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IoT-based on boiler fuel monitoring system: a case of Raha beverages company limited, Arusha-Tanzania

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IoT-BASED ON BOILER FUEL MONITORING SYSTEM: A CASE OF RAHA BEVERAGES COMPANY LIMITED, ARUSHA-TANZANIA

Boniface Ntambara

A Project Report Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in Embedded and Mobile Systems of the Nelson Mandela African Institution of Science and Technology

Arusha, Tanzania

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ABSTRACT

RAHA Beverages Company (RABEC) is the one of banana wine production companies that utilizes fuel in steam production in Arusha-Tanzania. Fuel usage and conditions monitoring in RABEC become a challenge due to inaccurate and unreliable current monitoring systems. Currently, RABEC uses a dropping stick into the fuel tank to investigate fuel level, temperature, and usage, which are time-consuming, give inaccurate readings, inefficiency, and provoked accidents. This study aimed to develop an IoT-based fuel monitoring system that can provide real-time fuel conditions to prevent plant breakdown and accidents. The flow meter, ultrasonic, fuel temperature, humidity, and pressure sensors were used to gather fuel data conditions. The GSM was employed to send fuel data messages to the operator's phone. An AT mega 328 microcontroller was used to process and analyze the fuel data. Thing Speak IoT platform was also used to visualize and aggregate fuel data using Wi-Fi connectivity. The results showed that when fuel level was less than the threshold value, an operator was alerted by refilling messages via GSM technology. At 0.1Psi pressure, fuel temperature of 120℃, and 80% of humidity, the system notifies the operator by an alert to check injector pressure and if fuel-air mixture is perfect. In addition, these data were observed on LCD and ThingSpeak webpage. To conclude, the developed system proves a high accuracy, security, and efficiency rates compared to the current monitoring system. Future work is recommended by deploying SCADA with HMI systems to monitor and control fuel usage.

DECLARATION

I, Bonface Ntambara, do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this project report is my original work and that it has neither been submitted nor being concurrently submitted for a degree award in any other institution.

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by The Nelson Mandela African Institution of Science and Technology, a project report titled ***"IoT-based on Boiler Fuel Monitoring System: A Case of Raha Beverages Company Limited, Arusha-Tanzania"*** in partial fulfillment of the requirements for the degree of Master of Science in Embedded and Mobile Systems of the Nelson Mandela African Institution of Science and Technology.

Dr. Devotha Nyambo	[signature]	29/8/2023
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DEDICATION

I dedicate this research to my loving parents, Mukamitari Clothilde and Michel Mirambi whose words of encouragement and push for tenacity ring in my ears.

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LIST OF ABBREVIATIONS AND SYMBOLS

AC	Alternating Current
AH	Amps-hour
AVR	Advanced Virtual RISC
BMS	Based Management Software
℃	Celicius degree
CDC	Capacitance to Digital Converter
DC	Direct Current
DHT	Digital Temperature and Humidity
GHz	Giga Hertz
GND	Ground
GPIO	General Purpose Input/Output
GPRS	General Packet Radio Services
GSM	Global System for Mobile Communications
HMI	Human Machine Interface
I2C	Inter-Integrated Circuit
ICT	Information and Communication Technology
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers
IIoT	Industrial Internet of Things
IoT	Internet of Things
KB	Kilo Byte
kHz	Kilo Hertz
L/H	Liter per hour
L/Min	Liters per Minute

LCD	Liquid Crystal Display
LED	Light Emitting Diode
mA	Milli-Amps
MHZ	Mega Hertz
MPa	Mega Pascal
mΩ	Mega Ohm
nF	Nano-Farad
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
RMS	Root Mean Square
RX	Receiver
SCADA	Supervisory Control and Data Acquisition
SMS	Short Message Service
SPI	Serial Peripheral Interface
TX	Transmitter
UART	Universal Asynchronous Receiver-Transmitter
V	Voltage
VCC	Voltage Common Collector
VDC	Voltage Direct Current
W	Watt
WEP	Wireless Encryption Protocol
Wi-Fi	Wireless Fidelity
WPA	Wi-Fi Protected Access

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

The IoT systems refer to the network of interconnected physical devices with embedded sensors, and software that collaborate to collect, exchange, and analyze data, enabling them to physical environment. These systems leverage the internet connectivity, embedded sensors, and communication technologies to enable devices to communicate, share data and perform intelligent actions (Chui, 2022). The IoT-based fuel monitoring system serves as a remote solution to track real-time fuel conditions from the storage tank to the boiler within production plant. It functions with multiple IoT sensors and internet-connected devices that support in gathering real-time fuel data and storing them on cloud platform (Matellio, 2023). In addition, these fuel monitoring solutions enabled IoT sensors to allow users the ability to remotely fuel tank levels, fuel temperature, fuel pressure, tank humidity, and usage to identify fuel condition issues like low fuel pressure, high/or low fuel temperature, fuel moisture and maximize fuel efficiency. It can also provide accurate real-time readings of fuel level, fuel usage, and alert boiler user if readings exceed threshold limits to prevent plant breakdown (Verma, 2021).

Fuel as one of the most significant consumables is highly considered in beverage industries to be monitored using IoT systems due to the economics of wine processing operations. To ensure that the fuel data conditions in the industry's tank during steam process are correct and valuable, a fuel monitoring system is necessary (Promise, 2020). In addition, the mechanical heat exchangers (boilers) utilize the fuel heat or waste heat energies from the factory output to steam the working medium to a given temperature and pressure. An IoT based fuel monitoring system that uses IoT-enabled sensors could enable industry users to remotely monitor fuel usage and other fuel parameters with fuel drawback identification like leakages or excessive idling, and maximize fuel efficiency (Leverage, 2020). Through the insertion of sensors, the real-time state parameters of the fueling system in RABEC can be collected and transmitted to the remote management platform or webpage using an IoT web server platform like ThingSpeak.

