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HbscIT

NETWORKING

TOPIC

IoT BASED SMART GAS LEAKAGE DETECTION AND ALERT SYSTEM

A RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE BACHELOR OF SCIENCE HONOURS DEGREE IN INFORMATION TECHNOLOGY – NETWORKING

Approval Form

The undersigned certify that they have supervised the student Japi Justin Tongai dissertation entitled the Application of IoT in Gas Leak Detection submitted in Partial fulfillment of the requirements for the Bachelor of Information Technology Honors Degree of Bindura University of Science Education.

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Name of student Date . ...

Name of supervisor Date ……..……………… …………………………………..

Name of chairperson Date …..……………………. …………………………………..

External examiner Date

Abstract

The Internet of Things aims to simplify life by automating all of the little tasks that we encounter. As IoT benefits can extend beyond automating jobs to improve other areas as well. The current safety requirements. The fundamental aspect of any project, safety, has not been overlooked. IoT is untouched by. Gas leaks can be fatal and harmful, whether they occur in open or closed spaces. Despite their remarkable precision, conventional gas leakage detector systems do not recognize a few elements in the field of leaking information to the public. Therefore, we have used the IoT technology to make a Gas Leakage Detector for society which having Smart Alerting techniques involving sending an email to the concerned authority and an ability performing data analytics on sensor readings. Our main aim is to proposing the gas leakage system for society where each flat have gas leakage detector hardware. This will detect the harmful gases in environment and alerting to the society member through alarm and sending notification.

Dedication

Therefore, I do not run like a man running aimlessly, I do not fight like a man beating the air. We were together in this research for you have given me the strength and wisdom to fight my good fight! For these reasons everything that I am Lord Jesus it all belongs to you. I love you so much

Acknowledgements

I would like thank and praises to God the Almighty for the gift of life. A further acknowledgement goes to my family, my Aunt, my big brother and dear my parents for the unconditional love and support throughout the journey. I would also like to express my gratitude to my supervisor Mr. Matombo for his support, encouragement and direction in the course of the research.

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CHAPTER ONE:

PROBLEM IDENTIFICATION

1.0 Introduction

One of the worst emotions that wrecks any human being, is regret. The aftermath of every catastrophic event triggers a tag of war in thought as to what have been done to prevent or at least mitigate its effects. The rapid adoption of clean energy has seen an exponential rise in the use of gas across multiple domains. Such a shift is bearing some tremendous fruits for the environment and simultaneously brought about new hazards. Countless lives and property have been lost in accidents triggered by gas leakages. This chapter serves to exhibit in depth the problems and challenges emanating from gas leaks and the possible mitigation measures that may be taken.

1.1 Background of the Study

Although naturally occurring gas has been known since ancient times, its commercial use is relatively recent. The first commercialized natural gas occurred in Britain. Around 1785, the British used natural gas produced from coal to light houses and streets. In 1816, Baltimore, Maryland used this type of manufactured natural gas to become the first city in the United States to light its streets with gas (American Public Gas Association, 2012). Looking at the continent, Africa has one of the largest natural gas deposits in the world especially in Egypt and Algeria. Closer to home, the Mozambique LNG project comprises the Golfinho-Atum gas field development in the offshore Area 1 Block of the deep-water Rovuma Basin and the construction of a 12.88 million tonnes per annum (Mtpa) onshore liquefied natural gas (LNG) facility on the Cabo Delgado coast of Mozambique (Akokaike, 2021).

Here at home, a large deposit of oil and gas was discovered in Muzarabani within the Cabora Bassa project and its mining has already commenced. In 2015, the United Nations (UN) hatched the Sustainable Development Goals (SDGs) in an effort to create a platform on which people could use the available natural resources in a profitable manner without destroying the environment particularly in light of Global Warming (Morton, 2017). As such, all industries and households globally have adopted the use of natural gas as a source of power as it is climate friendly. IoT stands for Internet of Things, this form of technology has been around for around two decades now. It is a process whereby things (objects) such as sensors are able to communicate with each other over the internet (Sharma, 2019).

In order to ascertain the safe usage of gas, a number of solutions have been developed worldwide. China has developed mobile gas leak detection robots for use in industry and other radioactive environments. The robots are smart and they sent real-time updates to a cloud server for analysis. In addition to that, they have designed and developed handheld and wearable gadgets which are capable of detecting gas leakages and radioactive material through a smart Geiger Mueller counter. Similar solutions have been developed and implemented in the West (Crowcon, 2021). In the African continent, there is no active product locally developed save for those imported technologies that are assembled in various factories. As for Zimbabwe, no locally developed solution is active and very few of the imported technologies are active due to costs and trade limiting sanctions.

1.2 Problem Statement

Friendly as these maybe, if poorly handled, they quickly turn into a lethal foe. The Vizag gas leak, was an industrial accident that occurred at the LG Polymers chemical plant in the R. R. Venkatapuram village of the Gopalapatnam neighbourhood, located at the outskirts of Visakhapatnam, Andhra Pradesh, India, during the early morning of 7 May 2020. The resulting vapour cloud spread over a radius of around 3km, affecting the nearby areas and villages. As per the National Disaster Response Force (NDRF), the death toll was 11, and more than 1,000 people became sick after being exposed to the gas. Preliminary investigations concluded that the accident was likely the result of insufficient maintenance of units storing the styrene monomer, improper storage, and operation errors resulting in a gas leakage (National Disaster Response Force, 2022). In October 2021, six people lost their lives when gas tanks exploded at SAS Gold mine in the Mazowe district of the Mashonaland Central province of Zimbabwe. A similar accident happened in Bindura were five people were injured in Bindura in August 2022 after a gas tank exploded (The Herald, 2022).In most cases, the leaks are tantamount to ignition which brings out heavy flames which convert property into losses worth millions of dollars in a very short period of time. Multiple solutions have been developed worldwide to prevent accidents, mitigate risk and to facilitate early warning systems. However, very few of these solutions were developed by Zimbabweans thus we are forced to import solutions at exorbitant costs. Furthermore, these systems are flawed as they are not well tested within the Zimbabwean ecosystem which leaves them being not as effective as they were in their home countries. As such, there is a dire need for us to innovate and develop our own solutions as is the aspiration of the African Union's Agenda2063.

1.3 Research Aim

To design and develop an IoT based gas leakage detection system that sends an email alert to the administrator and evaluate its efficiency.

1.4 Research Objectives

1. To design an IoT circuit that will detect gas leakages and send an email alert.

2. To identify how IoT has been used in gas leak detection and overall occupational safety worldwide

3. To evaluate the accuracy of the system.

1.5 Research Questions

1. Can IoT be used in gas leak detection and how efficient is it?

2. How and where has been IoT been used to detect gas leakages?

3. How accurate is the IoT gas leak detection system?

1.6 Research Hypothesis

H_0: The system will be able to detect the gas leakage and send an email alert.

H_1: The system will not be able to detect the gas leakage and send an email alert.

1.7 Significance of Study

This study enables us to bring about a system that facilitates early detection of gas leaks which gives us ample time to react and mitigate risks and ultimately save lives. Furthermore, it is a platform for us to innovate and develop robust home grown solutions.

1.7.1 Assumptions

It is assumed that all participants of the testing stage and respondents to the interviews gave honest and unbiased feedback.

1.8 Ethical considerations

In this research, simulative measures were taken in regards to the concentration of gas used so as to make sure that no hazards were created. Strict safety protocols were observed during experimentation and it was not done in the presence of minors.

1.9 Limitations of the study

1. Cost of prototyping equipment.

2. Access to a well-equipped lab for use of lethal gases in testing.

3. Time constraints in system development.

1.10 Scope of the research

This research is limited to the detection of only four gases by a gas sensor. These gases are hydrogen, LPG, carbon monoxide and methane. This is mainly because these are some of the most widely used gases in both industry and households. They are highly flammable if ignited and can be lethal if inhaled hence the focus on them.

1.11 Conclusion

This chapter served to exhibit the background of gases and the Internet of Things. Furthermore, it showed the problems within society that are emanating from the widespread usage of gases, and proposed a solution for them. The next chapter is Literature Review.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

A literature review is an overview of the work done and published by other researchers on a similar and or close research topic. A literature review is a comprehensive summary of previous research on a topic. The literature review surveys scholarly articles, books, and other sources relevant to a particular area of research. The review should enumerate, describe, summarize, objectively evaluate and clarify this previous research (Bloomsberg University of Pennysylvania, 2021).

