2021

An Air quality prototype for monitoring greenhouse gas emissions.

Ngugi, Maureen Njeri
School of Computing and Engineering Sciences
Strathmore University

AN AIR QUALITY PROTOTYPE FOR MONITORING GREEN HOUSE GAS EMISSIONS

By

Ngugi, Maureen Njeri

075358

A Thesis submitted to the School of Computing and Engineering Sciences in partial fulfillment of the requirements for the award of Master of Science in Computing and Information Systems.

Master of Science in Computing and Information Systems

Strathmore University

January, 2021

Declaration and Approval

I, Maureen Ngugi, declare that this research has not been submitted to any other University for the award of a Degree in Master of Science in Computing and Information Systems.

Student's Name: Ngugi, Maureen Njeri

Sign: ______________________ Date: 21-01-2021

Supervisor's Name: Dr. Vitalis Ozianyi

Sign: ______________________ Date: 21/01/2021

Abstract

In the world today, every human being wishes to live in a healthy, unpolluted and sustainable environment. This is because such a clean environment enables one to thrive and be productive in all aspects. Such environments are free from anything that may cause diseases and other physical injuries. Unfortunately, as years go by, our world has faced environmental degradation, global warming and high levels of pollution. This has not only affected wildlife and ecosystems in various parts of the world but it has also affected human health. This is evident by various respiratory diseases that have emerged such as pneumonia, bronchitis and many other diseases. This dissertation presents research work that focused on Green House Gas emissions which are a contributing factor to environmental degradation.

It is important to monitor the amount of greenhouse gases in the atmosphere as it enables individuals, governments and environmental bodies to take action to tackle these emissions.

This research used a prototyping methodology by developing an air quality monitoring system for greenhouse gases in the atmosphere. It incorporated an air quality monitoring prototype by integrating IoT with Wireless Sensor Networks.

Collected data was then uploaded into a cloud platform using the Blynk API which relayed real-time information to a mobile device. The developed prototype achieved 95% accuracy. The developed systems can be used by individuals and environmental bodies to draw various strategies on how to lower Green House Gas emissions and adapt greener technologies that will be of great benefit to the environment as well as for a sustainable ecosystem.

Contents

Definition of Terms

Air quality - The degree to which the air in a particular place is pollution free (Oxford, 2020).

Carbon Emission - This can be defined as the release of carbon dioxide and greenhouse gases into the atmosphere (Carbon Trust, 2019).

Green House Gas Emissions - These emissions refer to gases that absorb and release radiant energy into the atmosphere. They comprise of water vapor (H_2O), Carbon dioxide (CO_2), methane (CH_4), Nitrous Oxide (N_2O) and Fluorinated gases (Karl & Trenbert, 2003).

Global Warming - This is an increase in the earth's overall temperature and it is mainly caused by greenhouse gas emissions (Oxford, 2020).

Abbreviation and Acronyms

ADM	Atmospheric Dispersion Models
AUSEA	Airborne Ultra-Light Spectrometer for Environmental Application
CEMS	Continuous Emissions Monitoring System
COMS	Continuous Opacity Monitoring System
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DIAL	Differential absorption lidar
EEA	European Environment Agency
EPA	Environmental Protection Agency
GHG	Greenhouse gases
GIS	Geographic Information System
GSM	Global System for Mobile Communication
GUI	Graphical User Interface
GWP	Global Warming Potential
H_2O	Water
KT	Kiloton
NEMA	National Environment Management Authority
NOAA	National Oceanic and Atmospheric Administration
NO_2 and NO_3	Oxides of Nitrogen
Pb	Lead
PM	Particulate Matter
PPM	Parts Per Million

UART	Universal Asynchronous Receiver/ Transmitter
UNEP	United Nations Environment program
WBG	World Bank Group
WHO	World Health Organization
WSN	Wireless Sensor Network

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Acknowledgements

I would like to thank the Almighty God for His endless grace, favor and strength that He gave me during my Master's Program. He has been forever faithful.

I would like to pay special regards to my immediate supervisor, Dr. Vitalis Ozianyi for his guidance, patience, endless assistance and support during my entire research project as well as in my course work. I also wish to thank Dr. Vincent Omwenga for always being available for inquires and his mentorship during the entire duration of my course. I wish to express my deepest gratitude to all my lecturers who took me through various units in my program; thank you for your mentorship and assistance which contributed greatly to the success of my studies.

I also wish to thank my classmates for their continuous support and encouragement during the program as well as the fun moments that we shared. I would like to recognize the invaluable assistance of the entire Strathmore University staff for making my experience amazing and leaving a beautiful impact in my life. May you always be blessed.

Dedication

I wish to dedicate this research project to my father, Mr. Maurice Ngugi for always being there for me and believing in the beauty of my dreams; you are a blessing. I also wish to dedicate this research to my beautiful siblings; you mean the world to me.

Chapter 1 : Introduction

1.1 Background of the Study

In the past three decades, the earth's temperature has been rising rapidly. The rise in temperatures has led to the melting of ice in the Polar Regions as well as the increase of water levels in the oceans. According to a study done by the European Environment Agency (EEA), the global sea level had risen by approximately 17cm in the 20th Century and this has been caused by human activities that have released greenhouse gas emissions (European Environment Agency, 2020). These emissions have not only caused changes in the arctic region but also in the rest of the world. The effects of these emissions have been observed by the changes in the seasons whereby, there are long periods of drought and less periods of rain, wind patterns have also changed as well as frequency of heat waves and intensity of cyclones which have been very prevalent in most parts of the world today. According to a report done by the National Oceanic and Atmospheric Administration (NOAA), the year 2019 has so far been recorded as the second warmest year in the past 140 years after the year 2016 (National Oceanic and Atmospheric Administration, 2019). In that year, the ocean and land temperatures worldwide had an average temperature of +0.95 degrees Celsius. This report also shows that temperatures have continued to rise from the year 2015 as human activities intensify and the environment is neglected.

Green House Gases are majorly responsible for the rise of these temperatures as they are prone to withholding infrared radiation thus trapping heat in the atmosphere. This consequently leads to global warming (Archer & Pierrehumbert, 2013). The primary sources of these emissions include: electricity production, transportation, industries, commercial and residential houses, agriculture, land usage and forestry. According to the World Health Organization, harmful effects of environmental change can greatly impair the human health. This is because the release of the greenhouse gas causes air pollution and thus the air quality of a particular area worsens making it unsuitable for human habitation (World health Organization, 2020).

1.1.1 Elements of an Air Quality Monitoring System

According to the United States Environment Protection Agency (EPA), there are two basic types of air quality monitoring systems and they both have different functions. These systems include the ambient air quality monitoring system and stationary source emissions monitoring system (Environment Protection Agency, 2020). The ambient air quality monitoring system follows procedures in which it primarily collects and measures levels of pollutants in samples of ambient air so as to evaluate the status of the atmosphere. On the other hand, stationary source emissions monitoring system collects and uses measurement data at individual stationary sources of emissions which include; manufacturing industries and various work places so as to verify conducive work environments, (Environment Protection Agency, 2020). The practice of using air quality monitoring systems is very common in developed countries because the governments in such countries are fully aware of the adverse effects that can be brought about by pollution. Unfortunately, in low and middle income countries, the practice of monitoring the air quality in one's environment is not very common as most individuals have not been enlightened about its importance. This, consequently, has led to high rates of air pollution and various respiratory diseases.

A typical air quality monitoring procedure or standard in a developing or developed country can be described by the following steps;

i. generation of various emissions through various human activities and environment changes and this is followed by the,
ii. release of these emissions into the atmosphere, then;
iii. The air quality monitoring system monitors these emissions and the results are submitted to various environmental and government bodies.
iv. The information gained from these monitoring systems is then used to find solutions on how to lower the release of such emissions.

The collection and monitoring of emissions in the atmosphere in real-time is the core activity of an air quality monitoring system (Environment Protection Agency, 2020). This enables the system to know whether a particular area is safe for human habitation as great amounts of emissions can lead to respiratory diseases and other health complications. The ambient air quality monitoring system and the stationary source emissions system only take into account general emissions that are released into the atmosphere which include; Carbon Monoxide (CO), Oxides of Nitrogen (NO_2 and NO_3), Lead (Pb) and Particulate Matter (PM). The Ambient air quality monitoring (AQM) system has specifications on how each device should be designed. Each system is fit with a sensor in an analyzer module and the researcher chooses a parameter in which he or she would like to monitor. The AQM can measure up to 20 different gases and particulate pollutants simultaneously (Aeroqual, 2020).

1.1.2 Green House Gas Composition

Greenhouse gas emissions are a common term in both a typical household and in the industrial sectors. These emissions refer to gases that absorb and release radiant energy into the atmosphere. As a result of the radiation, the earth's temperature rises above the norm thus causing negative changes in the environment. The greenhouse gases are normally abbreviated as GHG and they comprise of; water vapor (H_20), Carbon dioxide (CO_2), methane (CH_4), Nitrous Oxide (N_20) and Fluorinated gases (Karl & Trenberth., 2003).

All these gases are emitted in different ways through human related activities as well as through natural means and their effects have been felt all over the world through changes in climate, emergence of deadly respiratory diseases, rise in ocean levels, premature deaths and an unhealthy ecosystem whereby vegetation and water bodies are polluted. Carbon dioxide is released into the atmosphere primarily through the burning of fossil fuels such as coal and natural gas. This gas is later on removed from the atmosphere through the carbon cycle whereby plants absorb it (Eggleton, 2012). The methane gas is released into the atmosphere through livestock and agricultural practices as well as through the production of coal, natural gases and oil (Khalil, 1999). On the other hand, Nitrous Oxide is emitted during livestock and agricultural activities, combustion of fossil fuels and during the treatment of waste water (Ravishankara et al., 2009). Lastly, the fluorinated gases are emitted into the atmosphere through industrial activities and even though they are released in small quantities, they are referred to as having high Global Warming Potential (GWP).

Figure 1-1 shows that greenhouse gases are quite prevalent in the atmosphere and therefore an air quality monitoring system is important so as to analyze areas that have high or low GHG and analyze ways in which greener technologies could be adapted so as to lower these emissions.

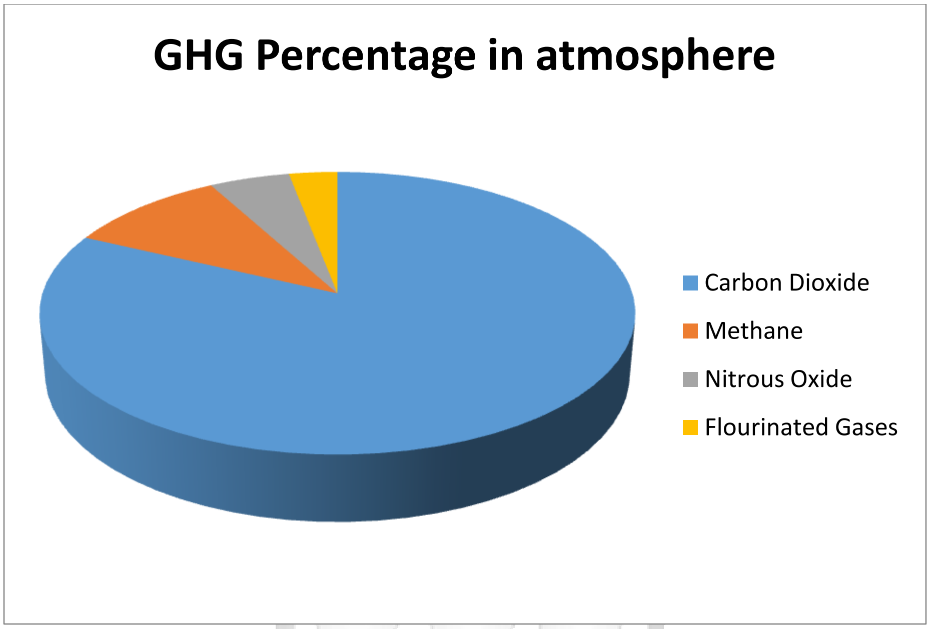

Figure 1-1 GHG percentage in the atmosphere

(Adopted from EPA.gov)

1.1.3 Current methods of monitoring Greenhouse gases

Over the years, developed countries have gained a keen interest in monitoring greenhouse gases. Systems such as the Continuous Emissions Monitoring Systems (CEMS) and the Continuous Opacity Monitoring Systems (COMS) monitor flue gases and particulate matter in effluent emissions (Environment Protection Agency, 2020). The major drawback in these systems is that the dilution systems found in them have to be regularly maintained and the system's analyzer has to be significantly more sensitive to monitor the diluted gases.

The other major problem with these existing systems is that they do not solely monitor greenhouse gas emissions. This research developed a solution on how to determine air quality by monitoring greenhouse gas emissions using sensors that track and monitor these emissions. The data collected from the prototype can be used to find solutions on how an individual can adopt green technologies that will reduce air pollution as well as protect human health.

1.2 Problem Statement

Greenhouse gas emissions are all around us and therefore it is important to realize the adverse effects that it could have on human health and the eco-system if allowed to increase to dangerous levels. Such effects include; respiratory diseases such as asthma and pneumonia, reduction in crop yield, lack of clean water, death of marine life and forest dieback among many other effects. Many organizations have created air quality monitoring systems however, these systems have proved to be expensive to acquire, cumbersome and do not focus solely on monitoring green house gas emissions.

This research developed a prototype solution that will enable individuals to monitor greenhouse gas emissions so as to determine the quality of air that is around them. This prototype aimed to be accurate, affordable and accessible. The data collected could enable individuals to raise an alarm if the pollution levels are high to various environmental bodies that are around them such as the National Environment Management Authority (NEMA) in Kenya and the United Nations Environment Program (UNEP) as well as the Ministries of Environment and Natural Resources in their respective countries.

1.3 Aim of the study

The main aim of the study is to develop an air quality prototype that is able to monitor greenhouse gas emissions in real time and that is accessible, accurate as well as affordable.

1.4 Research Objectives

i. To identify elements related to air quality status monitoring,

ii. To review the approaches used in air quality monitoring systems and their appropriateness in monitoring greenhouse gas emissions,

iii. To develop a prototype to monitor and alert users on the levels of green house gas emissions and the air quality in their current environment,

iv. To test the prototype.

1.5 Research Questions

i. What are the elements used for air quality status monitoring?
ii. What are the approaches used in air quality monitoring systems and are they suitable to monitor greenhouse gas emissions?
iii. How will the prototype to monitor the levels of greenhouse gas emissions and the air quality in the environment be developed?
iv. How reliable is the developed prototype?

1.6 Justification

The industrialization rate is growing at a fast pace globally and these activities are slowly causing damage to the environment because of the high rate of pollution. Various countries in the world are aiming at boosting their economy while neglecting the environment as some activities undertaken release high levels of greenhouse gases. This pollution has led to the rise of respiratory diseases and premature deaths all over in the world.

This study aims at developing a prototype that will be used by individuals to monitor greenhouse gas emissions and determine the air quality around them. The study aims at promoting the essence of a cleaner and purer environment by creating a prototype that is able to monitor emissions in real-time. It is also affordable and easily accessible. The research will also provide a platform for further studies to be carried out in regards to tracking and monitoring greenhouse gas emissions.

1.7 Scope and Limitations

The study aimed at creating a prototype for an air quality monitoring system that would be able to track and monitor greenhouse gas emissions. The proposed prototype monitored these emissions in real time and it provided accurate results as it used sensors. The prototype developed from this research will enable individuals to monitor the greenhouse gas emissions around them as well as know if the air is heavily polluted or not.

Chapter 2 : Literature Review

2.1 Overview

This chapter primarily presents a review of literature on air quality monitoring systems in order to identify the variables that are required in monitoring Green House Gas emissions. This section also identifies the gaps in existing literature that look at various systems that monitor greenhouse gas emissions. A theoretical and conceptual framework is developed as well as a foundation that will be used for empirical analysis using prototyping methodology.

2.2 Methods for monitoring and measuring Green House Gas emissions

2.2.1 Airborne Ultra-Light Spectrometer for Environmental Application (AUSEA)

This innovation has been created by the French National Research Centre to monitor and minimize greenhouse gases emitted into the air by oil and gas sites (Total, 2020). This technology uses Diode laser spectrometers which are based on sensors that are highly sensitive, accurate and fast. The advantage of this system is that it is able to monitor emissions in real-time. However, its main disadvantage is that it only monitors Carbon Dioxide emissions (CO_2) and methane gas (CH_4) hence it does not monitor all the greenhouse gases.