Furthermore, the monitored fuel utilizations in the ignition process can be safe and efficient when fuel parameters like fuel temperature and pressure can be analyzed, determined, and investigated remotely where the operational situation of the monitored fuel boilers can be instantaneously and in real-time released on the internet through a webpage (Qiang, 2014). The operational cost of fuel matters the most in RABEC. The increased cost of steam generation using fuel results in higher and this can be optimized by using fuel real-time data monitoring system and analytics utilizing web access. Fuel tracking strategy is critical in RABEC's production plant, which operates to feed steam to the boiler on a frequent basis for the manufacturing process (Design, 2022). Figure 1 indicates the current boiler that RABEC is using in steam production.

Figure 1: Current industrial Boiler from RAHA beverages limited

Figure 2 illustrates the fuel that is being used in the steam production process.

Figure 2: Fuel used in RABEC Ltd

The developed IoT based on fuel monitoring system is based on tree technological systems. These systems are GSM technology, ThingSpeak IoT platform, and IoT embedded sensor systems. The fuel usage and fuel parameters are delivered and accessed straightly to the ThingSpeak as webpage and operator cell phone through SMS via GSM module. The fuel monitoring is done continuously using web application as an IoT platform known as ThingSpeak. This platform permits ATmega 328 microcontroller, IoT-enabled sensors, and ESP internet module to operate effectively via internet usage. The platform has widgets such as API keys and visualizations which is capable to display real-time fuel data parameters and accessible at any time. The fundamental intention of this study research was to create an internet of things-based fuel monitoring system that can monitor fuel temperature, pressure, fuel usage, humidity, ambient temperature and deliver these fuel data to ThinkSpeak as a webpage.

1.2 Statement of the Problem

RAHA Beverages Company (RABEC) currently faces with the challenges related to manual fuel usage checks and fuel data monitoring. The reliance on manual processes for tracking fuel usage and the absence of real-time monitoring capabilities hinder operational efficiency, accuracy in data recording, and proactive decision-making. This current method of checking fuel usage involves manual recording and calculation. This process is time-consuming, prone to human errors, and requires significant effort to aggregate and analyse data accurately. Manual checks also limit the ability to capture real-time fuel data conditions such fuel temperature, fuel pressure, fuel level tank, and fuel moisture content. In addition, it can lead to impact fuel data condition records and subsequent analysis.

The absence of a centralized monitoring system prevents RABEC from gaining real-time visibility into fuel consumption patterns and trends. This lack of visibility hampers the ability to generate timely and accurate reports, hindering informed decision-making and strategic planning and without real-time monitoring of fuel data, RABEC's maintenance activities are often reactive. The inability to proactively identify anomalies or trends in fuel consumption and condition may result in missed opportunities for preventive maintenance and optimized fuel usage. Briefly, the fuel monitoring system in RABEC is done manually by recording the daily fuel consumption and fuel data condition by dipping the graduated stick in the fuel tank which is more dangerous to cause an accident. The risks to hazardous injuries and death accidents were confirmed by the operations manager when the operator tried to check the fuel usage and observe fuel pressure (Mohammed., 2022). The manual monitoring systems without remote access prevent real-time decision-making and quick emergency response. RAHA Beverages Company aims to address these issues by implementing an IoT automated system for fuel usage checks and comprehensive fuel data monitoring.

1.3 Rationale of the Study

The fuel monitoring at RABEC Ltd requires a reliable and efficient remote monitoring system. Industries are rapidly embracing the use of ICT to enhance fuel monitoring and management systems. Based on previous research, it shows that the existing monitoring systems comprise a lot of limitations such as time consumption, human errors, inefficiency, inconvenience, and poor monitoring. The manual monitoring systems without remote access and control, prevent real time decision-making and quick emergency response. Additionally, fuel and oil tanks are prone to hazardous fumes that are not only bad for the lungs, but combustible. So, by reducing human intervention, will reduce the risk of injury for the company staff involved in the fuel monitoring (Xytronix, 2022). Therefore, this study aims to develop an IoT-based fuel monitoring system which should monitor the fuel temperature, fuel pressure, and humidity of fuel so that the operator and or operation manager can be easier to monitor the fuel parameters via a web page and short message service in order to increase the fuel efficiency and effective fault check as soon as possible.

1.4 Research Objectives

1.4.1 Main Objective

The project's main goal was to develop an IoT-based fuel monitoring system of RABEC in Arusha-Tanzania.

1.4.2 Specific Objectives

The study aimed to achieve the following specific objectives:

(i) To gather the requirements for development of an IoT-based fuel monitoring system.

(ii) To develop the hardware and software systems for IoT-based fuel monitoring system.

(iii) To validate the developed IoT-based fuel monitoring system’s performance.

1.5 Research Questions

The study intended to answer the following questions:

(i) What are the user requirements in development of an IoT-based fuel monitoring system at RABEC?

(ii) What are the appropriate tools and methodologies in designing and developing an IoT-based fuel monitoring system at RABEC?

(iii) Did the developed IoT-based fuel monitoring system meet with RABEC's satisfaction and standards?

1.6 Significance of the Study

The research enabled scientists and industry to envision a new approach to use ICT in fuel monitoring systems. The practical use of the IoT-based fuel remote monitoring system helped and supported in trend analysis for quick fault diagnosis, predictive maintenance alerts, real-time alert management via SMS and webpage, early detection of unexpected changes or errors, check if there were unburned fuel, detect if there is fuel complete combustion, check the perfection mixture of fuel and air and minimize fuel consumption. To RABEC, a remote fuel monitoring system was convenient, fuel consumption irregularities could be monitored and managed, and boiler operator works was minimized at high efficiency. RAHA Beverages Company has saved the maintenance cost and operational costs was cut down. The real-time fuel data processing was improved. Moreover, IoT-based fuel monitoring system avoids the need for RABEC operators to frequently operate the boiler manually for fuel consumption reports.