2.2 Gas leak detection using IoT and Email alert notifications

Natural gas is a fossil energy source that formed deep beneath the earth's surface. Burning natural gas for energy results in fewer emissions of nearly all types of air pollutants and carbon dioxide (CO2) than burning coal or petroleum products to produce an equal amount of energy thus it has been adopted as green energy worldwide. (Bakar, 2010). Gas leak detection is the process of identifying potentially hazardous gas leaks by sensors. A gas detector is a device that detects the presence of gases in an area, often as part of a safety system. A gas detector can sound an alarm to operators in the area where the leak is occurring, giving them the opportunity to leave. This type of device is important because there are many gases that can be harmful to organic life, such as humans or animals. Gas detectors can be used to detect combustible, flammable and toxic gases, and oxygen depletion (Khan, 2020). This type of device is used widely in industry and can be found in locations, such as on oil rigs, to monitor manufacturing processes and emerging technologies such as photovoltaic. The Internet of things describes physical objects with sensors, processing ability, software, and other technologies that connect and exchange data with other devices and systems over the Internet or other communications networks. The IoT refers to networks of heterogeneous, devices rather than traditional networks of. Homogeneous devices. Things, in the IoT, involve a. variety of embedded devices and smart objects who are able to communicate over a network (Abdul-Qawy, 2015). Combining these concepts into one innovation, we come up with a system that uses an analog gas sensor in leak detection and utilises a network card on a microcontroller in order to send real time alerts whenever the threshold of gas is exceeded thereby allowing quick response from the authorities.

2.2.1 Existing Gas Detection Mechanisms

In the Globally North countries which are also referred to as the first world countries, very efficient and sophisticated detection systems have been designed, developed and implemented. Using the USA as a stencil, there exists a company called ION Science which specializes in the development of gas leak detectors. They have Portable gas detectors keep workers safe from atmospheric hazards. These detectors operate at a close range to the user, are handheld, and lightweight devices that can be held or attached to a belt. They have Personal gas detectors keep workers safe from atmospheric hazards by continuously monitoring the user’s breathing zone. These detectors must operate at close range to the user. The third line of products are Fixed gas detectors are generally installed in large facilities and are used to both detect major leaks and provide early warnings of gas leaking from a particular system. Fixed gas detection systems are configured using relays and customizable alarm point settings. These settings ensure that fixed gas detectors respond quickly to atmospheric hazards. (ION Science, 2019). Coming down to Africa, countries such as Nigeria, Egypt and South Africa have imported similar solutions from the East and the West. These solutions are mainly fixed within their heavy industries such as mining and chemical manufacturing. Tunisia has been researching into the construction of their own gas detector that is based on tunable diode laser absorption spectroscopy (Frish, 2015). Putting Zimbabwe under the microscope, high value companies also have imported similar solutions, however due to the costs, the rate of adoption is still low. As such, most companies and households still use the traditional method with utilises the olfactory sensory route of smell to detect a pungent smell which was deliberately put into gas by manufacturers (Wogalter, 2011).

2.2.2 Application of IoT in as a safety tool

The Internet of Things (IoT) is a network of physical objects that are embedded with sensors and other technologies to share data with other devices over the Internet. Evolution took place due to the convergence of multiple technologies, machine learning, embedded systems, commodity sensors, and real-time analytics. Traditional wireless sensor networks, control systems, and others enable the Internet of Things (Arslan, 2022). The ability of machines to communicate with each other has created new grounds for the use of smart objects as safety tools. They can continuously monitor and analyze a site floor, observing machinery, workers and assets to detect safety incidents, noncompliance and potential workplace hazards.

2.2.2.1 IoT in Workplace Safety

The most crucial thing in any company is making sure that the working environment is safe and secure. The invention of the Internet of Things has brought about workplace safety to another new level. Its application can also substitute as an accident prevention program that can be unified into a company's' safety system and help progress workplace safety. IoT in a working environment is one of the most advanced ways to increase safety that a company could implement. It has managed to help companies worldwide by improving working conditions, data collection, streamlining operations, and increasing productivity (Tsang, 2016). IoT devices do not entirely protect workers in risky industries. Instead, they help managers address large numbers of threats that can be prevented. IoT technology allows organizations to monitor environmental conditions, physical health of employees and can help limit employees' risks and exposure to prevent accidents from happening. IoT is used as a tool for predictive maintenance, employee health monitoring system and accident prevention across different sectors of industry.

2.2.2.2 IoT in Home Safety and Security

IoT technology is most synonymous with goods relevant to the idea of a smart home on the consumer market. This involves appliances and equipment such as surveillance systems, cameras, lighting fixtures, and other home appliances that can be operated by ecosystem-related devices and serve one or more common ecosystems (Ijaz, 2016). Most systems in this sector are used for intrusion detection, energy saving and reducing costs. IoT provides smart home security by combining AI to enhance the performance of devices such as CCTV cameras, smart lights, doorbells, and fire sensors. Everyday use cases of IoT smart security solutions include data loss prevention, secure connections, and device authentication and management (Rastogi, 2021).

2.2.3 Challenges with Existing Systems

Given that most of them are designed overseas, they are pricey to acquire and have additional costs for importation such as customs duty. More so, they come in foreign languages such as Chinese which present a myriad of challenges when it comes to maintenance and also leads to improper use because of the language barrier which tantamount to false alarms. The traditional method is no longer reliable as there is a high usage of masks in industry which make it harder to detect any smells. Narrowing down to community and household level, it is harder to detect the odd smell as some communities have odours emanating from blown pipes and septic tanks. None of these systems are homegrown solutions thus they do not meet our problems at all levels.

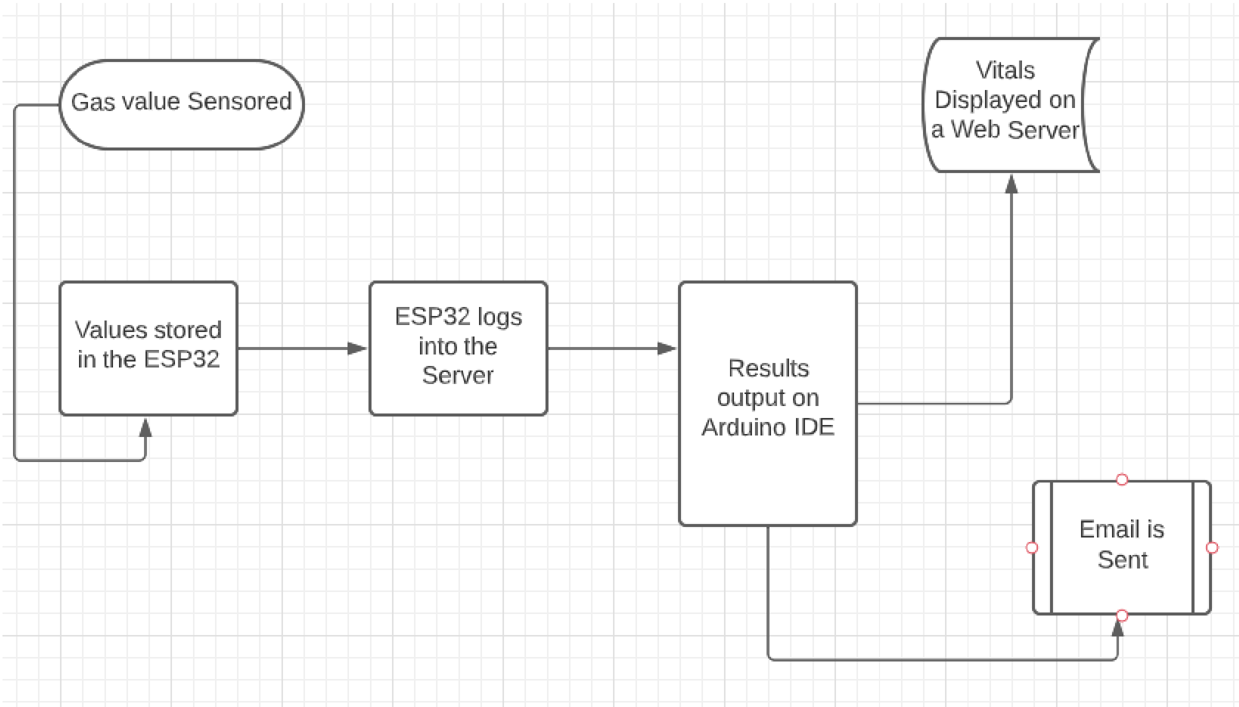
2.3 Review of Similar Work

(Nureni, 2022) Developed a gas leakage detecting project. This was in response to the development and implementation of gas powered vehicles. The system is based on a microcontroller that employs a gas sensor as well as a GSM module, an LCD display, and a buzzer. The system was designed for gas leakage monitoring and alerts with SMS via an Arduino microcontroller with a buzzer and an MQ2 gas sensor. The circuit contains a Microcontroller MQ2 gas sensor, buzzer, LCD display, and GSM module, when the sensor detects gas leakage it transmit the information to the Microcontroller while the microcontroller makes a decision and then forwarded a warning message to the user as SMS to a mobile phone for decision to be taken accordingly. The output of this research will be significant in averting problems associated with gas leakages now and in future. In the Philippines, a professor worked on a similar research project. The purpose of this project is to detect the presence of LPG leakage as a part of a safety system. Apart from sound alarm, an SMS alert will inform the authorized person and the solenoid valve will be triggered to shut down the gas supply to prevent any harmful effects due to gas leakage. Descriptively, we use a gas sensor to monitor the LPG if the gas leak reaches beyond the normal level. This proposed project will trigger the sound alarm. In addition, the authorized person will be informed about the leakage via SMS alert and the gas supply will be automatically shut down. The people can be saved from a potential explosion (Rhonnel S. Paculanan, 2019). In Bangladesh, another gas leakage detector was designed through a research project. The system uses an MQ-6 Sensor Module which is a generic gas sensor used to detect LPG presence. The Module has Digital Out and Analog Out. It Detects LPG from 200ppm to 10000ppm. Once the MQ-6 Sensor Module detected any gas/smoke a message is sent to the owner by their number by the GSM Module. They also use the NodeMCU which controls the Solenoid valve and fan (Hossain, 2019). From this review, we can derive that these solutions are all solving a similar problem in a similar manner however they are opting to use GSM module for alerts instead of an internet based platform.