2.2.2 Smart farming device to calculate greenhouse gas emissions in Indonesia

This device has been created in the Gadjah Mada University by Dr. Bayu Dwi Apri in order to calculate greenhouse gas emissions on agricultural land. The devise utilizes IoT technology which works by retrieving data each day using a router and it is sent to a server using GSM internet network. This device also has a website with which users can view the results after being analyzed. The data collected can be used to evaluate irrigation systems and also calculate the concentration of greenhouse gas emissions on a particular land. This devise also uses Artificial Neural Network to process the data. The main disadvantage with this system is that it has mainly been created for the agricultural industry hence cannot be used in any other environment (Opengovasia, 2019).

2.2.3 Orbiting Carbon Observatory

This satellite uses high-resolution spectrometers which acquire data from a common telescope. These spectrometers have been designed to detect molecular fingerprints of different gases but the main focus of this device is to measure carbon dioxide gas. The information gathered is sent back to earth by these spectrometers where carbon dioxide concentration would be retrieved in four separate footprints for each image collected. Global transport models are used to analyze the data to detect the locations of the carbon dioxide sources and sinks. The disadvantage with this devise is that it is not locally available as it is located in space and it focuses (just like the previous devices) on carbon dioxide emissions (NASA, 2020).

2.2.4 Continuous Emissions Monitoring Systems (CEMS)

This system was historically created to monitor flue gases such as oxygen, Carbon Dioxide and Carbon Monoxide. Flue gases refer to gases that are emitted during combustion. The system works in the following way; a small sample of flue gas is extracted by means of a pump into the system. The flue gas is diluted because it can be very hot at times, it can also be wet as well as polluted. Once the flue gas has been diluted to the required ratio, it is taken through a sample line to a manifold where the present individual analyzers can extract a sample. Once the analysis has been done and completed, the flue gas is passed through a data acquisition and handling system which receives signal output from each analyzer so as to collect and record data emissions. This system is currently being used as a way to adhere to the air emission standards in developed countries such as the United States Environmental Protection Agency (EPA). CEMS comprises of a sample probe, filter, sample line, gas conditioning system, calibration gas system and a series of gas analyzers that reflect the parameters being measured and monitored. The major drawback in the above system is that the analyzer has to be extremely sensitive to monitor the diluted gas.

2.2.5 Continuous Opacity Monitoring System (COMS)

This is a system that continuously monitors the amount of light that is attenuated by a particulate matter in effluent emissions. The amount in percentage of the visible light attenuated is referred to as the opacity of the emissions whereby if an emission is transparent, there is zero percent opacity whereas if it's opaque, then it has a hundred percent opacity (Environment Protection Agency, 2020).

These existing systems have so far been able to monitor different types of emissions. The major drawback of this system is that it can only monitor gases when polluted and it cannot monitor source operations of the pollutant.

2.2.6 Air quality devise to monitor Carbon Monoxide emissions in Popayan

This devise has been created in the city of Popayan, Colombia to monitor the rate of Carbon Monoxide being released into the environment. The main aim of the researchers is to empower the community by enabling them to monitor such emissions easily and affordably. Consequently, the members of this community can be able to improve their environmental health through acquiring knowledge of their air quality index in regards to Carbon monoxide emissions. This devise utilizes IoT technology and the data is collected using an arduino, raspberry pi and mq-135 gas sensor. The data is then displayed on a mobile phone. The air quality data collected is generated into a regression equation so as to calculate the Carbon monoxide value in the environment (Ordonez et al, 2019).

The main disadvantage with this devise is that it focuses on monitoring Carbon monoxide emissions in Popayan and not all the other green house gas emissions.

2.2.7 Real-Time air quality monitoring system using MQ-135 and ThingsBoard in India

This system has been created to monitor air pollution levels in India by integrating IoT technologies such as ThingBoard and MQ-135 sensor. The data collected is transferred by the system using an internet network protocol. This data is displayed on web pages which are easily accessible by anybody in any part of the world (Rani, 2020).

However, this system experiences various drawbacks and they include the lack of a GPS module which is able to track the current location of the system user. This module is important as researchers can use these locations to identify places that experience high emissions and be able to come up with the right solutions to address such problems. Another drawback is that this system does not store real time data and hence it is impossible to retrieve historical data for analysis purposes. Lastly, this system displays the data on web pages and this poses a major drawback especially for people who lack computers or laptops. Moreover, displaying data on web pages also makes it hard to monitor these emissions on a continuous basis because laptops and computers can be quite cumbersome to carry especially when one is always on the move.

2.2.8 An air quality monitoring system using Raspberry Pi and web socket

This system has been created to monitor green house gas emissions, temperature and humidity in the environment. The sensors used are MQ-135, MQ-7 and MQ-135. Raspberry pi has been used to integrate the sensor nodes. The results obtained from these sensor nodes are evaluated by ruby on rails server through web sockets. The arduino mega acts as the system interface and it uses a power source so as to enable the sensors to work (Kirthima, 2017).

The major drawbacks in this system include; lack of proper storage management hence the data collected is lost immediately after being received by the arduino mega. This proves to be difficult to analyze historical data over lengthy periods of time. The system is also stationary and that means that it only collects data in the current location that it has been fixed and cannot be used on the move by an individual. Lastly, this system lacks proper security measures that can be used to protect the data that is being sent through the components. This is dangerous as it poses a higher chance of being targeted by hackers who can steal the data and use it in all the wrong ways.

2.2.9 Existing models that have been developed to monitor Green House Gases

Air pollution modeling has slowly been developed and improved over time so as to predict the way pollutants behave in the atmosphere (Aeroqual, 2020). These models have proved to be advantageous as they can assist a researcher to assess a hypothetical situation even before it occurs. The most common models that exist are known as Atmospheric Dispersion Models (ADM) and they use mathematical assumptions to monitor how the atmosphere behaves in order to assess the impact of environmental emissions.

CALPUFF is one of the most common Atmospheric Dispersion Model that is quite powerful as well as complex. This model can be used to measure air pollution in a large area and it can deal with complex terrain and it outputs data in an easy way that can be visualized in Geographic Information System (GIS) packages. This model also uses 3 major inputs that include; a meteorological model, a dispersion model and a post processing package.

The other widely used model is called AERMOD which has been designed to measure air pollution in a steady state. Its main disadvantage is that it cannot adapt to abrupt changes in the atmosphere. However, it can be used in large regional areas.

CALINE4 is another model that is commonly used in small scale. It is used to monitor air quality at roadways or intersections. This model utilizes traffic characteristics on a particular road and a set of mathematical equations in order to assess the pollution impact on that road.

Land use Regression models are quite different from Atmospheric Dispersion Models in that they approach pollution assessment from the point of the researcher having prior knowledge of the air quality in that region and also knowing what activity in that region is mainly carried out.

For instance, a region could be known for farming, grazing, mining activities or it could be an industrialized region. With this prior knowledge, a relationship between mining activities (for example) and pollution concentration can be developed. Consequently, this leads to the modeling of various regions (Aeroqual, 2020).

2.2.10 Algorithms and Architectures used to develop an Air Quality Prototype

Various studies have been conducted to monitor air quality across the globe. One researcher by the name Zhuo Li conducted a study in 2017 to monitor environmental air using an arduino and this research formed a basis for my study as it is also based on Internet of Things (IoT). The architecture and algorithms used in this study formed a foundation for my conceptual framework.

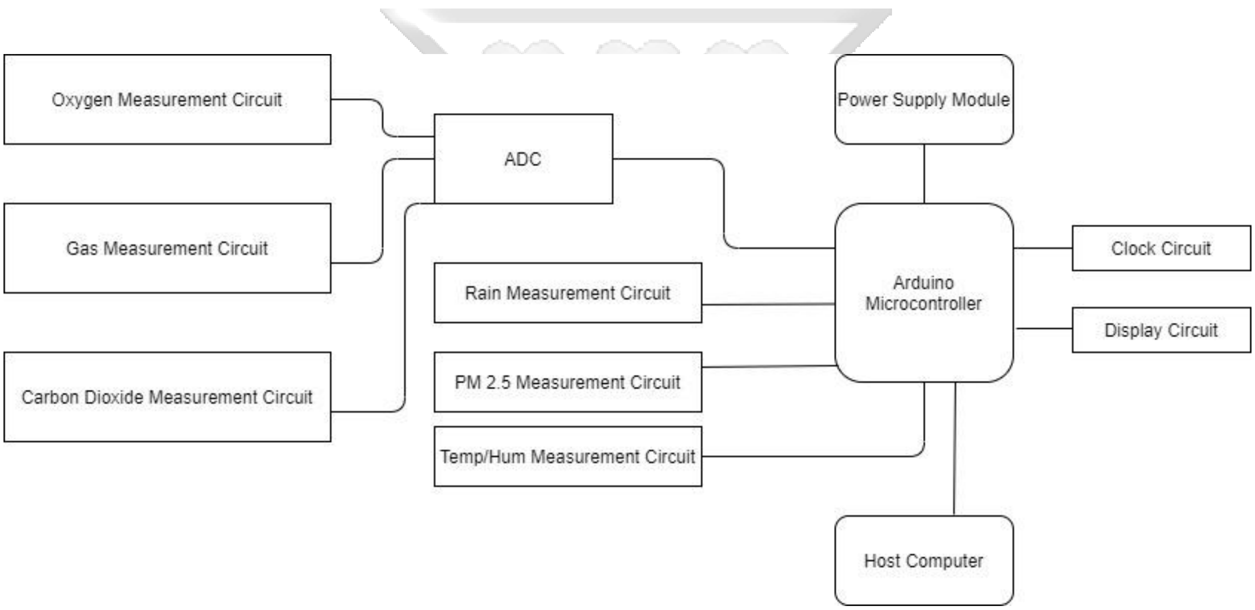

Figure 2-1 Architecture System Block Diagram

Figure 2-1 above shows the architecture system block diagram that has two main parts which are the data acquisition and processing parts on the left while the right parts are the system display components. The left part of the diagram shows the measurement circuits of oxygen, Carbon Dioxide and other atmospheric gases. These gases are digitized using an AD Converter (Zhuo, 2017). The right part of the diagram shows the clock circuit, power supply module and the screen display circuit. The clock circuit's main function is time keeping whereas the power supply module contains voltage regulators that control the power in the system. Lastly, the screen display circuit displays the measurements from the air parameters. The main use of the arduino microcontroller is to process the data collected from the sensors and convert them into usable form (Zhuo, 2017).

In the above architecture, an electrochemical gas sensor was used to primarily measure different gas emissions in the atmosphere. These were analog sensors that gave output in the form of analog signals. The ADC in this architecture converted these signals into digital form while the arduino microprocessor processed these digital signals in order to display the relevant information. The oxygen sensor used was the GS Oxygen KE-50 sensor that is known for its 10 year's life expectancy, excellent chemical durability and its best feature is that it's not influenced by other atmospheric gases. The following is the chemical reaction that occurs when the KE sensor is exposed in the atmosphere;

Cathodic reaction: O_2+4H^++4e^- →2H_2O

Anodic reaction: 2Pb+2H_2O →2PbO+4H^++ 4e^-

Total reaction: O_2+2Pb →2PbO

The architecture also used MG-811 CO_2sensor which is primarily known for its high sensitivity and long stability. The sensor module is operated at DC 6volts (V) and its measurement range is 0-10,000 ppm (parts per million). When this sensor is exposed into the atmosphere, the following reaction occurs;

Cathodic reaction: 2Li^++ CO_2+1/2o_2+2e^2 =Li_2CO_3

Anodic reaction: 2Na^+ + 1/2o_2+2e^-= Na_2O

Total reaction: Li_2CO_3+ 2Na^+= Na_2O+ 2Li^+ + CO_2

This architecture formed a basis for the use of MQ-135 sensor in this research which is basically a sensor for monitoring the air quality in the atmosphere. This sensor has been designed such that it applies SnO2 that has higher resistance in pure air as a gas sensing material. When there is an increase in pollution in the atmosphere, the resistance of the gas sensor decreases along with that.

2.3 Various Integrated Technologies

2.3.1 Geographic Information System (GIS)

A Geographic Information System is a system that captures, stores, manipulates, analyzes and manages geographical data through integrating specialized hardware and software (Clarke, 1986). This system is user friendly as it allows users to interact with the information that it relays to them. GIS application tools are used in day to day activities such as in businesses, industries, transport sector, telecommunication and for personal use. These tools are available in many location-enabled services since they rely on its analysis. This system can be used in a monitoring system as it can map out the location and movement in a geographical map (Chalkias & Lasaridi, 2009). This technology is relevant in this research as the prototype requires to monitor greenhouse emissions in real-time as well as be able to tell the location of an individual at that particular moment. The main advantage of GIS technology is that it is easy to integrate it into any framework and it can also easily capture, analyze and display all forms of information in a specific geographical region. While its disadvantage is that it requires a lot of data for some tasks to be achieved.

2.3.2 Wireless Sensor Networks (WSN)

The Wireless Sensor Networks is a group of dedicated sensors that monitor and record the physical conditions of an environment. These networks mostly measure environmental conditions such as air pollution, temperature, sound, humidity etc. The WSN is built of hundreds to thousands of nodes depending on its purpose and these nodes are connected to sensors. The sensor node is made up of several parts which include the radio transceiver which could either have an internal or an external antenna, a microcontroller and a battery which acts as an energy source for instance (Dargie & Poellabaeur, 2010). These sensors are relevant in this research as they are able to capture greenhouse gas emissions in real-time and send the data to the cloud through the microcontroller. The advantage of wireless sensor networks is that it can work in harsh environments and it can also facilitate long-distance data collection and transmission. This technology also has a disadvantage which is that it can be vulnerable to malicious security attacks as these sensors lack any robust security systems that can be used to protect them from the attackers.

2.4 Green House Gas Measurement Challenges

The existing technologies and studies conducted by various researchers have played a huge role in terms of monitoring air pollution in general. However, some of these technologies have proved to be expensive to acquire hence can only be used in organizations found in developed countries such as the United States Environmental Protection Agency (EPA). It is therefore difficult for individuals in developing countries to monitor such pollutants.

Another major challenge is that there exist no devices which can be able to solely monitor greenhouse gas emissions and this is quite a challenge for individuals who would like to specifically know their daily emissions.

Devises such as COMS and CEMS can also not monitor pollution in real time because they are individually programmed to monitor pollution only when it's emitted at a particular period in time by the researcher. This therefore portrays a level of inaccuracy especially when an individual would want to monitor pollution on a continuous basis. The other challenge that exists when monitoring greenhouse gas is that the existing systems are quite cumbersome hence cannot be used on the "go" by individuals. Lastly, various studies conducted also show that their developed systems cannot store data and hence proving it difficult to retrieve historical data for analysis purposes.

The proposed prototype will address these challenges as it will be able to work on an individual's mobile phone and thus one can solely monitor green house gas emissions around him or her while on the move. The prototype will also collect data in real time and will also be readily available in various applications stores hence it will be cheap and easy to acquire it. The prototype will also have a database that will be used to store the real-time data for future analysis. The prototype will also incorporate a GPS module that will track the location of the user as some of the previous studies conducted lacked this feature.

2.5 Conceptual Framework

The air quality prototype will comprise of MQ-135 gas sensors that will detect greenhouse gases and provide accurate readings. These sensors will be controlled by NodeMCU microcontroller and it will act as an interface between the system and the Blynk platform that acts as a cloud which stores the data collected. A room in any preferred area chosen by the researcher will be connected with cheap and low power MQ-135 gas sensors that are linked to the cloud. The cloud in this research will be the central hub for all rooms connected to these sensors. The room chosen during the research will transmit the greenhouse gas emission and measurement levels to the cloud platform. The information gathered will be then relayed to the researcher through her mobile device and this data will be collected and stored in real-time. This will create room for accuracy and reliability of the prototype. The figure 2-2 illustrates the conceptual model.