1.7 Delineation of the Study

The study defines how an IoT system should be used in RABEC to gather and monitor information about fuel usage and fuel data conditions such as fuel temperature, fuel pressure, fuel flow rate, humidity, and environmental temperature using the ThingSpeak IoT platform and GSM module. The selection of this IoT platform and the GSM module was based on statistics of maintenance technicians and operators that are familiar with the platform and GSM technology usages which indicate that platform and the module were very easier in fuel monitoring processes. In addition, the project focused and limited only to fuel monitoring because it was the RABEC case study that was being dealt and challenged with. The ATmega 328 microcontroller, GSM module, and connected sensors were involved in the IoT-developed system. These components have been integrated with a web-based fuel monitoring system to gather and evaluate the fuel data. Then, an operator could be able to access and download these data for reference. During this project, the following challenges like COVID-19 pandemic which caused restrictions of access to some industrial places and people during data collection, delays in shipment of equipment and time constraints of different activities in the research process were encountered.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

The fuel level accuracy, fuel temperature, and fuel pressure, fuel tank environment temperature, and fuel tank humidity are not given the great importance in the past time at RABEC. The motive behind monitoring the fuel parameters have been to display the information on the dashboard where the boiler operator, operation and maintenance managers can make observation of the fuel usage with an IoT-based on fuel monitoring system. Rather than providing accuracy to the fuel metering and monitoring systems, the focus is to improve the display of fuel parameters and the fuel monitoring system must indicate when the fuel is below the predefined amount of volume, indicate the fuel temperature, fuel pressure, fuel tank environment temperature, and fuel tank humidity. Then, it sends that information to IoT Thing-Speak platform and to operator's mobile phone. The current fuel monitoring method used by RABEC is a dipping stick immersed in the fuel tank which is incapable of displaying the precise amount of fuel available in the tank.

Thus, this flaw encourages poor fuel monitoring monthly basis that yield profits of huge amounts to be used during combustion process. It has become vital to create an IoT-based boiler fuel monitoring system that can digitally display the precise quantity of fuel consumed, the balance in the fuel tanks, and other fuel characteristics. This project detailed the related works of previous and current fuel monitoring system with the technologies used with existing challenges and demonstrates the motivation of this project work.

2.2 Related Works

It has been suggested to use an embedding system to build and deploy a GSM-based computerized fuel monitoring system as shown by Geethabai (2020). To maintain accountable for the amount of fuel in the tank, the cloud-based technique was employed. When fuel fraud is detected, the sensor generates a notification, and a real-time text message was sent to the owner, who is monitoring the forgeries.

An Arduino-based sensor for fuel tank monitoring was developed (Baste, 2020). The technology demonstrator device might be effective in the automotive sector, where it can be used to quantify fluid balance using an LED indicator. The device's accuracy and reliability are constrained through the use of passive components for both identification and detection.

2.2.1 Automated Fuel Monitoring and Measurement System

In a study conducted by Promise (2020), a computerized fuel monitoring technique was tested. The method involved using an Arduino microcontroller along with ultrasonic and LM35 sensors. The ultrasonic sensor sensed and displayed tank level, whilst the LM35 sensor detected fuel temperature. The system was able to show fuel usage, tank level and detect fuel temperature. However, this approach had some drawbacks. The fuel monitoring sensor provided inaccurate outputs due to its frequency fluctuation problems. Additionally, the LM35 sensor was not suitable for detecting fluid fuel temperature as it was designed for body temperature measurement.

In another study by Suleiman (2019), an IoT system was proposed for monitoring fuel storage tanks in the brewery industry. The system utilized an ultrasonic sensor, Blynk application, and Node MCU. However, this method had limitations. It could only monitor fuel tank capacities up to 10 liters and was unable to detect the fuel tank condition, such as humidity. In addition, technical gaps can arise if there are delays or disruptions in data transmission, connectivity issues, or limitations in the system's ability to handle and process large volumes of data in real-time.

2.2.2 Remote Fuel Monitoring Using Embedded System Design

The control system for wirelessly accurate measurement and monitoring of fuel usage using an integrated system has been created and developed by Marouf (2021). This method used the ultrasonic sensor for a height of tank measurement together with a water flow sensor for fuel level monitoring. The Arduino microcontroller was attached for system control and collects the sensor data and then analyzes the data via a web page. The system has drawbacks such as Inaccurate readings that lead to incorrect fuel consumption calculations and unreliable monitoring data., sensor drift, poor data transfer, and high-power consumption.

In a study by Verma (2021), a fuel management system was developed using a microcontroller-based approach. The system utilized a fuel monitoring technique based on a reed switch operating on the Hall effect principle. This approach allowed the fuel level in the tank and the volume of fuel spent to be determined. Fuel data was stored in onboard storage. An embedded guidance system with multiple functions was also implemented to monitor the fuel level. However, the study identified and reported challenges related to the insensitivity and inefficiency of this system design. Additionally, the system also relies on reliable and continuous communication between the embedded system and the remote monitoring platform. However, challenges can arise in areas with poor network coverage or unstable internet connections.

2.2.3 Autonomous Fuel Level Real-Time Monitoring Development, and Implementation

The first stage in developing a remote fuel-level monitoring system was to create a fuel level sensor. Subsequently, a secure Aplicom 12 GSM network was established to integrate the sensor. Automatic fuel monitoring became feasible once the subsystem was deployed by sending control packets from a cell phone. These packets would enquire about the condition of the autonomous fuel monitor and relay data on the tank's fuel levels. The module's state alerts would be sent through Bluetooth to the mobile phone that started the investigation or command messages (Daniel, 2014).

In a study conducted by Roshan (2019), a precise analog fuel meter with a fuel pump guidance system was developed. To correctly estimate the amount of fuel in the tank, the fuel meter used electromechanical floats, capacitive sensors, and optical sensors. A microprocessor was used to collect and analyze data from these sensors. Additionally, a load gauge strain cell detector was connected to the microcontroller to provide and detect readings, and the fuel level was displayed using a needle. However, a drawback of using a load cell was identified as it cannot be used to estimate extremely sensitive materials and ignore the other fuel parameter detections. Furthermore, ensuring the accuracy and reliability of these sensors is crucial for obtaining precise and dependable data. Factors such as sensor drift, calibration requirements, and environmental conditions can introduce technical gaps that affect the accuracy of fuel level measurements.