2.4 Proposed Solution

A locally created gas leak detection system that sends an email alert each time the gas level exceeds the preset threshold value. The system will use a gas sensor that detects LPG, methane, hydrogen and carbon monoxide gases and sends the value to a microcontroller. The results will be displayed on an online dashboard and if need be, an alert email is sent to the administrator.

2.5 Conceptual Model



2.6 Conclusion

This chapter delved deep into the work that has been done by other scholars in regards to solving the same problem. The scholar did an assessment on the designs, algorithms and implementations of these solutions and found gaps which need to be filled prior to the development of a more evolved system. As such, the next chapter shall contain the proposed solution and its research methodology.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter identifies the circuit hardware components, software programming tactics, materials and methods that were instrumental in the design and development of the prototype so as to attain the set objectives. This is in tandem with the work carried out in the previous chapters that has set a building ground for innovation in problem resolution.

3.2 Research Design

A research design comprises of the blueprints upon which a researcher selects methods and techniques to conduct a research. The research design refers to the overall strategy that you choose to integrate the different components of the study in a coherent and logical way, thereby, ensuring you will effectively address the research problem; it constitutes the blueprint for the collection, measurement, and analysis of data (Boru, 2018). At this stage, the primary goal was to develop a system which had functionalities that allowed the researcher to experiment and collect results that meet the objectives. As such, the scholar zoomed in deeper into the problem to fully comprehend it, thus they designed a prototype to simulate a gas leak and its detection. The following steps were taken in prototype development:

3.2.1 System Design

This is where the scholar identified the individual components required to build a circuit, the programming languages which were to be used to interface with the hardware, the networking and security protocols to be used in data communications, the hosting and output platforms for the data gathered and received for analysis.

3.2.2 Prototype Components

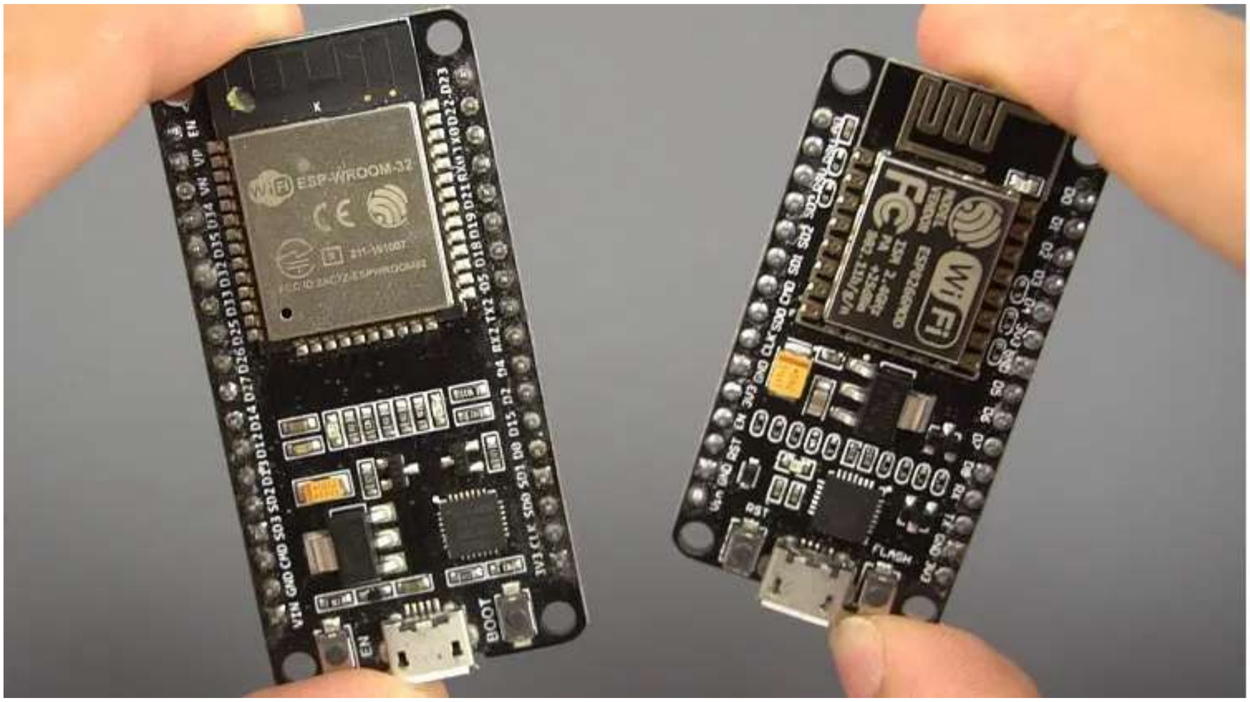
In this section, the researcher identified and described each and every component that was used in prototype development and that is for both tangible and non-tangible components.

3.2.2.1 MQ3 or MQ5 Gas Sensor

The most popular Analog Gas Sensor used is MQ5 Gas Sensor. The MQ5 gas sensor detects the presence of various gases such as hydrogen, carbon monoxide, methane and LPG. The sensor interacts with a gas to measure its concentration ranging from 100ppm to 3,000ppm. When a gas interacts with this sensor, it is first ionized into its constituents and is then adsorbed by the sensing element. This adsorption creates a potential difference in the element which is conveyed to the controller unit through an output analog pin in the form of current. Thus we are measuring the Analog current as an output which increases on increasing Gas Level. The Sensor works on 3V-5V & has both the Analog & Digital output. It has 4 Pins as VCC, GND, D0 and A0. This is the sensor that was used as the gas detector because of the above described capabilities. The figure below shows a sample of the appearance of the sensor.

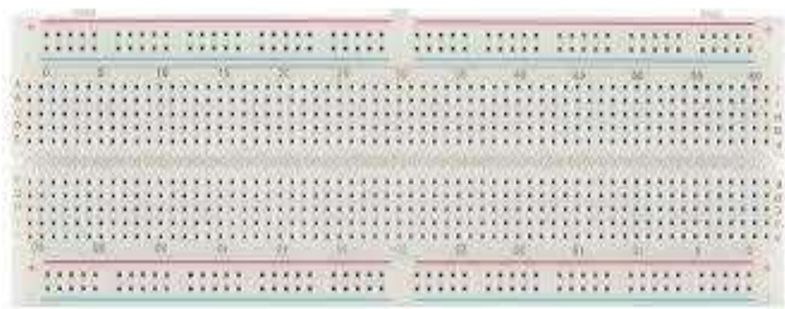
3.2.2.2 ESP32 Microcontroller

The ESP32 is a series of low-cost and low-power System on a Chip (SoC) microcontrollers developed by Espressif that include Wi-Fi and Bluetooth wireless capabilities and dual-core processor. If you're familiar with the ESP8266, the ESP32 is its successor. The scholar used this as the chip on which the preprogrammed code was embedded into as this was essentially the CPU. Furthermore, the chip has the capability to host web servers thus it was used to host the web server for the system's dashboard. Below is a snippet of the ESP32.



3.2.2.3 Breadboard

A Breadboard is simply a board for prototyping or building circuits on. It allows you to place components and connections on the board to make circuits without soldering. The holes in the breadboard take care of your connections by physically holding onto parts or wires where you put them and electrically connecting them inside the board. The scholar used a breadboard as the holding ground of the ESP32 and the MQ5 sensor. Below is an image of the breadboard.