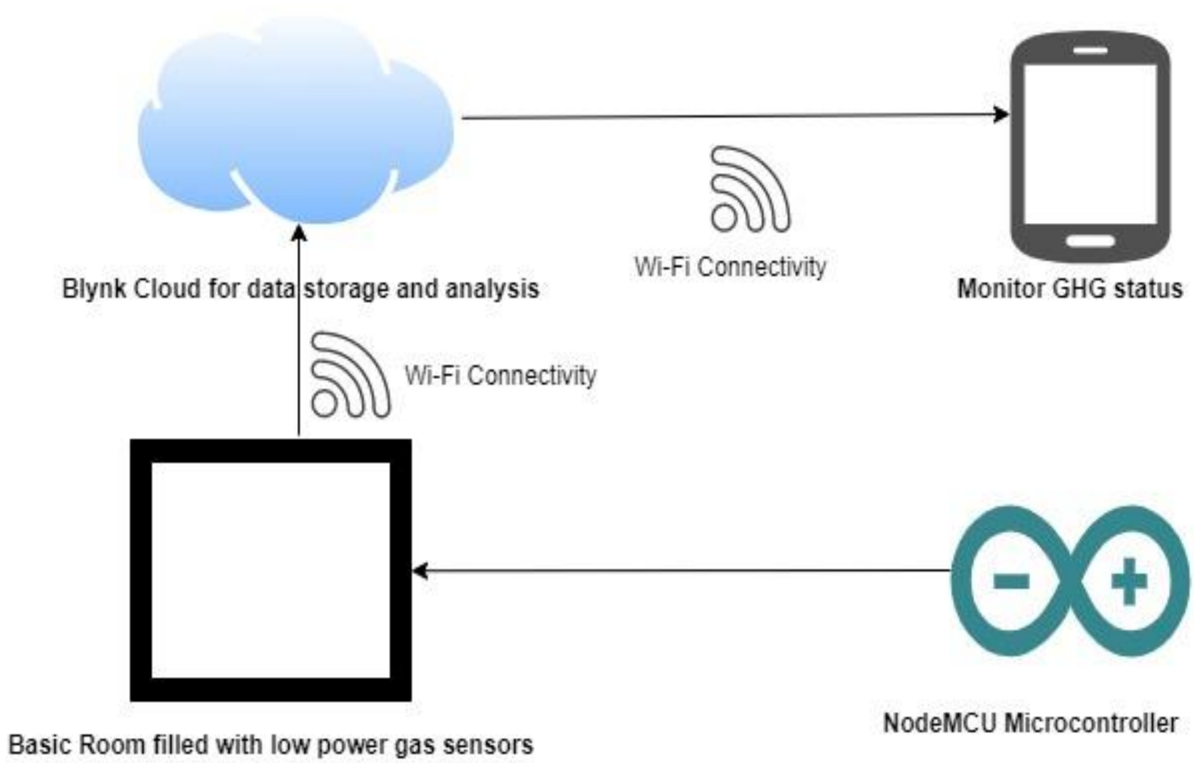

Figure 2-2 Conceptual Model Diagram

Chapter 3 : Research Methodology

3.1 Overview

This chapter mainly covers the methodological framework used in the study. The design is guided by objectives that had been stated in chapter 1 and it also focuses on the target population that the researcher intended to request to participate in the study. Additionally, this chapter also looks at the sample size and the sampling techniques to be used. Finally, this chapter expounds on the type of data to be used, how the researcher intended to collect the data, the data analysis and the test design.

3.2 Research Design

This can be defined as a set of methods and procedures that a researcher uses when collecting data (Creswell, 2014). This design is intended to give a framework to the study and the direction that the study is supposed to take. This is an applied research which has two main phases which are the planning phase and the execution phase. In the planning phase, the researcher defines the scope and the research plan is developed while in the execution phase, the research is implemented and monitored. The aim of the research design is to enable the researcher to solve the problem at hand logically and effectively.

The researcher aimed to develop an air quality prototype to monitor greenhouse gases and this prototype would collect data from sensors and use the results to monitor the amount of GHG in an area or in a particular environment.

3.2.1 Prototyping Methodology

This research used prototyping methodology which ensured that the system created was essential to the users as it enables changes to be made before the final product is rolled out.

The advantage of this methodology is that it elaborates on the functional process of the system. It also reduces the risk of system failure because it is usually first tested severally before it is finally rolled-out into the public for use. Finally, it is useful in data gathering and overall system analysis.

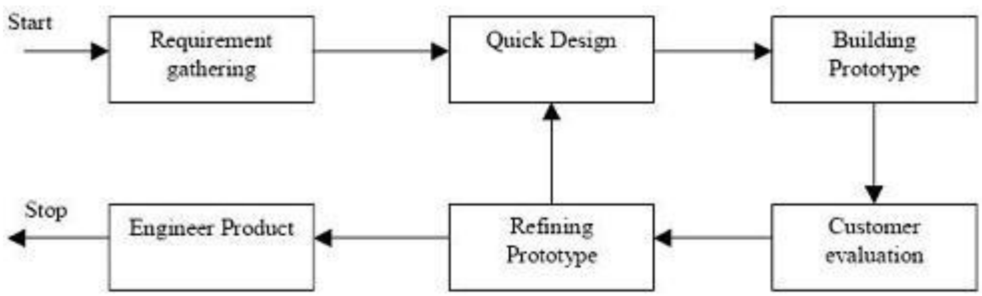

Figure 3-1 Prototyping Methodology

There are several phases that are involved in this methodology and they include the following:

System analysis- In this phase, the existing system is analyzed thoroughly so that the new system requirements will be defined in as much detail as possible.

System design- In this stage, a preliminary design is created for the new system and how it will operate.

System Implementation- After the final system is constructed; it is thoroughly evaluated and tested. The researcher will also carry out routine maintenance so as to avoid system failure.

This research used questionnaires to gather information from various stakeholders who would use the system once it was deployed. The questionnaire was administered informally through various social media platforms such as Whatsapp, mails and even through Google Docs. These platforms enabled the users to access the information needed in a faster way. Also these platforms ensured that the messages shared were encrypted from end-to-end and this ensured that the participant's responses were generally safe. The questionnaires were necessary in order to analyze the user requirements of the prototype and also to analyze whether the users were satisfied with the overall functioning of the prototype.

The study used both primary and secondary data in order to collect information. The primary data was collected using questionnaires as well as from the data collected by sensors and sent to the cloud infrastructure. Questionnaires were used because they offered the researcher the platform to interact with the participants hence acquiring first hand and authentic information. The respondents of this study were a total of 50 people. The data gathered was regarding the user requirements of the prototype and it was used to analyze whether the system was functioning as required by both the researcher and the intended users.

On the other hand, secondary data was used in Chapter 2 of this study so as to analyze the previous work done by other researchers on GHG and air quality systems.

The quantitative data was analyzed using Microsoft excel spreadsheets while the user requirements data gained from the questionnaire were also summarized and tabulated using pie charts because they are easily interpretable to the users of such information.

3.3 System Design

The air quality prototype design was achieved based primarily on the analysis of the existing methods of monitoring Green House Gas emissions as well as user requirements. The structured system design was employed and its main aim was to obtain a blueprint of the system developed. At this level, the study used various diagrams developed by the researcher and they included; workflow diagrams, use case diagrams, sequence diagrams and data flow diagrams. Sensors, NodeMCU shield and a wireless module for data communication were used for the hardware component. The development was done on a windows environment using the arduino IDE that employed C++ language.

3.4 System Implementation

In this stage, the software and hardware parts of the system were integrated so that they can turn into the working parts of the proposed prototype. This means that the developed designs were converted to actual system functionalities such as the data flow diagrams. Sequence diagrams, use case diagrams and the workflow diagram were utilized as inputs when the system was being implemented. These diagrams were created in my chapter four of my research which discussed the system analysis and design.

The software development tools that were primarily deployed included the Arduino IDE which is the development environment; the Blynk server was used as the web API interface for communication between the sensors and the end user. The Blynk mobile application was used for end user setup and dash board interfacing.

After the study was completed, several other tests were conducted so as to ensure that the end product matched the user requirements and that it was working efficiently and effectively.

3.5 Target population and sampling frame

The target population used in the study comprised of households from Kajiado County. The population for this county is approximately 687,321 people. The researcher used convenience non-probability sampling method because of limited cash and time constraints. The researcher required this target population to fill out the user requirements questionnaire that would assess the functionality of the system.

The formula of obtaining the sample size is as follows;

$$n = \frac{N}{1 + N(e^2)}$$

Equation 3.1

e=10%, N=687,321 and the n results to 99.985 which when rounded off comes to 100 people.

In this case;

E is the marginal error

N is the population size

And n is the sample size

3.6 Research Validity and Reliability

The research validity was taken into great consideration by making sure that the data collected was relevant to the study. The qualitative and quantitative data collected were relevant to the development of the prototype whereas in the research reliability, proper documentation and practices in developing the prototype were adhered to so as to make sure that the research yielded the same results even when undertaken by other researchers.

3.7 Ethical Considerations

Ethical standards were highly considered in this study whereby, information received from respondents was treated with confidentiality. Also the researcher obtained consent from her participants before proceeding on giving them the questionnaires. The researcher also ensured that there was no manipulation of primary data and all previous work used as secondary data was cited appropriately.

The results collected during the research were mainly used to improve the prototype as well as provide a platform to enlighten individuals on the importance of monitoring the air quality in their environment.

Chapter 4 : System Analysis and Design

4.1 Overview

In this chapter, the researcher analyzed on how the system was built, its design and architecture based on the requirements specification which had been identified from the data collected. This chapter also showcases the stakeholders of the prototype created, the system components as well as the system data models. It also includes the design of the database that was used for the prototype.

4.2 Data analysis and Observations

While creating the air quality prototype to monitor greenhouse gas emissions, the researcher distributed questionnaires in Kajiado County so as to analyze the system requirements needed for the prototype to be efficient and effective.

4.2.1 Ease of monitoring Greenhouse gas in the environment

According to the responses received from the questionnaire, 44% of the respondents disagreed that it was easy to monitor greenhouse gas emissions in their environment with some citing that they were not aware that this was a possible task to conduct. On the other hand, 40% of the respondents strongly agreed that it was easy to monitor such emissions while 10% of the respondents were neutral and 6% left that particular question blank. This is shown in Figure 4-1 below.

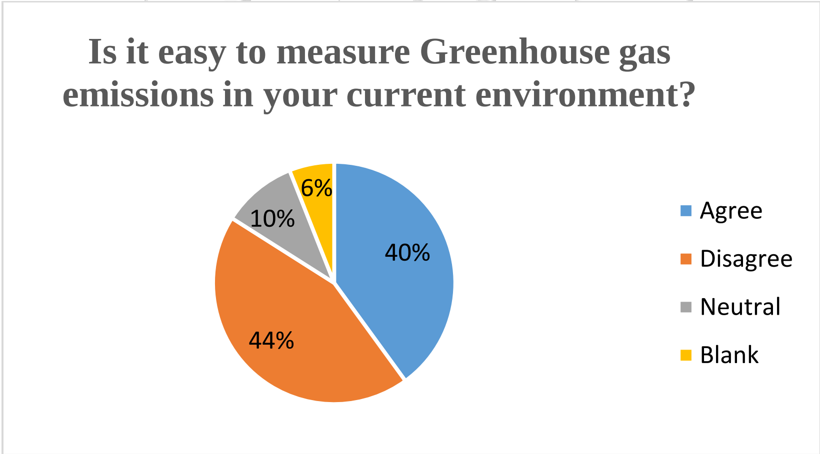

Figure 4-1 Ease of monitoring Greenhouse gas emission in the environment

4.2.2 Awareness of the Air Quality

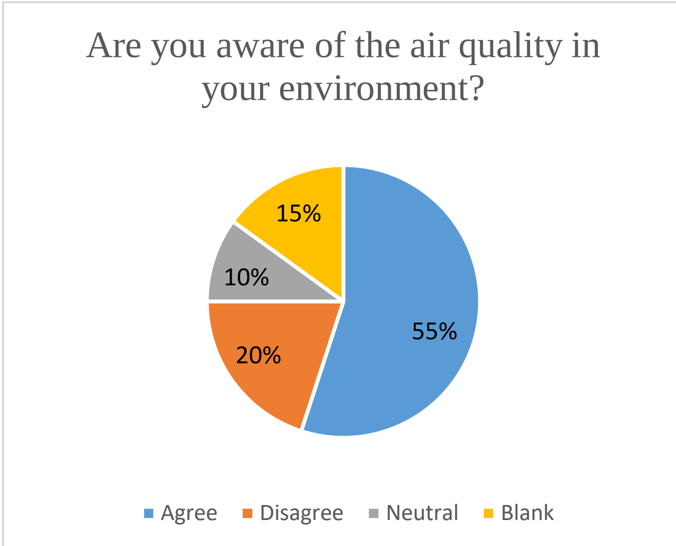

Figure 4-2 Awareness of the Air Quality

The responses given in this particular question showed that only 55% of the respondents agreed that they were aware of the air quality that was around them while 20% did not agree to this question. 10% remained neutral while 15% left that particular question blank.

4.2.3 Systems Alert capability

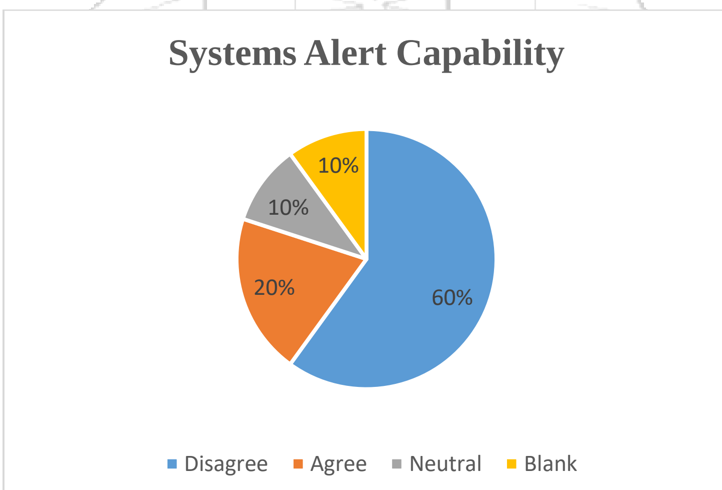

Figure 4-3 Alert Capability of the Current System

60% of the respondents of this particular question disagreed that the current systems put in place in the environment gave alerts on the rate of greenhouse gas emissions in their environment. 20% of the respondents agreed that the systems put in the society gave alerts on the rate of greenhouse gas emissions while 10% were neutral and 10% left the question blank.

4.2.4 Reporting and dashboard capability

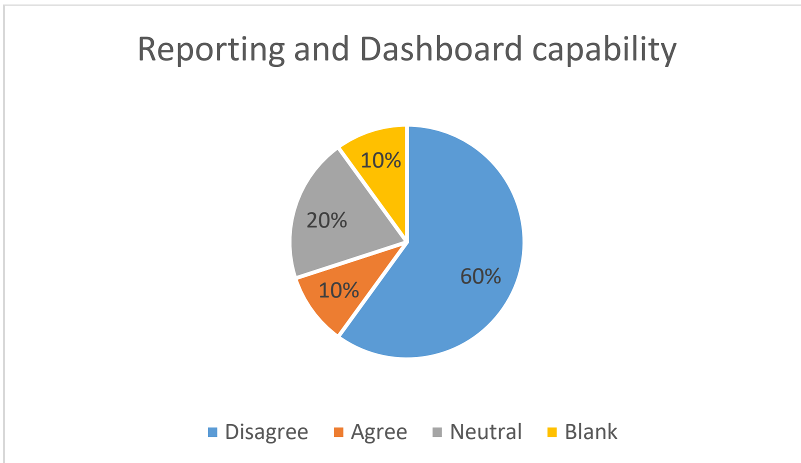

Figure 4-4 Reporting and Dashboard Capability

60% of the respondents disagreed that the current systems have an efficient reporting and dashboard capability. 10% of the respondents agreed that the system had a good reporting and dashboard capability while 20% were neutral and 10% left the question blank.

4.3 User and System Requirements

The researcher conducted a study in order to find out the required user and system functionalities that would make the system efficient and effective. The researcher was able to identify the gaps and user needs that eventually formed a basis for the study.

