for targeted environment.
7	Thu et al. [13	Smart air quality monitoring system, ML model is used for prediction of expected values of parameters, LoRaWAN is used as a gateway and TTN server acting as publisher and broker.	Reliability, Cost effective, wide coverage.	No LoRaWAN coverage in targeted environment.
8	Rane et al. [11]	Real-time AQI monitoring system, sensor nodes transmit data to central hub (cloud gateway) which then forward to Firebase for storage and analysis. Users access data through custom-application on Android and IOS phone.	Cost effective	Not suitable for targeted environment.

The summary of related work in Table 2.1 shows the existing work reviewed and the gaps for each study. Unlike the existing studies which focuses on air quality in outdoor and indoor environment, my work focuses on air quality in public buses.

The existing transport system currently in place do not have air quality monitoring component, therefore, the authority in charge of transport need to upgrade the current system with air quality functionalities to make public bus environment safer for passengers.

2.3 Air Quality Case Statistics in Rwanda

According to WHO press report 2014 [17], poor air quality is considered the world's largest environmental health risk, around 87% of the global death occurs in low and middle income countries with over three million premature deaths due to poor air quality. Out of three million premature deaths, 211,000 which is 7% occurred in Sub-Saharan Africa.

According to WHO report 2016, 2227 deaths were caused by ambient air pollution in Rwanda and the main cause was acute respiratory and stroke [3].

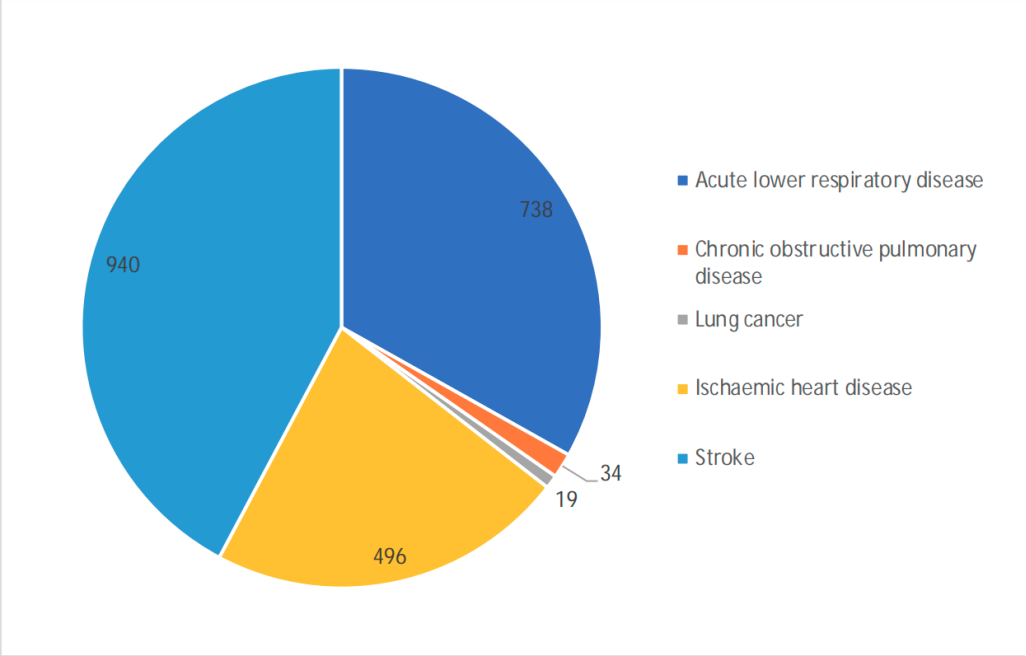


Figure 2.1: Deaths in Rwanda, attributed to ambient air quality 2012 (WHO 2016)

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

Key pollutants of concern in Rwanda are:

- Nitrogen oxides (including oxides of nitrogen (NOx) and nitrogen dioxide (NO2))
- Sulphur dioxide (SO2)
- Particulate matter (PM10) and 2.5 microns (PM2.5))
- Ozone (O3)
- Carbon monoxide (CO)

According to REMA inventory of Sources of Air Pollution Report conducted in 2018 [19], no one sector is biggest contributor of air pollution within Rwanda as the air pollution levels are dependent on the sources of pollution such as locations adjacent to the road, emissions from vehicle which are the biggest contributor to poor air quality, domestic cooking stoves also contribute to pollution in residential areas. Emission from industrial centres or power plants has high pollutants, but the effects are minimal since plants are located in less populated residential areas.

The air we breathe is composed of different gases and other particles, the concentration of pollutants such as oxides of sulphur and carbon determines the quality of air. The authority concerned that is government agencies and environmentalists use the air quality index (AQI) to confirm to the general public whether the air is polluted or not for residents. Countries have different ways of calculating AQI for instance the United States use four pollutants (ozone, particulate Matter, sulphur dioxide and carbon monoxide) to calculate air quality with the index scaling from 0 to 500 [20].

Chapter 3: Methodology

This chapter presents a high-level architecture of the proposed air quality monitoring system. The system is subdivided into three layers (see Figure 3.1): sensing, computing, and data analysis and visualization. Sensors are used to detect different environmental parameters: MQ7 sensor used to detect carbon monoxide gas, MQ135 is air quality sensor used to detect carbon dioxide, DHT11 sensor for detecting temperature and humidity, and GPS sensor for location. The gas sensors are connected to ESP8266 through a multiplexer since Nodemcu has only one analogue pin and other digital sensors like DHT11 are connected directly. The collected data are sent to Adafruit IO cloud through esp8266 Wi-Fi module. Adafruit platform analyzes and visualizes processed data on the dashboard and also stores the data in Adafruit.

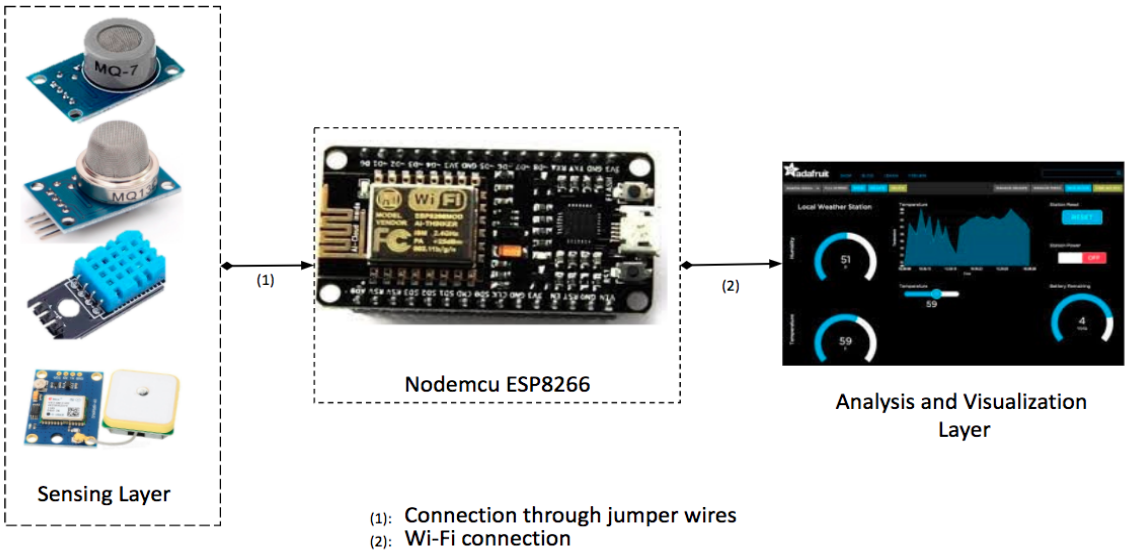


Figure 3.1: High level architecture of IoT-based air quality monitoring system

3.1 Sensing Layer

The sensing unit consists of 4 sensors: MQ135, MQ7, DHT11, GPS

Table 3.1: Sensing unit measurement parameters

Sensors	**Operating Conditions**	**Range**	**Parameters Measured**
MQ135	5V	10-10000ppm	Carbon dioxide
MQ7	5V	10-10000ppm	Carbon monoxide
DHT11	3.3V-5V	20% - 90% 0°C – 50°C	Humidity Temperature

