ASHESI UNIVERSITY

DEVELOPING A MONITORING SYSTEM FOR EARLY DETECTION OF LPG LEAKAGES FOR GAS FILLING STATIONS IN GHANA

THESIS

B.Sc. Computer Engineering

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TITLE OF THESIS

THESIS

CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University College in partial fulfilment of the requirements for the award of Bachelor of Science degree in Computer Engineering.

Emmanuel Nimo

2019

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

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Candidate's Name:

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Date:

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I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University College.

Supervisor's Signature:

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Supervisor's Name:

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To all the people whose encouragements and academic advice has helped me undertake this project.

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Abstract

Following the dreadful gas explosion at Atomic Junction, Accra-Ghana in the year 2017[2], the innocent public and owners of gas filling stations across the country continue to face fear in managing Liquified Petroleum Gas (LPG) filling stations. Gas explosions have caused loss of precious lives and huge economic loss to owners of gas filling stations and the government. In the past four years, the rate of fire explosion in Ghana has plummeted steadily and if measures are not put in place, the nation will be thrown into another series of gas explosions. To avert this situation, this project presents a monitoring system for the early detection of LPG leakages using the concept of Internet of Things (IoT). The proposed solution presents the design and implementation of an integrated circuit unit which employs sensors, LCD display, buzzer and some other components all connected to ATMega8-p microcontroller. The sensor data obtained from these devices are sent from the microcontroller to a web application via GSM. The main features of the web application include data collection and analysis, database and tracking of gas stations. The impact of the LPG monitoring system is high. The results presented show that gas explosions are minimized if prompt precautions and safety knowledge about gas leakages are given to stakeholders involved in managing gas filling stations.

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Chapter 1: Introduction

The rampant incidents of gas explosion at major filling stations in Ghana have recognized the need for an early detection system that can prompt the arms of the Environmental Protection Agency (EPA) to work effectively to annul the occurrences and impacts of fire explosions caused by gas leakages. As at October 8, 2017, Ghana recorded eight major gas explosions between 2014 and 2017 [1]. Within these years, the gas explosions resulted in the loss of lives, injuries, damage to properties and unemployment. Up until today, gas leakages at filling stations are serious faults that affect the system operational safety and leads to economic losses. It appeared that little or nothing has been done by the government and individuals in the country to stop the recurring situation.

Since Ghana decided to sell LPG for home consumption, there have been many instances of leakages which have caused human loss not to mention the monetary damages. The call has been made from many people on the need to provide a solution to diminish such catastrophes. Presently in Ghana, there are no monitoring technologies to analyze and report on the emission of LP gas from filling stations. There are assumptions that leakages are low and hence pose no danger. It is believed otherwise hence the proposal to use a technological system to detect the natural gas that escapes from these filling stations. Safety at gas filling stations is very important to the oil and gas industries dealing in mass distribution because it is a major risk to the distribution process. Therefore, we cannot depend on the human senses to only maintain safety at the filling stations.

It is highly important to address this issue by applying Internet of things (IoT) to enable us conveniently and readily view the calculated concentration of leakages emanating from the gas filling station. This will also aid the study of environmental factors such as temperature and humidity. The objective is to provide a monitoring solution that proactively warns station managers and the public at large on the level of gas leakage during off-loading.

The same will be used to measure and warn any gas tank leakage. The true beneficiaries of this solution shall be the innocent public, owners of the gas stations, and the regulator-the Environmental Protection Agency (EPA).

Liquified Petroleum Gas

Liquified Petroleum Gas (LPG) is a source of energy, which is clean and environmentally friendly. It is now becoming a substitute for wood and other biomasses in developing countries such as Ghana [2]. The chemical composition consists of ethane, ethylene, propane, propylene, normal butane, butylene, isobutane, and isobutylene. Research shows that upon the ignition of heat or fire, LP gas is probable to explode when its mixture with air ratio ranges from 1.8% to 10%. Within this range, any explosion is categorized as a perfect explosion with an enormous blast power [3].

A gas explosion is an exothermic chemical reaction which occurs during a flammable gas spill (when an accumulation of LPG mixes with the air and potentially catches fire). Because the gas is stored in a tank, the explosion occurs when the rapid expansion of gas produces high pressure during leakage.

In the Greater Accra and Ashanti regions of Ghana, the availability of LPG is continuously increasing because LPG remains the primary source of fuel for most households, and even the usage paradigm is shifting from petrol to LPG for automobiles. Regarding the Government of Ghana's decision on reducing deforestation by initiating the 2013 Rural LPG promotion program, LPG usage has increased over the years, and LPG filling stations have doubled across the country to meet the increasing demand [4]. The graph (Figure.1) below shows the economic indicator on the increasing consumption of LPG in Ghana with a minimum of 1.3 thousand barrels per day in the year 2000 and a maximum of 8.6 thousand barrels per day in 2012. In Figure 2, we see an increase in the number of gas filling stations between 2003 and 2013 across the regions of Ghana [5].

And in 2017, the LPG supplied was about 27 percent higher than in 2016 [6]. The growing demand together with the pervasive incidents of gas explosion has led us to question the mechanisms that ensure the safety of LPG at homes and filling stations.

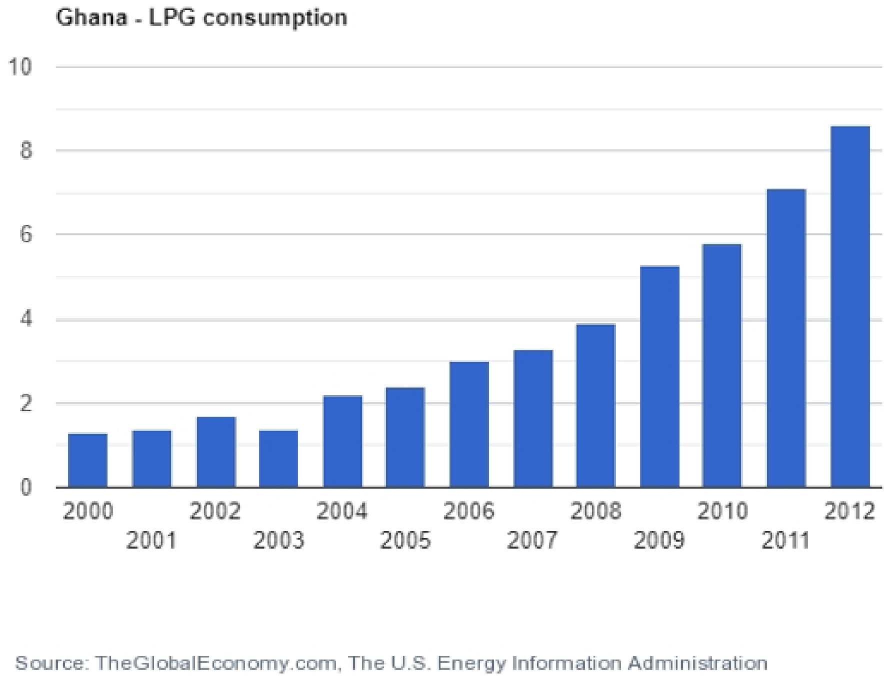

Figure 1. LPG consumption in Ghana.

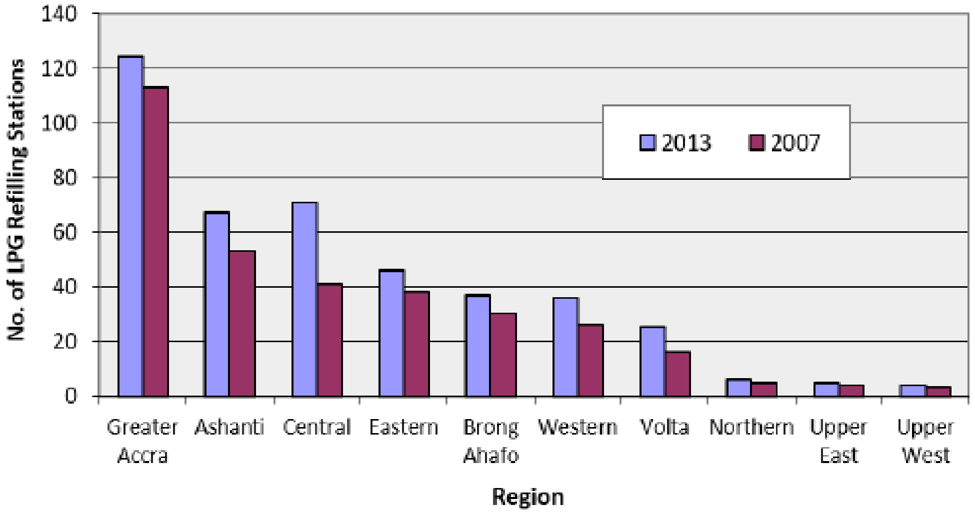

Figure 2. The trend of LPG Stations in Ghana.

This project presents in a nutshell, an early warning detection system that comprises a remotely routed integrated circuit with sensors for detecting LP gas leakages at filling stations. The information gathered (temperature, gas concentration, humidity) from this detection is channeled to a web application via the Internet so that the station owners, as well as the regulated body - the Environmental Protection Agency (EPA), can take safety measures to protect both human lives and property. In addition, it is also proposed that the application of image processing can be used to detect pumps used in the offloading process. This is because it has the capability to visualize discharge pumps and enhance the smart monitoring of the gas leakage.

1.1 Background

In Ghana, there are high levels of LPG that escape unchecked from storage tanks at filling stations and home cylinders each day. This accounts for the many massive explosions that have occurred in the past, causing huge loss of lives, injuries and destroying filling stations worth more than millions of dollars [7]. The incidents are mostly caused by leakages which spout out from gas appliances, connection or fittings with a hiss. Other causes are poor management and maintenance, misjudgment, narrow overlook, etc. [8].

The government of Ghana, coupled with the sector of disaster management, has embarked on fire relief education, LPG usage sensitizations to the public, and performed routine maintenance of gas fillings stations. The results obtained are not different especially across the southern regions of Ghana. These highly concentrated urbanized regions of Ghana record high consumption rates of LPG; hence safety mechanism is required to keep gas filling stations safe and reliable to the public. This creates a need to implement a technological mechanism in our fast-growing cities. These mechanisms would aid us in measuring the daily concentrations of the LPG released into the atmosphere, and we can base upon it to prevent possible dangers of gas explosion.

1.2 Objectives and Motivation

The aims of carrying out this project are:

1. To design a circuit system that is useful to the detection of LPG leakages.
2. To devise a plan for the development of an engineering product.
3. To apply engineering concepts in the improvement of existing technologies in IoT.
4. To research current efforts in the detection of gas leakage and identify the most promising.