3.2.2.4 Jumper Wires

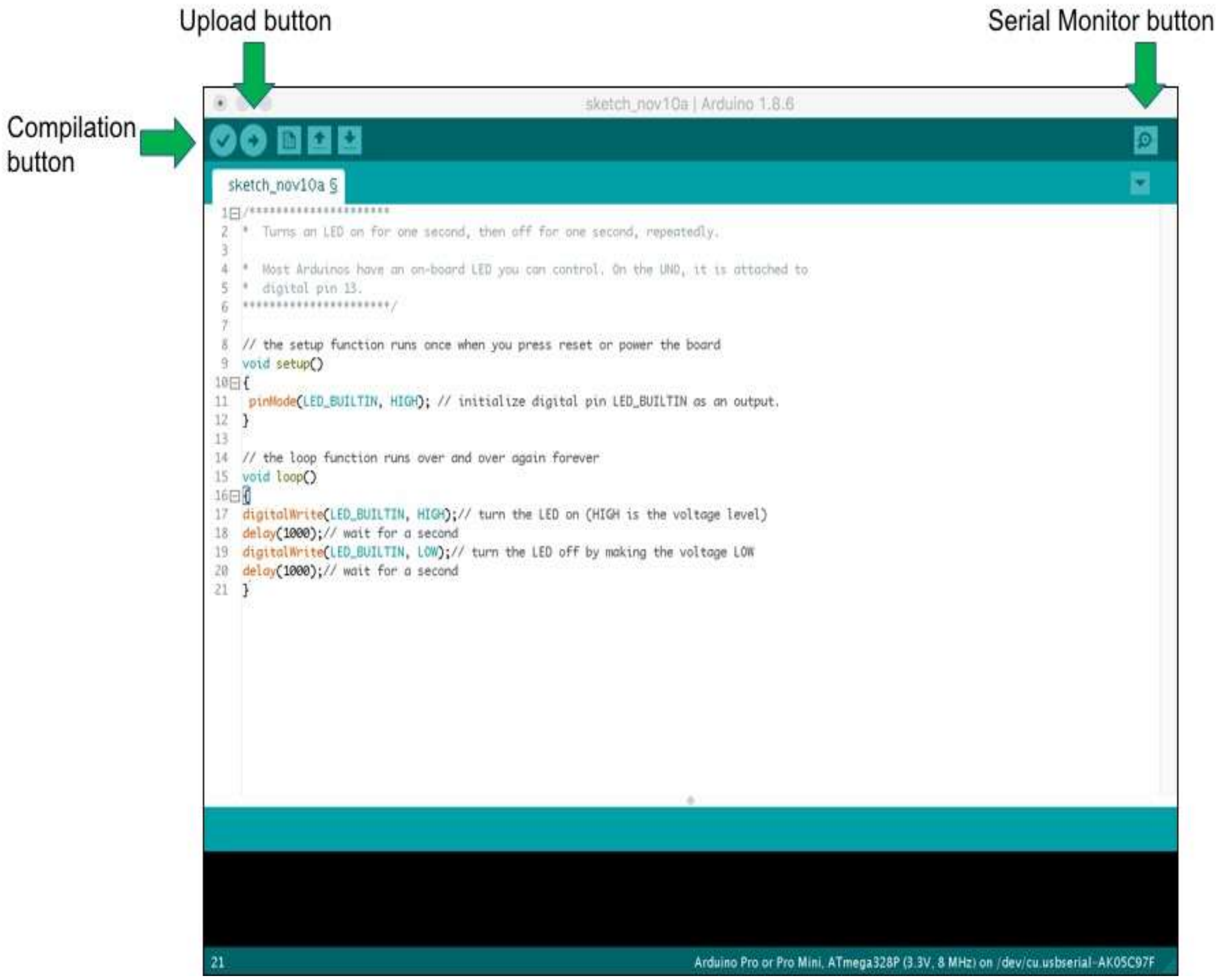
Jumper wires are electrical wires with connector pins at each end. They are used to connect two points in a circuit without soldering. You can use jumper wires to modify a circuit or diagnose problems in circuit. The scholar used jumper wires to connect points on the breadboard.

3.2.3 Programming Languages

Given that the designed solution was an embedded system with hardware components, the scholar used the C++ programming language in software development. This is because it is a low level language much closer to machine language thus it executes quicker. Furthermore, it is Object Oriented which makes it easier to optimize. For the Web Server, the scholar utilised HTML and CSS to create a dashboard for the system and this because they are lightweight thus can be hosted on a chip with little memory like the ESP32. The Wi-Fi, AsyncTCP and WebServer libraries were also included in the development of the system.

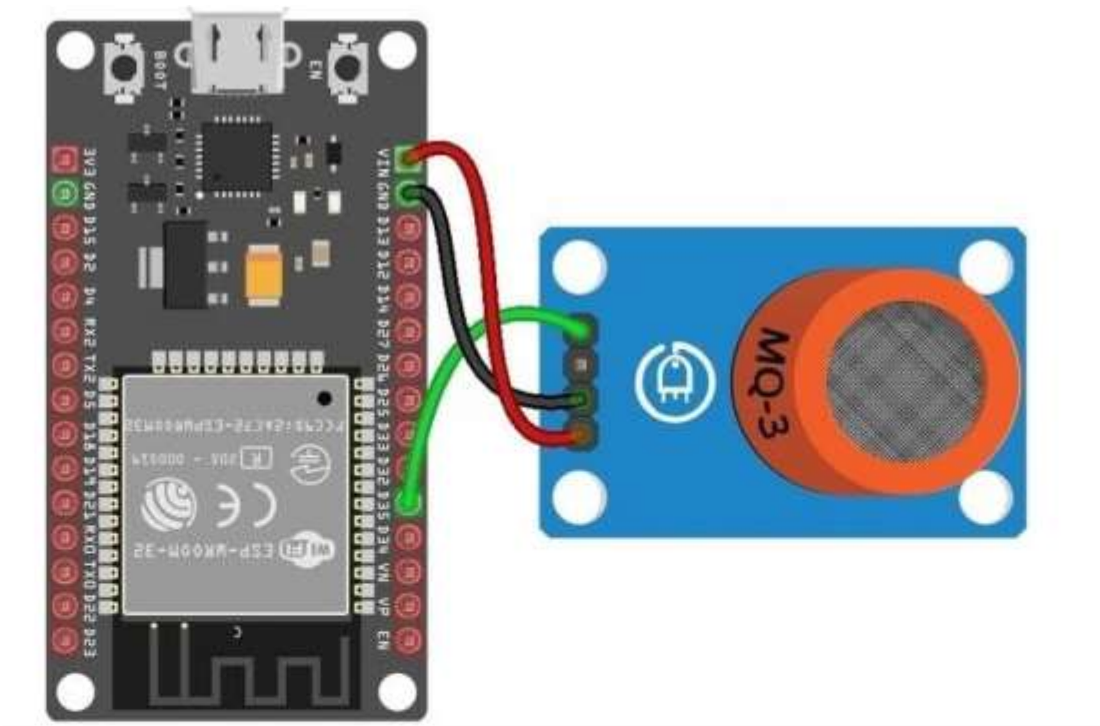
3.2.4 Arduino IDE

The Arduino IDE is an open-source software, which is used to write and upload code to the Arduino boards. The IDE application is suitable for different operating systems such as Windows, Mac OS X, and Linux. It supports the programming languages C and C++. Here, IDE stands for Integrated Development Environment. The scholar used the IDE to write, debug, compile and upload the code into the ESP32 board. More so, the IDE provides a Serial Monitor interface which enabled the scholar to read feedback from the chip, for instance, the host IP Address for the Web Server.



3.2.5 Circuit Design

Below is a snippet of the circuit design which comprises of the hardware components described above. It was drawn on the PCB circuit design software. The ESP32 is powered by a computer through a classic USB cable.



3.3 Validation Phases

This is the stage at which the scholar came up with strategies to test out the system from its infancy up to the maturity of stage of completion.

3.3.1 Unit Testing

The first stage of testing was early into the system development in which the scholar tested the developed code. This was done on the Arduino IDE which enabled the user to write the code and debug it. Syntax and logical errors were identified and rectified for each line and function until the program was clean, ready for compilation and upload into the ESP32.

3.3.2 Integration Testing

At this stage, the scholar was gradually integrating the components of the system. After successfully writing the software, the ESP32 came into the picture and was tested on whether it was able to store the code, create a web server and connect to a network. After encountering no challenges, that is when the gas sensor was added. Essentially, the system was tested each time a component was added.

3.3.3 System Testing

This was the final test on the relatively mature system. The scholar tested whether the analog gas sensor was able to detect external stimuli, transmit its readings to the microcontroller for interpretation and analysis prior to the display of results on a dashboard. The scholar tested on whether the system was able to detect input, process it and provide a logical output as designed.

3.4 Target User Population

The desired population of system users are individuals at household and or industrial level thus the scholar and colleagues interacted with the system during testing and provided critical feedback.