3.1.1 MQ135

The MQ-135 is a gas sensor used for air quality control and is suitable for detecting NH3,NOx,alcohol, benzene ,smoke ,CO2,etc. Sensitive material of MQ-135 gas sensor is SnO2,which has lower conductivity in clean air. When the target combustible gas exists ,the sensor's conductivity is higher along with the gas concentration rising. Please use a simple electric circuit, convert change of conductivity to correspond to output signal of gas concentration [21]. The MQ135 gas sensor has high sensitivity to ammonia , Sulphide and Benzene steam, also sensitive to smoke and other harmful gases. It has low cost and is suitable for different applications.



Figure 3.2: MQ135 gas sensor *[22]*

3.1.2 MQ7

According to the MQ7 datasheet, the sensor has to run through high- and low-heating cycles in order to get proper measurements. During low temperature phase, CO is absorbed on the plate, producing meaningful data. During high temperature phase, absorbed CO and other compounds evaporate from the sensor plate, cleaning it for the next measurement. Therefore 5V is applied to heat the sensor for about 60seconds at this

stage readings are not considered since it is false values, the next reading after applying 1.4V for about 90seconds is considered to get the measurements for CO [23].



Figure 3.3: MQ7 gas sensor *[22]*

3.1.3 MQ135 and MQ7 Connection

These gas sensors have 4 pins: VCC, GND, DO (Digital Output) and AO (Analog Output) [22]. The analog output of MQ7 and MQ135 is between 0-5V while the analog pin of Nodemcu can only read between 0 to 3.3V. Therefore, voltage step down is needed. Voltage divider with two resistors is used in this project.

Three pins of each gas sensors are connected:

VCC to 5V power supply

GND to Nodemcu GND pin

A0 to CD4052BE channel multiplexer Pin 1 and 13

3.1.4 DHT11

The DHT11 is a commonly used Temperature and humidity sensor**.** The sensor comes with a dedicated NTC to measure temperature and an 8-bit microcontroller to output the values of temperature and humidity as serial data. The sensor is also factory calibrated and hence easy to interface with other microcontrollers.

The sensor can measure temperature from 0°C to 50°C and humidity from 20% to 90% with an accuracy of ±1°C and ±1%. So if you are looking to measure in this range then this sensor might be the right choice for you [23].

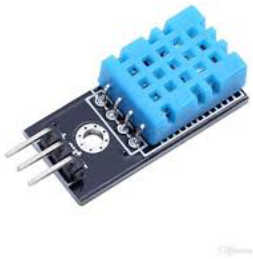


Figure 3.4: DHT11 sensor [23]

3.2 Processing Layer

3.2.1 Nodemcu ESP8266

The Nodemcu ESP8266 development board comes with the ESP-12E module containing ESP8266 chip having Tensilica Xtensa 32-bit LX106 RISC microprocessor. This microprocessor supports RTOS and operates at 80MHz to 160 MHz adjustable clock frequency. Nodemcu has 128 KB RAM and 4MB of Flash memory to store data and programs. Its high processing power with in-built Wi-Fi / Bluetooth and Deep Sleep Operating features make it ideal for IoT projects.

Nodemcu can be powered using Micro USB jack and VIN pin (External Supply Pin). It supports UART, SPI, and I2C interface.

The board can be easily programmed with Arduino IDE since it is easier to use, using only Arduino IDE, USB cable and Nodemcu board [21].

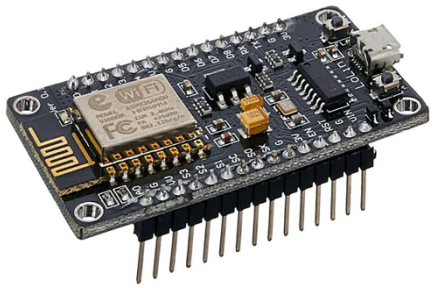


Figure 3.5: Nodemcu ESP8266 [24]

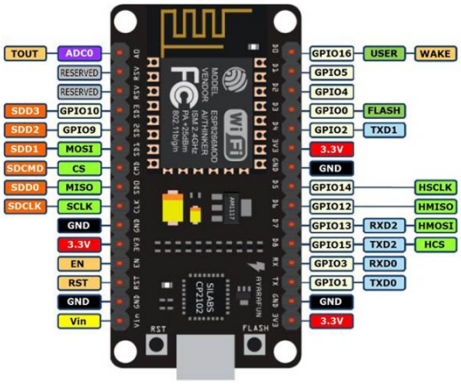


Figure 3.6: Nodemcu pinout diagram *[24]*

One of the drawbacks of Nodemcu is that it supplies only 3.3V output. It cannot provide enough power to run these gas sensors from its pins - sensor's heater requires 150 mA at 5V to operate, while ESP8266 pin can provide no more than 40 mA at 3.3v, so if attached directly, the controller pin will burn and sensor will not work. So we must use some kind of current amplifier that takes small input current to control large output current. Logic level converter is used to bridge between 5V DC devices and 3,3V DC for Nodemcu ESP8266 microcontroller.

Another limitation of Nodemcu is that it has only one analog I/O pin. Both gas sensors use analog pins to overcome this drawback analog multiplexer CD4051BE is used which is an 8 channel multiplexer.

3.2.2 CD4051BE Analog Multiplexer

Is a single 8-channel multiplexer with three binary controls input A, B and C, an inhibit input. the three binary signals select 1 of 8 channels to be turned on and connect one of the 8 inputs to the output [25].

Figure 3.7 shows the pinout of 8 channel multiplexer and table 3.2 shows the functions of each pin.



Figure 3.7: CD4051BE Pinout diagram *[25]*

Table 2.2: CD4052BE Multiplexer Pin Functions

Pin		I/O	Descriptions
NO.	**NAME**		
1	CH 4 IN/OUT	I/O	Channel 4 in/out
2	CH 6 IN/OUT	I/O	Channel 6 in/out
3	COM OUT/IN	I/O	Common out/in
4	CH 7 IN/OUT	I/O	Channel 7 in/out
5	CH 5 IN/OUT	I/O	Channel 5 in/out
6	INH	I	Disables all channels.
7	V_{EE}	-	Negative power input
8	V_{SS}	-	Ground
9	C	I	Channel select C
10	B	I	Channel select B
11	A	I	Channel select A
12	CH 3 IN/OUT	I/O	Channel 3 in/out
13	CH 0 IN/OUT	I/O	Channel 0 in/out
14	CH 1 IN/OUT	I/O	Channel 1 in/out
15	CH 2 IN/OUT	I/O	Channel 2 in/out
16	V_{DD}	-	Positive power input

3.2.3 4-Channel Low Level Converter

The main reason for this DC converter is to bridge between the 5V DC device and the Nodemcu microcontroller used in the prototype which uses 3.3V DC. It shifts 3V up to 5V power supply required by gas sensors. For this to work the board needs to be powered from two power sources, high voltage and low power voltage that system is using [26].