4.3.1 User requirements

i. A system that is user friendly and interactive such that the users can be able to understand the information that it renders concerning greenhouse gas emissions.

ii. A system that is efficient and can be able to monitor greenhouse gas emissions and render the information rapidly to the users.

iii. A system that has good security policies and will protect the privacy of its users.

iv. A system that stores the history of the information that it has gathered over time. This will make it easier for the users to refer back to old information as time goes by.

4.3.2 Functional Requirements

These are the desire operations of a system that are required for it to solve the necessary research problem.

In the study, the researcher was able to identify the following functional requirements.

i. **Set Optimal Greenhouse gas content level in the environment.**

The system will have an in-built optimal greenhouse gas level that will enable the user to know whether the emissions are high or low and there afterwards send notifications to alert the user.

ii. **Check Greenhouse gas content level.**

The user will able to check the GHG level in his/her environment using a mobile phone browser.

iii. **Notifications**

The system will be able to send alerts/notifications to the user whenever he/she is in an environment that has high GHG level.

iv. **Reporting**

The prototype will be able to generate reports whenever required by the user. This is because the system can store historical information.

4.3.3 Non Functional Requirements

These are requirements that specify the system's capabilities and constraints during its overall performance. These capabilities affect the stakeholders' attitude and the overall satisfaction that they may have while working with the system (Chen et al., 2013). In this research, the non-functional requirements include;

i. **Usability**

This refers to the aspect of the system whereby it can easily interact with the user and render information in a simple and efficient way that one can easily understand.

ii. **Security**

This aspect ensures that the user's private data and information gathered while using the system is safe and can only be accessible by the user only. This feature promotes the aspect of confidentiality and trust.

iii. Recoverability

This refers to the system's ability to recover historical data efficiently and effectively when required by the user.

iv. Environmental Friendly

This feature ensures that the system created is environmental friendly and will not release dangerous emissions during its usage period.

v. User Support

This offers a section whereby the users can be able to learn more about the system and also ask for help when they encounter a problem. This section also notifies users of any upgrades or any other relevant information that is happening in the system.

vi. Capacity

This aspect shows that the system can be able to hold a certain amount of data. It also shows where the data has been stored and when the system's memory is full.

4.4 System Architecture

In this section, the researcher showcases on how the system will be built as well as the different layers that it will have. The three main layers of this system include presentation, data and application layer. In the presentation layer, the user of this system will be presented with data collected and analyzed by the prototype using a mobile interface. On the other hand, the application layer provides a platform in which the data from the data layer can be linked to the presentation layer. This is made possible by servers and the NodeMCU microcontroller. The data layer stores the data that is collected by the MQ-135 sensors in the system. The layers are shown below in figure 4-5.

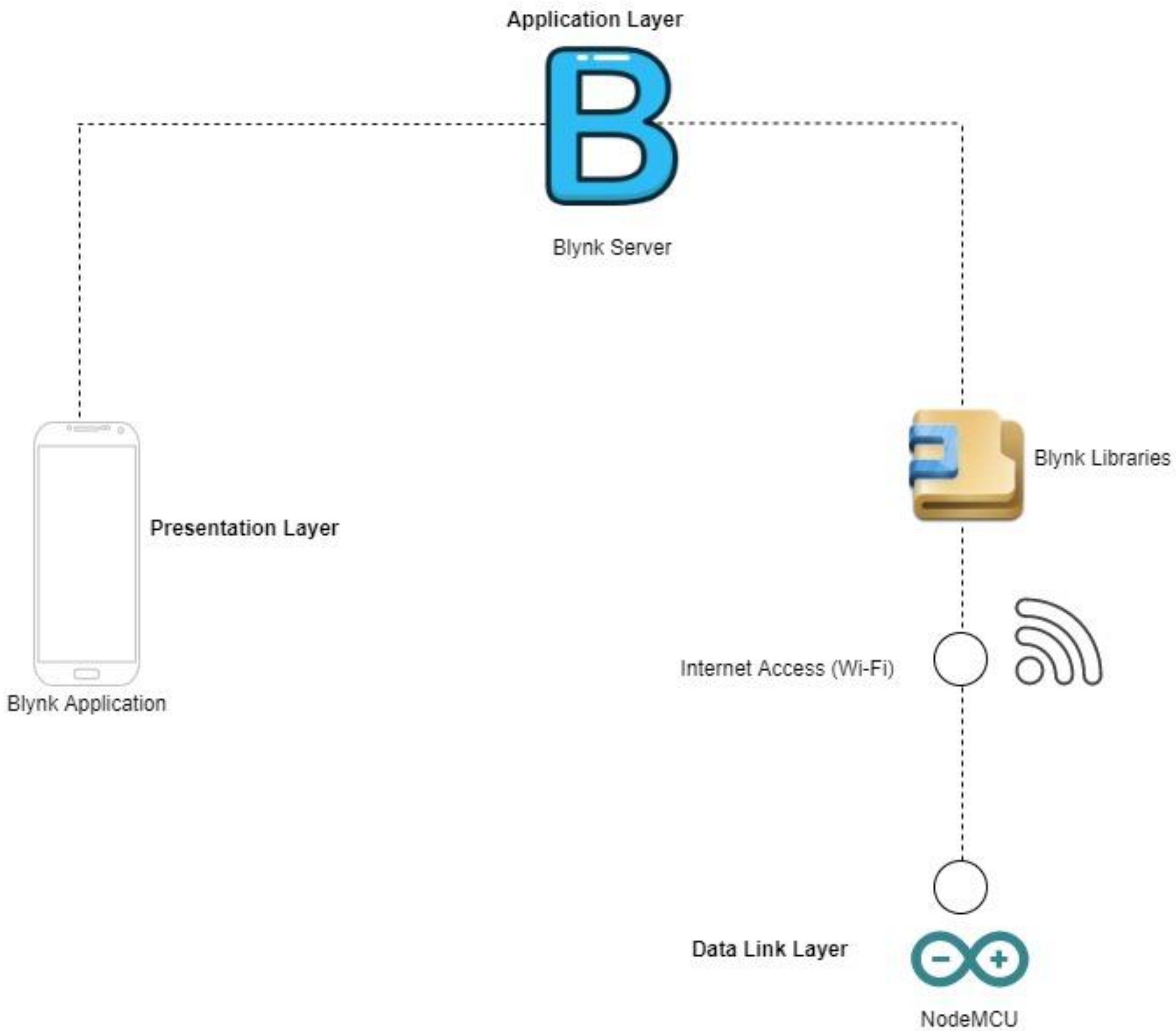

Figure 4-5 Layers found in the System Architecture

4.4.1 Architecture Design

The architecture design consists of NodeMCU microcontroller and it acts as an interface between the system and the Blynk cloud.

The system works in such a way that the researcher connects MQ-135 sensors in a room of her choice and links these sensors to the Blynk cloud. The cloud in this research is the central hub for all rooms connected to these sensors. The room chosen during the research transmits the greenhouse gas emission to the cloud platform. The information gathered is then relayed to the researcher through her mobile device and this data is collected and stored in real-time. This creates room for accuracy and reliability of the prototype.

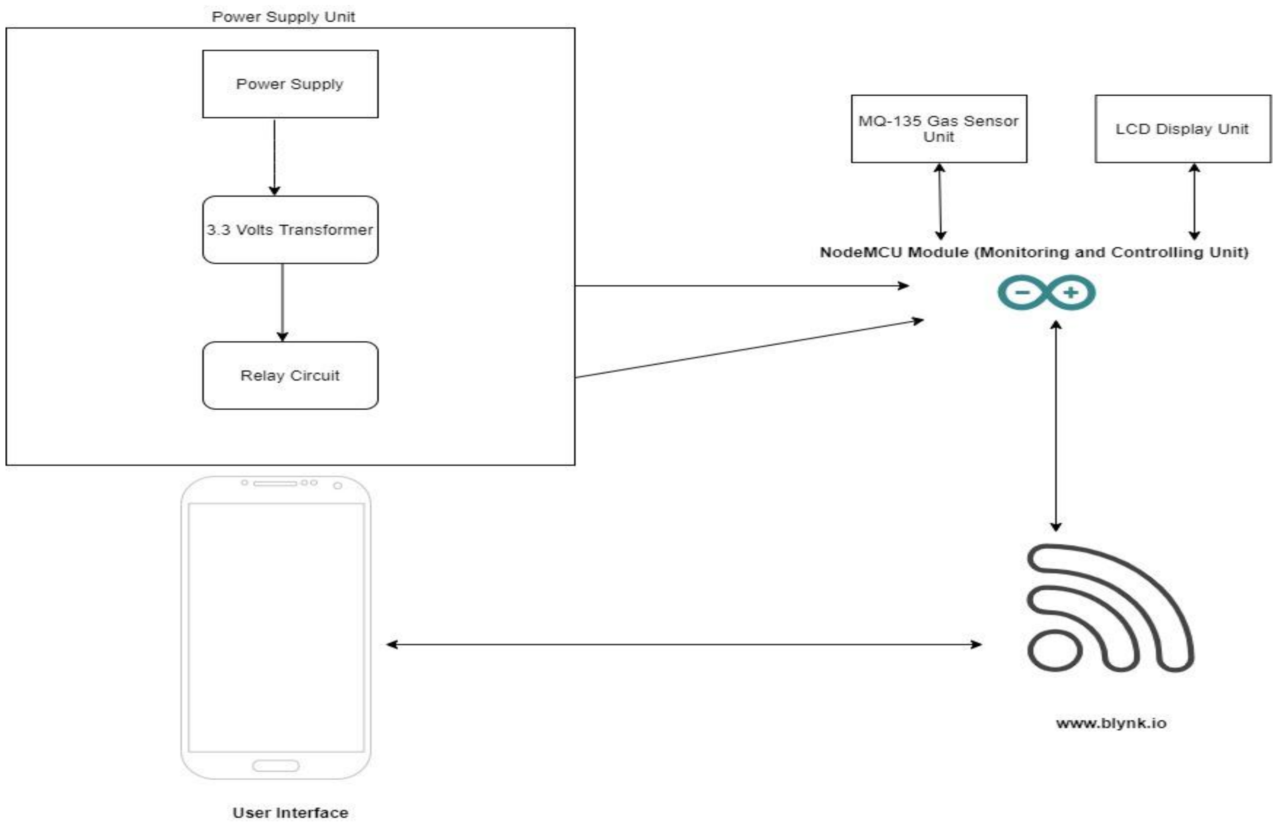

Figure 4-6 System Architecture Design

4.5 Process Workflow

The process workflow showcases a series of steps that are carried out within a system based on user-defined rules in order to make a system work efficiently and effectively. The aim of this system is to monitor greenhouse gas in the atmosphere by checking the air quality level. Once the system starts, it checks whether the air quality is at the optimum level, if yes, it repeats the process. However, if the system monitors that the air quality is above the optimum level, it sends a notification to the user concerning the same.

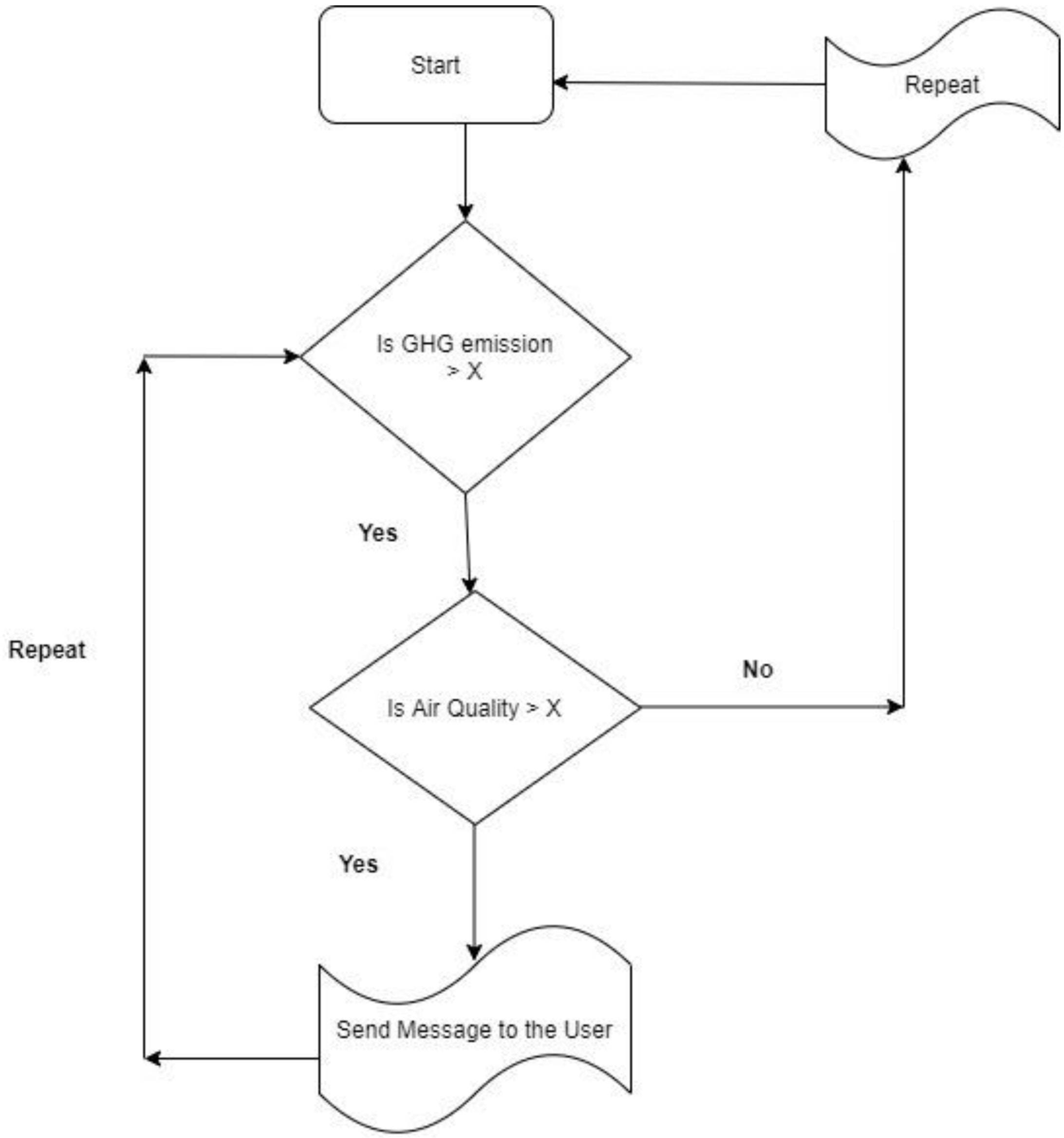

Figure 4-7 Process Workflow

4.6 Use Case Modeling

Use case models show how the users of a system interact with the system in order to solve the researcher's problem. It normally consists of use cases, the actors and the relationship between them. In this use case model, the MQ-135 gas sensor monitors the greenhouse gases by checking the air quality level in the atmosphere and sends the feedback on the same to the system user.