My motivation stems from a published piece by Ghanaian News Outlet MyJoyOnline on the horrifying event of a fiery explosion that shook the entire city of Accra [9]. The fire explosion which happened on October 7, 2017, resulted in the death of over 7 people and injured a little over 130 others. The primary cause of this undesirable event was insufficient experience and narrow overlook. The research report on the incident revealed that it was an attempt to discharge LPG by an untrained driver's mate that caused the gas to leak at the MANSCO gas station at Atomic Junction, Accra. This incident caused a stir in the media as to whether the Environmental Protection Agency (EPA) is doing its job well. In 2016, there was also another new publication of gas explosion by Graphic Online which happened near the International Trade Fair Center at La, Accra [10]. This gas explosion incident led to the loss of nine lives and 12 others injured. And the cause is no different from negligence, poor management, and misjudgment. Considering this unfortunate incident, I would like to embark on this topic to experiment the viability and progress of Internet of Things (IoT) in the field of detecting early signs of gas leakages to prevent an explosion. Again, this project is pursued because it will significantly attach greater credibility to my practical knowledge as a computer engineer. It will further raise awareness for the prevention and mitigation of gas explosions at filling stations in Ghana.

1.3 Expected Outcome

This project presents an integrated circuit system that makes use of IoT to define the path of data aggregation and transfer between hardware and software. The circuit will be controlled by a microcontroller, which gathers sensor data on temperature, humidity, and gas concentration at the LPG site. The system will send data from the hardware to a web application for monitoring using GSM interface. The web application analyzes the data using graphs and values. Additional features such as a google map iframe will be included to assist the location of gas stations for fire service personnel. A sound alarm and light will be incorporated in the circuitry to assist the communication of LPG leakages to station managers around the site.

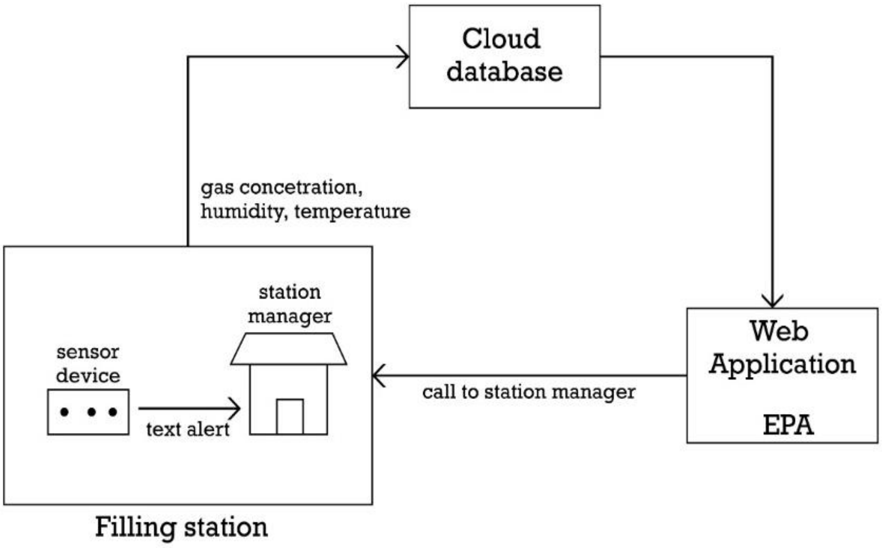

Figure 3. A high-level description of the system.

1.4 Research Methodology

The project incorporated expert judgment, sampling, brainstorming, interviews, data and data analysis. To investigate the questions of safety at the gas filling stations, a field research was conducted at 6 gas filling stations. A survey questionnaire was examined to obtain insights on operational safety and current technologies. The survey also looked more closely at how the stakeholders assess the measures that were put in place to minify the occurrence of gas explosion. Three of the stations are situated in Accra, and the rest also in Kumasi. Popular among them are NextBons gas and Trinity oil. The data obtained unveiled some of the major issues related to safety measures, with the most compelling results elaborated below.

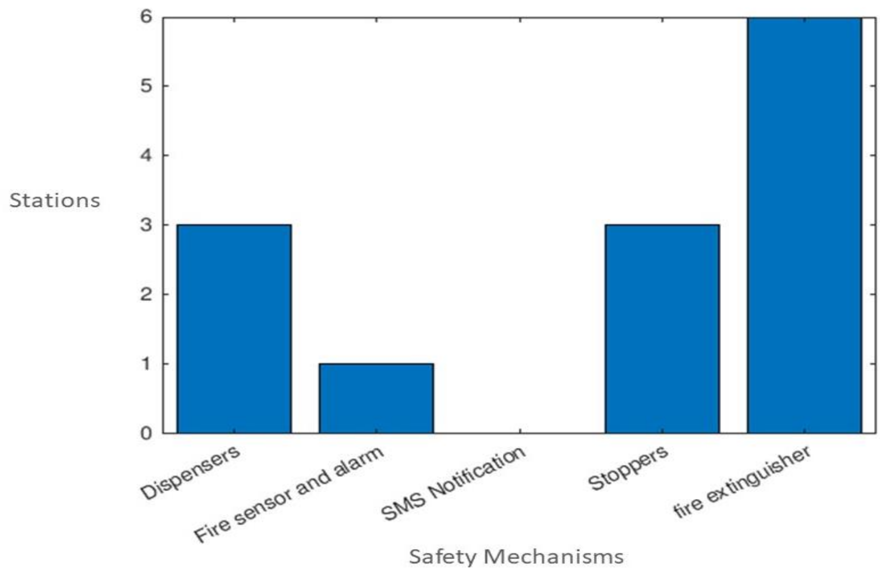

Figure 4. A statistical summary of the research findings.

Figure 4. depicts a 50% of the stations which use the digital dispenser to service customers. This is because it is faster, reliable and easier technical know-how. The remainder still uses a scaler pump for servicing customers' containers because it is precise. A half of them uses stoppers at the source tank for blocking the outflow of gas in case of leakage from external pipelines. One out of the six stations use a fire sensor and alarm for triggering leakages, but devoid of SMS alert functionality. All of them had fire extinguishers to nullify the concentration of the gas leakage when there is any. However, there was a lack of gas sensor in all the six stations for detecting leakages because their Management Board has not agreed on its usage.

Concerning the findings above, it shows that safety problems still exist at the gas filling stations in Ghana. According to the K.N.U.ST fire service department and the EPA in Kumasi, monitoring systems for gas leakages are more liable to help them to prevent or mitigate the event of a gas explosion.

Chapter 2: Literature Review

Many researchers such as Medilla Kusriyanto and Anandhakrishnan have tried to address this issue of gas leakages and find ways of improving safety around filling stations. The approach to solving this issue is not far from what is presented in this research study. This chapter presents reviews on some technical efforts, current solutions, and challenges that have been investigated in the detection of gas leakage.

2.1 Internet of Things

Internet of Things (IoT), which was first described by Kelvin Ashton, the Executive Director of Auto-ID Labs at Massachusetts Institute of Technology (MIT), has been around for a while [11]. It became even popular in 2013 when computers evolved into multiple technologies ranging from the internet to wireless communication to embedded systems. It brings together the traditional form of automation which includes wireless sensor networks, GPS, control systems, and so forth. The applications of IoT are enormous: it is applied in medical devices, security systems, financial systems, automation of complex processes, etc. Due to the convergence of information and communication technologies and the internet, it is rapidly evolving in major cities across the world and offering beneficial solutions to all aspects of our daily activities. IoT is also playing a major role in the field of disaster prevention and management control, and as a result, many research articles have been published in that area. Published articles such as "Early detection of LPG gas leakage based Wireless Sensor Networking", and "IoT Based Smart Gas Monitoring System" are some evidence of the applications of IoT to prevent a fatal accident caused by gas leakage in homes and industries. In the aim of accomplishing the purpose of this project, the following articles were reviewed to know the trends and the gaps.

2.2 Reviewed Articles

1. Early detection of LPG gas leakage based Wireless Sensor Networking

Medilla Kusriyanto and colleagues published an article, *Early detection of LPG gas leakage based Wireless Sensor Networking,* which examined the potential dangers of LPG leaks that occur annually and designed a solution for it [12]. They found out that most often gas leaks detected through smelling are underrated and this leads to fatal accidents. The authors proposed and designed an integrated electrical system that communicates via the internet using a wireless network technology with a microcontroller as the interface and control system.

The research paper showed the pictorial observation of the methodology and results obtained in the research. The solution consisted of both transmitter and receiver designs. The designed parts relied heavily on serial communication using the Xbee PRO S2B. The system is integrated with AVR microcontroller (ATMega8) for controlling the peripheral components such as a buzzer for alarm, LCD for display of data, and MQ-4 gas sensor for gas detection. They are all used in the sensor data aggregation and transmission to monitor (PC) using a wireless networking system. A GUI (Graphical User Interface) was designed with Java programming in a NetBeans IDE 7.3.1 to display and interpret the result from the data gathered from the sensors. The system also uses text messaging through *Gtalk,* a web-based application service provided by Google, to communicate to users. Continuous monitoring is performed using the LCD, PC server and mobile alerts. The performance was measured in areas of testing for gas concentration, wireless serial communication, the monitoring system for graphs and data values, and Gtalk application.

The article focused solely on the study of LPG leaks to thwart explosion, leaving out factors such as temperature and humidity of the regions. These two factors are also potential causes of gas explosion when not checked. Unlike MQ-4, MQ-5 is super sensitive to detecting chemicals in natural gas such as LPG gas. Incorporating it in the design will increase the efficacy of the detection time speed of the system.

2. IoT Based Smart Gas Monitoring System

In the same way, when author Anandhakrishnan and his associate professors found that natural gas leak is a major domestic problem, they designed a smart IoT monitoring system to reduce the risks in kitchens, in what they published as *IoT Based Smart Gas Monitoring System* [13]. The proposed and final solution was an SMS based gas leakage alert system that detects gas leakages in a kitchen using an infrared sensor coupled with ATMega328, MQ-2, and a buzzer. It uses the WIFI module (ESP 8266) to interface with an Arduino software to send alert messages to users. Other beneficial features that were included were an online booking system for gas cylinders from a gas agency that allows users to book when the weight of the gas cylinder falls below a specific threshold value. There was also another mechanism called stopper which controls the gas cylinder valve to prevent wastage (through leakage) when the gas is not in use. However, in the absence of WIFI, data cannot be sent as a text message. This situation can be resolved using GSM, which operates on mobile networks that are ubiquitous and very affordable. MQ-5 is very sensitive to LPG than MQ-2 [14].

3. Design and construction of a GSM-based gas leak alert system.

Gas leakages are deadly occurrences in Nigeria, hence in 2006, researchers in Federal University of Technology, Nigeria, designed and built an alert system for LPG leakages. In the research, the authors described their system to have a unit each for power supply, sensing, microcontroller, and alert. All these units were regulated by the microcontroller and interfaced with a software environment called Kiel micro vision. The sensing unit had two separate MQ-6 sensors at two locations, both communicating with the microcontroller with the physical quantity detected from their site. In their proposed flowchart diagram of the software, upon the detection of leakage, the GSM sends an alert to a target user mobile number [15].