Figure 3.8 shows the connection of logic level converter:

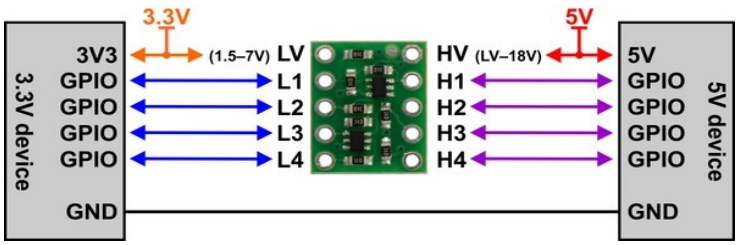


Figure 3.8: 4-Channel logic level converter [27]

3.3 Data Analysis and Visualization Layer

3.3.1 Adafruit IO

The platform used for this prototype is Adafruit IO server which is an open source platform with varieties of libraries for implementing Internet of Things projects. The libraries are available in different languages such as Python, C, Java, JavaScript and many others. For this project C programming language is used in Arduino IDE platform, a general-purpose MQTT library for Arduino that is built to use few resources so that it can work with Arduino Uno and Nodemcu is used. MQTT or message queue telemetry transport, is a lightweight protocol for device communication that Adafruit IO supports [27]. Using a MQTT library or client you can publish and subscribe to a feed to send and receive feed data. For this project different feeds for each parameter is created and linked to the dashboard. The feed stores the data of specified parameters for instance humidity or temperature feed to store data collected by DHT11 sensor from the environment, Air quality feed to store data collected by MQ135 gas sensor. The data collected will be continuously fed to the server and timely updated on the dashboard.

Figure 3.9 shows the block design of how prototype works from data collection stage to data visualization.

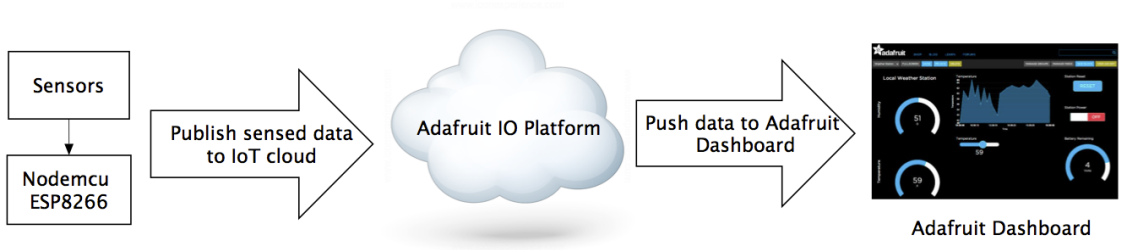


Figure 3.9: Block Diagram of Cloud Data Analysis

3.3.2 MQTT Protocol

MQTT (Message Queuing Telemetry Transport) is a lightweight publish/subscribe messaging protocol for internet of things applications. It is suitable for devices with limited resources [30].

The MQTT protocol is based on principle of publishing massages and subscribing to topics. Multiple clients connect to broker and subscribe to different topics of their interest, clients

also connect to broker to publish messages to the topics. Figure 3.10 shows the publish subscribe working principle of MQTT.

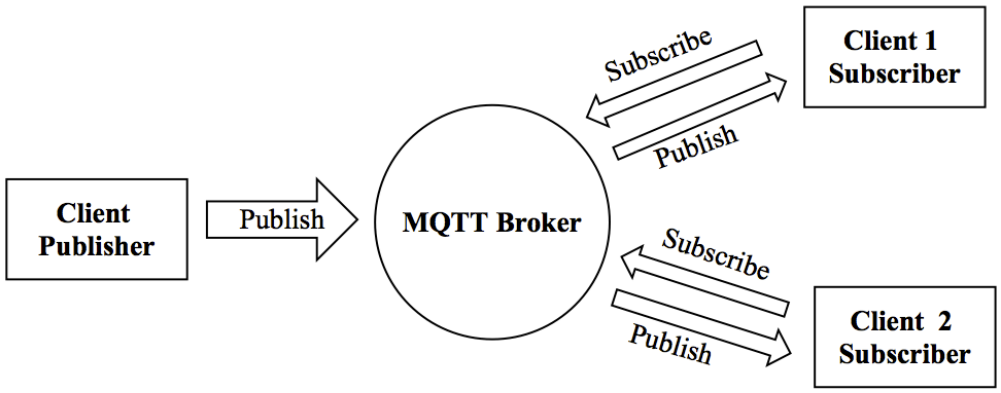


Figure 3.10: MQTT Publisher Subscriber

3.4 Other Tools Used for Data Management

In this system implementation, Node-RED was used to wire incoming data from sensor node, Node-RED process the data and is stored in influxDB and Grafana query data stored in influxDB and visualize in customizable dashboard.

3.4.1 Node Red

Node-RED is an open source flow-based development tool for the integration of IoT hardware devices, APIs (Application Programming Interfaces) and online services developed by IBM Emerging Technology [28]. Node-RED is a free JavaScript-based tool, built on Node.js platform, which provides a visual browser-based flow editor. The system contains nodes that are represented by appropriate icons. It can operate in two ways: drag, drop and wire up nodes, or import JavaScript code.

Node-RED enables developers to wire up input, output and processing nodes in order to create flows for data processing, controlling things, or sending alerts [29].

Node-RED merges IoT devices and services and stays within local area network, Is based on a graphical interface and relies on three components;

- Flow-this is a project, consisting of data and functions linked together.
- Nodes-are functions that generate, transform and use messages.
- Messages-carries the data from one node to another.

Figure 3.11 shows Node-RED control system with MQTT nodes, database and the display node.