2.2.4 Framework Development of an Automated Fuel Indication System

In the development of an electronic fuel display system, a computational model was developed by Ghenand (2022). The system features advanced fuel indicator mechanisms, although it does not provide an exact measurement of the fuel volume in the tank. Instead, it represents the fuel amount using bars rather than specific units like liters or milliliters. The system incorporates a gas sensor, LCD display, ultrasonic sensor, a power source unit, and MATLAB/Simulink program. Controlled power is distributed to all the integrated components through a DC power supply. The ultrasonic sensors are positioned on top of the fuel tank to monitor the fuel level, and the collected data is sent to the microcontroller unit for further processing. Computed values are then displayed on the LCD display device.

To simulate the system, the information is transmitted to a PC via a serial to USB converter. This system has limitations in accurately measuring and displaying fuel levels, leading to discrepancies and unreliable readings. It was also unable to update and display fuel level information promptly. However, processing large volumes of fuel data from multiple sensors in real-time posed computational and latency challenges in this system. In addition, it also offers complex user interfaces or inadequate usability that can hinder operator adoption and lead to errors or confusion in fuel data.

2.2.5 Fuel Level Monitoring Using a Resistive Float

Fuel monitoring with resistive float model sensor was conventionally used as indicator system to verify fuel threshold in the tank. The transmitter unit model was responsive to quantify fuel level while the gauge unit module was responsible for displaying that quantified level and sent the information to the driver (Dhande, 2014). These fuel thresholds concerned with the identification sensors are widely utilized in the brewing and wine-making industries. These detectors are mechanically linked to a float that moves upward and downward in response to fuel levels. The susceptibility of the sensor changes as the float moves, and the needle's position changes in response to the passage of energy via the coil.

The drawback of the resistive contact-based detector element is sensing wear and damage induced by the sliding contact within the sensor elements, which also affects the sensor lifespan (Processing, 2022). The sensor's sensitivity and the location of the gauge's needle are dependent on the movement of the float, which may not always provide precise and consistent measurements. The mechanical nature of the resistive float sensors can introduce errors and inaccuracies in fuel level measurements. The factors such as friction, vibration, and external disturbances can affect the movement of the float and lead to incorrect readings. Figure 3 shows the resistive float type fuel level in brewery industries that is common in the recent years to indicate the fuel tank monitoring.

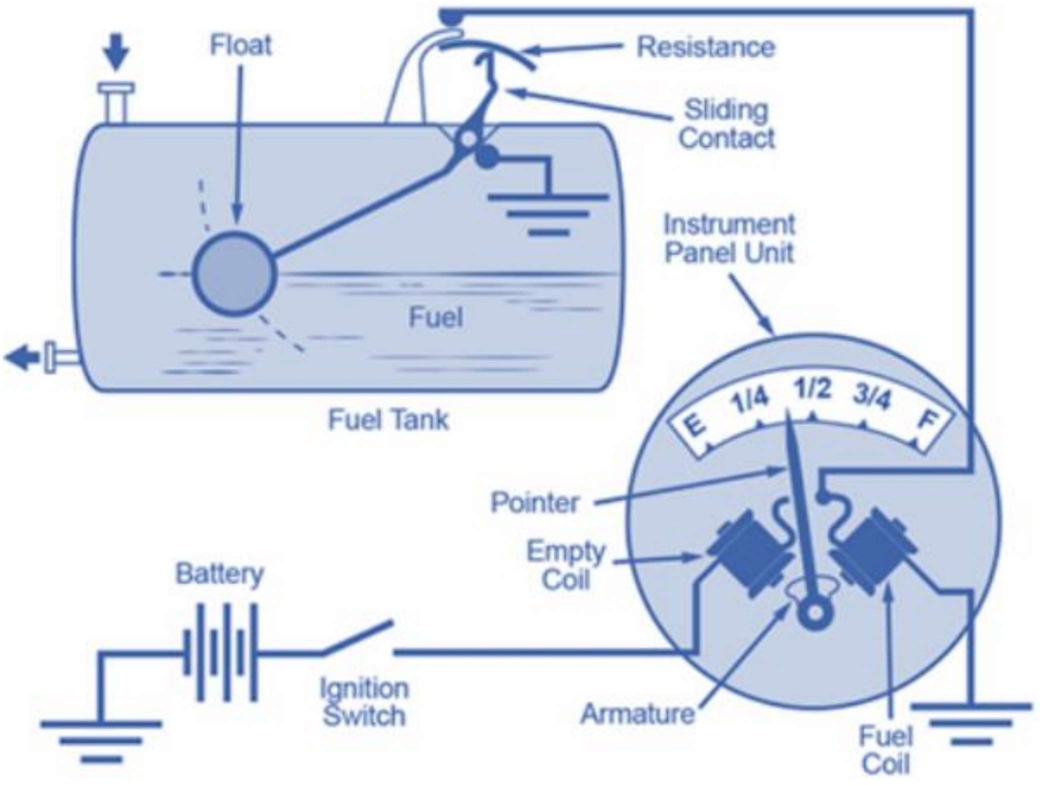


Figure 3: Resistive sensor-based fuel level monitoring type

2.2.6 Fuel Level Measurement Capacitive Fuel Level Sensing Technique

A capacitive fuel level monitoring system that uses capacitors with plates attached to the exterior wall of the tank was developed by Geethamani (2018). These plates extend towards the bottom of the tank, and as the fuel level changes, the capacitance between the plates varies due to the changing dielectric substrate. To ensure accurate readings, a second capacitive sensor near the bottom of the tank serves as a reference channel. The capacitance measurements from the sensory and reference capacitors are digitized and sent to a microcontroller via the I2C interface.