3.5 Sample and Sampling Techniques

To avert costs and in the interest of time, the scholar conducted convenient sampling to allow BUSE students and other citizens in the vicinity as the sample population.

3.6 Data Collection

Data collection is the process of gathering and measuring information on variables of interest, in an established systematic fashion that enables one to answer stated research questions, test hypotheses, and evaluate outcomes (Parveen, 2017).

3.6.1 Observation

Having witnessed a couple of accidents emanating from gas leakages, the scholar made crucial observations around the problem thus it enabled them to innovate a possible solution. They were able to identify the causes of the accidents, how to mitigate their risk and or outright prevent them.

3.6.2 Interviews

The scholar employed interviews as a data collecting tool from the respondents who interacted with the system during testing, and also those who had fallen victim to similar accidents before. These were contacted in person, via phone calls, WhatsApp and other digital platforms.

3.7 Requirements Analysis

The Requirements Analysis process results in the decomposition of end-user needs (usually identified in operational terms at the system level during implementation of the Stakeholder Requirements Definition process (Apvrille, 2013). In simpler terms, it is the process of identifying the expectations of the users as a system is being developed, and the scholar did exactly that. The requirements are categorized into two units and these are functional and non-functional requirements.

3.7.1 Functional Requirements

A functional requirement is a verb as it describes what the system does or should do, it entails the services and functionality of a system. It is simply evaluating the processes of input, processing and output within a system. The functional requirements are as follows,

- The sensor should be able to detect a gas level and transmit it to the microcontroller,
- The microcontroller should be able to process the data received from the gas sensor,
- The data should be displayed on a dashboard as output and depending on the reading, an email alert is sent, if need be.

3.7.2 Non Functional Requirements

A non-functional requirement is essential to ensure the usability and effectiveness of the entire software system. Failing to meet non-functional requirements can result in systems that fail to satisfy user needs. The non-functional requirements are as follows,

- The system should be reliable,
- The system should be stable,
- The system should be scalable,
- The system should be secure.

3.7.3 Software Requirements

Listed below are the required software specifications for the development of this system,

- Arduino IDE and its libraries.
- Operating System of Windows 10 or later, any Linux or MacOs.
- Gmail Account (with app specific login enabled).

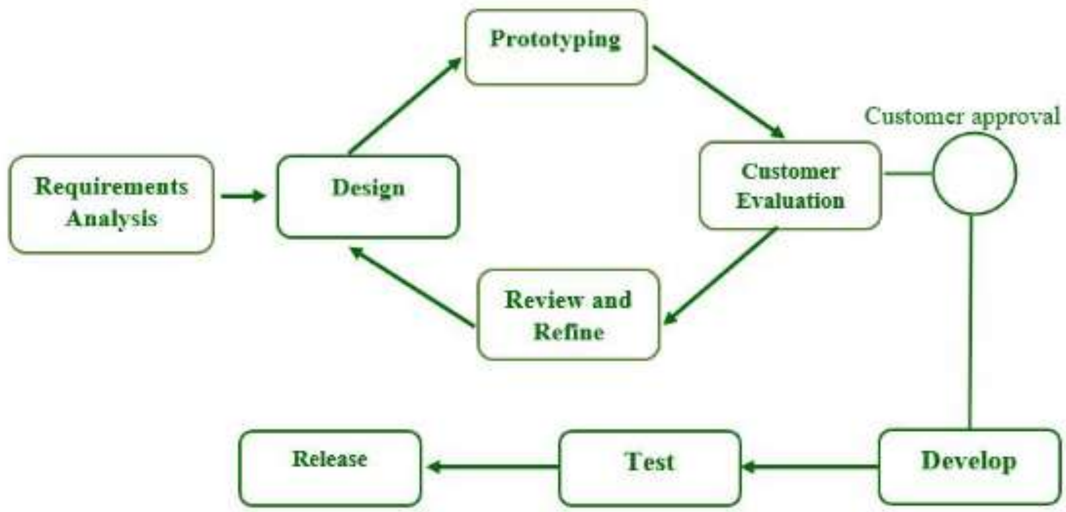
3.7.4 Hardware Requirements

Listed below are the required hardware specifications

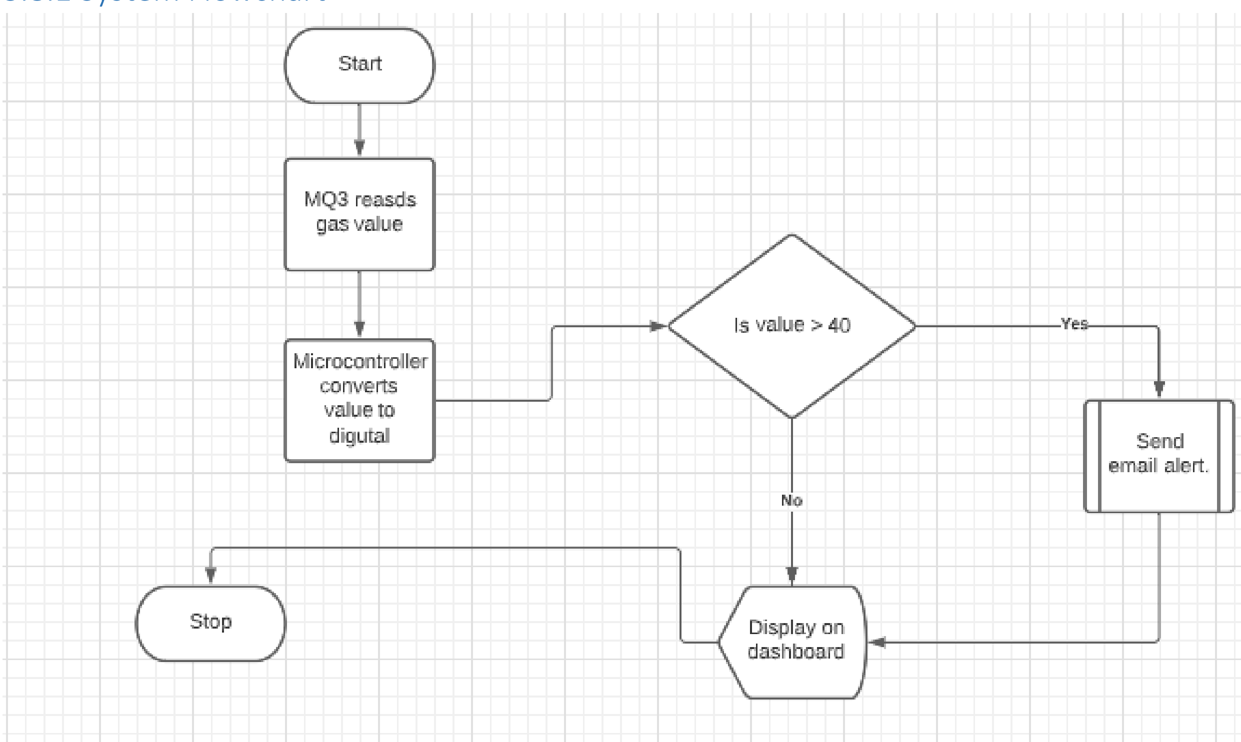
- Minimum processor of Core i3 @1.2GHz,
- Circuit Components stated earlier in the chapter,
- USB 3.0 ports (3.3 volts or more) to interface the ESP32 and the computer.

3.8 Development Methodology

The scholar used the prototyping model which is a systems development method in which a prototype is built, tested and then reworked as necessary until an acceptable outcome is achieved from which the complete system or product can be developed. The prototyping System Development Life Cycle comprises of six stages. The first one is requirements gathering in which the scholar made observations and conducted interviews. They proceeded to the second stage in which they made a quick design of the project. As for the third stage, the scholar went on to build the prototype and conducted initial user evaluation as the fourth stage, this enabled them to identify the strengths and weaknesses of the system. The fifth and sixth stage were all about iterating on the prototype so as to refine it and finally, deploy it. The figure below illustrates the stages of prototyping.



3.8.1 System Flowchart



3.9 System Summary

The basic functionality of the system is as this, the gas sensor is constantly monitoring the gas level and displaying its value on the dashboard on the web server. Once the level rises above a preset threshold value of 40, it is deemed as a leak and an email alert is sent to the responsible email for further action.

3.10 Conclusion

This chapter served to exhibit the research design, development and the methodology used. It cast a microscope upon the tools, techniques, strategies and models that were used at this stage of the research. The next chapter will focus on the analysis of the results output by the application.

CHAPTER FOUR: RESULTS ANALYSIS

4.1 Introduction

The previous gave an in-depth account of how the scholar designed and developed the system. In this chapter, the scholar collected the results output from the system so as to analyse them and determine its efficiency. The system's response to input and how it delivers output was also observed by the scholar in order to properly document and present the findings.