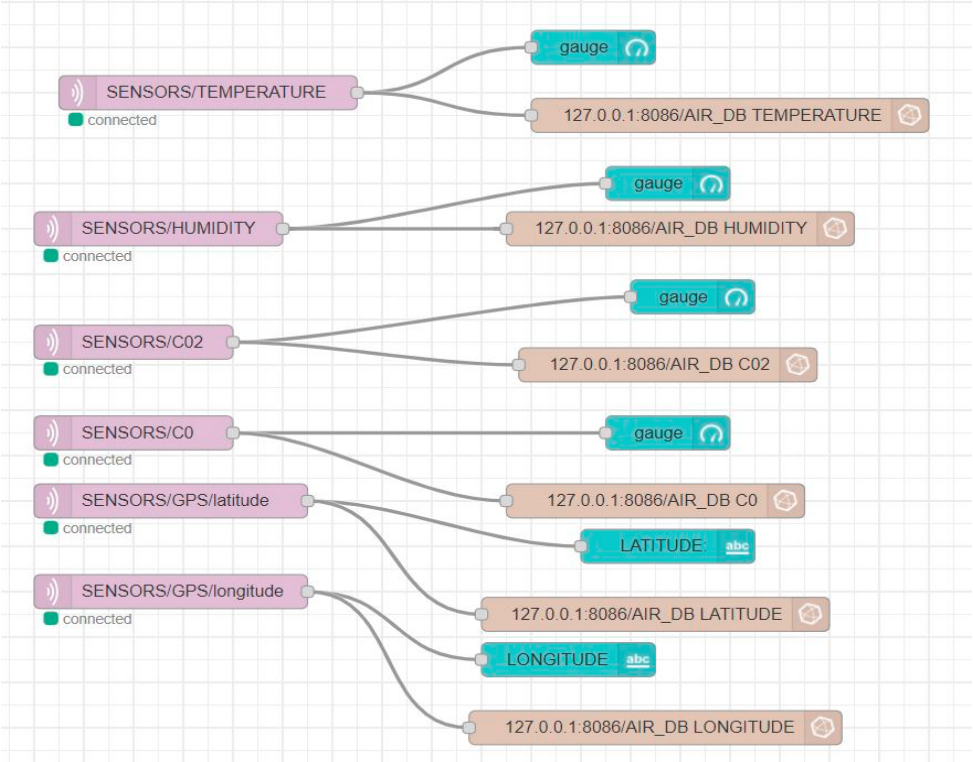


Figure 3.11: Node-Red flow control

3.4.2 InfluxDB

InfluxDB is an open-source time series database developed by InfluxData. It is written in Go and optimized for fast, high-availability storage and retrieval of time series data in fields such as operations monitoring, application metrics, Internet of Things sensor data, and real-time analytics [31].

3.4.3 Grafana

Grafana is an open-source platform for data visualization, monitoring, analysis, Querying and alerting. In Grafana, users can create dashboards with panels, each representing specific metrics over a set time-frame. Grafana supports graph, table, heatmap and freetext panels [32].

Chapter 4: Configuration and Deployment

This chapter tells us how sensors have been connected to Nodemcu ESP8266 with external power supply from a 10000mAh power bank connected through USB cable. For data collection, the system was placed in public bus transportation routed Nyamirambo-Nyabugogo-Kimironko Kigali City, Rwanda. The system is used to monitor the air quality in public which is overcrowded most of the time but due to current pandemic Covid-19 a lot of restrictions are set and the number of passengers have been reduced by half which will definitely affect the result.

In this prototype (Figure 4.1 shows), four sensors were used to collect data on humidity, temperature, carbon monoxide and carbon dioxide sensors. The system collects data and transmits over wireless to cloud platforms which analyze and visualize on dashboard.

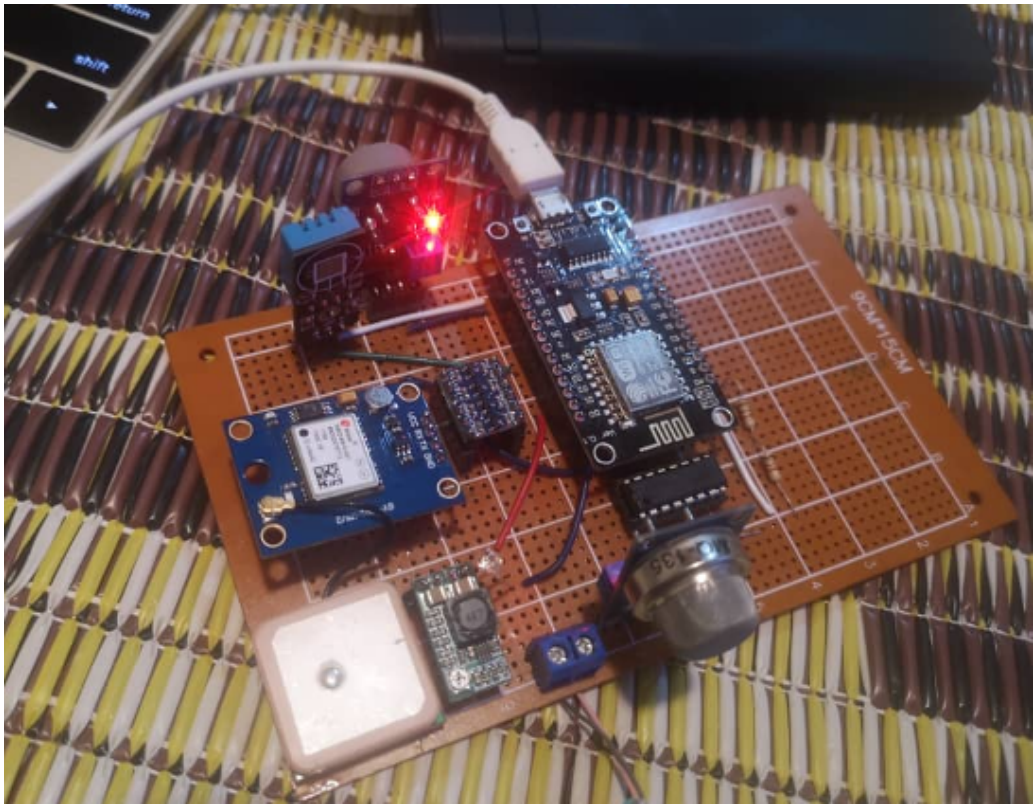


Figure 4.1: Experimental setup of prototype

4.1 Components Configuration

The circuit diagram in figure 4.2 shows how components are connected to the Nodemcu microcontroller. The analog pin of two gas sensors MQ7 and MQ135 are connected to analog pin of Nodemcu through a multiplexer pin 13 which is channel (CH0) and pin 1 which is channel (CH4), the ground pin of all sensors are connected to ground of Nodemcu, gas

sensors require 5V but Nodemcu supply only 3.3V to overcome that DC converter is used to step up 3.3V from Nodemcu to 5V power. Analog multiplexer is used because Nodemcu has only one analog pin, the output of DHT11 is connected to a digital pin (D5) of Nodemcu. MQ 7 and MQ135 collect carbon monoxide and carbon dioxide data, DHT11 detects temperature and relative humidity inside bus environment and location data and transmit to Adafruit cloud platform, an IoT open source platform at a certain interval. Adafruit has different feeds for all parameters that is temperature, humidity, carbon monoxide and air quality (carbon dioxide), the data transmitted to the Adafruit IO feeds are stored as csv and then fed to dashboard in graphs and gauge for visualizations.

The data can be downloaded from Adafruit feeds for further analysis and visualization using other tools of analysis.

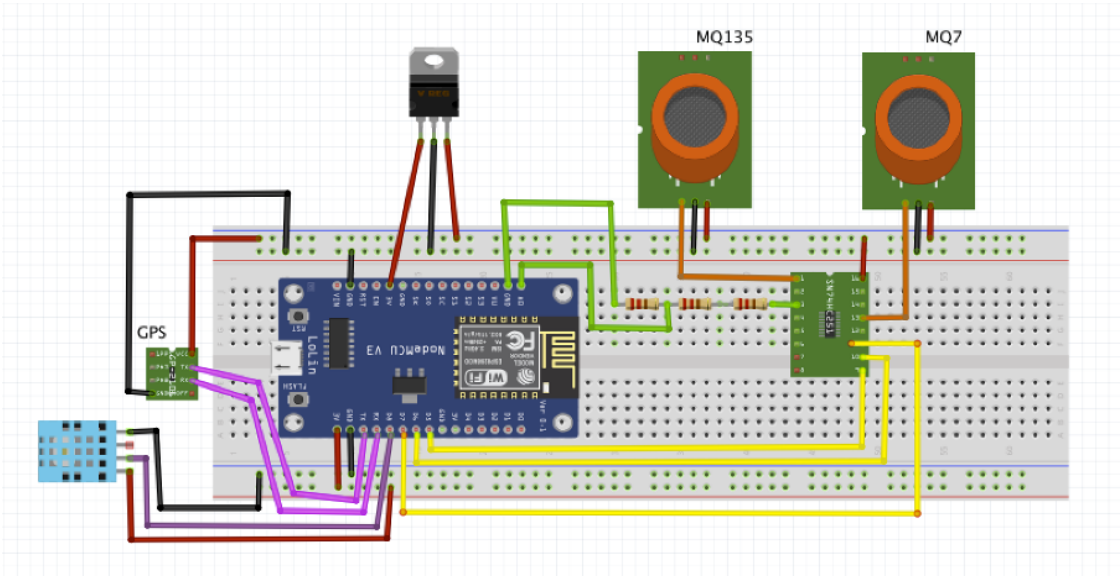


Figure 4.2: Circuit diagram

Figure 4.3 shows the architectural design of the second prototype used. Sensors are connected to ESP8266 Nodemcu which act as a publisher. Nodemcu collect sensor data and transmit to MQTT broker (mqttdashboard.com) server.