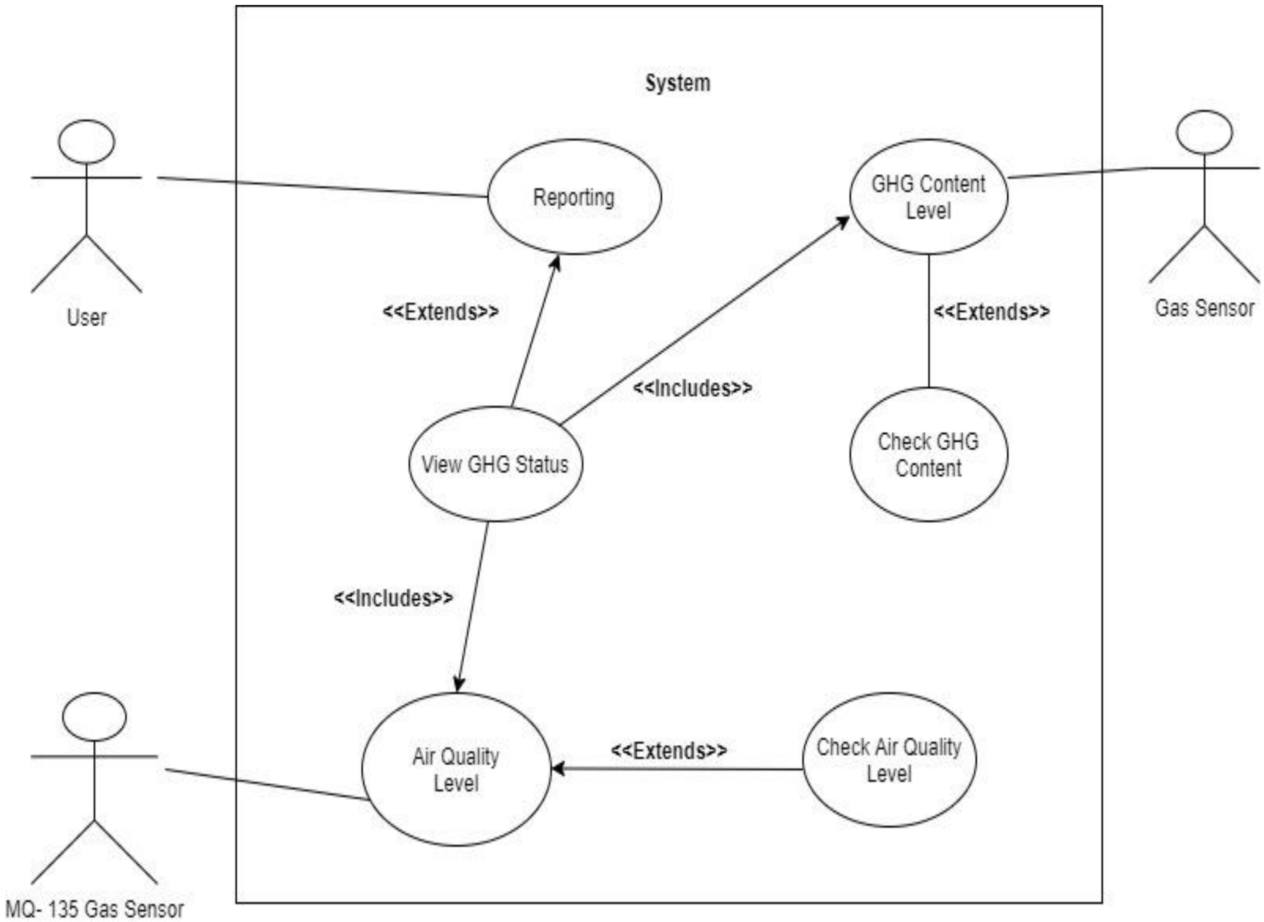

Figure 4-8 Use Case Modeling

4.7 System Sequence Diagrams

These are interaction diagrams that detail how operations are carried out within a system. Sequence diagrams show the interaction between the objects in the system in an orderly manner and they assist the developers of the system to document and understand the requirements for either new and existing systems.

In this system, the user would have to login to be able to interact with the system. Upon successful login, the user then prompts the system to display the level of air quality in his/her environment from a mobile browser. This will prompt the system to check the GHG emissions and air quality level and it transmits the values through the NodeMCU microcontroller to the user's mobile browser.

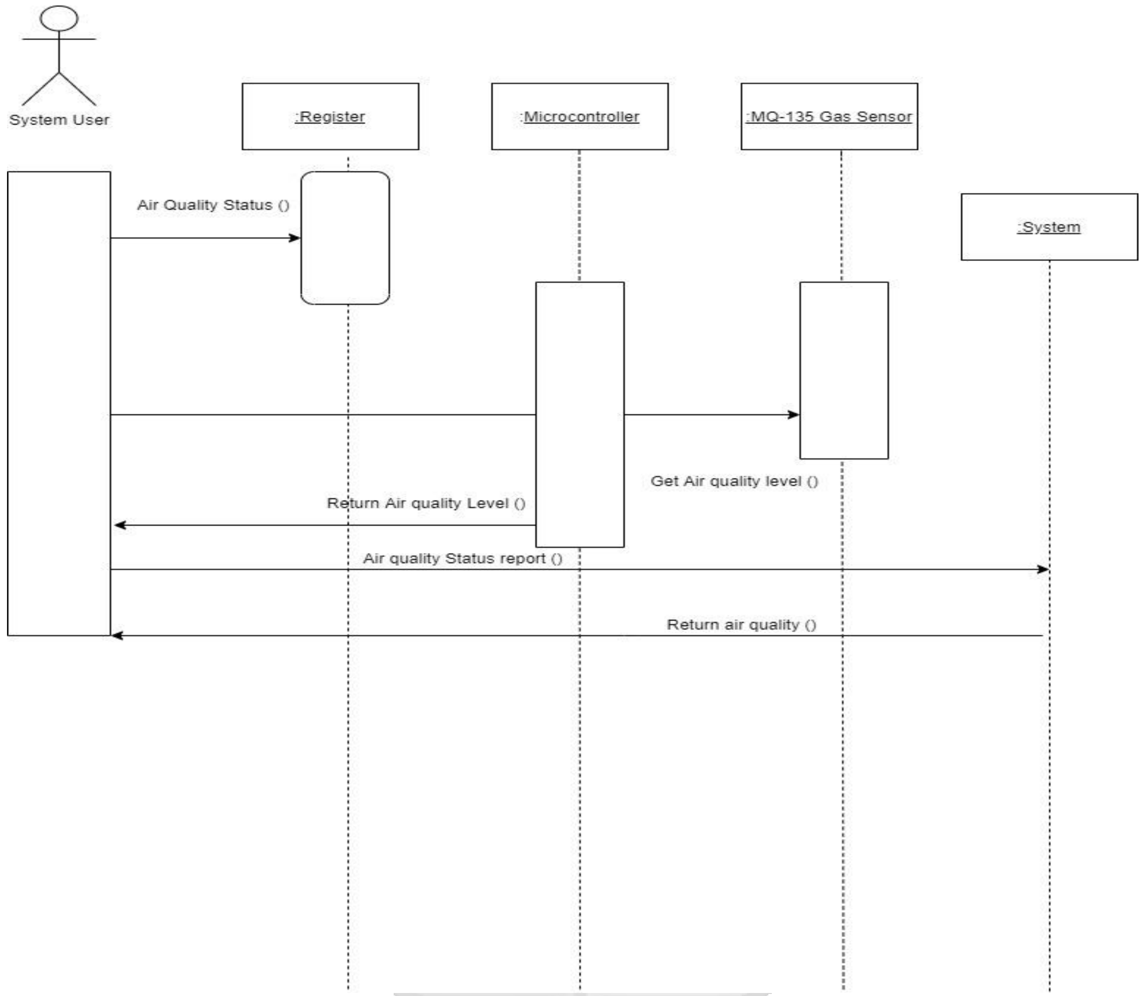

Figure 4-9 System Sequence Diagrams

4.8 Database Schema

The database used was that of Google Firebase which provides a backed application platform that a developer can use to develop android and web apps. In the database, the user table is automatically generated by the cloud server that contains user data. The microcontroller sends data to the user and report table. The microcontroller collects data from the chosen room and the report table also sends data to the user table thus relaying results collected from the microcontroller.

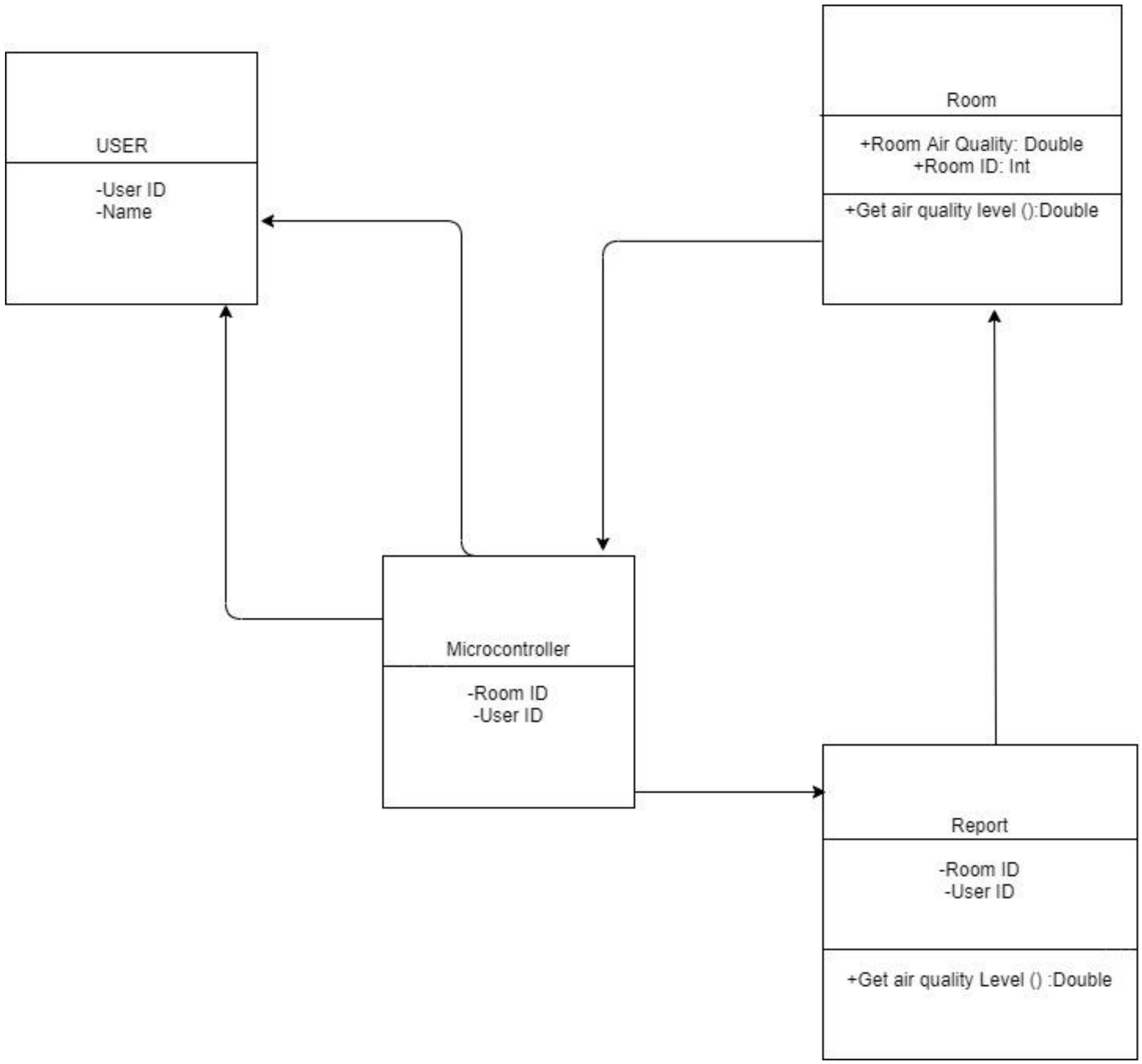

Figure 4-10 Database Schema

Chapter 5 : Implementation and Testing

5.1 Overview

This chapter mainly discusses the implementation and testing process done on the air quality prototype. The implementation section discusses the development environment, the development tools and platform used to create the prototype. While the testing section shows the type of testing mechanisms used and an analysis is made on the results.

5.2 Development Environment

This chapter will also give an in-depth analysis on the development environment used to build the prototype. These environments are important as they enable the prototype to be efficient and effective as well as to operate smoothly. This section will have the hardware and software requirements that were used when developing the prototype.

5.2.1 Software Requirements

Table 5-1 below shows the software requirements for creating the air quality prototype for monitoring greenhouse gas emissions.

Table 5-1.Software Requirements

SOFTWARE	DESCRIPTION
Operating System	Microsoft Windows 10 pro
Internet Browser	One can use any internet browser.

Arduino IDE	Arduino IDE version 1.8.12 or higher.
Arduino App	Blynk is used for monitoring sensors via local wi-fi.
Blynk API	This is an IoT platform that uses HTTP REST API to read and write values from apps or devices. It also provides a platform to share data to the public.

5.2.2 Hardware Requirements

Table 5-2 below shows the hardware requirements for creating the air quality prototype for monitoring greenhouse gas emissions.

Table 5-2.Hardware Requirements

HARDWARE	DESCRIPTION
NodeMCU	This is an open source microcontroller board that runs on the ESP8266 Wi-Fi module. It is equipped with sets of digital input/output (I/O) pins that may be interfaced to various boards.
A solderless PCB Bread Board	This board is mainly used for prototyping and designing applications. It is comprised of bus strips, terminal strips and binding posts that have hundreds of connecting points.
Jump wires	These are electrical wires with connectors at each end that are used to interconnect the components of a breadboard with other equipment without having to solder them.

3.3v power source	3.3v power source powers the NodeMCU wireless module.
MQ-135 Gas Sensor	This is an air quality sensor that detects a wide range of gases. It has a high sensitivity to smoke, ammonia, sulfide, benzesteam and other harmful gases.
Real-Time Clock (RTC)	This is an electronic device that measures the passage of time.
Light-Emitting Diode (LED)	This is a semi-conductor light source that emits light when current flows through it.
Light-Crystal Display (LCD)	This is a flat panel display that uses the light modulating properties of liquid crystals combined with polarizer.
U-blox Neo 6M GPS	This Global positioning system module is composed of a ceramic patch antenna, an on-board memory chip and a back-up battery. It is integrated with a broad range of microcontrollers and it is cost effective as well.

5.3 Wireframes representing the possible interfaces expected

This research used Blynk application to monitor air quality in the atmosphere. This is because it is able to record data in real time, store the data collected and even give notifications to the user in regards to the air quality monitored at particular periods of time.

Blynk application provides a good platform to create Internet of Things (IoT) projects such as for this research. The researcher came up with various wireframes that show how the Blynk application works and the possible interfaces expected while monitoring the air quality.

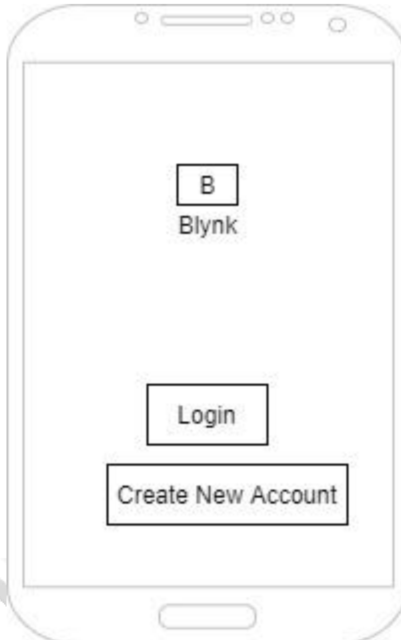

Figure 5-1 Login Page

Figure 5-1 shows the Login page which is the landing page of the Blynk application and it requires the user to first register herself before logging in. During registration, the user is required to fill in some details such as her name, e-mail address and phone number. After successful registration, Blynk will send the user an e-mail confirming her details.

Figure 5-2 Welcome Page

Figure 5-2 above shows the welcome page. Once the user has successfully logged into the Blynk application, she is led to this page that shows her whether she would like to create a new project, the other applications connected to Blynk and a community forum that she could possibly interact with.

The figure 5-3 below shows the process of creating a new project in the Blynk application. The user is directed to select the means in which the NodeMCU will communicate with Blynk as well the theme that she wishes to view the Blynk application. That is whether she would like to view the application in light or dark theme. Once the user has set all the parameters that she wishes to use, she clicks on the 'Create' button that forms her new project.

Figure 5-3 Creating the New Project

After the user has successfully created the new project, she is led to the dashboard platform that shows her how her project is operating. In this research, she sought to monitor air quality in the atmosphere. Therefore, she set various indicators that showed her when the air quality was good, moderate or severe. These indicators were accompanied by a gauge that monitored the exact amount of air quality in a particular area at a particular period of time.