4.2 Testing

Software Testing is a method to check whether the actual software product matches expected requirements and to ensure that software product is defect free. It involves execution of software or system components using manual or automated tools to evaluate one or more properties of interest. The purpose of software testing is to identify errors, gaps or missing requirements in contrast to actual requirements (Kassab, 2017). As such, this system was tested in regards to the predetermined functional and non-functional requirements. Furthermore, as stated in the previous chapter, the system was tested at unit, integrated and completed stages.

4.2.1 Black box and White box Testing

Black box testing assesses a system solely from the outside, without the operator or tester knowing what is happening within the system to generate responses to test actions. A black box refers to a system whose behavior has to be observed entirely by inputs and outputs. Black box testing refers to any type of software test that examines an application without knowledge of the internal design, structure, or implementation of the software project. Black box testing can be performed at multiple levels, including unit testing, integration testing, system testing, or acceptance testing (Kassab, 2017). White Box Testing is a testing technique in which software's internal structure, design, and coding are tested to verify input-output flow and improve design, usability, and security. In white box testing, code is visible to testers, so it is also called Clear box testing, open box testing, transparent box testing, Code-based testing, and Glass box testing.

4.2.2 Presentation of Results

In order to retrieve results, the scholar interacted with the system and documented findings of each step for further analysis. The scholar conducted observations on the application to assess its performance, behaviour and reaction to input if any.

The first result to be obtained was the successful acquisition and construction of the hardware prototype as designed in the previous chapter. The figure below shows the ESP32 and the Gas sensor being correctly connected on a breadboard.

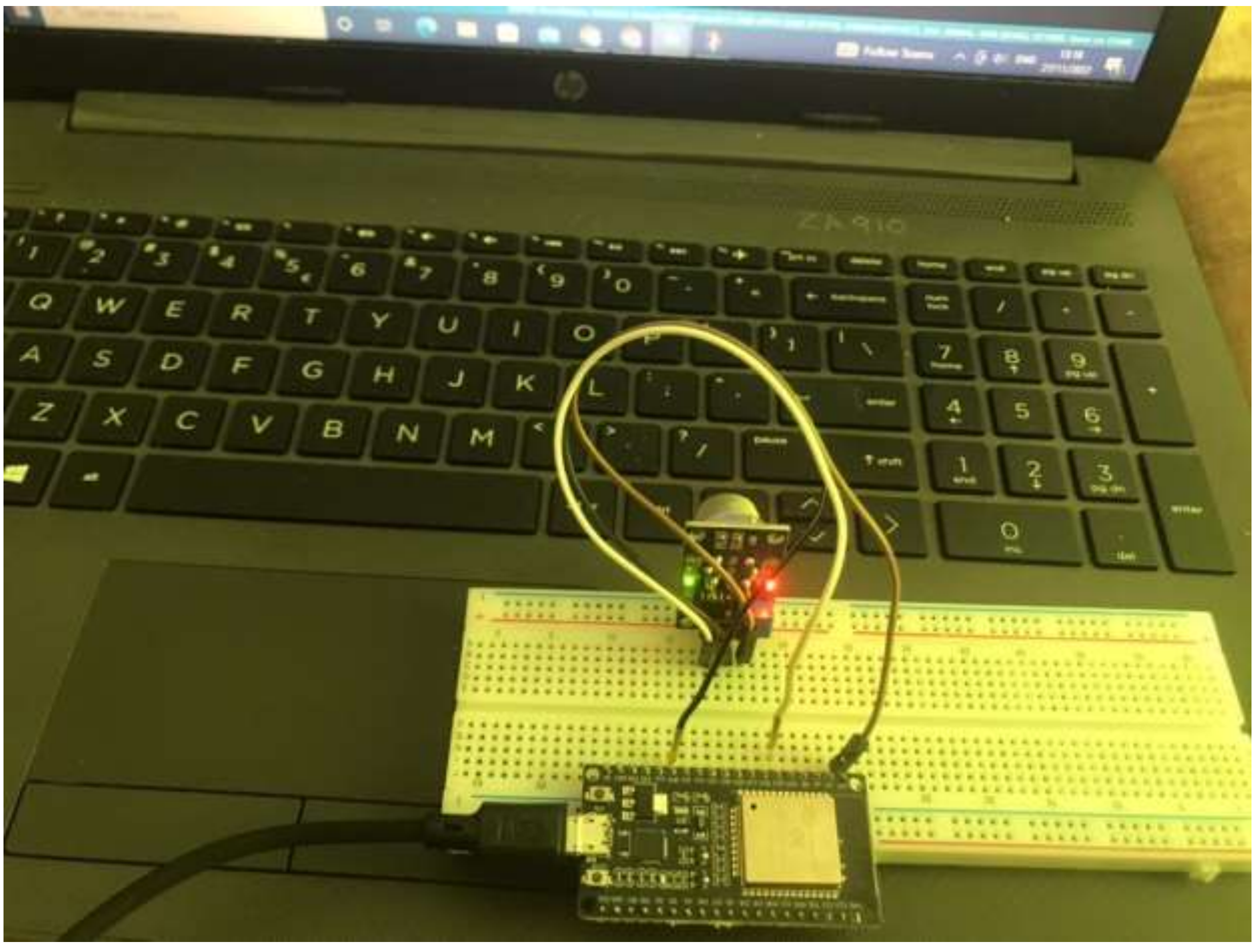


Figure 1 Fully Integrated System

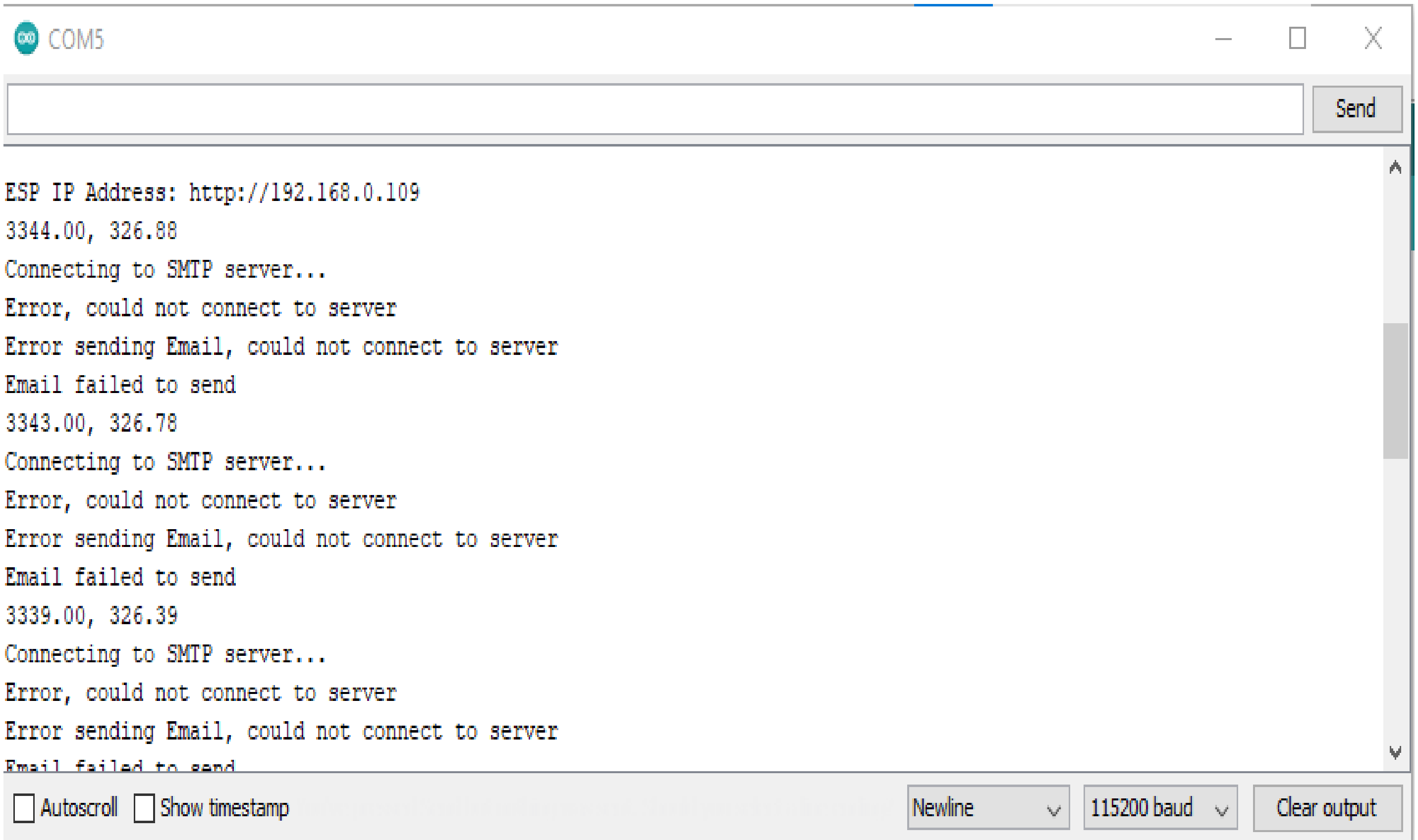


Figure 2: Server IP

The figure above shows the IP Address on which the microcontroller successfully hosted the web server. This was after the successful login into a Wi-Fi connection by the system which is the paramount step in enabling IoT through the establishment of an internet connection. From a black box standpoint, the feedback is that the system worked as expected thus the input matched the output. From a white box perspective, this exhibits that the C++ functions to login into a network using a preset SSID and password, the Arduino WebServer library and the function to display the host IP Address were all functional and defect free.