The realization of their project went through a prototype stage where the various components were assembled on a breadboard. When expectations were met, a Veroboard was used in the construction of the final design. The final design achieved the aim of sending a message alert to the user. However, there was a gap, thus, the user was unable to read the exact value of gas concentration leaking at that very moment.

In 2016, Kumar et al. designed an alert system like the one just previously mentioned [16]. It included a mechanism which switches off the mains or power supply to the house upon detection of gas leakage. Also, it has a load sensor which updates the user about the weight of the remaining gas in the cylinder. Then again, it automatically places an order for users to refill their empty cylinders by sending an SMS to the distributor company [17].

4. Customized IoT enabled wireless sensing and monitoring platform for smart buildings.

This research paper aimed at providing a platform for monitoring temperature, relative humidity, and light in the field of building automation [18]. Traditionally, the authors used to store the data values collected from sensors such as temperature and humidity sensor (SHT11) and light sensor (TSL2561) in an excel sheet which is then analyzed using LabView. For a continuation of the former project, the author developed an android app for this project to read data values from LabView. The system described in this paper contains a transmitter node (with sensors and a low power microcontroller), repeater node and a sink node. One-Way communication from the transmitter to the receiver node and more repeater nodes were employed in the design of the system. The data which is viewed in LabView is then sent to MySQL database via a personal computer connected to the internet. The android app on a smartphone then retrieves information stored in the database using PHP API executions. When the developed system was tested successfully on a smartphone based on android 4.3, it worked as expected, apart from high average power consumption (43.24mW) that was recorded.

An observation is that these reviewed papers capture the detection of gas leakages in homes and not the industry including gas filling stations. They are also driven by the fact that gas filling stations are in the open, hence gas monitoring is challenging [19].

5. Current technological devices

Existing technological devices such as ALEVEL 02F5 [20] and Battery-Powered Telemetry Unit Netris [21] are also providing highly reliable in monitoring fuel levels at filling stations for public safety. They operate remotely using Lora, Sigfox Networks and GSM module for transmitting aggregated sensor data to the cloud. With a back-office server, stations managers can monitor fuel levels and leakages through web portals with unique presentation and analysis interfaces.

Chapter 3: Design

This chapter discusses the key design of the monitoring system including the schematic of its hardware unit and the software unit, flow charts, specifications, and justifications for materials used, and how the various components of the system interact to solve the problem of gas detection.

3.1 Review of Existing Designs

To address the above expected outcome, the existing solution schemes such as the use of microcontroller with peripheral I/O devices to exchange data are discussed and incorporated in the system design. Internet access points such as Arduino shield, GSM Module, XBee Pro, Bluetooth WIFI Module, etc. are also assessed to facilitate seamless data exchange with the server and web application.

In order to provide an excellent monitoring system, I propose the current incorporation of controller and peripheral components (DHT22 and MQ-5 LPG sensor) which will collect data on temperature, humidity and LPG concentration at the site. An efficient data transfer mechanism to the server will be required using the GSM module. When the data is collected from the site, the GSM module will publish it to the server, which then forwards it to the web application for monitoring. The information that is published on the web application will be analyzed using graphs. Additional features of sound alarm and LEDs will be incorporated on the circuit board to operate in relation to the detection of LP gas. A Google iframe map will be integrated into the web application to show the exact location of the gas filling station site. This is to facilitate smooth direction for the fire service department in the case of fire explosion.

3.2 Thesis Design Objective

1. To design a circuit system that is useful to the detection of LPG leakage

2. To understand the systematic structure of the intended circuit system.
3. To develop high level and technical description of the system.
4. To develop the architectural design of the system.

3.3 Design Decisions

In selecting the right components for the system, it was important to use a Pugh matrix and literature review insights to guide the material selection decision. The Pugh matrices included factors such as cost, feasibility, reliability, compatibility, power consumption, etc. in the feature comparison process.

Pugh Matrix

In comparing the number of design candidates or materials that best fit the design criteria, Pugh matrices for the major categories was conducted [22]. Tables 2-3 show the Pugh matrices that were constructed to analyze and decide amongst the several material candidates selected in the brainstorming phase. This allowed a comprehensive review of the available hardware components for building the system.

Table 1. Design Key for Pugh Matrices.

Symbol	Meaning
s	Same or netural
+	Better than
-	Worse than
0	Baseline

Table 2. Pugh chart for gas sensors.

	Baseline	Weight	Alternatives		
Criteria	MQ-2		MQ-3	MQ-5	MQ-6
Cost	0	1	s	+1	+1
Aesthetic	0	1	s	S	+1
Feasibility	0	2	+1	+1	+1
Response	0	2	+1	+1	+1
Installation	0	1	s	+1	+1
Accuracy	0	1	+1	+1	+1
Total Plus (p)	**0**	**7**	**5**	**7**	**7**
Total Minor (m)	**0**	**0**	**3**	**1**	**0**
Total Neutral	**0**	**0**	**3**	**1**	**0**
TOTAL (p + m)	**0**	**7**	**2**	**6**	**7**

Table 3 Pugh chart for temperature and humidity sensors

	Baseline	Weight	Alternatives	
Criteria	DHT22		DHT11	DS18B20
Cost	s	1	+1	-1
Humidity range	+1	3	-1	-1
Temperature range	+1	4	+1	+1
Sampling rate	+1	3	+1	-1
Accuracy	+1	2	+1	+1
Power consumption	+1	2	+1	+1
Total Plus	14	15	12	8
Total Minor	0	0	3	7
Total Same	1	0	0	0
TOTAL	14	15	9	1

Table 4. Pugh chart for internet devices.

	Baseline	Weight	Alternatives		
Criteria	Arduino shield		GSM Module	ESP WIFI Module	Bluetooth
Cost	0	1	s	+1	+1
Speed	0	4	-1	+1	-1
Connectivity	0	4	+1	+1	+1
Range	0	3	+1	-1	-1
Accuracy	0	2	s	+1	s
Power consumption	0	1	+1	-1	-1
Total Plus	**0**	**15**	**8**	**14**	**5**
Total Minor	**0**	**0**	**4**	**4**	**8**
Total Neutral	**0**	**0**	**3**	**0**	**2**
TOTAL	**0**	**15**	**4**	**10**	**-3**

Table 5. Pugh chart for microcontrollers.

	Baseline	Weight	Alternatives	
Criteria	ATmega8a		ATmega16A	ATmega328p
Cost	0	1	s	s
Memory segments	0	3	-1	+1
Performance	0	4	+1	+1
Peripheral features	0	3	+1	+1
Accuracy	0	2	+1	+1
Power consumption	0	2	-1	+1
Total Plus	**0**	**15**	**9**	**14**
Total Minor	**0**	**0**	**5**	**0**
Total Neutral	**0**	**0**	**1**	**1**
TOTAL	**0**	**15**	**4**	**14**

3.4 System requirement

3.4.1 Functional Requirement

To clearly define what the system will do, the functional requirements are stated below.

i. The system should detect and measure gas concentration, temperature and humidity.

ii. The system should display sensor data on the LCD.

iii. The system should push data to the cloud using the GSM module.

iv. SMS Notification should be sent by the GSM to the user when gas leakage is high.

v. The server should receive and publish data in a database for reference and analysis.

vi. The buzzer should sound to alert station managers on the leakage of gas.

vii. The system's web application should allow the user to locate the filling station site.

3.4.2 Non-functional Requirement

The following provides a description of the criteria that judge the functional requirement.

i. Performance: The system should function to enhance the early detection of gas through alert notification and publishing of data to the cloud.

ii. Speed: The speed of publishing data to the server and web application should be faster.

iii. Accuracy: The system will interpret gathered data correctly and act accordingly.

iv. Timing: The system will be turned on for 24 hours per day. The data will be pushed to the server, except for scheduled days of maintenances and unavailability of gas.

v. Failure contingency: The system should be resettable to recover from an error.

vi. Security: The system will be shielded against weather conditions and reaction with leaked gas.

3.4.3 Use Case

The use case scenario has been presented in Figure 5 and the main actors of the system include the station manager, EPA, and the fire service department.

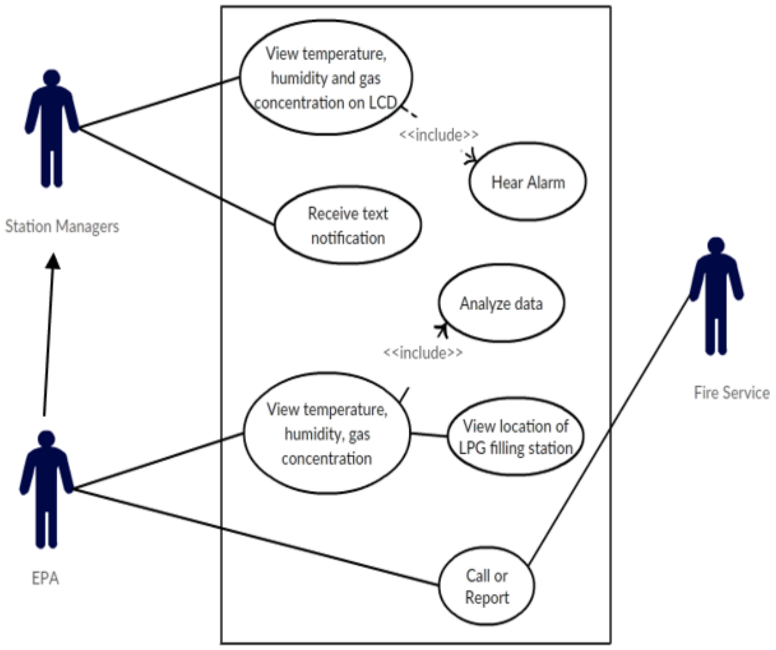

Figure 5. Use case of the system.