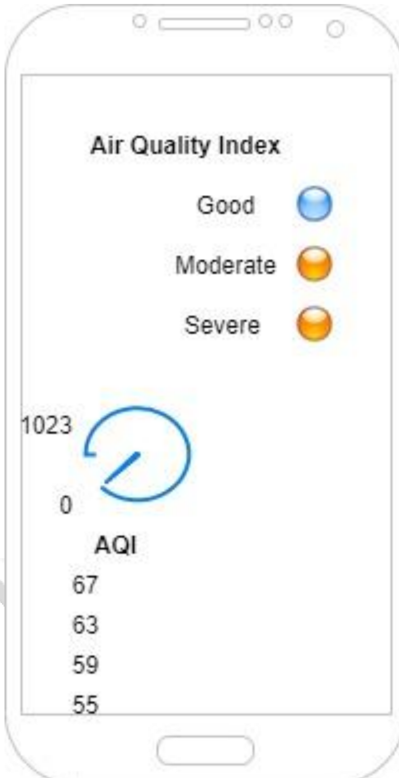

Figure 5-4 Dashboard of the Prototype

5.4 Actual Interfaces that show case when the air quality is good and when it is severe

The World Health Organization has put up guidelines that show how air quality should be monitored. The researcher used these guidelines while creating the prototype. Table 5-3 below shows how WHO has classified good air quality that has been considered normal and that lead to a healthy environment. It also shows severe or bad air quality that has been classified as a dangerous environment for human beings to live in.

Table 5-3.Air Quality Index Values and their interpretation in the environment

Air Quality Index values (AQI)	Levels of Health Concern		Colors
0-100 pm	Good/ Healthy		Green
100-150 pm	Moderate		Orange
150-300 pm	Bad/ Unhealthy		Red

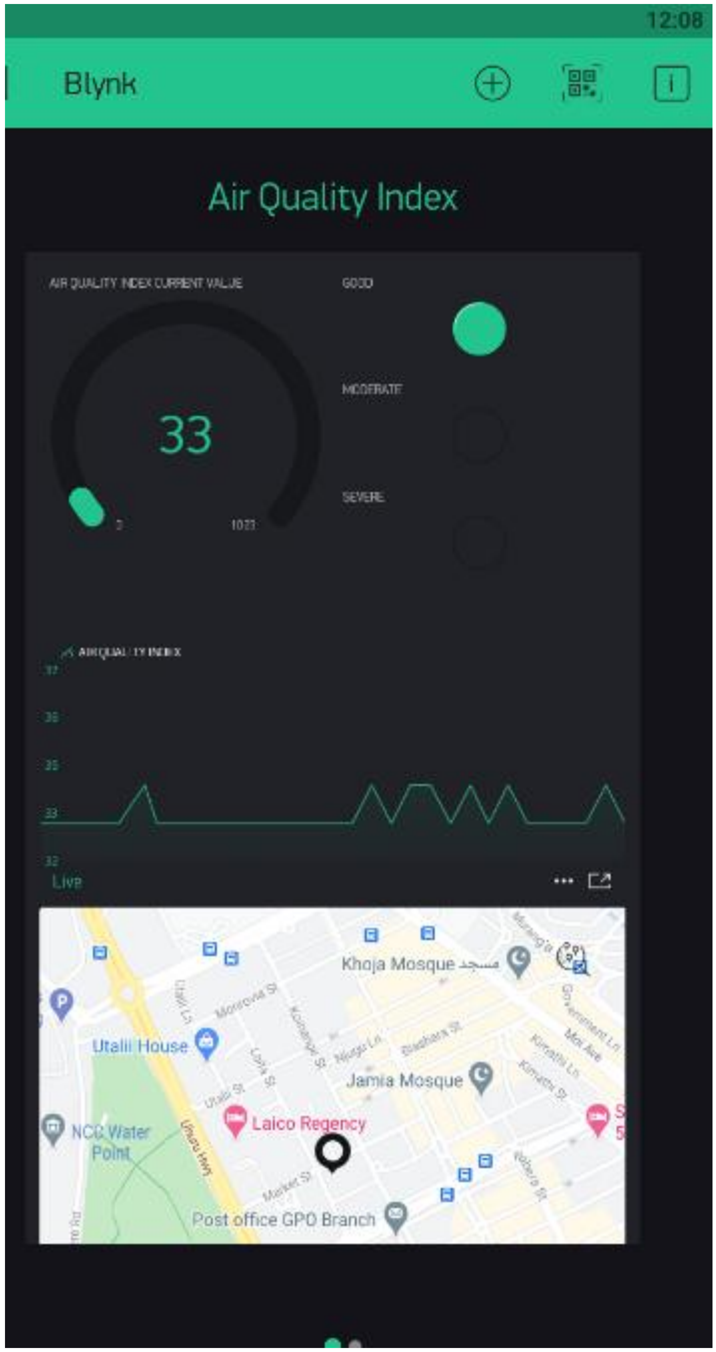

Figure 5-5 Normal Air Quality

Figure 5-5 above shows a normal air quality in the researcher's environment. The Blynk indicator showed green and that indicated that the air surrounding the researcher was healthy and conducive and therefore the greenhouse emissions in that area were low. The prototype also contained a green LED that lit up when the air quality monitored was good. The figure also shows the researcher's location which was made possible by the U-blox GPS module installed in the prototype.

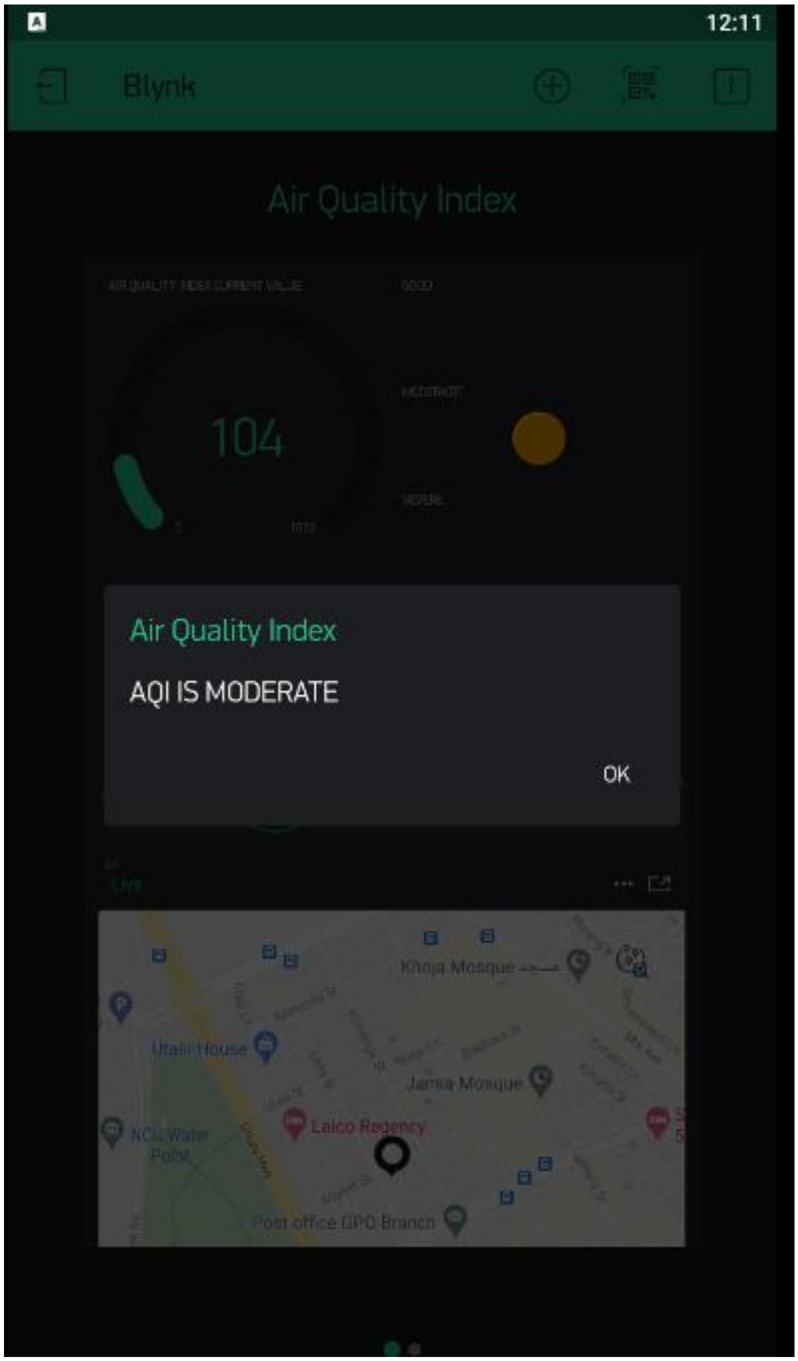

Figure 5-6 Moderate Air Quality

Figure 5-6 above shows a situation whereby the researcher was in an environment that had moderate air quality, that is, above 100pm (particulate matter). Such an environment is not conducive for persons who have underlying health conditions (such as asthma or pneumonia) although it is livable to a certain degree. The orange LED in the air quality prototype lit up to indicate this factor in the environment. The Blynk app also has an in-app notification for this situation that warns the researcher that her environment is not quite conducive for her.

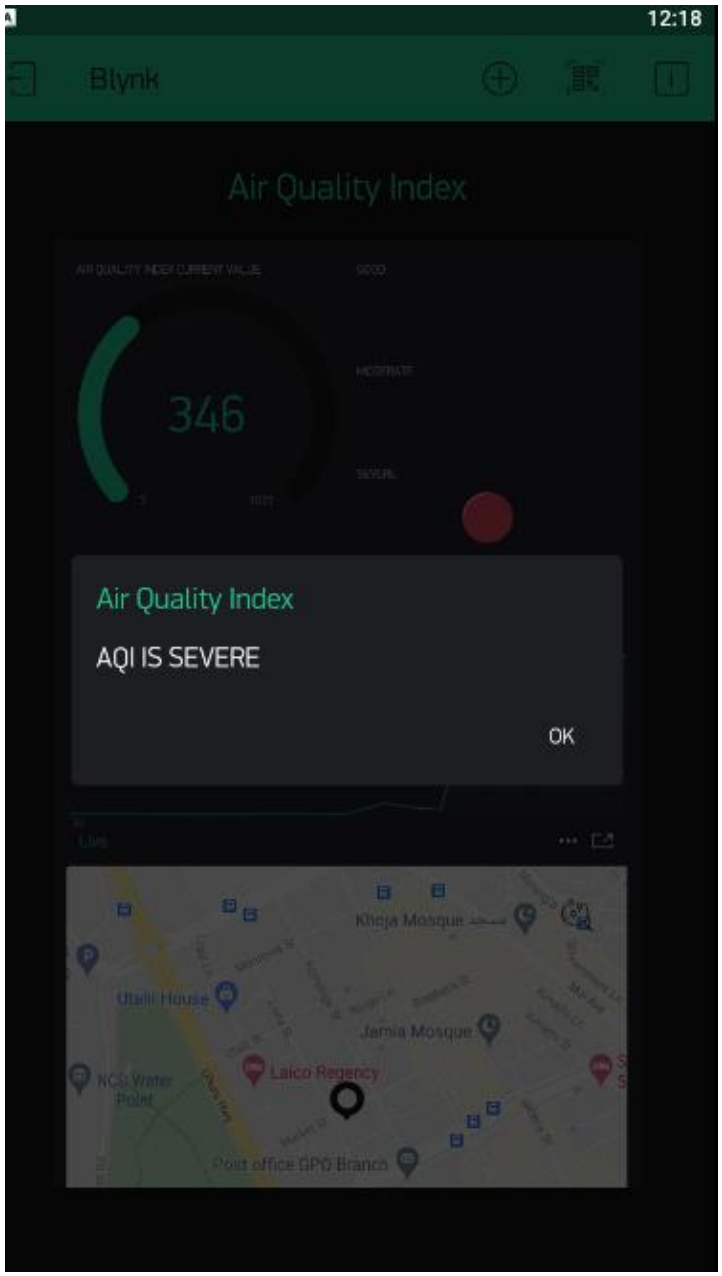

Figure 5-7 Severe Air Quality

Figure 5-7 above shows an environment that had unhealthy air quality which is quite harmful for living. This showed that the greenhouse gas emissions in that area were extremely high. Such an environment had surpassed the air quality recommended by the World Health Organization. The red LED in the air quality prototype lit up to indicate this factor in the environment and in-app notification popped up in the researcher's phone to notify her that she was in a harmful environment.

5.5 Database showing real time data for Air Quality

The data from the Blynk server was configured with Google firebase database so as to save the real time data. This made it easier for the researcher to be able to retrieve historical data when needed. The figure below shows a screenshot of the database in the researcher's Google account.

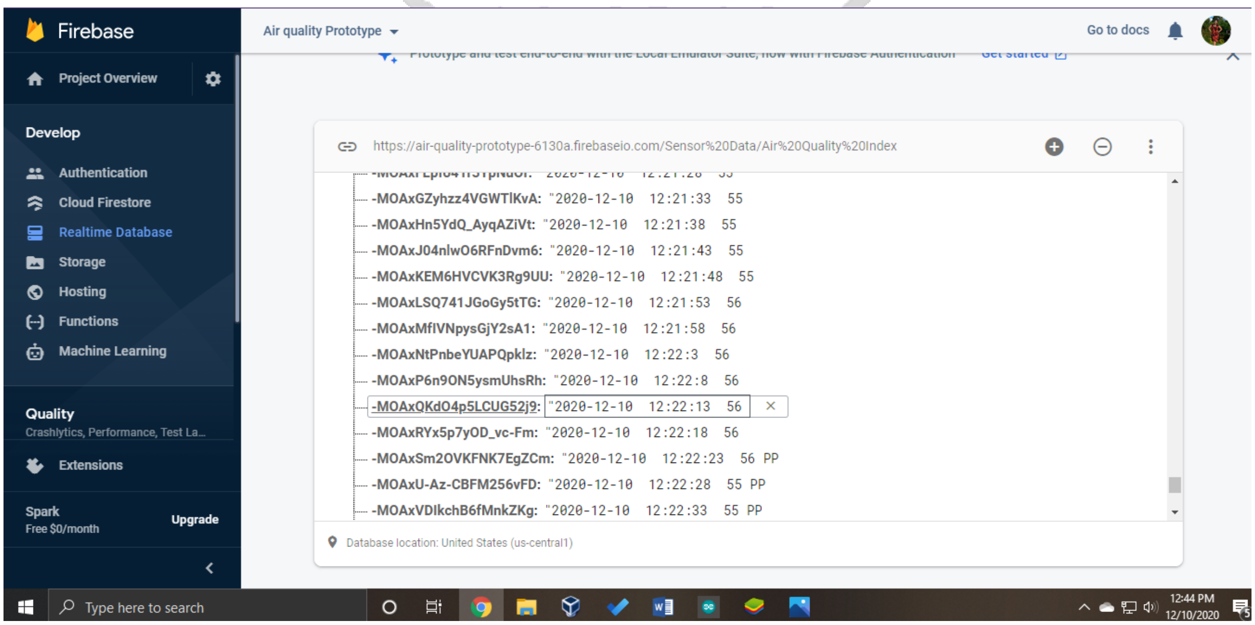

Figure 5-8 Google Firebase Database for Air Quality Data

5.6 The pseudo code for monitoring Greenhouse gas emissions and Air quality

The main aim of the prototype was to monitor the greenhouse emissions through measuring the air quality of a particular environment. Hence it was necessary for the researcher to do a configuration setup so that the prototype could work efficiently and effectively. The information was captured by the MQ-135 sensors and relayed the information to the Web API via the HTTPS protocol. The following shows the pseudocode that was used to create the main code for monitoring Air Quality;

This program calculates the Air Quality Values for monitoring Greenhouse gas emissions

SETUP Function

1)Set the board up in its initial state

2)Open the USB port to listen for output from the Air Quality monitoring program

LOOP Function

If (the air quality is moderate or severe)

Then

send notification

else DO Nothing

SERIAL INPUT FUNCTION (this runs whenever new data comes in via USB)

Get the pm data

if (the pm is good) Then

Store this data and LED should turn on Green

if (the pm is moderate) Then

Store this data and LED should turn on Orange and send a notification

If (the pm is severe) Then

Store this data and LED should turn on red and send a notification

5.6.1 Configuration Setup

The NodeMCU microcontroller was setup in this research by first setting up with the local computer (the researcher’s laptop). After the application was successfully compiled, the blue lights on the NodeMCU board (TR/RX) began blinking. That meant that the installation of the Arduino IDE with the NodeMCU board was successful and that data was being successfully transmitted and received. The communication was also happening over Wi-Fi which also had to be successfully set up within the Arduino IDE. The home Wi-Fi was therefore connected with the NodeMCU module so as to PUSH the values and REST format via the web service to the Blynk Cloud web API. Please see page 61 that shows a screenshot of the Configuration setup code.