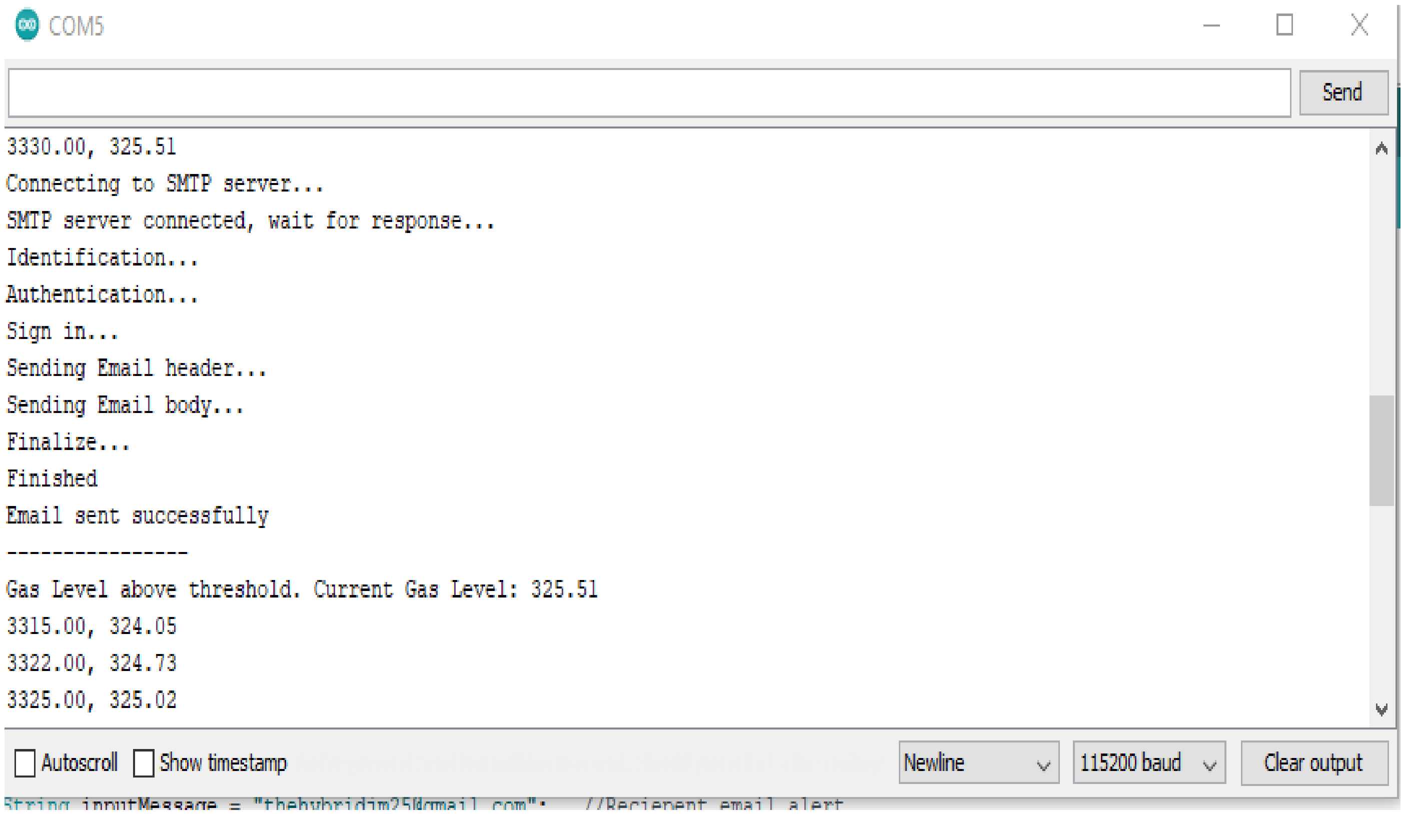


Figure 3Email Alert

The figure above shows the output from an Arduino Serial Monitor running on Port (COM5). At this stage, the gas sensor detected a gas level of 325.51 which is far beyond the normal and expected threshold of 40. As such, the system went on to attempt to send an email alert. In order to do so, it had to log in to the email account, and as show above, the account was identified authenticated and the sign in was successful. The system went on to coin the email with a header (subject) and a body that explicitly mentions the current gas value. From a black box standpoint, the gas sensor was able to read the gas value and the output was an email alert which shows that the system was working as expected. From a white box perspective, the OOP function to enable the analog gas sensor to accept input and send it to the ESP32 was working properly. Furthermore, the function carrying the comparative logic was defect free as it was able to establish that the received value was greater than the preset 40, which was tantamount to the dispatch of an email alert. Prior to the email, the Arduino Simple Mail Transfer Protocol (SMTP) library was working perfectly as the system was able to login into GMAIL using an app specific password and send out the alert.

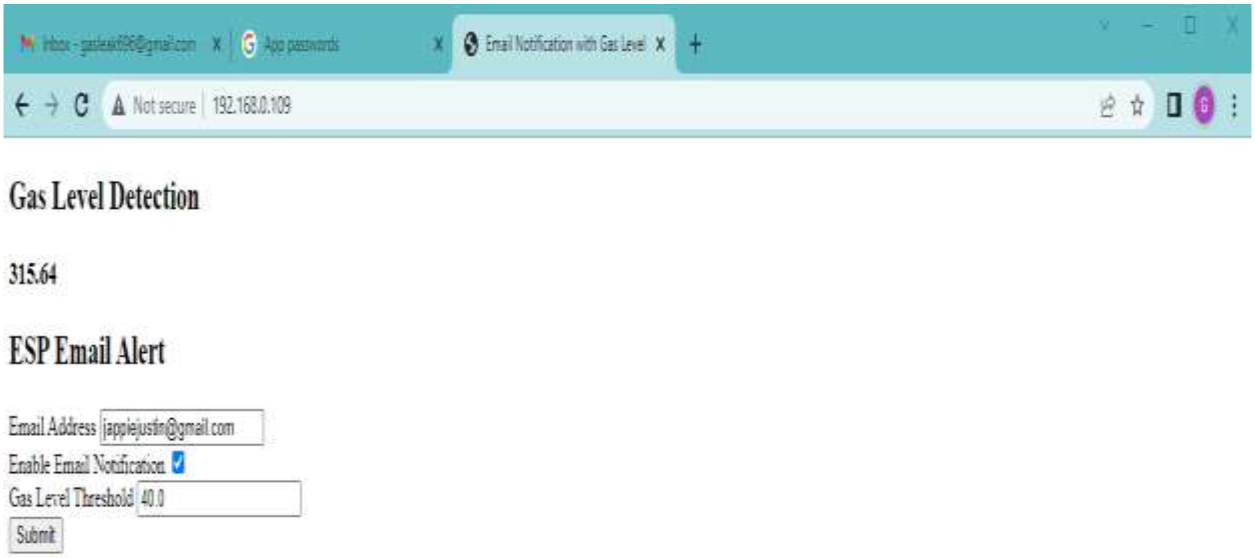


Figure 4 System Dashboard

The figure above shows a snippet of the system's dashboard hosted on the same IP Address that was displayed in the previous figures above. The gas level is also displayed along with the preset destination email for alerts which can be manually changed to another. The dashboard also exhibits the currently set threshold which can be reduced or increased using the buttons there present. In black box testing, it was attained that the system was capable of creating a web server and host it on a local IP so as to display the dashboard, as anticipated. From a white box standpoint, the WebServer and AsyncTCP libraries were fully functional as evidenced by the dashboard. In addition, the HTML and CSS functions were all defect free as they were able to present a User Interface for the dashboard.