3.4.5 Flowchart

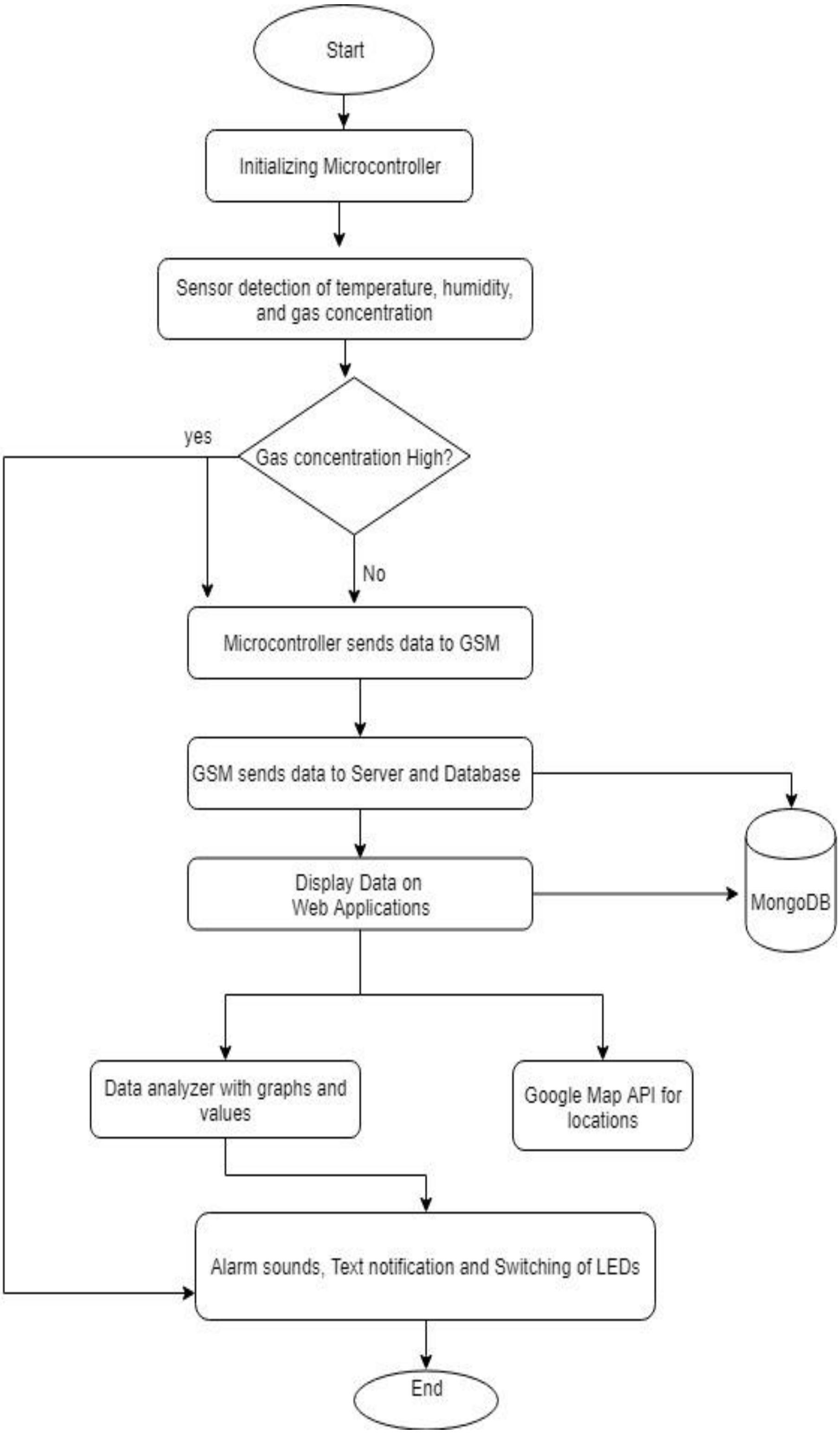

Figure 6. Flowchart of the system.

3.5 Architectural Design.

The architectural model which defines the overall functionality and relationship within the system is illustrated in Figure 7.

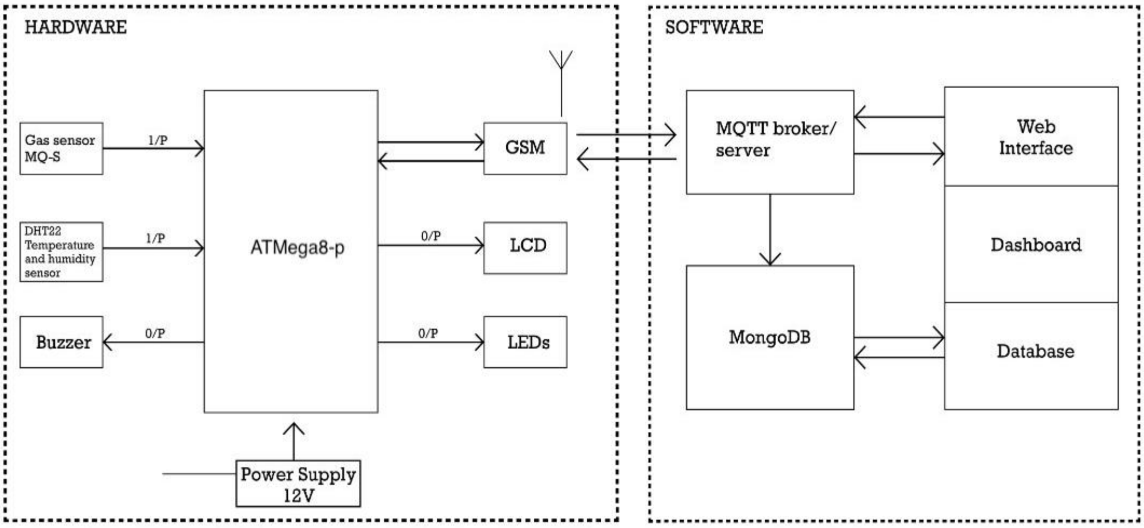

Figure 7. The Architectural design of the system.

3.5.1 Hardware and software implementation

An illustration of the circuit schematic and board design is shown below in Figures 8 and 9. In this circuit, the peripheral devices such as MQ-5, LEDs, LCD, GSM, DHT22, and Buzzer are all connected to the microcontroller (MEGA8-P). An input voltage is regulated by a linear voltage regulator (LM7805) or IC2 to produce an output voltage of 5V. The schematic therefore utilizes parallel connected capacitors $470\mu \; and \; 100\mu$ as filters for elimination of noise when an input voltage of 9V is supplied to the system. The output voltage of 5V is then supplied to the microcontroller and all the peripheral components, except the GSM module whose voltage is regulated to 4V with the aid of LM317.

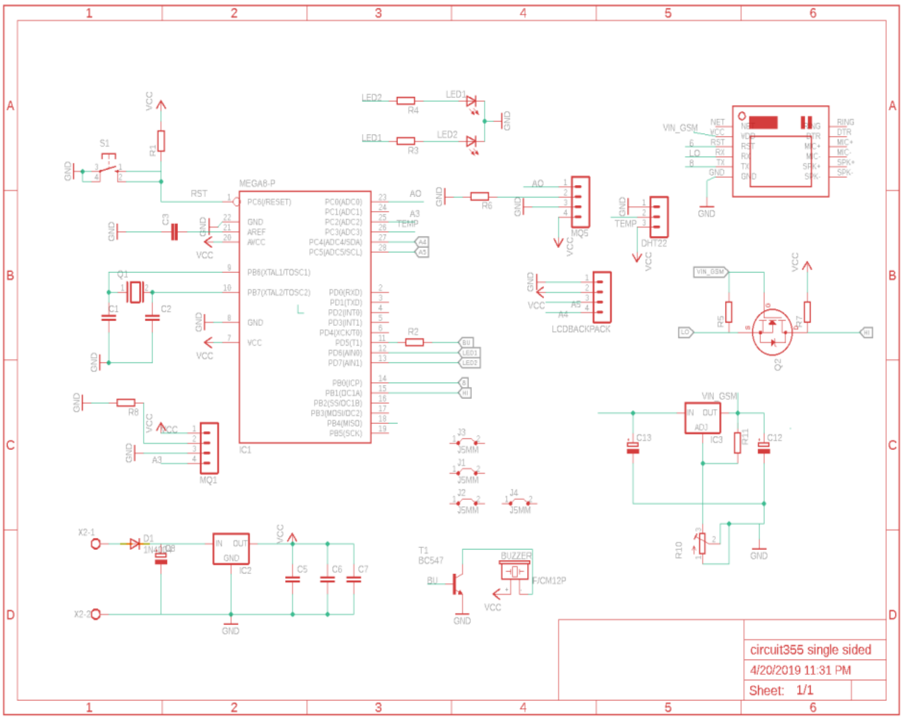

Figure 8. Schematic of the integrated circuit.

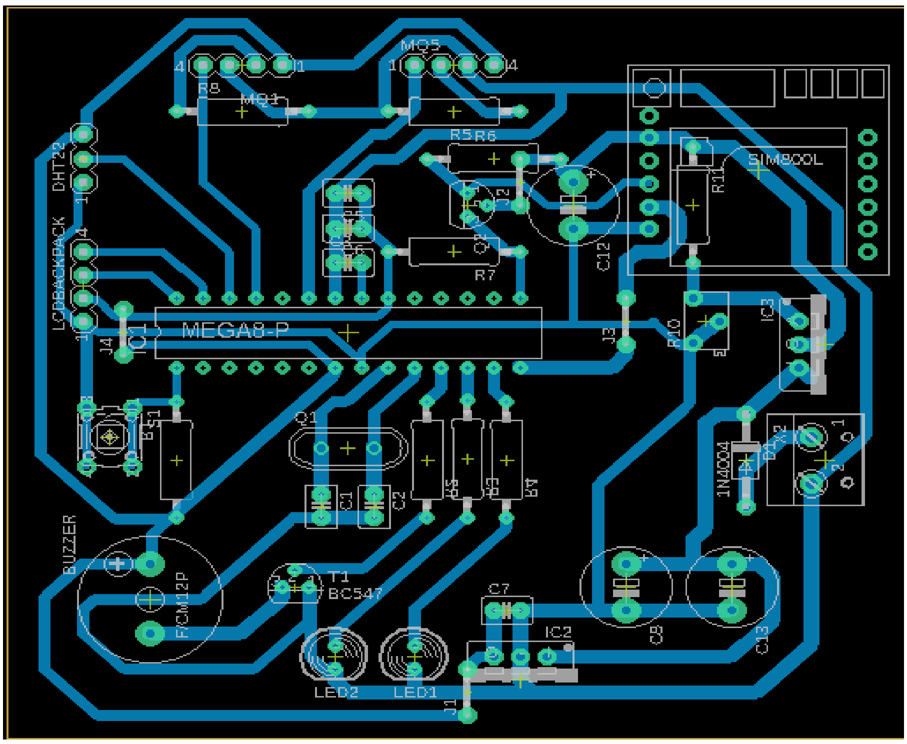

Figure 9. Board design of the integrated circuit system.