To maintain accuracy, the AD7746 (a specific component) is positioned on the upper surface of the PCB, close to the metallic plates inside a feasible 4-layer PCB board. Unfortunately, the capacitive sensors are highly sensitive to changes in ambient conditions such as temperature, humidity, and electrical noise. These variations can affect the accuracy and stability of capacitance measurements, leading to potential errors in fuel level readings. In addition, implementing a capacitive fuel level sensing system can be relatively expensive compared to other sensing technologies. The need for specialized sensors, microcontrollers, and calibration equipment adds to the overall cost of the system. Moreover, the capacitive fuel level sensing technique for fuel level measurement was influenced by fuel properties and environmental conditions on sensor performance. As the capacitive fuel level sensors depend on the dielectric constant of the fuel to measure the fuel level accurately, the variations in fuel properties, such as temperature, density, or composition, can impact the dielectric constant and introduce measurement inaccuracies. The sensor module with the capacitive fuel sensing and monitoring technique is illustrated in Fig. 4.

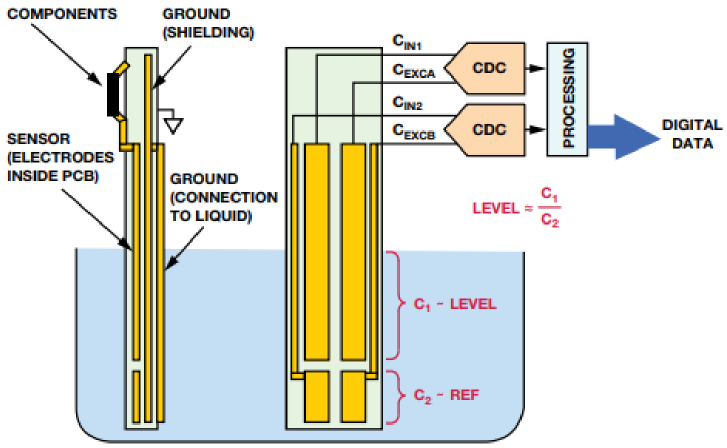


Figure 4: Sensor board and CDC capacitance level connection

2.2.7 Optical Industrial Fuel Sensing and Monitoring Systems

The optical fuel sensing and monitoring system was developed by PST (2022). These fuel monitoring methods include a variety of solid-state liquid level optically switched, which eliminate the need for unreliable mechanical parts. They are tiny and only penetrate a short distance into the application which can identify trace quantities of liquid. These systems employ optical liquid sensors with minimal responsiveness to diffuse lights and are unaffected by fluff or tiny bubbles in air and liquid respectively. Their capability to survive in a wide range of working temperatures and hostile liquid environments for extended periods of time result in an extremely robust switch. Unfortunately, these optical-based fuel monitoring systems may have limitations in measuring extremely high or low fuel levels.

The measurement range of the system was constrained by the optical principles and components used. Other disadvantages of these monitoring systems are lack of built-in features such as PWM outputs and unresponsive to flowing liquids with low reflectivity or opacity, which may pose challenges for accurate measurements. Nevertheless, environmental variables such as humidity, temperature, and prevailing light conditions may all affect the optical characteristics of fuel.

The variations in these factors can introduce measurement errors or reduce the reliability of optical fuel sensing systems. Lastly, the system was not robust and reliable due to industrial environments in which often involved harsh conditions, including temperature extremes, vibrations, and or exposure to chemicals. Figure 5 shows the optical fuel sensing and monitoring system attached with optical liquid sensors.

Figure 5: Optical fiber fuel monitoring system attached with optic fiber sensors

2.2.8 Fuel Supervision and Remote Monitoring Using an Industrial Internet of Things (IIoT) System with Fuel Gauge Consumption Display

A fuel monitoring system based on IIoT (Industrial Internet of Things) has been developed and integrated with remote monitoring and management technologies like Easy IO and BMS (Building Management System) (Energy, 2022). These technologies enable efficient fuel management and performance monitoring of industrial boilers, resulting in cost savings and eliminating the need for on-site engineer visits. The Easy IO modem sends data on fuel levels and the boiler's gauge meter to cloud-based management software (BMS). Operators receive alerts through the BMS software and can remotely make changes to the boiler. This system allows industries to monitor fuel levels, predict fuel usage using the BMS software, and display fuel data on a gauge.

However, it should be noted that this monitoring system does not provide real-time output when operators are away from the industry during shift working hours. Additionally, the system provided poor robust network infrastructure and poor data management strategies. It also could not consider other fuel data conditions like fuel temperature, fuel pressure, and humidity. Figure 6 depicts the adapted fuel monitoring system used in many European industries, particularly in the United Kingdom, utilizing BMS technology for fuel usage prediction while Fig. 7 illustrates the fuel monitoring system used in Alko vintages for steam production during the ignition process.