5.6.2 Execution of the main program

In executing the main program, the void loop () function was used in the main block to enable program iterations to be carried out. The data from the MQ-135 sensor was parsed so that the data obtained could be manipulated into meaningful information into the Web API in the Blynk server for analysis and storage. Please see page 61 that shows a screenshot of the execution of the main program code.

5.6.3 Push to Web API server

This is usually the last phase of the prototype whereby the data collected by the microcontroller is “pushed” to the Blynk cloud server for analysis and storage purposes. In this situation the REST web service was facilitated by the Blynk before starting the transmission. Once the code was running, it was expected to bring forth either a “successful post” or a failure. This was an iterative process, hence in case of any changes in the air quality levels, the PUSH iterations were initialized and a change would be detected successfully. In case of a system failure, the system would respond with an error code and a PUSH iteration would be re-established with fresh data. Please see page 61 that shows a screenshot of the push to Web API server code.

5.7 Testing the prototype

This involved integration, system usability testing and acceptance testing. Integration testing involved combining all the units and ensuring that they worked together as the system. While system testing involved testing the whole application to ensure it meets the quality standards. The application was tested thoroughly to ensure that it met the functional and technical specifications. The acceptance testing gauged whether the application met the intended specification and satisfies the user's requirements. The acceptance test generally enables the researcher to deduce how the application will perform once released for public usage. In this scenario, the researcher handed out questionnaires to various test users of the system so as to receive feedback on the use of the system and the appeal of the interface to the users.

Chapter 6 : Discussions

6.1 Overview

This chapter discusses the research findings based on the prototype built. The discussion is grounded on the research objectives, relevant literature review and data variables. It also analyses the strengths of the prototype as well as the shortfalls experienced during the research process.

6.2 Review of the prototype's Research Objectives: Findings and Achievements

During the research process, the researcher came up with various objectives that would help to develop the air quality prototype to monitor greenhouse gas emissions. The first objective was to identify the elements related to air quality status monitoring. The researcher identified a number of characteristics required to build the prototype. These characteristics included the prototype model, the relevant hardware and software that are required to build the prototype, guidelines from the World Health Organization (WHO) regarding air quality and lastly the air quality monitoring process for Greenhouse gas emission. These characteristics provided the ground work for the design and development of the prototype, the database and the monitoring process. After a survey by the users of the product, the researcher also realized that these users required a prototype that was accurate, reliable, had a good system performance and a good user interface as well.

The second objective was to review the approaches used in air quality monitoring systems and their appropriateness in monitoring greenhouse gas emissions. This was achieved by comparing the current methods and those that have been documented over the past years by other researchers. The researcher established that the current methods that exist have faced various challenges and thus have not been quite appropriate in monitoring greenhouse gas emissions. This is because some systems are expensive to acquire such as the Continuous Emissions Monitoring Systems (CEMS) and Continuous Opacity Monitoring Systems (COMS). These systems are also bulky and they do not monitor air quality in real time. From these results, the researcher sought to build a prototype that was affordable, less bulky and that could monitor air quality in real time. The researcher also aimed to build a prototype that was accessible to everyone and not limited to organizations in developed countries. This would consequently lead to tackling greenhouse gas emissions all over the world as everybody was aware of their own environmental impact.

The third objective was to develop an air quality prototype to monitor and alert users on the levels of greenhouse gas emissions and the air quality in their current environment. This particular prototype was built by integrating both the necessary hardware and software. As mentioned in the previous chapters, the researcher sought to build an IoT project which would make use of hardware equipment such as the NodeMCU microcontroller, MQ-135 gas sensor, U Blox GPS for tracking the location, Light Emitting Diodes (LEDs), Real Time Clock (RTC) module, Liquid Crystal Dispay (LCD) and the Blynk servers which served as the software part of the prototype. The researcher successfully integrated the hardware and software equipment to form the prototype which worked using the researcher's mobile phone and the results received were recorded in real time and stored in Google Firebase Database.

The last objective was to test the prototype developed. The researcher tested the prototype in different environments which had varying air quality levels. The researcher also set the prototype to test the air quality in accordance to the guidelines given by the World Health Organization (WHO). These guidelines stated that air quality should be monitored in three main stages that is; normal air quality (0-100 ppm), moderate air quality (100-150 ppm) and severe air quality (150-300 ppm). The researcher used several techniques to test the prototype and these included; functionality testing, usability testing, software metric testing and compatibility testing. The prototype proved to be 95% successful after the testing was done and it was also reliable after being used by several users on their mobile phones. Testing the prototype was a necessary procedure as it enabled the researcher to compare the developed application to the existing applications in the industry so as to validate the superiority of the new prototype.

6.3 Findings with regards to User feedback

Once the prototype was created, the researcher was able to get feedback from some users who used the prototype in various environments in order to monitor greenhouse gases and also receive the air quality surrounding them. The findings were analyzed from the system usability questionnaire that had been issued to the users.

The main areas that the researcher had key interest on were the prototype's user interface, its performance, accuracy as well as its reliability.

6.3.1 User Interface

Figure 6-1 below shows that 80% of the respondents agreed that the prototype's user interface was very good and it provided a good platform to interact with. 10% of the respondents found the prototype's user interface to be average while 10% of the respondents did not like the interface at all.

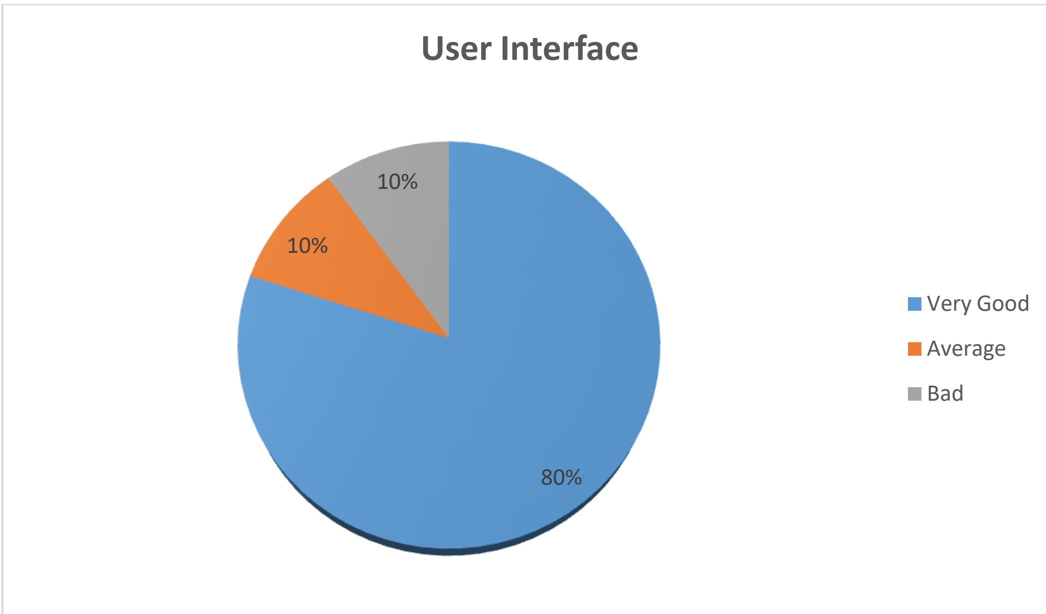

Figure 6-1 User Interface

6.3.2 System's performance

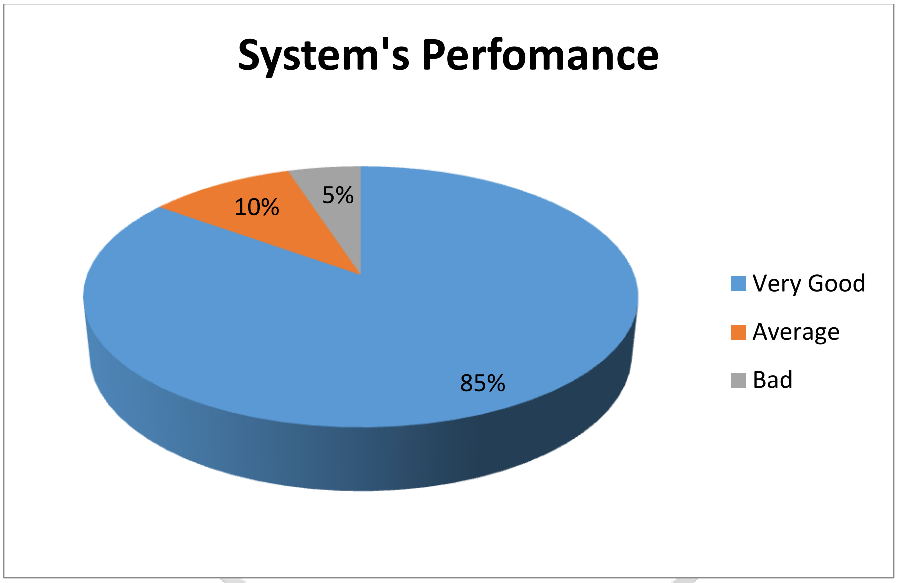

Figure 6-2 System’s Performance

Figure 6-2 above shows that 85% of the respondents agreed that the prototype’s performance was very good while 10% commented that it was average while 5% did not like its performance at all.

6.3.3 Accuracy

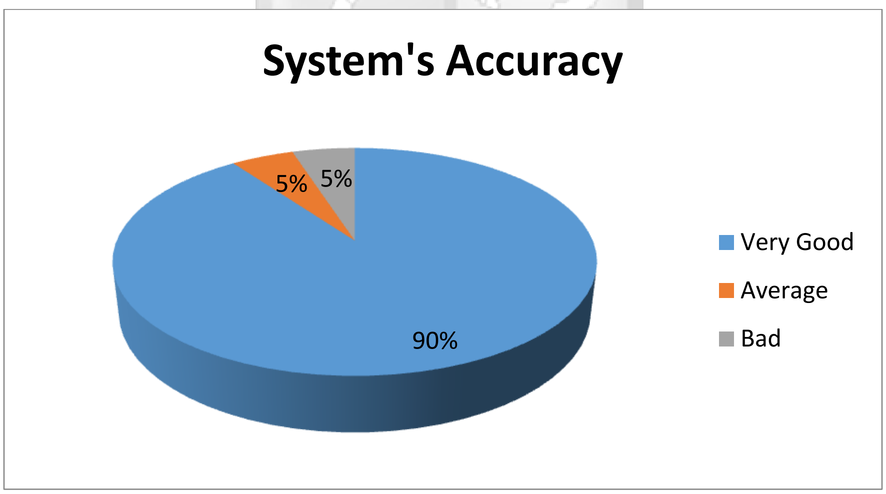

Figure 6-3 System’s Accuracy

In Figure 6-3 above shows that 90% of the users found the system’s accuracy to be very good. While 5% of the users found the system to be average as well as bad.

6.3.4 Reliability

Lastly, figure 6-4 below shows that 80% of the system's users found its reliability to be very good this is because the system depended on Wi-Fi which was readily available to them. 15% found its reliability to be average while 5% found it bad because of the system's heavy dependence on Wi-Fi.

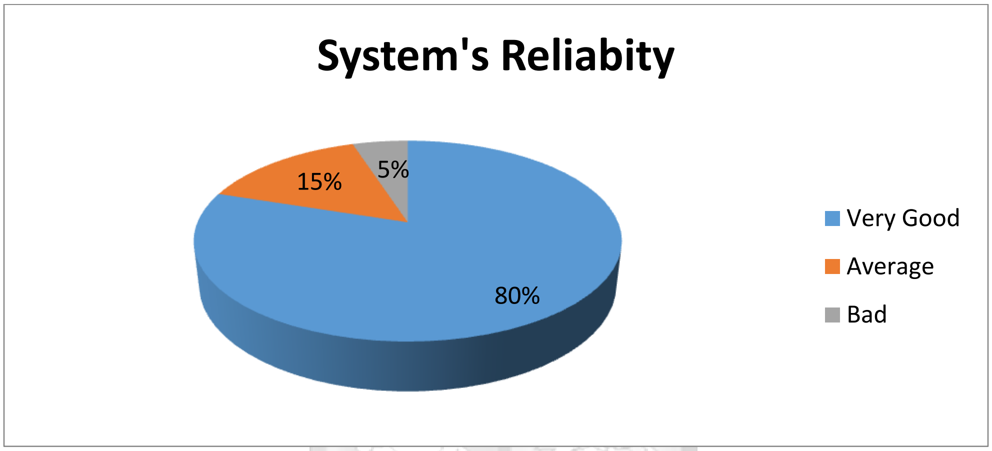

Figure 6-4 System's Reliability

6.4 Advantages of the developed prototype

The prototype created had several advantages as compared to the existing systems. They include;

i. The prototype is compatible to a mobile device and therefore it is easy for a user to use it in any location.

ii. The air quality prototype sends real time data collected in the environment to the user's phone and therefore it proves to be accurate, efficient and reliable. This data is sent in form of pm (particulate matter) which is the standard form of measuring air quality.

iii. The prototype created also has a feature in which it can show the user's current location and this feature is important as it enables the user to analyze different locations according to their air quality. Consequently, this can enable the user to raise awareness in case a certain location has severe air quality due to high greenhouse gas emissions.

iv. It also sends notifications to the user when he is in an environment with moderate to severe air quality. These alerts enable the user to take the necessary precautions.

v. The prototype also has a database platform which stores the air quality data. This enables the user to retrieve historical information when needed.

6.5 Shortfalls of the developed prototype

The main disadvantage that was encountered during the creation of the prototype is that it heavily depended on Wi-Fi hence could only be used with smart phones and in areas that there was network. It was therefore difficult to use it in areas which had poor reception and users who wanted to take part in the research but did not own smart phones found this to be a really big challenge.

Chapter 7 : Conclusions and Recommendations

7.1 Conclusions

Environmental pollution is a serious global threat that has affected millions of lives through extreme changes in seasons and weather patterns that have been experienced across the world. Intense human activities are to blame for the rise in pollution such as greenhouse gas emissions. Unfortunately, human beings have not been able to accurately monitor these emissions as well as monitor the air quality in their environment. This factor has made the rate of global warming to rise in the past century.

This research sought to investigate and attempt to address the challenges that are faced in monitoring air quality and greenhouse gas emissions in the environment. To achieve this goal, a review of literature was conducted which identified the challenges that are faced in monitoring greenhouse gas emissions. The literature also provided the groundwork on the requirements for building the prototype. A survey was also conducted that involved different users of the prototype and this survey was important as it gave the researcher an idea of the features that the prototype needed to have for it to be efficient and effective.

The literature showed that monitoring greenhouse gas emissions was becoming a trend in developed countries. However, this practice involved the use of expensive, bulky and sometimes inefficient tools that were only accessible to organizations. This study determined that by creating an air quality prototype to monitor greenhouse gas emissions, it would be easier and efficient for any individual to analyze the air quality in their environment. This research found out that users required simple and accurate applications that were easily accessible, affordable, efficient and reliable for them to monitor the greenhouse gas emissions as well as the air quality around them.

This research used concepts in IoT to come up with a sensor-based prototype for detecting and monitoring greenhouse gas emissions and air quality in the environment. This information was then relayed to the user of the system through dashboards and in-app notifications. The research also discovered that it was important to enlighten the general public on the purpose of monitoring the emissions and air quality in their environment as it enabled individuals to practice sustainable and environmental friendly economic activities.

7.2 Recommendations

As observed in the research, monitoring greenhouse gas emissions not only makes one aware of the air quality in their environment but it also motivates individuals to practice environmental friendly activities that will lower emissions and pollution in general. Therefore, in light of this, it is recommended that:

i. The air quality prototype to incorporate the use of sending notifications to environmental bodies in the country such as the Ministry of Environment when the air quality in the user's environment is severe.
ii. Integration of a purifier with the air quality prototype that can clean the air once the prototype has reported that the user is in an environment that has severe air quality. This added feature is important in a scenario when the greenhouse gas emissions are high and they could potentially harm the user's health.