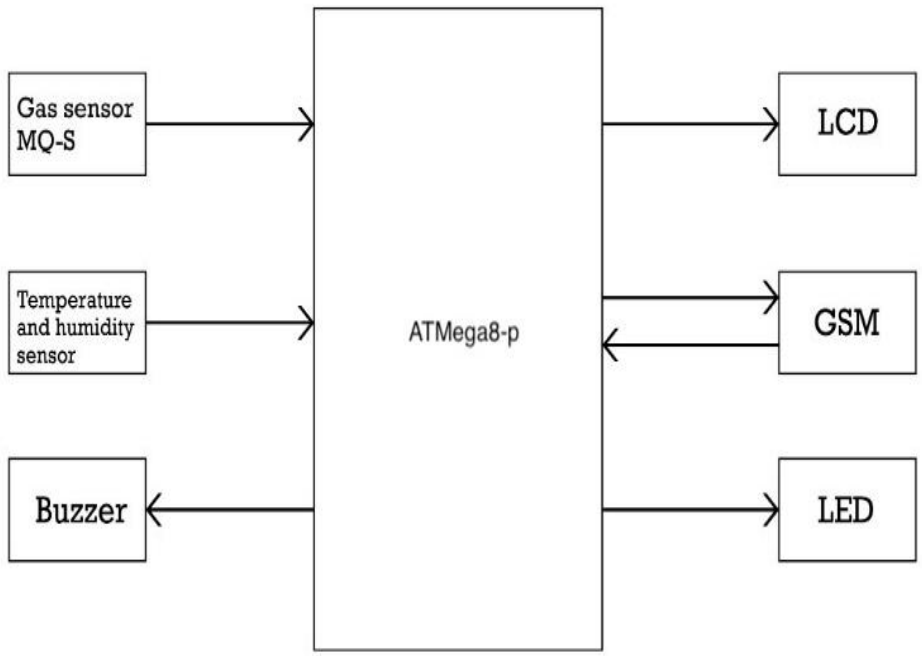

Figure 10. Block diagram of the hardware circuit system.

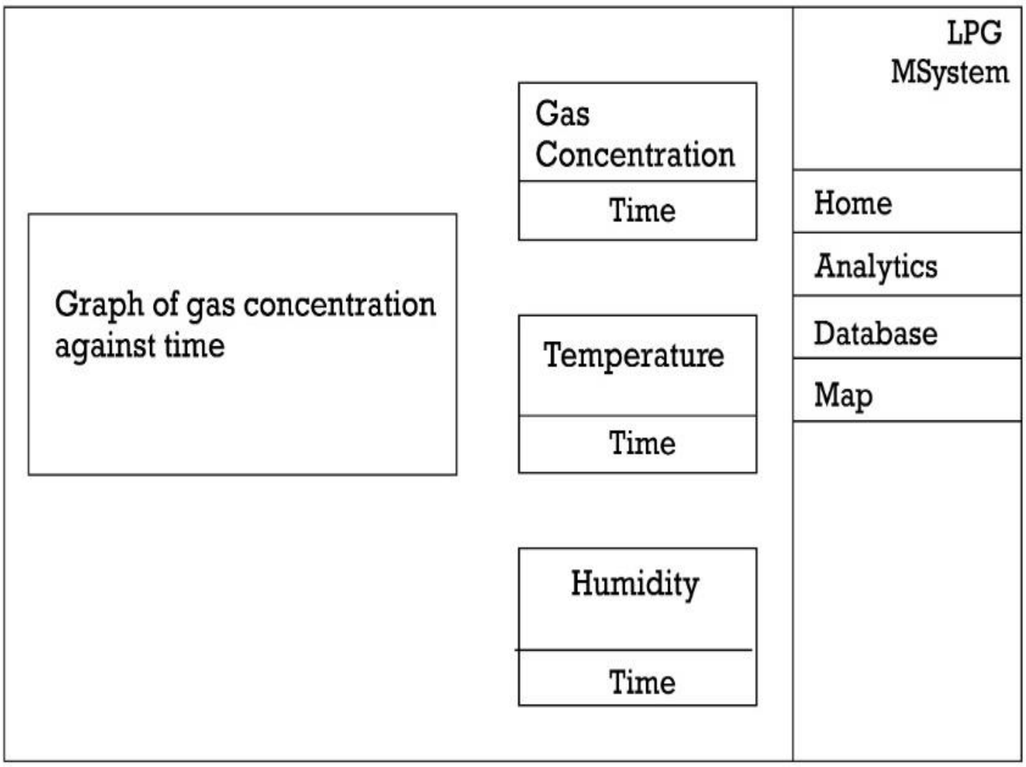

Figure 11. Expected web application design.

Here, we describe the devices and software that are essential to the development of the system. The images of the hardware components used can be seen in Appendix A.

Table 6. Hardware and Software.

Hardware and functions	
Device	Application
Liquid Crystal Display	This is a basic electronic display module used together with a microcontroller to output information on its glass screen [23].
SIM800L GSM	SIM800L is used in sending SMS notification to the user upon detection of leakage [24] . The same is used to connect to a network to push data to the server. It has a data rate ranging from 1200bps to 115200bps.
DHT 22 Sensor	This electronic component is used to read analog temperature and humidity signals from the environment when connected to a microcontroller [25].
MQ-5	An LPG sensor which converts gas concentration into electrical quantity to the microcontroller [26].
ATMega8-P	The central device which coordinates communication among the sensors and other peripheral components [27].
Software and functions	
Arduino software	It is an open source software which allows one to program a microcontroller by coding and uploading the sketch to the board of the microcontroller. The version 1.8.8 is the current version used for the project.
Node Js Express	For the development of a web server and application.
MQTT	It is a message-based protocol that enables the sending or publishing of information

	about a given topic to the server that functions as an MQTT message broker.
MongoDB	For storing published data.
Bootstrap	It is a framework which is used to design the web-based application interface.
Heroku	For hosting the web application.

Chapter 4: Methodology

4.1 Experimental/Computational Setup

In developing the monitoring system, the following approaches were carried. The first approach is the gas sensor calibration, the second approach is PCB design and implementation, the third is server and web development, and the fourth is deployment, and system testing.

4.1.1 Gas sensor calibration

The system is calibrated using clean air in the open as a reference. Placed near an open valve 9kg gas cylinder, the analog readings of gas concentration are read and recorded using the microcontroller and PLX-DAQ excel respectively. The values recorded for the open-air test are then compared with values for LPG filled air to find the difference. The time-space and the difference help to determine the sensitivity of the gas sensors. The results obtained by H. Yan and Y. Rahayu [28] in a research on gas concentration levels guide the decision on choosing the threshold level (See Appendix A).

4.1.2 Hardware development

The hardware design process is divided into two: the prototype and the final product (PCB).

a) The prototype design made use of the Arduino Uno board to achieve the various functionalities. The sensors (gas, temperature, and humidity) were all interfaced with Arduino and the LCD. Components such as LEDs, Buzzer, GSM, were also incorporated to achieve detection and internet functionality.

b) The final product is circuit board designed with Eagle CAD software, simulated with Proteus Design Suite, printed and its components soldered together as expected in the schematics. It is powered with a 9V battery, but 5V is supplied to the system with the aid of a linear voltage regulator (LM7805). The hardware is programmed using Arduino software and the unit test of each component is performed.

4.1.3 Software development

This section is divided into three subsections: Arduino program, NodeJS framework, MQTT broker and deployment of the web application.

a) Arduino program: This entire hardware circuit is programmed using Arduino software to aggregate sensor data on gas concentration, temperature, and humidity. The data are shown on the LCD display, and an alert notification is sent to the user when the gas concentration exceeds the specified digital output of the gas concentration. Adafruit Fona library [29] is used to support the GSM functionality. The GSM pushes the aggregated sensor data to an MQTT broker using a GET request via the GSM. The GPS code employed were developed by Adafruit Fona [30].

b) NodeJS Framework: The web application is created using NodeJS Express in a Windows development environment (Visual Studio). The Node package manager (NPM) enables the installation of modules and libraries to form the skeleton of the web application. Supported by the middleware, it is then populated with routes, views, and database.

c) MQ Telemetry Transport: The application of MQTT in this project is understood as the GSM (client publisher) publishes the aggregated sensor data to the broker. In this case, an open source broker (Mosquitto) is installed using the Homebrew package manager. All held together by the NodeJS framework, the broker or server then forwards or publishes the data to the web application which has subscribed to the broker. The web application (client subscriber) is subscribed to the broker to receive messages on topics such as gas concentration, humidity, and temperature. Only subscribed topics and messages are received and displayed in the web application. In the published data, for example, gas_concentration:50ppm, the payload is the 50ppm whereas gas_concentration is the topic. The broker also populates the MongoDB which has subscribed to it with published data (See Appendix C).

d) Deployment: The web application is deployed on Heroku. Paper trails (See Appendix E) and MLab MongoDB add-ons are installed to keep track of events of all requests and responses, and storage of published data. Postman is used in analyzing whether the data is received on the web application page. Contents in the MLab MongoDB (See Appendix F) is published in the database section of the web application.

The final web application has three main interfaces. The first is the Analytics which monitors the sensor data that is published. The second is the Google map iframe API for determination of site location and the third is the database for reference. The web application is responsive and can be viewed on both PC and mobile devices.

4.2 Image processing

In the researching findings, it was discovered that some of the gas pumps at the filling station are left unclosed; station managers or workers sometimes forget to turn them off after offloading. This issue allowed for the applicability of a pi-camera that will consistently monitor pumps during discharge operation to alert station managers whenever they are left opened. With the help of this, a potential risk during discharging can be identified. In this paper, only the program to compare the images of dial of the pumps was written in python language.

To achieve that, a python program was developed to compare a given image to a collection of images of the same pump when turned off. The images contained the dial of an analog meter. The core components of the algorithm include pixel extraction and difference. Python Skimage library has methods such as *im.read* which enable the program to extract the pixels of the images (RGB) [31]. The OS and Numpy libraries enable the program to load these pixels of the images and store them in an array using the method *listdir*. Once the pixels of an incoming image are extracted, the program compares them to the pixels already in the array, produce the result as True or False and plot the given image. Hence, it contrasts an image of a turned-off pump from that of a turned-on pump. The flowchart below guides the designed algorithm.