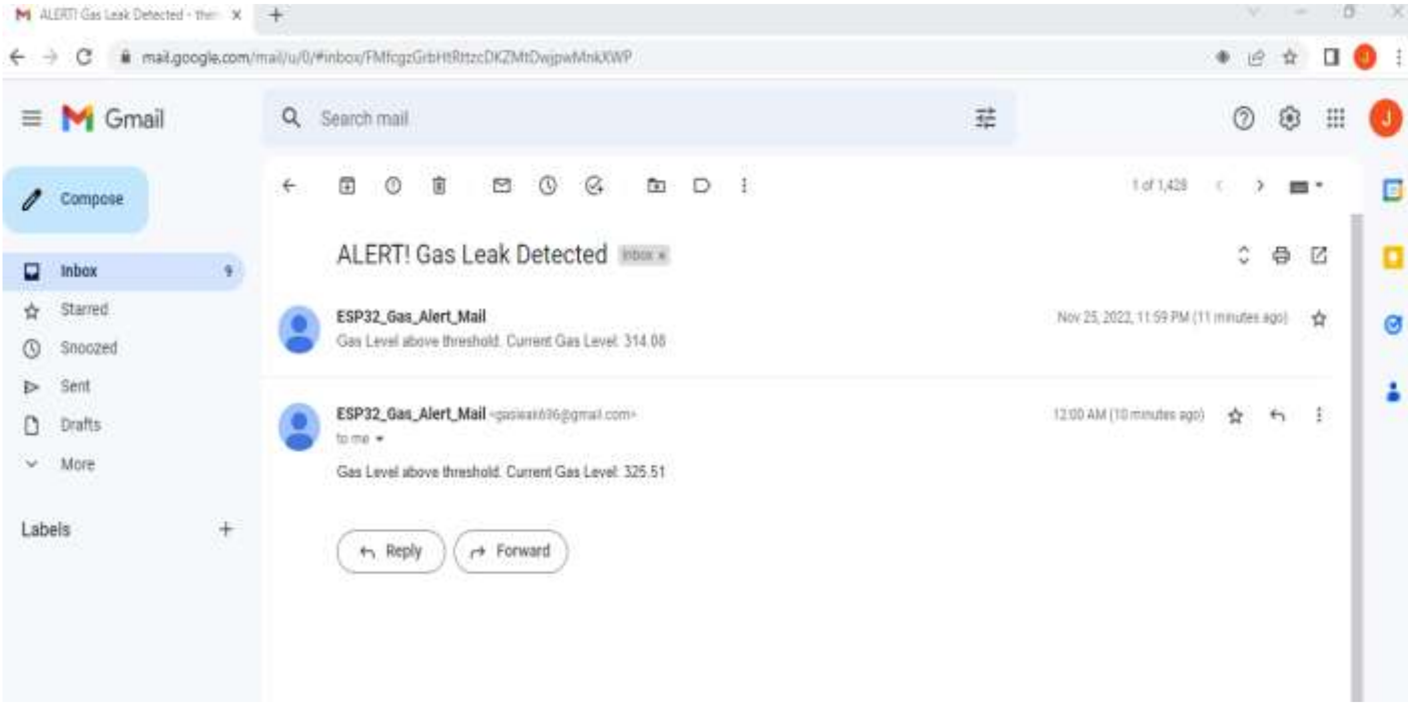


Figure 5Email Received

The picture above shows two emails received under the subject "Alert! Gas Leak Detected'. This is evidence that the email which was sent by the ESP32 after reading values greater than the threshold, were successfully received on the administrators email address. From a black box test, it is evident that the administrator received an email alert carrying a value above the threshold as was expected thus it was concluded that the system was working perfectly. From a white box standpoint, it is evident that the function carrying the default destination email address was behaving as instructed thus the code was flawless.

4.3 Evaluation Measures and Results

Evaluation is the structured interpretation and giving of meaning to predicted, or actual impacts of proposals or results. It looks at original objectives, and at what is either predicted or what was accomplished and how it was accomplished (Wanzer, 2019). The IoT system was evaluated on its security, stability, reliability and efficiency as its performance metrics.

4.4 Measuring System Performance and Accuracy

The performance of the system was evaluated against its ability to detect input through the gas sensor, processing it on the microcontroller and giving output on a web dashboard and email where necessary.

4.4.1 Test of the System Accuracy in regards to stimuli detection

Gas	**Number of Tests Done**	**Correct Reading and Action**
LPG	55	55
Methane	45	45
Carbon Monoxide	50	50
Hydrogen	5	2

Accuracy = (Total Number of Tests (T) – Number of Inaccurate Predictions (N)/ T) x 100.

Therefore (4-1)/4x100 = **75%,** is the application's accuracy as per the researcher's findings. A total of four different gases were tested as input into the system to evaluate the accuracy of the system. The system was not accurate in measuring hydrogen samples which resulted in a drop in accuracy.

4.5 Evaluating System Performance

The IoT system was evaluated on its security, stability, reliability and efficiency as its performance metrics.

4.5.1 System Security

The system utilised secure logins into a Wi-Fi network through SSID and password, Gmail app specific passwords to authenticate and sign in to the email account without exposing the account to hackers and the SMTP protocol to send and receive emails. Furthermore, it had the AsyncTCP library enabling communications which also provides encryption services by default. As such, the system was highly secure.

4.5.2 System Stability

In this case, stability was measured against the consistency of output in relation to the input. Following this notion, the system was very stable as it provided output that logically corresponding input. It had no fluctuations unless there was a change in the stimuli which provided consistent results for the greater part of the testing.

4.5.3 System Reliability

The system had a significantly above average reliability value and this is due to the inaccurate reads and decisions whenever it was tested using hydrogen. Outside of that, the system was considerably reliable as it was consistently accurate and had no misfiring on the other three gases.

4.5.4 System Efficiency

From a software engineering dimension, the system was efficient since the effort and resources put in developing it was congruent to the outcome attained. Furthermore, the system is energy efficient as it only used 3.3 volts to power up the ESP32, such power can be carried on most battery sizes worldwide.

4.6 Statistical Analysis of Data

Interviews were successfully carried out and response rate was a 100 %. Data was obtained from the interviews that were carried out from the people who participated in system testing.

4.6.1 Interviews

The scholar sought to assess the efficiency and effectiveness of the system thus they interviewed the same people who volunteered and participated in testing the system. The results were combined and consolidated and they indicated the following;

The respondents assessed the security, reliability, stability, efficiency and efficiency of the system.

Security	**Reliability**	**Efficiency**	**Stability**	**Percentage**
✓	✓	✓	✓	**75**
✓	✓	✓	**x**	**17**
✓	✓	**x**	**x**	**5**
✓	**x**	✓	**x**	**3**

The table above shows the consolidated feedback from the respondents that were interviewed about the system. Only 3% considered the system to be secure and efficient but reliable and stable. A total of 5% of the respondents considered the gas leakage system to be secure and reliable but not efficient and stable. A significant 17% were in agreement on the verdict that the system was secure, reliable and efficient but not stable. The final and majority of the respondents who constitute 75% were all in agreement that the system was secure, reliable, efficient and stable.

4.7 Conclusion

Following the collection, analysis and presentation of the results from the system, the scholar concluded that the application of Internet of Things in gas leak detection is very efficient, reliable, stable and secure as it enables the swift mitigation of accidents.

CHAPTER FIVE: CONCLUSION

5.1 Introduction

The previous chapter brought up a clear presentation of the results obtained from the system and the overall outcome of the results after analysis. This chapter swiftly wraps up the research project by highlighting the key findings from the research and recommendations for future use.

5.2 Attainment of Objectives

The first objective was to design and develop and IoT circuit that detects gas leakages and sends out an email alert to responsible authorities. This objective was realised as a functional prototype of the circuit was created using a gas sensor, an ESP32 microcontroller, breadboard and Objective Oriented programing. The second objective was to identify how IoT has been utilised in gas leak detection systems worldwide. This was realised in the second chapter which carried literature review which showed that it was used in first world countries mostly but using SMS services for alerts. The third and final objective was to evaluate the accuracy of the newly designed gas leak detection system. This objective was attained through statistical methods through interviews and observations on various performance based metrics. Furthermore, mathematical methods were employed in evaluating the accuracy as the values of accurate detections were recorded against the inaccurate in order to calculate the accuracy and efficiency of the system. As such, it can be concluded that all the objectives of the research were successfully realised.

5.3 Major Conclusions Drawn

The major finding from the research was that Zimbabwe is at a high risk of encountering accidents emanating from gas leakages and thus there is a need and market for the innovation that was developed in this research project. Furthermore, it was discovered that the Internet of Things plays an imperative and effective role in creating safer working and living environments if property and timeously implemented. There is need for more home grown solutions in order to cut costs and bridge language barriers.

5.4 Recommendations

It is recommended that responsible authorities continue to support STEM based programs so that we create a more skilled local group of innovators towards the attainment of Vision 2030. More so, academics are encouraged to collaborate with industry in developing solutions so as to meet the aspirations of Education 5.0 which are Innovation and Entrepreneurship.

5.5 Conclusion

The gas leak detection system was developed and it efficiently addressed the problem statement. All research questions were answered through the realization of the objectives and the results were documented and presented. As such, it can be confidently concluded that this research project was a success.

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