Node-RED act as a subscriber to receive data on temperature, humidity, carbon monoxide (CO) and carbon dioxide (CO2) from MQTT broker where sensors publish the data and store information into the InfluxDB database.

Grafana reads the data in influxDB and visualizes on the dashboard which is a local server.

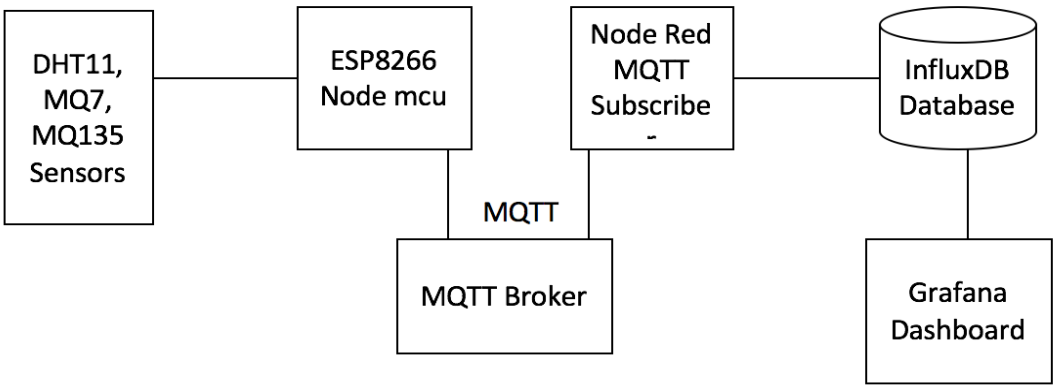


Figure 4.3: Setting 2 System and Software Design Architecture

4.2 Deployment

Figure 4.4 shows temporary deployment of prototype in public bus and the data collected being transmitted to the cloud platform through Wi-Fi.

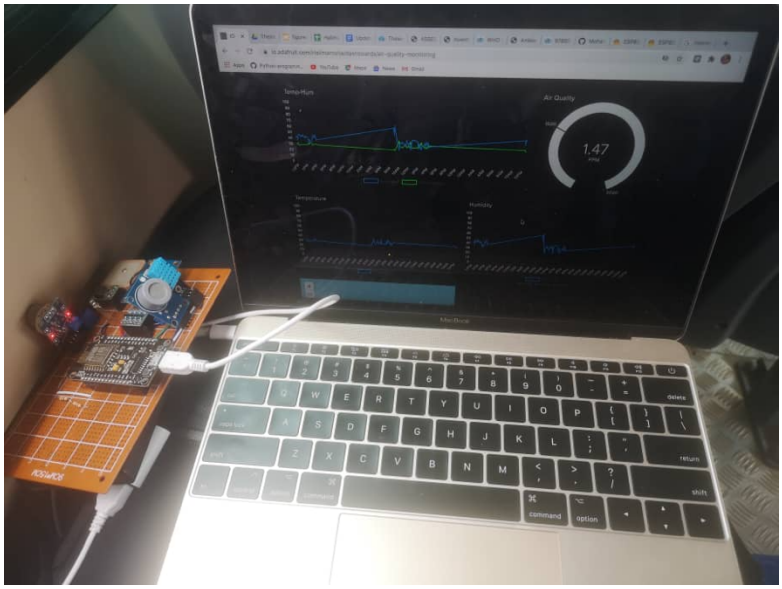


Figure 4.4: Deployment of Prototype in Public Bus

4.3 Challenges faced

The ongoing Covid19 pandemic has affected the general output of the system and also limited movement due to precaution guidelines set in all public transport. The bus company restriction not to install or solder the prototype , the safety and security of the prototype deployed is not guaranteed because different passengers and buses stop at different points to wait for passengers to board.

Chapter 5: Results and Discussion

5.1 Introduction

In this system air quality monitoring system,the prototype switches on once powered and the sensors are active to detect data of each parameter individually with the public bus after every 5 seconds, the gas sensors need to be preheated to obtain close to accurate data but in our case due to limitation in access vehicle battery by the bus company our gases sensors are only supplied with power through 10000mAh power backup.

The system collects humidity, temperature, carbon monoxide and carbon dioxide data within bus transportation and the collected data are transmitted to Adafruit IO cloud platform dashboard via Wi-Fi after every 10seconds.

The data transmitted are stored under feeds of each parameter for that is temperature, humidity, carbon monoxide and carbon dioxide.

5.2 Setting one

The data was collected in public bus for 10 days route 401 Nyamirambo to Downtown big bus with capacity of about 60 passengers but because of Covid-19 restrictions the bus was carrying about 28 passengers and route 402 Nyamirambo- Nyabugogo-Downtown 30-seater with about 15 passengers. The two routes used are shown in Figure 5.1.

- Route 401 Nyamirambo-Downtown
- Route 402 Nyamirambo- Nyabugogo-Downtown

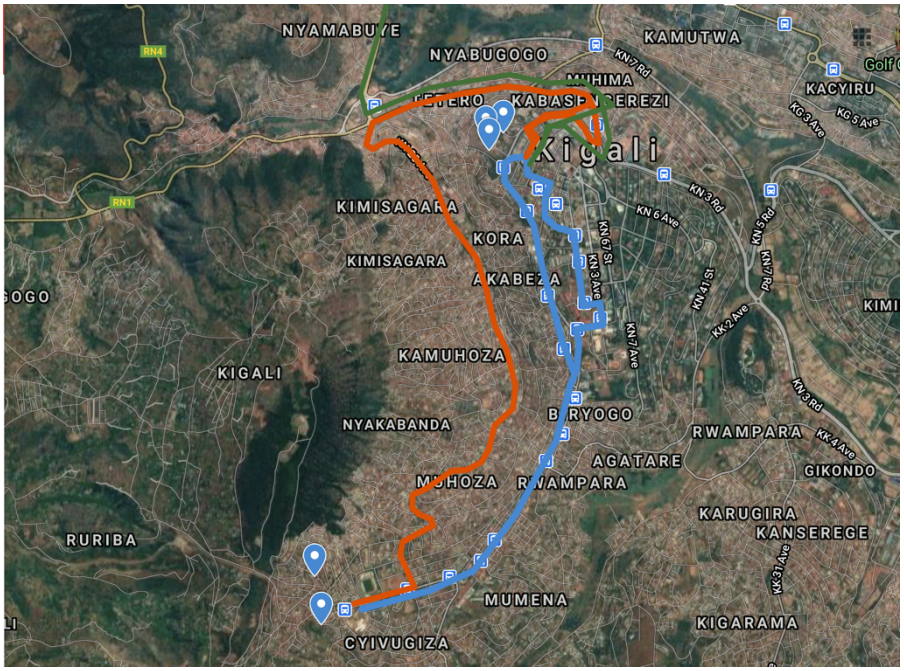


Figure 5.1: Zone 4 Bus Routes for Setting 1

According to the results on the graphs shown in figure 20 the quality of air is very good in public transportation over the period data was collected since the values of carbon monoxide and carbon dioxide are below the thresholds but these results are misleading because it is influenced by conditions in place due to Covid-19 pandemic.