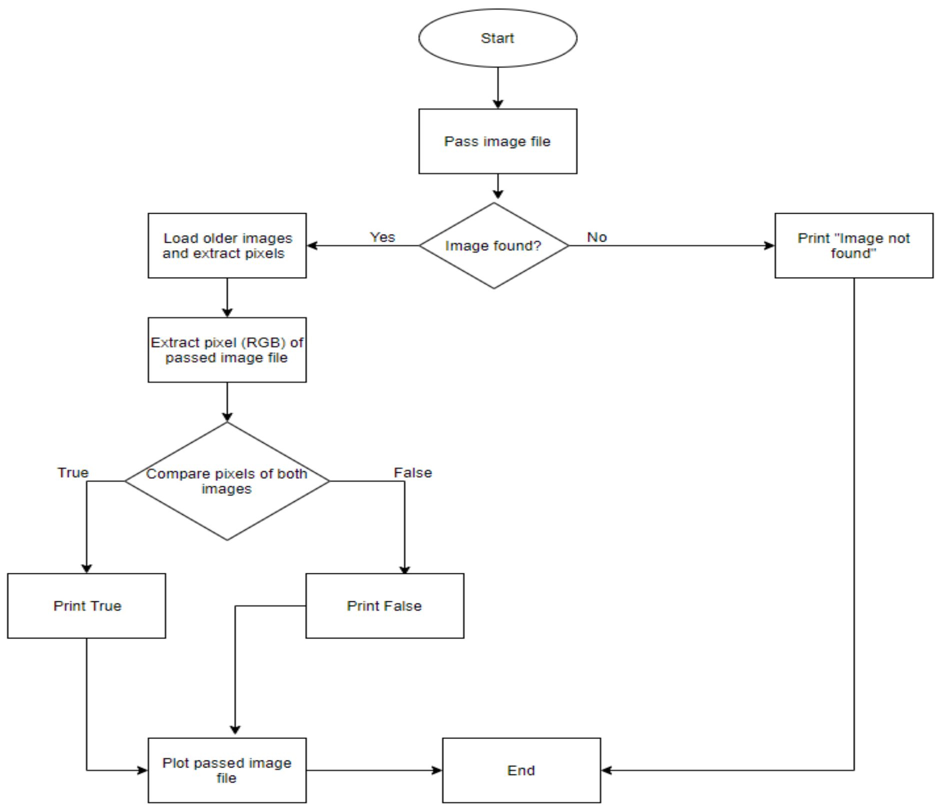

Figure 12. Flowchart of the image processing python program.

Chapter 5: Results

5.1 Detection of Parameters

Figure 11 shows the experimental set-up of the system with gathered data shown on the LCD and a graph produced using ThingSpeak online IoT platform in Fig.12. The data including gas concentration, temperature and humidity have illustrated in Table 5.

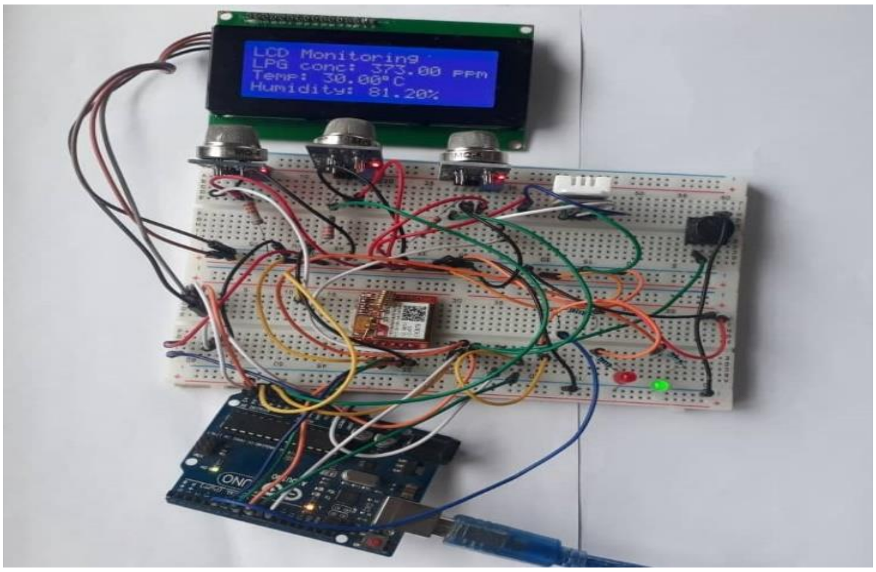

Figure 13. Experimental setup of prototype.

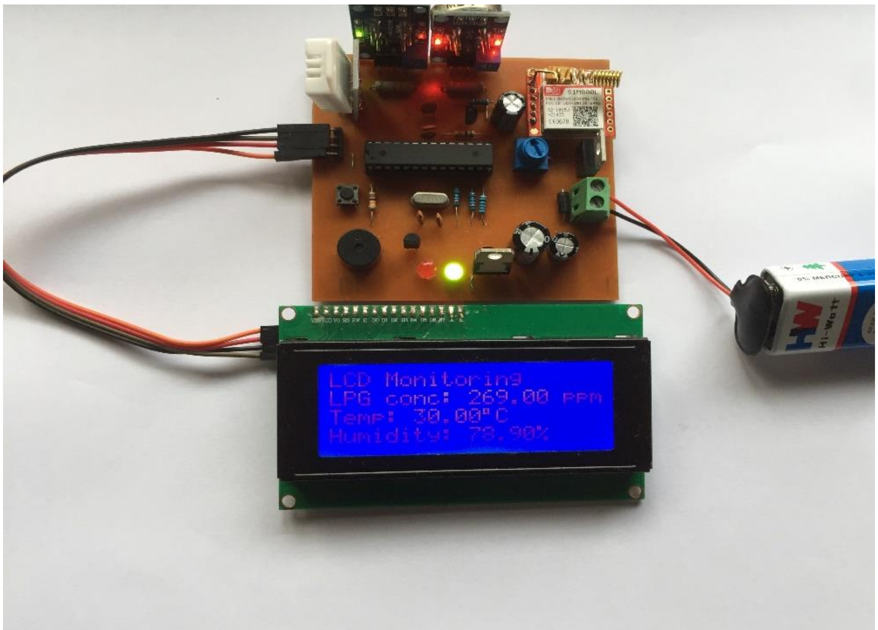

Figure 14. Experimental setup of final hardware product.

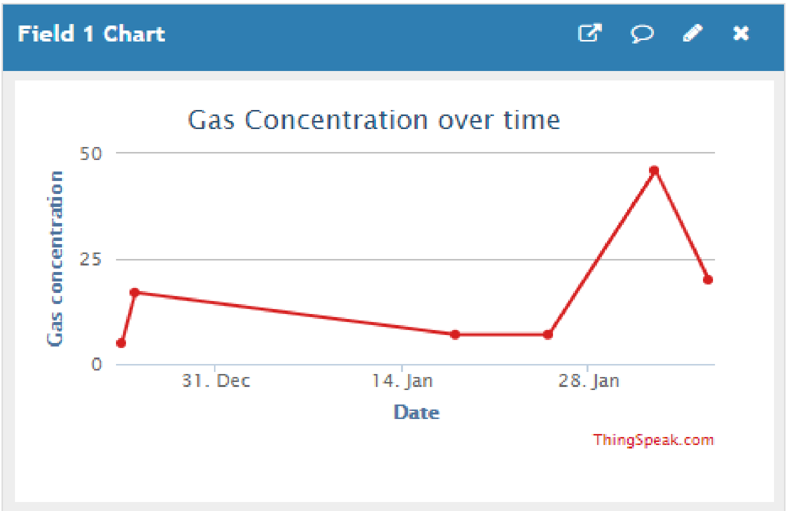

Figure 15. The concentration of gas over days.

Table 7. Results for parameters.

Parameters	Minimum	Maximum
Gas concentration	170	690
Temperature	27	31
Humidity	30	80

Regarding these experimental results (See Appendix G), coupled with results obtained from the research conducted by H. Yan and Y. Rahayu on gas leakages, a digital output of 400ppm which is equivalent to 1.95V is chosen as the threshold or precaution limit for the gas concentration (See Appendix H). In Figure 12, the green LED is turned on while the red LED is off because the gas concentration is below the specified threshold, thus, 373 < 400pp. This threshold also made it possible to specify a condition for the GSM to issue a text alert. In addition, the system was able to send an SMS alert to the user within 5 seconds when gas concentration exceeded the specified or precautionary value (400ppm) (See Fig.

16). The sensor data were sent to the server and continuously updated after the TCP/IP connection was established within 2 minutes between the publisher and the server.

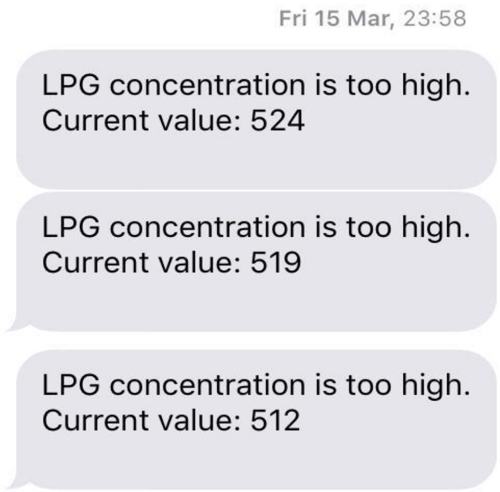

Figure 16. Alert user notification from GSM.

5.2 Web application

The web application was deployed on Heroku (http://lpg-mon.herokuapp.com/). An Arduino code made an HTTP or GET request to the server, and it published the aggregated data on gas concentration, temperature and humidity to the server. The server forwards the data to the web interface which has subscribed to it. The web interface displayed the information online. Paper trails and postman software enabled the monitoring of requests and responses of the published data stream in terms of logs or events. The data storage is also confirmed by checking the MLab MongoDB cloud storage to see if the data stream has been stored.

Figure 17 shows the gas concentration, temperature and humidity tracked live data with timestamps.

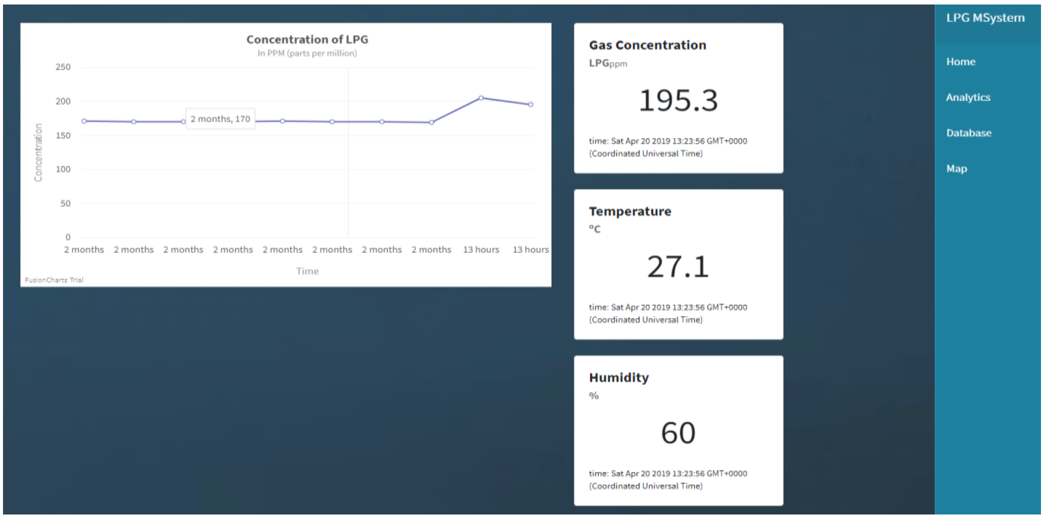

Figure 17. Final web application design.

Table 8. Results from database storage.