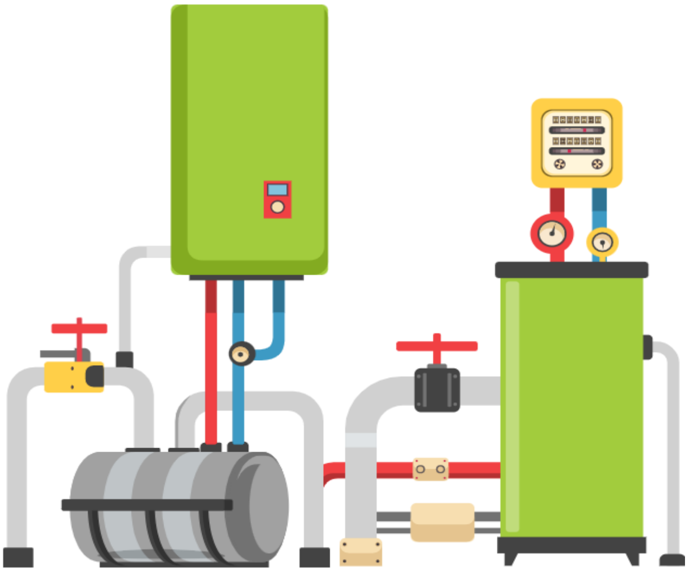


Figure 6: Remote fuel monitoring and management in UK

Figure 7: Fueling monitoring system in Alko vintages

2.2.9 Dip Stick Fuel Monitoring System at RABEC

A fuel monitoring system using a dip stick developed and utilized by Damas (2023). This system is simple and manual method of measuring fuel levels in a tank. It involves using a long rod or stick, typically made of metal or plastic, which is inserted into the fuel tank. The stick is marked with measurements indicating the fuel level. To determine the fuel level, the dip stick is inserted into the tank until it reaches the bottom. It is then slowly withdrawn, and the fuel level is determined by observing the point where the fuel ends on the stick. The dipstick markings offer a visual indicator of the fuel level in the tank. While this method is straight forward and does not require any complex technology, it has several technical gaps where the accuracy of a dipstick largely depends on the user's ability to interpret the markings correctly. Small measurement errors or misjudgments can lead to inaccurate fuel level readings. It is not also suitable for continuous or automated monitoring of fuel levels, especially in large-scale industrial applications.

Checking fuel levels with a dipstick can be time-consuming, particularly when monitoring multiple tanks or tanks located in hard-to-reach areas. It may also involve shutting down equipment or interrupting operations to access the tanks. Using a dipstick can expose the operator to safety risks, especially when dealing with flammable or hazardous fuels. Accidental spills, ignition, or exposure to harmful substances are potential risks during the measurement process.

Dip sticks do not provide real-time or continuous data on fuel consumption rates, trends, or alerts for low fuel levels. Figure 8 shows the current fuel monitoring system at RABEC with inherent risks where the fuel tanks are tall structures, and the risk of falling become high.

(a) (b)

Figure 8: RABEC Fuel monitoring (a) using stick and a manual meter (b) descent of RABEC operator from top of the fuel tank

2.3 Technical Research Gaps

Table 1 outlines the various developed systems for fuel monitoring as well as the highlighted research drawbacks.

Table 1: Developed solution with research drawbacks

S/N	References	Problem addressed	Developed solution	Research gaps
1.	Suleiman (2019)	Fuel level recognition in the tank and sending a diagnostic warning.	Development of an IoT system that can monitor fuel level in the storage tank.	Inability to detect other fuel data parameters like fuel pressure, fuel temperature, and moisture content condition, delays or disruptions in data transmission, or limitations in the system's ability to handle and process large volumes of data in real-time, lack of cloud storage data, unreliable, inefficient, and inaccurate
2.	Sadeem (2020)	Fuel management become difficult and cause operator multitasks	To design a remote monitoring technology using embedded system	Poor data transfer, inaccuracy, poor network coverage and unreliable
3.	Roshan (2019)	Fuel conditional monitoring and checking	To implement a precise fuel metering system using load cell	Load cell weakness in estimation of responsive material, Load cells can experience drift over time, leading to inaccuracies, Extreme temperatures or high humidity levels can degrade load cell accuracy and reliability.
4.	Vaibhav (2022)	Simulation of fuel usage fuel modeling condition monitoring	To design and develop a digital fuel indication mechanism using computerized technique	High power consumption, unreliable, inaccurate, sensor drift and irrestistance to environment change, and limited USB storage capacity in sending fuel data to PC for simulation
5.	Sensing Tech. (2022)	Monitoring and measuring of fuel level in forwarding direction of fuel pressure condition	To measure fuel level using resistive float type	Sensor wearing and strain attributed to sliding contact with sensor parts, which results to sensor life span, fuel temperature, and pressure were not taken into account. In addition, variations in the float design, fuel type, and environmental conditions can impact the accuracy and calibration curve

S/N	**References**	**Problem addressed**	**Developed solution**	**Research gaps**
6.	Sheeba (2018)	Recognition of fuel usage according to the industry production	To design and provide a capacitive sensing technique in relation of production	Analog system, hard to maintain, and inefficient, inaccurate in measuring the fuel level in the presence of varying dielectric constants and environmental conditions.
7.	Process sensing technologies (2022)	To sensing and monitoring fuel to detect its usage and managing its statues	To develop an industrial sensing and monitoring system using optical liquid switches and sensors	High environmental inference, inaccurate due to the presence of impurities and additives, low sensitivity to ambient light, susceptible to be contaminated due to dust accumulation, poor data flow and communication protocol in real-time data processing and integration, and insensitivity to moving liquid
8.	Energy (2022)	To limit the necessity of operators and engineers to attend various fuel management tasks	To develop a remote fuel management and monitoring system based on IIoT incorporated with Easy IO and BMS technologies	This is an analog fuel reading system, fuel temperature, fuel pressure, humidity of the tank was not considered, inaccuracy of the system, poor robust network infrastructure and poor data management strategies.
9.	Damas (2023)	Mitigation of staff's injuries and accidents and enhancement of fuel monitoring system at RABEC	To develop a dipstick with a tape measure	Dip sticks do not provide real-time or continuous data on fuel consumption rates, trends, or alerts for low fuel levels, staff's accidents, unsafe and inefficient system.

2.4 Proposed Fuel Monitoring System

This research project developed an internet of things (IoT) system that monitor fuel usage per hour, fuel pressure, fuel temperature, humidity of the fuel tank, fuel tank environment temperature and host these fuel parameters on ThingSpeak webpage. The project also developed a fuel monitoring prototype, which communicates using a globally mobile telecommunication system (GSM) technology to broadcast fuel metrics into operator's portable phone, reduce the need of physical fuel status inspections. Finally, the project presented RABEC with the operational (functional) and non-operational (non-functional) requirements of the suggested fuel monitoring solution.