The prototype is installed on bus transport with the assumption that the public transportation is always overcrowded, however, the ongoing Covid-19 pandemic affected the expected output due to the restrictions on the limit of passengers, social distancing and use of face masks. The data needs to be interpreted well to make conclusions on the quality of air.

The study targets full buses with overloaded passengers but the results obtained is for buses with very few passengers, this study may be repeated in future when the normality resumes.

Figure 5.2 shows representation of sample data collected for 5 days; the results shows the quality of air is normal.

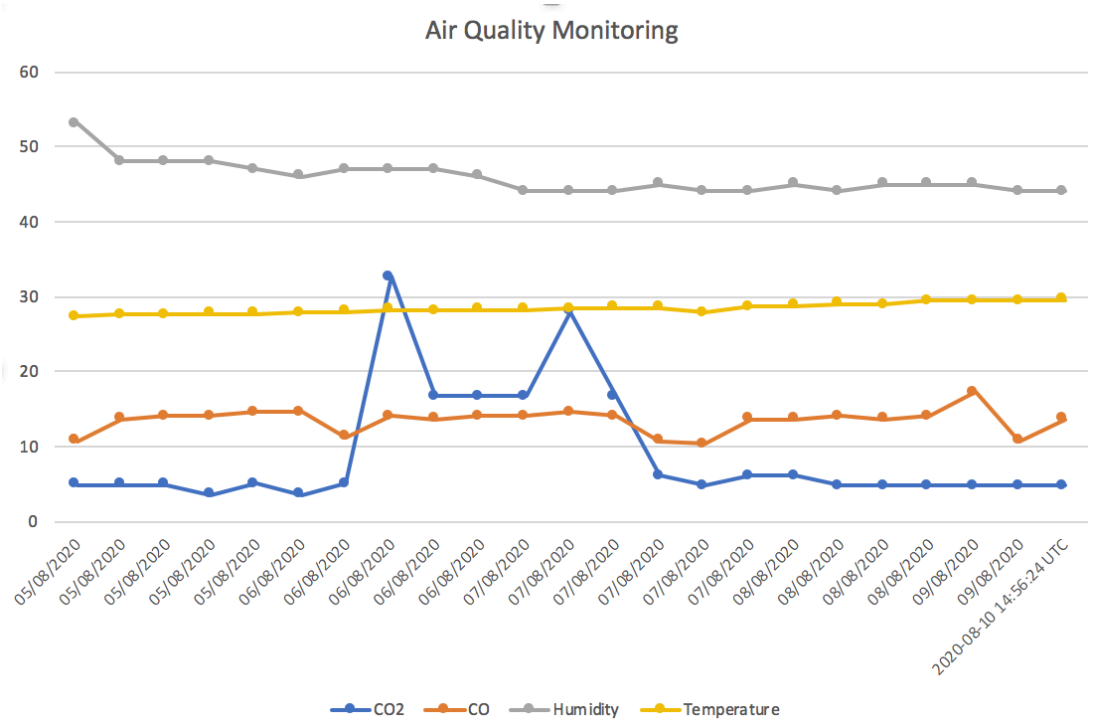


Figure 5.2: Setting 1 Data Representation in Excel

Figure 5.3 shows Air Quality Monitoring Dashboard of the average value of data collected over period of two weeks. The dashboard is developed using Adafruit IO opensource platform.

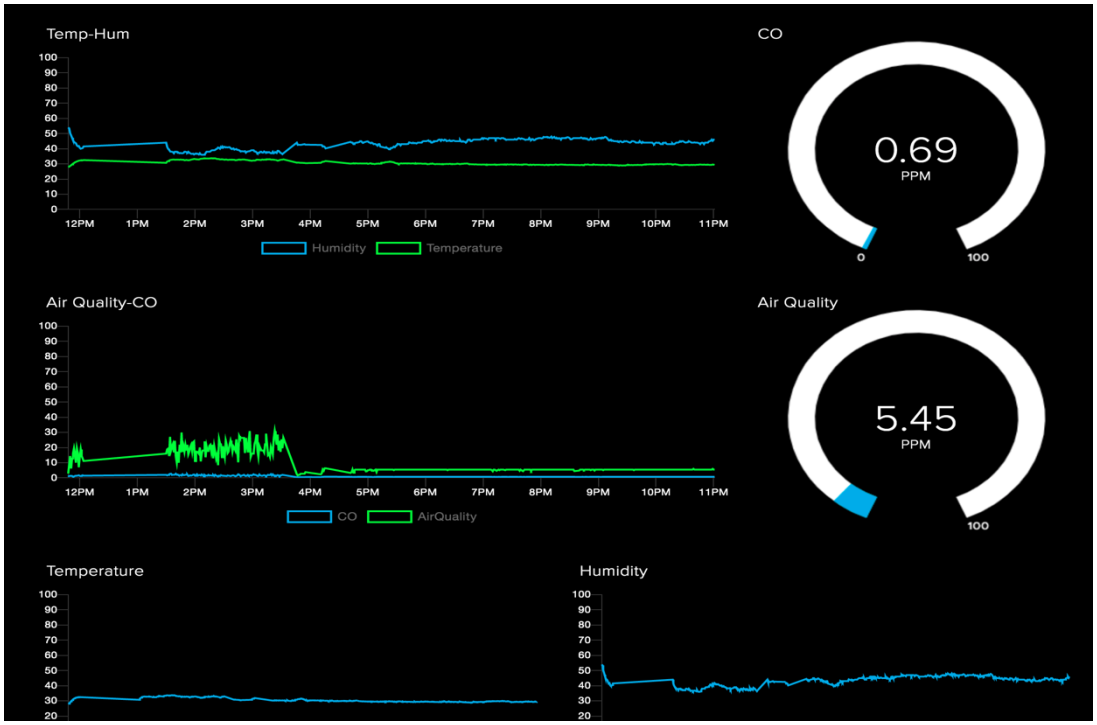


Figure 5.3: Air Quality Monitoring Dashboard

5.3 Setting Two

During the second phase data was collected in public buses route 401 Nyamirambo-Downtown, route 402 Nyamirambo-Nyabugogo-Downtown and route 305 Kimironko-Kacyiru-Nyabugogo. Two big buses with 40 passengers in each bus and the 30-seater bus with about 20 passengers.

Figure 5.4 shows the bus route in zone 3 used for data collection.