#	Date	Concentration	Temperature	Humidity
1	2019-04-20T13:23:56.035Z	195.3	27.1	60
2	2019-04-20T12:49:20.456Z	205	28.3	50
3	2019-02-23T16:11:11.223Z	169	27.2	46.7
4	2019-02-23T16:10:58.716Z	170	27.2	47.4
5	2019-02-23T16:10:46.100Z	170	27.2	47.7

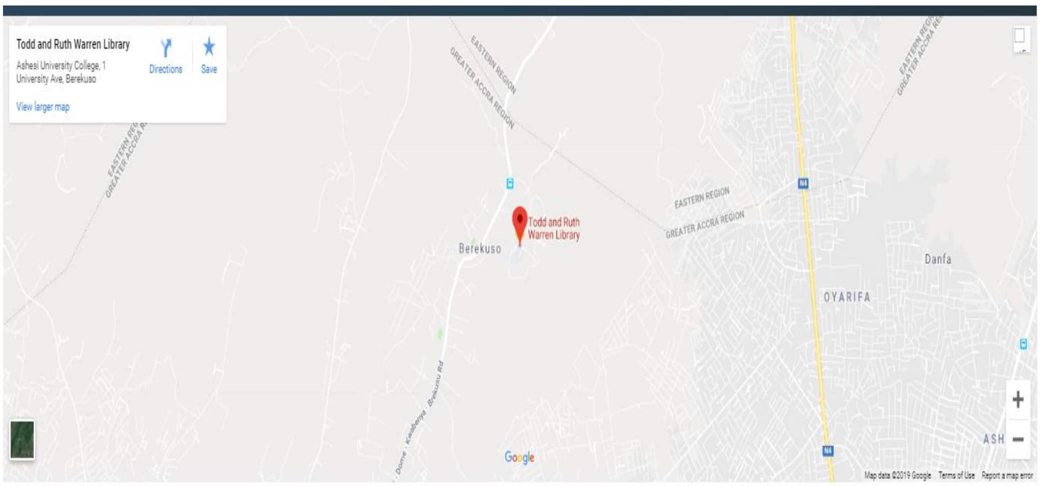

Figure 18. Google iframe map for tracking gas filling stations.

5.3 Image Processing

On the aspect of the image processing, the pixel comparison algorithm developed was able to predict True or False on the test case image, and plotted the image using the matplotlib (See Appendix D). This allowed the user to know whether a pump is turned on or off.

Chapter 6: Conclusion

6.1 Discussion

In this project, a unique system of monitoring gas leakages at the filling station has been presented using the concept of IoT. Based on the results, we can measure and send gas concentration, temperature and humidity of a gas filling station site to a server and a web application for monitoring. The major drivers which include the hardware circuitry, web application and the communication between the two have been explicitly illustrated.

To verify the accuracy of the monitoring system, two factors were considered. Alert notification and data publishing are the two key factors to ensure early detection of the gas leakages. The GSM was reliable and convenient for these two factors. The results obtained were discussed in relation to the system performance; the sensors are sensitive and produce accurate results. The communication between hardware system, target mobile phone and web application is faster. The end users (station managers and EPA) can also view the real-time measurement of the three main parameters understudy. By embracing the data, research and the system developed, it is possible that gas explosions at gas filling stations will become a thing of the past. It is evident that Internet of Things (IoT) plays an important role in data collection and the prevention of a gas explosion.

6.2 Limitations

The core technological challenges which includes GSM DNS errors, network connection problems, insufficient power, and refined calibration must be overcome to pave way for the system to function effectively and efficiently. These challenges affected the seamless transfer of sensor data to the server. Other external factors such as windy days and the release of other gases such as carbon monoxide (smoke) affected the detection process when sensors are left in the open. This is because it became more challenging tracking only

LPG when the weather was windy. To explore more about the detection of LPG leakage at a gas filling station, the system's environment should be studied to tune a good threshold for LP gas concentration. As for the image processing aspect, the proposed pixel comparison algorithm was computationally intensive for folder with copious images, hence, it required more time to produce the desirable result. Again, placing the unshielded system close to the gas tank can cause sparks which can trigger an explosion; hence, this gives a system installment problem. A 3D casing will be built to enclose the system; this approach, it will limit the impact of sparks in areas where there is too much leakages.

6.3 Future Work

Despite the challenges and limitation addressed above, the current adoption of IoT technologies are potential for detecting gas leakages explosion in the shortest possible time. This goes to avert a gas explosion since the challenges are outweighed by the system performance. Based on the acquired experience in the project, it is possible to create a mobile app for stakeholders to monitor gas leakages conveniently. Some specifications such as sensitivity of sensors and seamless internet connectivity will be improved to enhance the early detection process. Future research will cover areas where the system will be able to use a machine learning algorithm to learn inputs from sensor data and automatically analyze the patterns of the current parameters understudy and additional factors such as pressure. This will be in addition to providing a prediction model for a potential gas explosion using collected data. Moreover, the image processing algorithm will be reinforced and integrated with the monitoring system to capture visual flaws during offloading at the filling station.

As an addition to current research on the applications of smart technology to prevent gas explosion, this capstone project shows that Internet of Things (IoT) has a great potential in the early detection of gas leakages at filling stations in Ghana.

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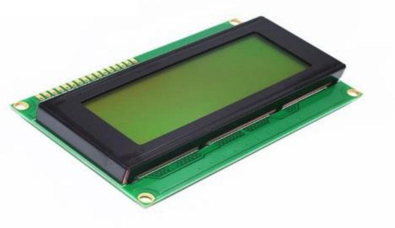
Appendix

A. Hardware and functions

SIM800L 	 LCD 20x4
DHT22 	MQ-5 
Atmega8-p 	Buzzer 

B. Detection of parameters: Gas concentration.

Results obtained from research by H. Yan and Y. Rahayu

TABLE I. THRESHOLD VALUE FOR GAS CONCENTRATION OF CO AND CH4 GASES [10]

Value of gas concentration (ppm)	
Carbon monoxide CO	Methane CH4
20 - 2000	500 - 10000

TABLE II. OSHA MEASURED VALUE FOR MQ-9 USING LPG [2]

Level	Light Indicator	LPG (ppm)	Sensor value in MQ-9	Voltage (V)
Safety	Green	<500	<342	<1.67
Precaution	Yellow	> = 500 < = 1000	> = 342 < = 512	>=1.67 <=2.50
Dangerous	Red	> 1000	> 512	>2.50

A snippet of the Arduino code implemented on microcontroller showing the declaration of pinouts and helpful libraries.

main | Arduino 1.8.1

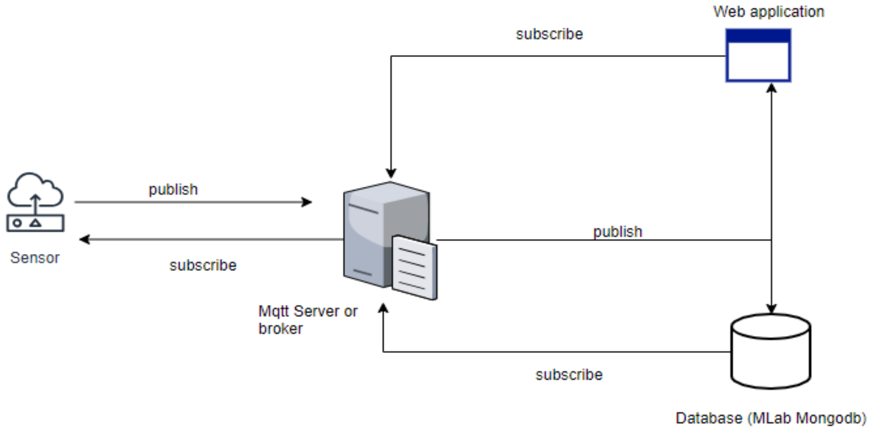
File Edit Sketch Tools Help

Upload

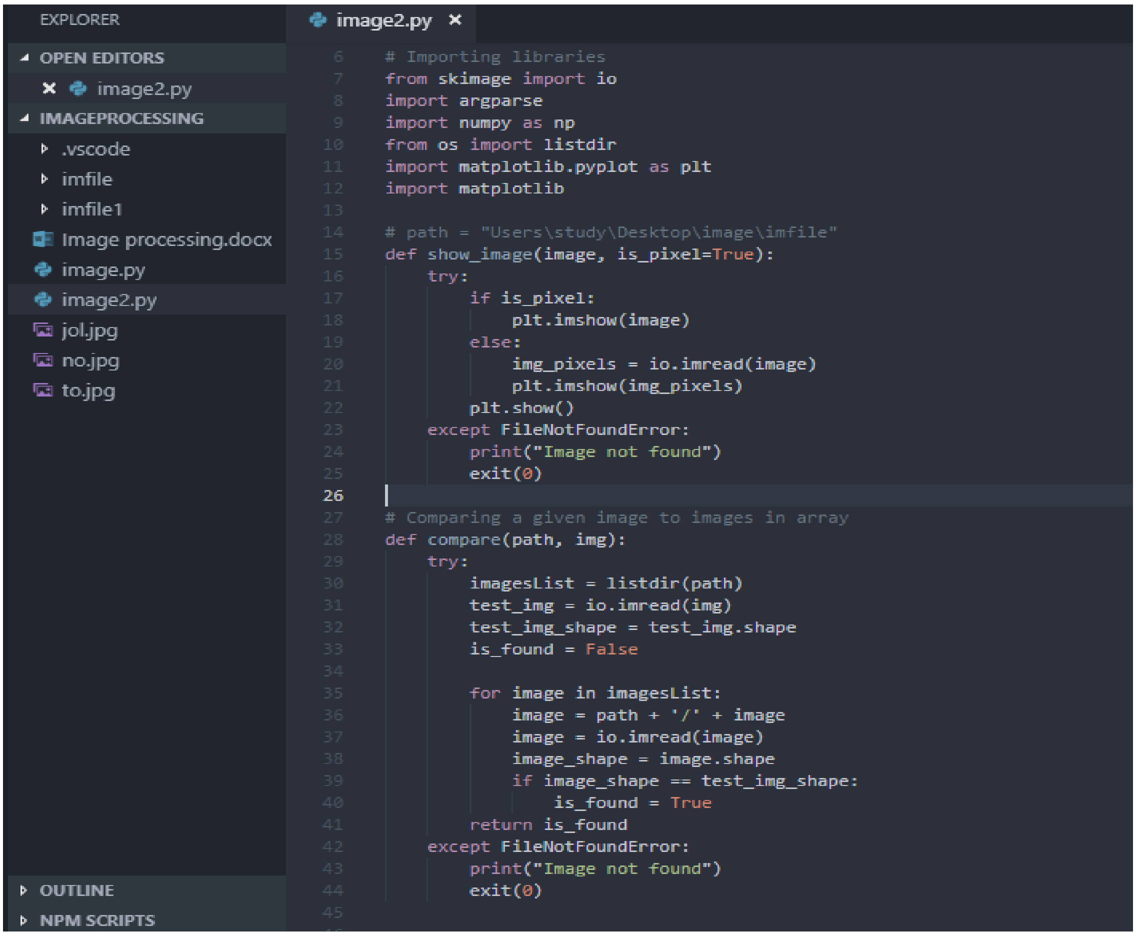
main §

```
#include "Adafruit_FONA.h"
#define FONA_RX 9
#define FONA_TX 8
#define FONA_RST 6

char replybuffer[255];

#include <SoftwareSerial.h>
SoftwareSerial fonaSS = SoftwareSerial(8, 9);
SoftwareSerial *fonaSerial = &fonaSS;

Adafruit_FONA fona = Adafruit_FONA(FONA_RST);
uint8_t readline(char *buff, uint8_t maxbuff, uint16_t timeout = 0);
uint8_t type;

//DHT libraries
#include "dht.h"
#define dht_apin A3
dht DHT;

//LCD
#include <Wire.h>
#include <LiquidCrystal_I2C.h>

#define I2C_ADDR   0x3F
#define En_pin     2
#define Rw_pin     1
```