The IoT-based system consist of a web application to enable remote monitoring and display the fuel conditions. This study has helped in trend analysis for quick fuel flow fault diagnosis, fuel burn perfection checks during ignition process, fuel quality checks, fuel-air mixture checks, fuel-oxygen combustion system improvement, boiler predictive maintenance alerts, fuel real-time management via webpage, early detection of unexpected fuel pressure, temperature, flow rate changes at RABEC. The industrial boiler fuel monitoring system in RABEC with cloud-based remote monitoring, alarm notifications, and remote boiler control capabilities can increase fuel efficiency and increase production (Remforce, 2020).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Project Case Study

The study was conducted in RABEC which is situated in Arusha city in the United Republic of Tanzania. This project area was also selected because being a banana wine production company in Tanzania, it is one of the most affordable wine prices within the country which has a manual fuel monitoring system by digging the graduated stick into the fuel tank to check fuel usage and fuel condition by observations. The RABEC plans to switch from manual to totally automated operations system in fuel data conditions monitoring during the boiler steam production process. Figure 9 shows the direction and location of RABEC as the study area.

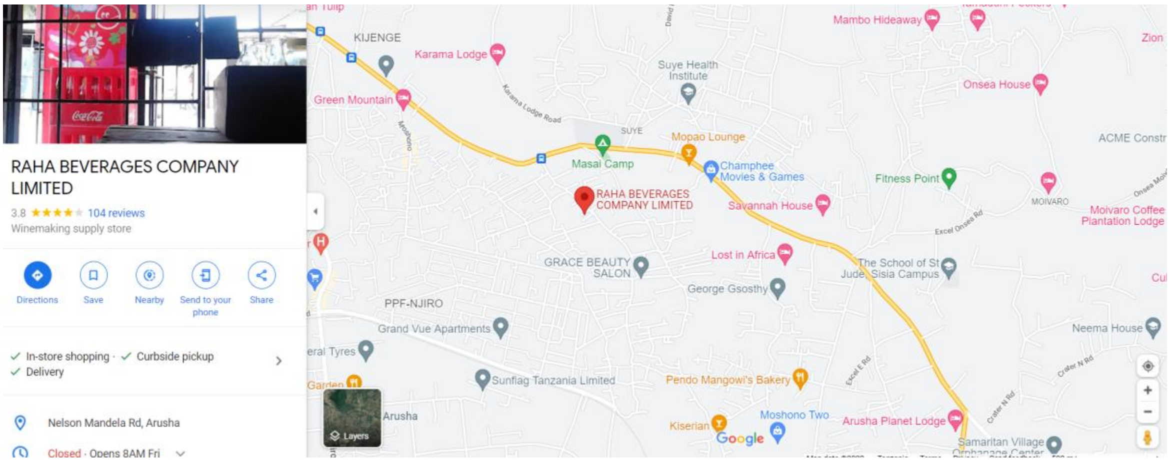


Figure 9: RAHA Beverages Company limited Google map location

3.2 Research Methods

In this project, a mixed-methods for data collection which are an integration of qualitative and quantitative approaches were utilized for data collection, analysis, and interpretation. This is because there was a need to understand the RABEC’s behavior with the previous fuel monitoring system regarding fuel usage, fuel pressure, fuel temperature, humidity of the fuel tank, and boiler environment temperature and how the company ought to adapt to the new system, and to demonstrate the system's experiments and to get extra system design ideas.

The interview surveys were undertaken to acquire qualitative data from RABEC's boiler operators and operation manager, and the interview guide is included in Appendix 1. The document study included an evaluation of relevant studies comprising a number of peerreviewed academic publications and books. Quantitative data was also gathered from boiler operators using the organized questionnaire as shown in Appendix 3.

3.3 Target Population and Sample Size

Employees of RABEC who worked on the fuel data condition monitoring system were targeted. The estimated size was 25 workers, with the operational management department providing the managing director, production manager, operation manager, and boiler operators, and the boiler maintenance department providing the other engineers.

The selection of these employees was simple random, cluster sampling, and systematic sampling where it was critical in saving time and resources by dividing employees into groups, and collecting systematic data while also having a fair and higher motivation of the employees. These employees were sampled based on education level and employment positions. In addition, the sample size was based on identification and gathering the requirements to develop the IoT based fuel monitoring system.

3.4 Sampling Techniques

In this project, the sampled combination of qualitative and quantitative participants for interview and questionnaire administration were chosen conveniently. This method was picked since the selected individuals could be readily contacted and reached, as well as there existed knowledge in their particular fields of expertise ensuring that they could respond to all questions related to fuel monitoring methods efficiently and effectively.

3.5 Methods of Data Collection

The operation manager, factory manager, and boiler operators in charge of the fuel and boiler plant provided previous fuel monitoring related data. These acquired data were divided into two categories: main and secondary data.

3.6 Primary Data Sources

In this study, group discussions, interviews, observations, surveys, and experiments from the fuel boiler industry operators, and operation and production managers were used as primary data. Those various data sources were assisted and used to gather data for system requirements that were viable and feasible for the industry.

3.6.1 Interviews

The essential purpose of this interview guide (Appendix 1) was to get data related to fuel management in order to identify serious issues that RABEC is currently facing. The boiler operator was selected to be interviewed because all relevant information regarding to fuel monitoring and management systems were enclosed to the operator.

Figure 10 depicts the interview procedure carried out in the boiler plant room to accurately describe and explain how the fuel parameters and monitoring are carried out.

Figure 10: The interview carried out with boiler operator

3.6.2 Questionnaire

The RABEC's boiler operators were given the questionnaire sheet (Appendix 2) to react to the questions posed in order to establish the existing circumstances of fuel monitoring systems and how to know the fuel use on an hourly and daily basis.

3.6.3 Observations

The structured observation approach was utilized to perceive the current fuel monitoring system and fuel conditions within the fuel tank where the graduated stick and tape measure were used in the fuel tank that supply fuel to boiler for combustion process and fuel storage tank as shown in Fig. 11.