- Route 305 Kimironko-Kacyiru-Nyabugogo

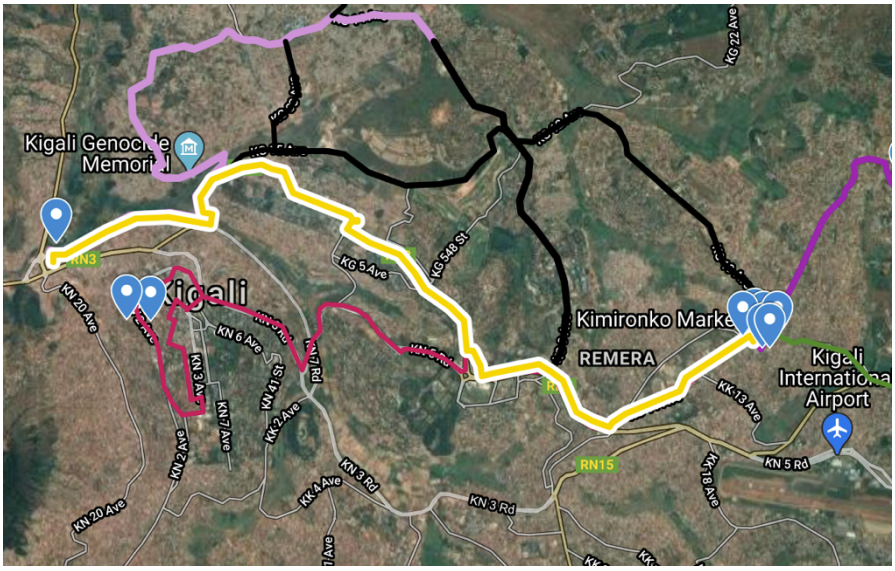


Figure 5.4: Zone 3 Bus Routes Used for Setting 2

The data was collected for 5 days 2 hours each day, the condition was not favorable for the research due to few restrictions which was still in place because of the pandemic.
Figure 5.5 shows sample of data collected for 4 days in public buses; the results is different from results obtained in setting one because of changes in restrictions.

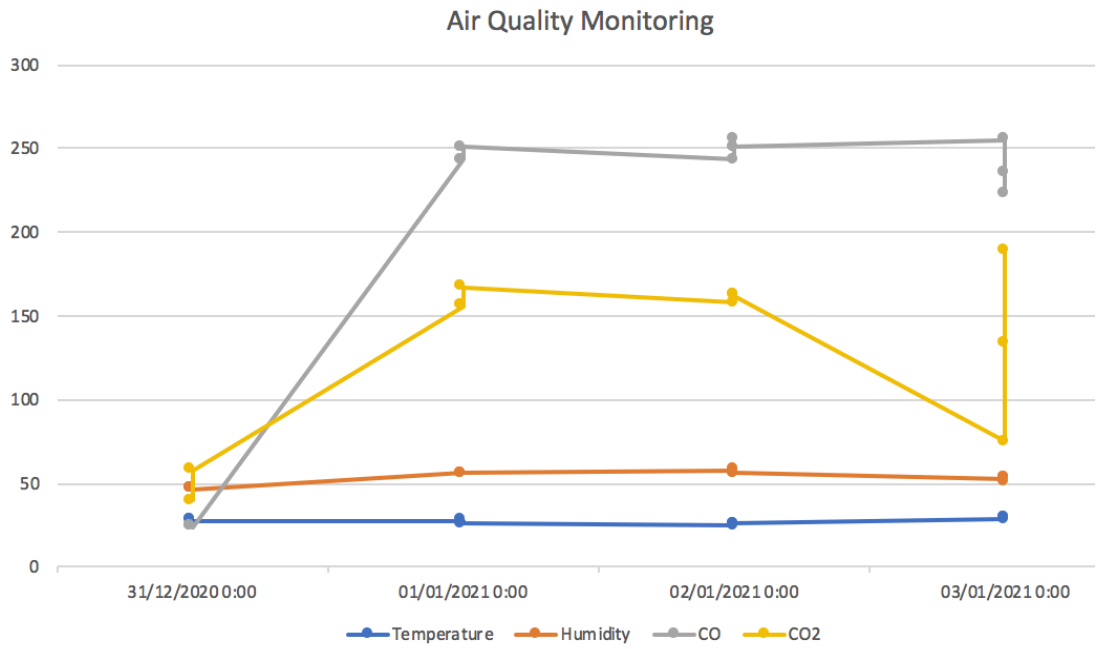


Figure 5.5: Setting 2 Data Representation in Excel

Figures 5.6 shows the visual representation of data on temperature, humidity, carbon monoxide and carbon dioxide collected in a public bus early January 2021. The platform used here is Grafana which allows manipulation of data in several ways.



Figure 5.6: Air Quality Monitoring Dashboard

Figure 5.7 is Grafana graphical interface showing the values of carbon monoxide and carbon dioxide at specific temperature and humidity. The reading shows CO and CO2 values 255ppm and 253ppm respectively, CO2 is normal as long as it kept below 1000ppm, but CO is above the threshold limit value which is 35ppm for 8 hours of working for both indoor and outdoor environment.

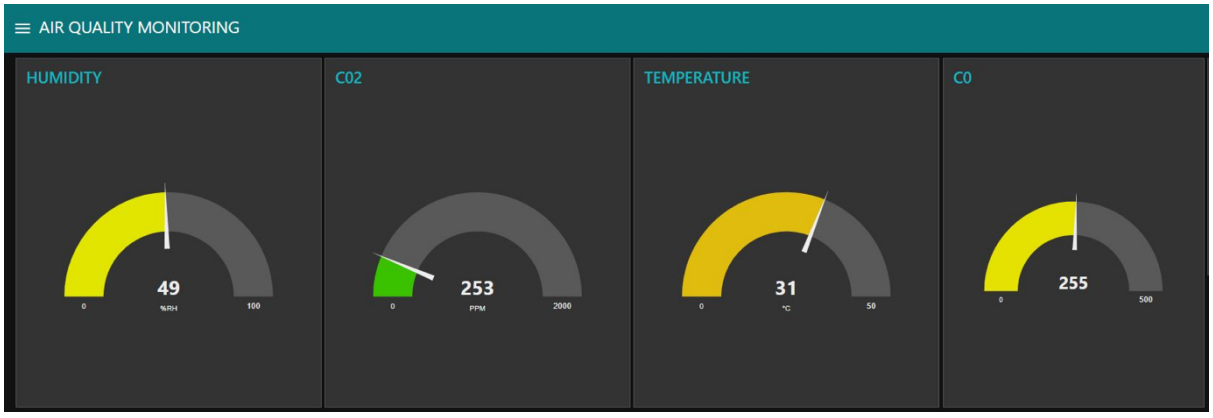


Figure 5.7: Grafana Interface showing sensor readings

Figure 5.8 shows the variation of measured values, Grafana offers real time monitoring and dynamic approaches to data visualization.

The value of CO2 is normal, but CO keeps fluctuating which can be influenced by different exposures such as fragrance oil, gasoline and other compounds present.



Figure 5.8: Graphical representation Air Quality Sensor Data

Table 5.1: Comparison between Setting1 and Setting 2 Experiment

	Setting 1	**Setting 2**
1	This phase of experiment was conducted in August and September 2020 with buses operating in half capacity.	Experiment conducted end of December until early January 2021 with Covid19 restrictions, buses operating in half capacity.
2	Route covered was 401 Nyamirambo to Downtown and route 402 Nyamirambo-Nyabugogo- Downtown.	Route covered was 401 Nyamirambo to Downtown and route 402 Nyamirambo-Nyabugogo- Downtown and route 305 Nyabugogo to Kimironko.
3	The results obtained from this setting shows that the quality of air in public bus is normal in relation to hypothesis of this study.	The results show the quality of air is normal beside carbon monoxide values which may be influenced by fuel from bus, fragrance and sanitizer from passengers.