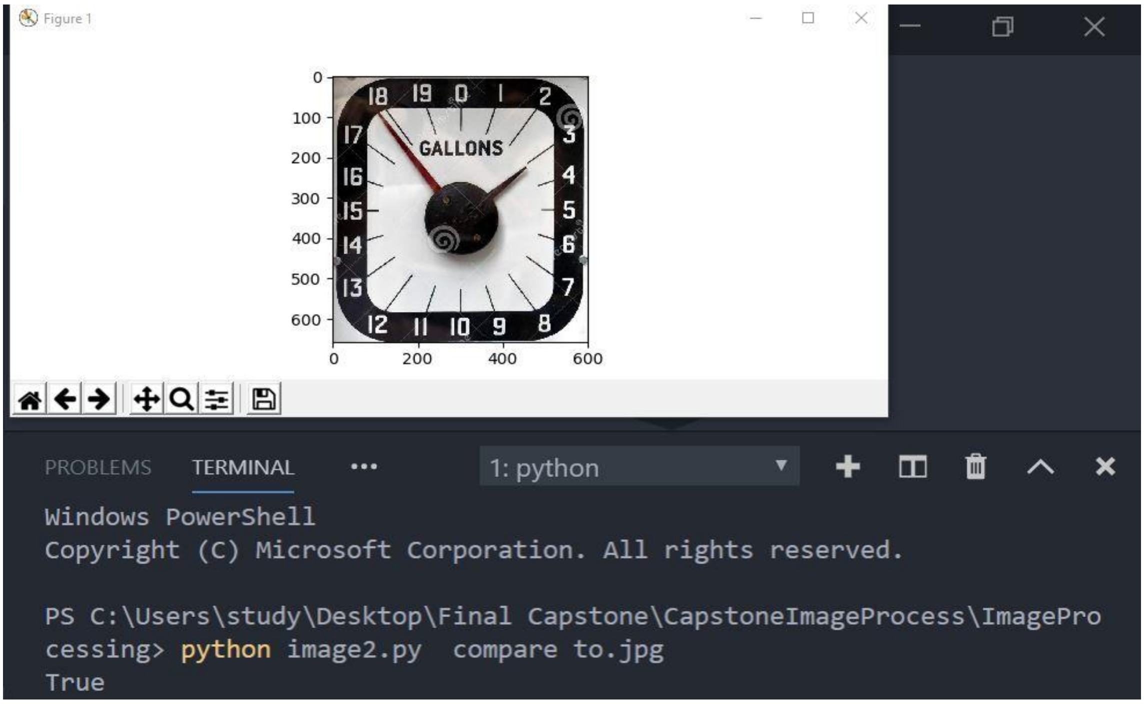
C. MQ Telemetry Transport: Subscriber and publisher



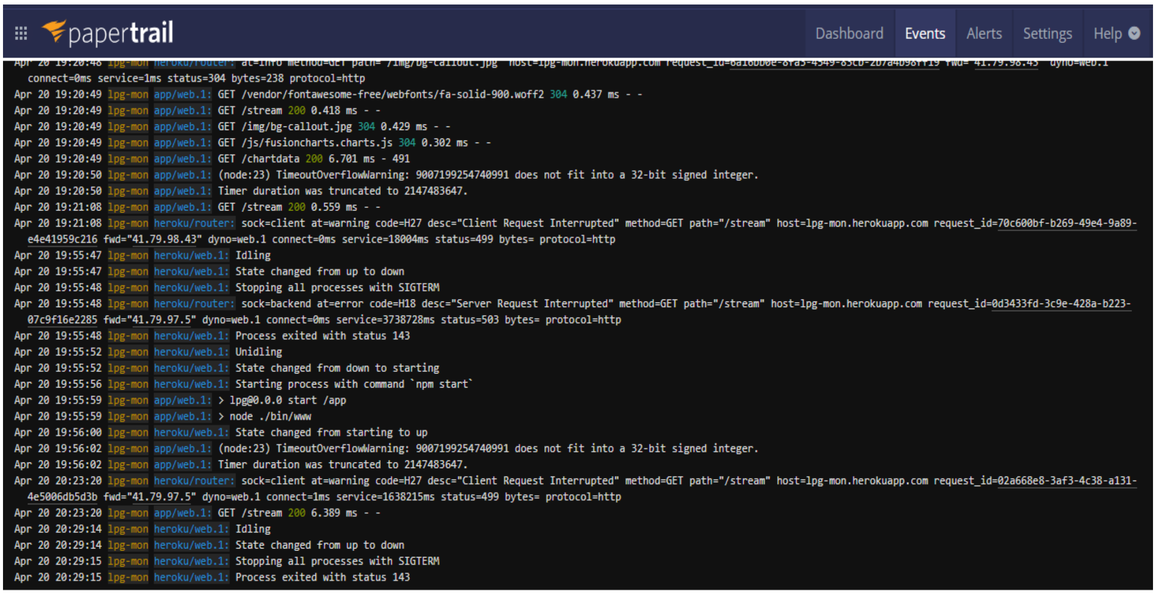
C. Results on image processing



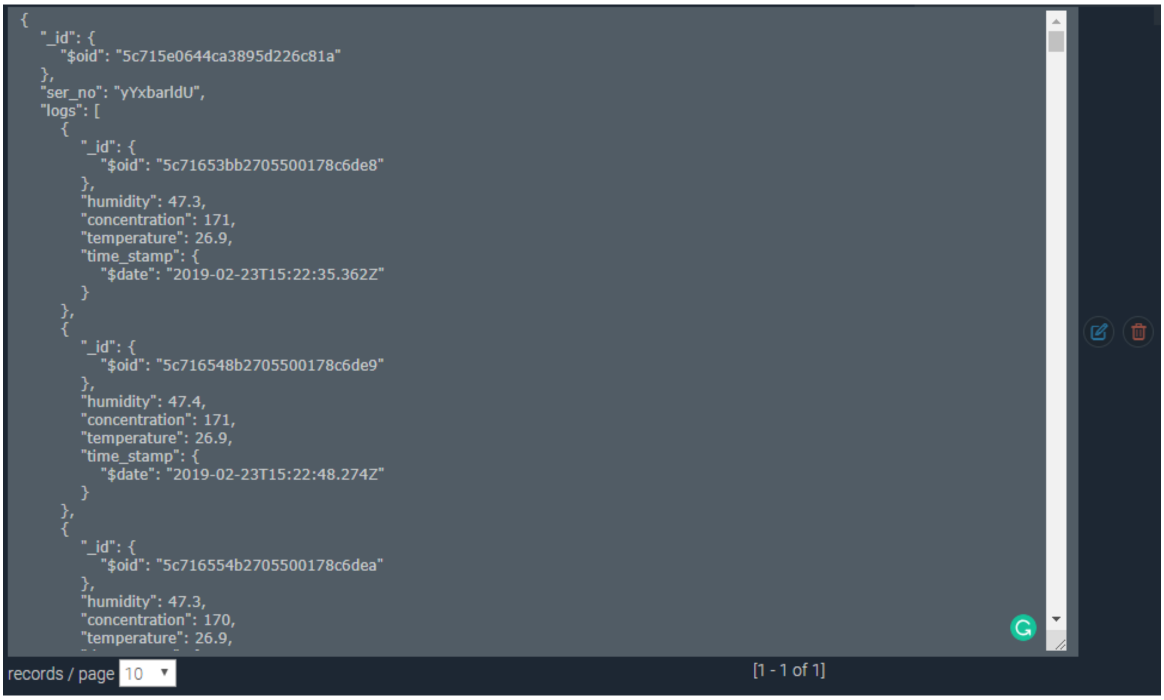

```python
# Importing libraries
from skimage import io
import argparse
import numpy as np
from os import listdir
import matplotlib.pyplot as plt
import matplotlib

# path = "Users\study\Desktop\image\imfile"
def show_image(image, is_pixel=True):
    try:
        if is_pixel:
            plt.imshow(image)
        else:
            img_pixels = io.imread(image)
            plt.imshow(img_pixels)
        plt.show()
    except FileNotFoundError:
        print("Image not found")
        exit(0)

# Comparing a given image to images in array
def compare(path, img):
    try:
        imagesList = listdir(path)
        test_img = io.imread(img)
        test_img_shape = test_img.shape
        is_found = False

        for image in imagesList:
            image = path + '/' + image
            image = io.imread(image)
            image_shape = image.shape
            if image_shape == test_img_shape:
                is_found = True
        return is_found
    except FileNotFoundError:
        print("Image not found")
        exit(0)
```



E. Deployment: Papertrail



F. Deployment: MLab Mongo Database



G. Result from gas concentration test.

Test for LPG concentraion					
Time elapsed(s)	Initial Sensor Value	Final Sensor Value	Difference	Distance (cm)	Mean (Difference)
30	187	364	177	10	
30	170	387	217	10	
30	201	418	217	10	203.6666667
29	211	391	180	5	
29	176	318	142	10	
29	172	408	236	10	186
30	210	361	151	5	
30	188	683	495	5	323

Setup for gas concentration test (9kg gas cylinder)

H. Voltage threshold calculation for gas concentration

$$Input\ voltage, V_{in} = 5V$$

Analog reading range = 0 -1023 which correspond to 0-5V

Output voltage of the gas sensor, $V_{out} = ?$

Analog reading from Arduino = 400 ppm

$$400 = \frac{V_{out}}{V_{in}}\ x\ 1023$$

$$400 = \frac{V_{out}}{5V}\ x\ 1023$$

$$V_{out} = \frac{400\ x\ 5\ V}{1023}$$

$$V_{out} = 1.96V$$