7.3 Suggestions for future work.

This research mainly used smart phones in its study hence it proved to be quite limiting to persons who did not own such devices. I, therefore, would recommend that a further study to be conducted for individuals who own "analog" phones as this would cover a majority of groups across the world. The research also heavily depended on availability of Wi-Fi and this is quite a challenge as there are some places in Kenya and across the world that do not have access to Wi-Fi. I believe that this aspect would be a keen interest for future work.

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Appendix A: User Requirements Questionnaire

User Requirements Questionnaire

Researcher: Ngugi, Maureen Njeri

MSc. CIS, Strathmore University

This survey will be used for Academic purposes only. Its main objective is to collect User requirements to create an air quality prototype for measuring greenhouse gas emissions for environmental purposes in Kenya.

Kindly provide your honest answers to the following questions. Please note that this questionnaire targets adults.

Also note that your answers will be treated as private and confidential and will be used for this study only.

1. What is your County of residence? ……………………………………………………

2. Which Estate? …………………………………………………………………………

3. Is it easy to measure Greenhouse gas emissions in your current environment?

- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Blank

4. Are you aware of the air quality in your environment?

- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Blank

5. Are the current systems put in place able to give good systems alert concerning greenhouse gas emissions?

- ☐ Agree
- ☐ Neutral
- ☐ Disagree

- Blank

6. Do the current systems have a good reporting and dashboard capability?

- Agree
- Neutral
- Disagree
- Blank

7. Is the current process of measuring greenhouse gas emissions user friendly?

- Agree
- Neutral
- Disagree
- Blank

8. Does the current system allow users to check on the greenhouse gas emissions and the air quality in their environment any time?

- Agree
- Neutral
- Disagree
- Blank

10. I believe the current systems, if any, for measuring greenhouse gas emissions are secure and the data is kept safely?

- Agree
- Neutral
- Disagree
- Blank

11. I believe that if a proper computer system is implemented, monitoring and measuring greenhouse gas emissions would be made easier.

- Agree

- ☐ Neutral
- ☐ Disagree
- ☐ Blank

Appendix B: System Usability Questionnaire

System Usability Questionnaire

Researcher: Ngugi, Maureen Njeri

Msc. CIS, Strathmore University

This survey will be used for Academic purposes only. Its main objective is to analyze the user experience when using the air quality prototype for measuring greenhouse gas emissions for environmental purposes in Kenya.

Kindly provide your honest answers to the following questions. Please note that this questionnaire targets adults.

Also note that your answers will be treated as private and confidential and will be used for this study only.

1. The prototype has a user friendly interface.
    - ☐ Strongly Agree
    - ☐ Neutral
    - ☐ Strongly Disagree
2. I can use the prototype with minimum training.
    - ☐ Strongly Agree
    - ☐ Neutral
    - ☐ Strongly Disagree
3. Monitoring and measuring Greenhouse gas emissions are faster and easier using this prototype as compared to other existing methods.
    - ☐ Strongly Agree
    - ☐ Neutral
    - ☐ Strongly Disagree
4. The system provides a convenient way of monitoring and measuring greenhouse gas emissions.
    - ☐ Strongly Agree
    - ☐ Neutral
    - ☐ Strongly Disagree

5. I am willing to use this system to monitor and measure greenhouse gas emissions in my environment.
    - Strongly Agree
    - Neutral
    - Strongly Disagree
6. How likely are you to recommend this system to others?
    - Strongly Agree
    - Neutral
    - Strongly Disagree
7. Would you have any other comment? Please feel free to write it below

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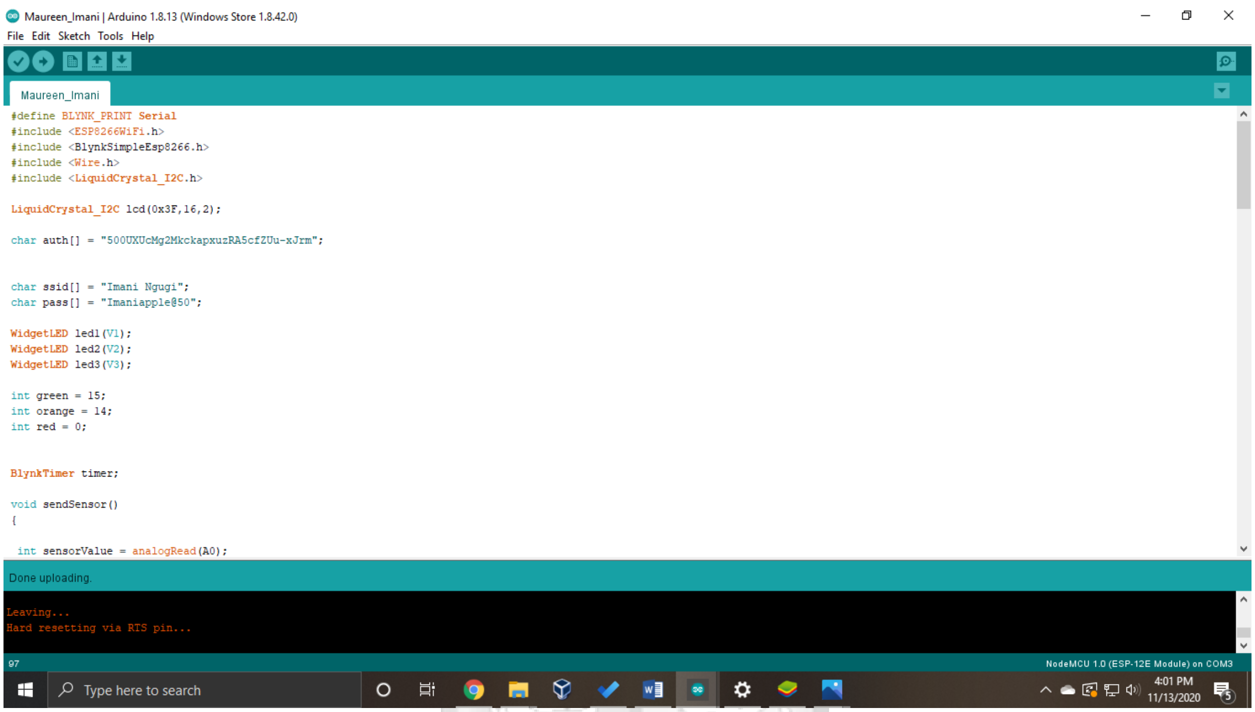
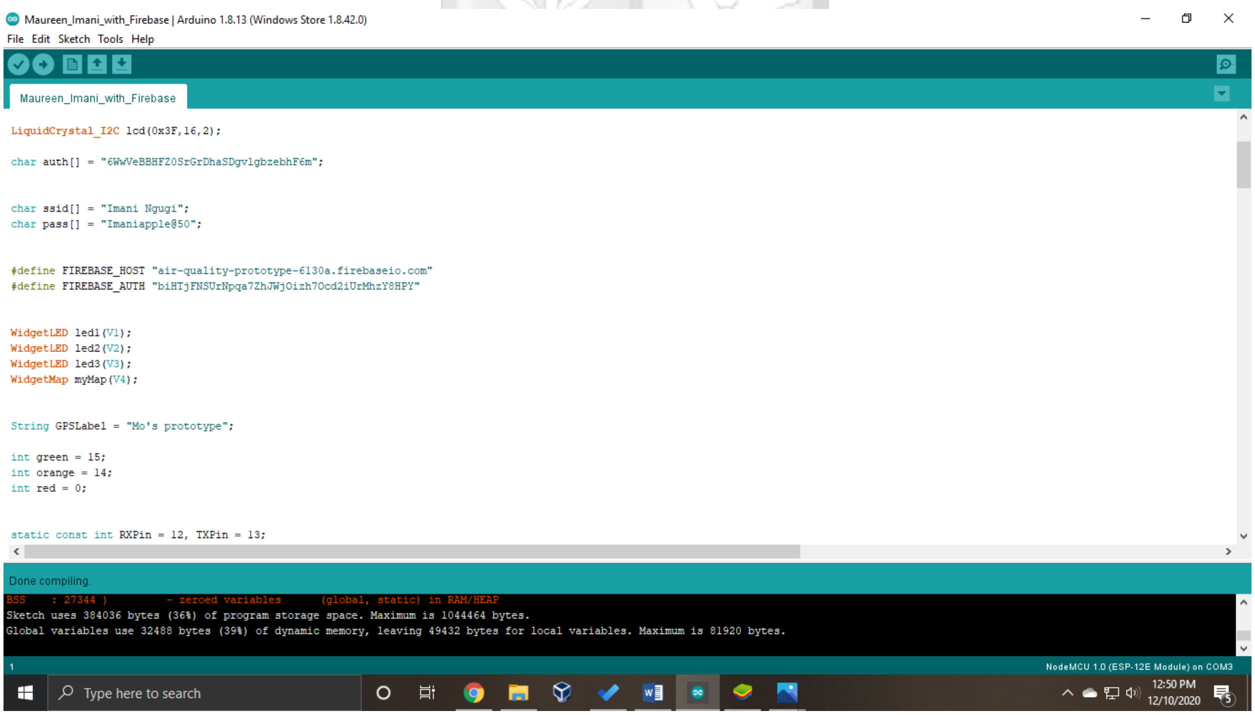
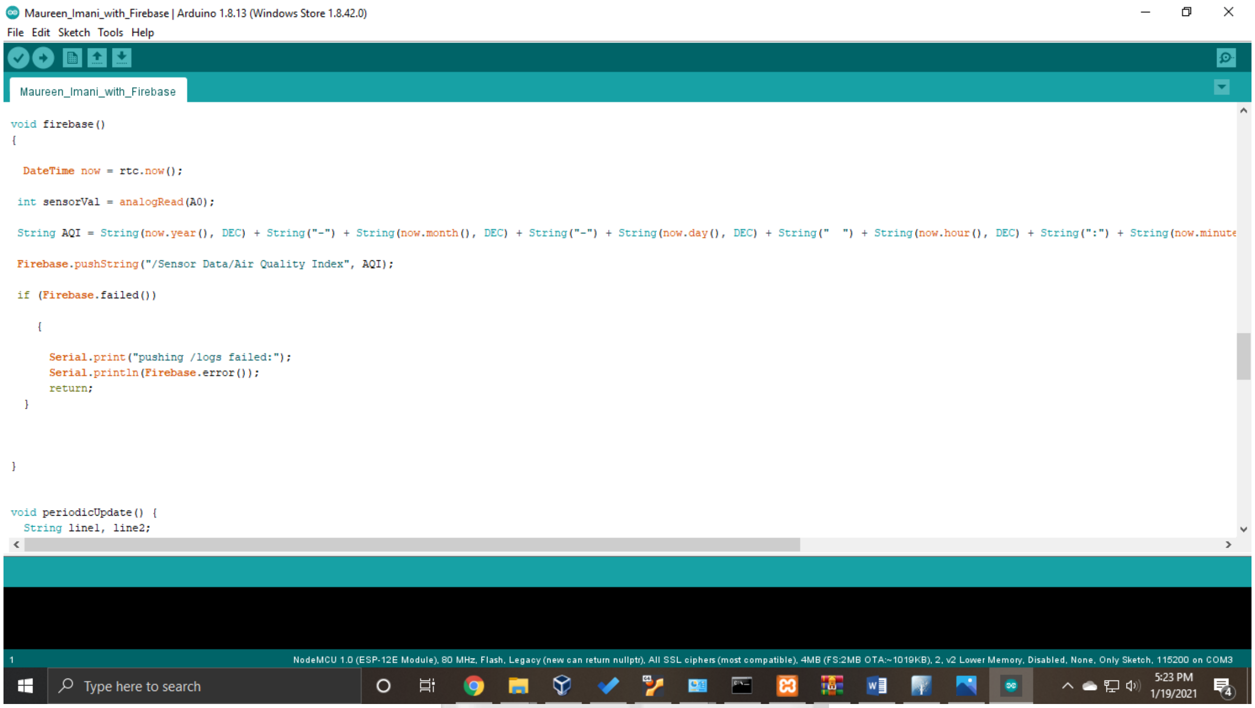
Appendix C: Screenshots of codes used to create an Air Quality Prototype.



Configuration setup

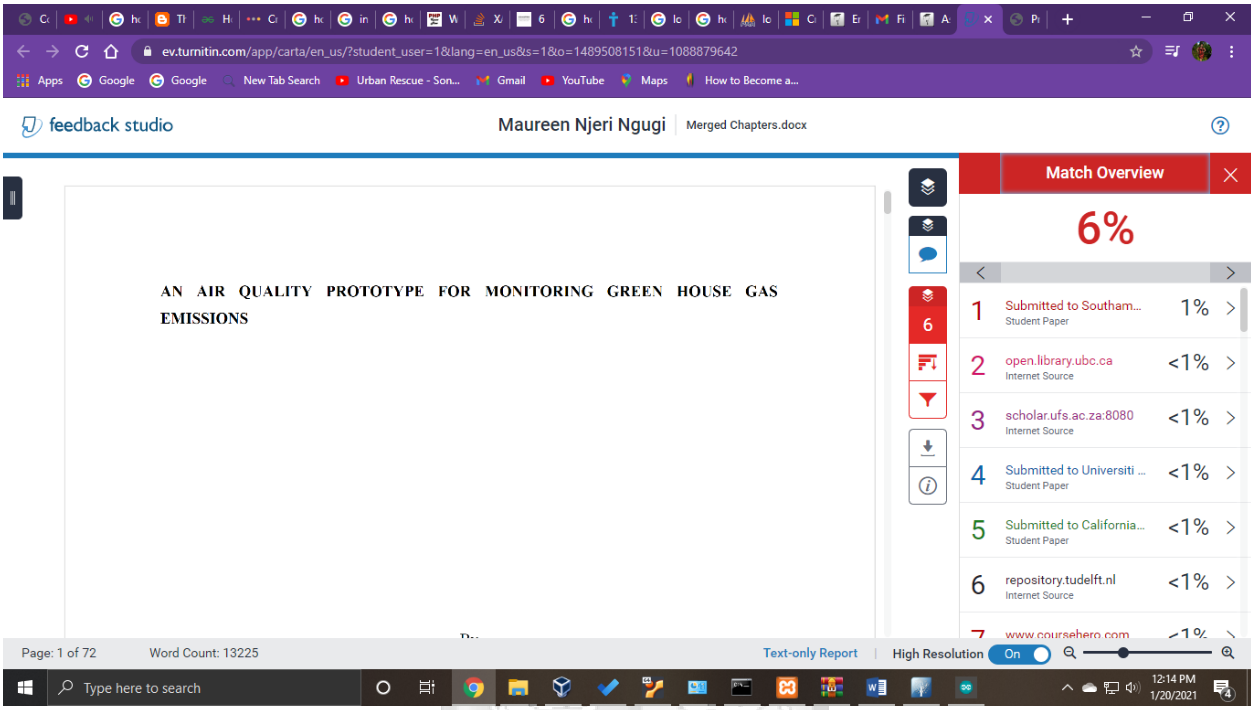


Execution of the main program



Push to Web API

Appendix D: Turnitin Report



Appendix E: Ethical Clearance Letter

Strathmore
UNIVERSITY

16th April 2020

Ms Ngugi, Maureen
nmaureen10@gmail.com

Dear Ms Ngugi,

RE: An Air Quality Prototype for Monitoring Greenhouse Gas Emissions

This is to inform you that SU-IERC has reviewed and **approved** your above research proposal. Your application reference number is **SU-IERC0729/20**. The approval period is **16th April 2020 to 15th April 2021.**

This approval is subject to compliance with the following requirements:

i. Only approved documents including (informed consents, study instruments, MTA) will be used
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by SU-IERC.
iii. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to SU-IERC within 48 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to SU-IERC within 48 hours
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to SU-IERC.

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely,

STRATHMORE UNIVERSITY INSTITUTIONAL ETHICS REVIEW COMMITTEE (SU-IERC)
16 APR 2020
TEL: +254 (0)703 034 000
P. O. Box 59857 - 00200
NAIROBI - KENYA

Dr Virginia Gichuru,
Secretary; SU-IERC

Cc: Prof Fred Were,
Chairperson; SU-IERC