Chapter 6: Conclusion, Recommendation and Future Directives

6.1 Conclusion

The effects of air quality may not be felt over a short period of time but the damage it has on human health over a certain period of time cannot be ignored. The air quality monitoring system is a simple and effective way to monitor air quality where sensed data is sent to the cloud via Wi-Fi for analysis and visualization on adafruit IO cloud platform.

The air quality monitoring system collect carbon monoxide, carbon dioxide, temperature and humidity data with public bus, the data is transmitted to Node-Red platform for processing and stored in influxDB. Grafana query the data and visualize on customizable dashboard. This system will allow authority concerned with air quality and bus companies to take necessary precautions to ensure safety of the passengers.

The first phase of data collection in September 2020 indicates that the quality of air in public buses is very good this is mainly because of restrictions set by the authority concerned due to covid-19. The second phase of data shows different results, the data was collected towards the end of December until early January 2021 and the air quality is moderate. During this second phase a better tool for data management tool was used which is very easy to manipulate data and the data is stored locally. The set objectives of the study have been achieved despite the ongoing pandemic

The ongoing global pandemic is an eye-opener to policy makers when it comes to controlling air pollution which is associated with viruses. The temporary lockdown due Covid-19 has restored the environment and general ecosystem, a sustainable mitigation is required to control air pollution which will also regulate covid-19 rate.

This pandemic has indicated that the quality of air can be managed through some precautions which are currently in place, despite great negative impact on the global economy, covid-19 restrictions have improved the quality of air in general. The lockdown imposed to contain the spread of virus has restricted most economic activities and has reduced the level of pollutants in air.

6.2 Recommendation

The system can be used in different environments such as buildings beside public transport and more sensors can be added in future if needed, to increase on the coverage area long range connectivity such as LoRaWAN and Sigfox can be used.

MQ series gas sensors are not very accurate and needs to be pre-heated therefore, other type of gas sensors can be deployed to improve on accuracy and to obtain reliable results.

6.3 Future Directives

The experimented need to be repeated when normality resumes in City of Kigali and the authority concerned with public transport need put ventilation system in place. More advanced and reliable sensors and other Internet of Things technologies can be used in future works.

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Appendices

Appendix 1: Data collection letter to RURA

UNIVERSITY of RWANDA

ACEIoT

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

COLLEGE OF SCIENCE AND TECHNOLOGY

23th June, 2020

To: Director General

RURA

Kigali, Rwanda

Dear Sir

Subject: Introduction letter for data collection for ACEIoT Master's student, HALIMA Mohamed

This is to introduce **Miss Halima Mohamed**, a master student with reference number **219013563,** who is doing his research for her master's thesis under the Africa Center of Excellence in Internet of Things (ACEIoT) established at the University of Rwanda (UR), College of Science and Technology (CST) in MSc. Internet of Things-Embedded Computing Systems (ECS) option.

Her research title is "**Air Quality Monitoring in Public Transport using IoT and MQTT**".

She needs to collect data for her master's thesis from your Institution.

Your support with the needed information will be highly appreciated.

Yours truly,

Dr Damien HANYURWIMFURA

Ag. Director, ACEIoT College of Science and Technology

University of Rwanda

Tel: 0787394447

AFRICAN CENTRE OF EXCELLENCE IN INTERNET OF THINGS
ACEIoT
UNIVERSITY OF RWANDA

Appendix 2: Letter to Jali Transport Company

UNIVERSITY of RWANDA

ACEI T

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

COLLEGE OF SCIENCE AND TECHNOLOGY

To Jali Transport, Managing Director

Kigali, Rwanda

13th August, 2020

Dear Sir/Madame

Subject: Introduction letter for data collection,

of ACEIoT Master's student, HALIMA Mohamed

This is to introduce **Miss Halima Mohamed**, a master student with reference number **219013563,** who is doing her research for her master's thesis under the Africa Center of Excellence in Internet of Things (ACEIoT) established at the University of Rwanda (UR), College of Science and Technology (CST) in the programme of Embedded Computing Systems (ECS) option.

Her research title is "**Air Quality Monitoring in Public Transport using IoT and MQTT**".

She needs to collect data for her master's thesis from your Institution.

Your support with the needed information will be highly appreciated.

Yours truly,

AFRICAN CENTER OF EXCELLENCE IN INTERNET OF THINGS ACEIoT UNIVERSITY OF RWANDA

Dr Damien HANYURWIMFURA

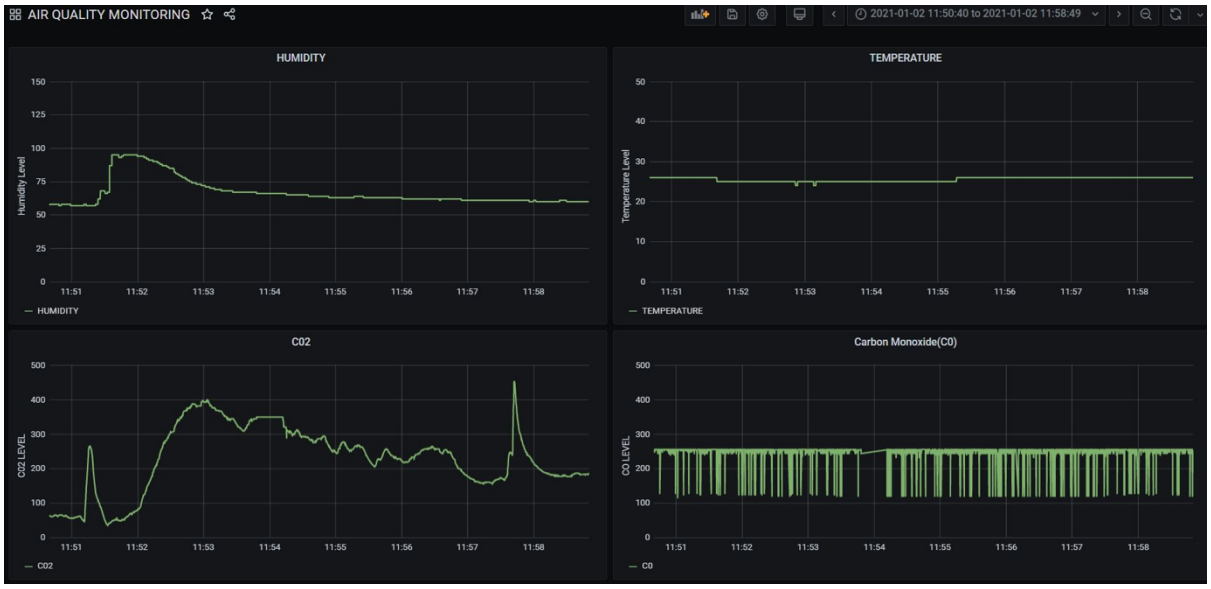
Ag. Director, ACEIoT College of Science and Technology

University of Rwanda

Tel: 0787394447

Appendix 3: Air Quality Monitoring Dashboard


AIR QUALITY MONITORING DASHBOARD
2020-12-31 14:48:53 to 2020-12-31 15:15:19
DATA ANALYTICS
Values
TEMPERATURE
HUMIDITY
C0
C02


AIR QUALITY MONITORING
2021-01-02 11:50:40 to 2021-01-02 11:58:49
HUMIDITY
Humidity Level
TEMPERATURE
Temperature Level
C02
C02 LEVEL
Carbon Monoxide(C0)
C0 LEVEL