Figure 11: Fuel monitoring (a) using stick and tape measure in fuel tank (b) Graduated stick in storage tank

3.7 Secondary Data Sources

Secondary data on existing fuel monitoring systems were gathered from journals, websites, and other related research articles and papers. The recent related IoT based boiler fuel monitoring system research articles were carefully reviewed to find additional guidance. The document analysis was used to define and identify the research gaps from the different current monitoring systems.

3.8 Data Analysis

The fuel data conditions like fuel usage, fuel temperature, fuel pressure, moisture content, environmental temperature of the fuel tank surrounding, toxic gas around the fuel tank were collected and analyzed using spreadsheet software. In this study, Excel was used because it’s highly available, easy to use, and has very fast performance. Google sheets were handy in this study’s data analysis because of their visualization tools and embedded capabilities to easily transform and analyze data.

3.9 System Development Approach

3.9.1 System Development Methodology

In this study, the developed IoT-based fuel monitoring system used agile software development technique, namely extreme programming (XP) paradigm. This model reduces the risks like modifying both software and hardware requirements by including new functionalities and new features in all agile methods. The changes and revisions in requirements as viewed through the eyes of stakeholders are expected, and an agile strategy enabled such continual improvements. It accepts continual collaboration among builders, clients, and stakeholders.

The XP, as shown in Fig. 12, was utilized in this project because both the software and hardware developers concentrated on coding and preventing useless operations by generating basic code that was enhanced in the purpose of preserving both money and time. The developer's relationship with RABEC as the customer has been maintained to ensure that RABEC receives the suggested and produced operational IoT-based fuel monitoring system.

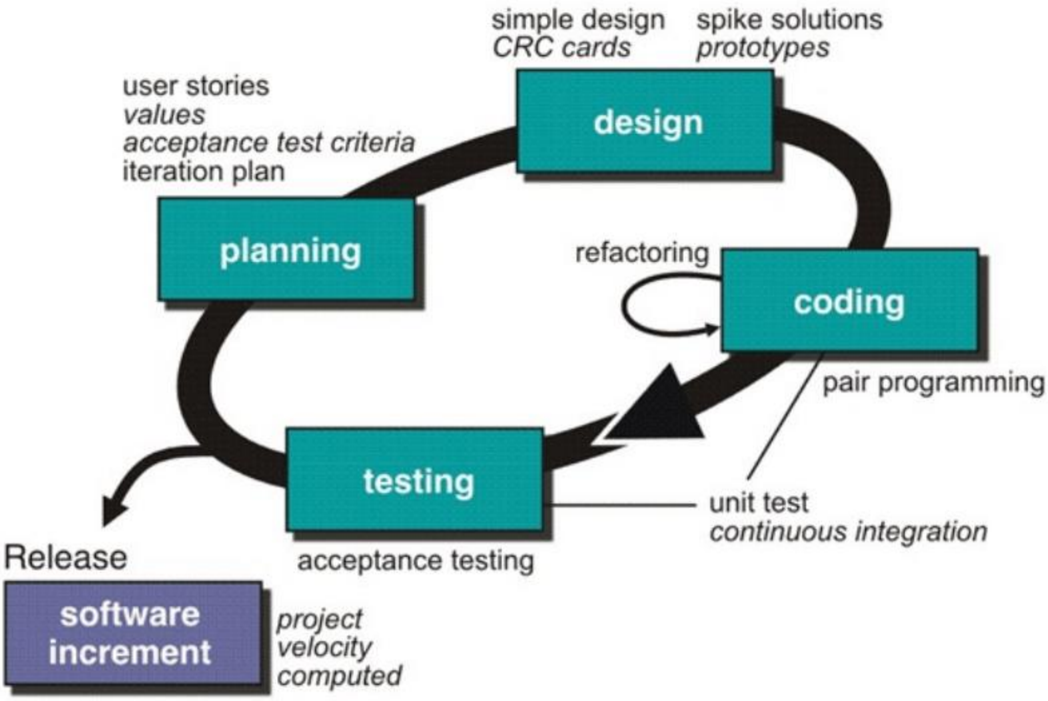


Figure 12: Stages in Extreme Programming

3.9.2 System Analysis

The fuel monitoring system is relevant if it is monitored remotely (automatically) by taking into account fuel pressure, fuel temperature, real-time monitoring of fuel usage, and limiting the digging stick with tap measure that was previously used to observe the fuel usage, and the volume of fuel available in the tank and alerting the user to refill the tank.

3.10 System Design

The subsequent components composed the developed IoT-based fuel monitoring system: A perspective on a block diagram, a flowchart diagram, system design, and a circuit diagram.

3.10.1 System Design View

ATmega 328UP microcontroller was chosen because it has high efficiency, a compact size, real good performance, and configurability and it was powered by 5 VDC where the data perceived and actuated by the sensing and actuating components was transferred to this microcontroller for storage, processing, and analysis. This information also was sent to IoT platform using ESP Wi-Fi internet module for data integration and visualization where fuel conditions were monitored and analyzed.

The ultrasonic sensor was used to measure the fuel level within the fuel tank by delivering the transmitter signal to the fuel in the tank and returning the signal information, which was then sent to the ATmega 328 microcontroller for processing. The flow rate sensor was employed to measure fuel flow rate in order to detect the amount of fuel usage per hour. The pressure and thermistor sensors were labored to sense the fuel pressure and fuel temperature respectively.

The DHT 22 sensor was also maneuvered to measure the fuel tank humidity to detect any kind of moisture in fuel that may causes all sorts of issues that can lead to unplanned downtime and boiler failure. The GSM module was utilized to send the fuel parameters like fuel temperature, fuel pressure, and fuel usage using SMS to mobile phone where the boiler operator can get fuel conditions and display them to the LCD. The buzzer was used also to alert if the fuel was reached below the predefined fuel value. Figure 13 indicates the overall system design view that was developed in this project.

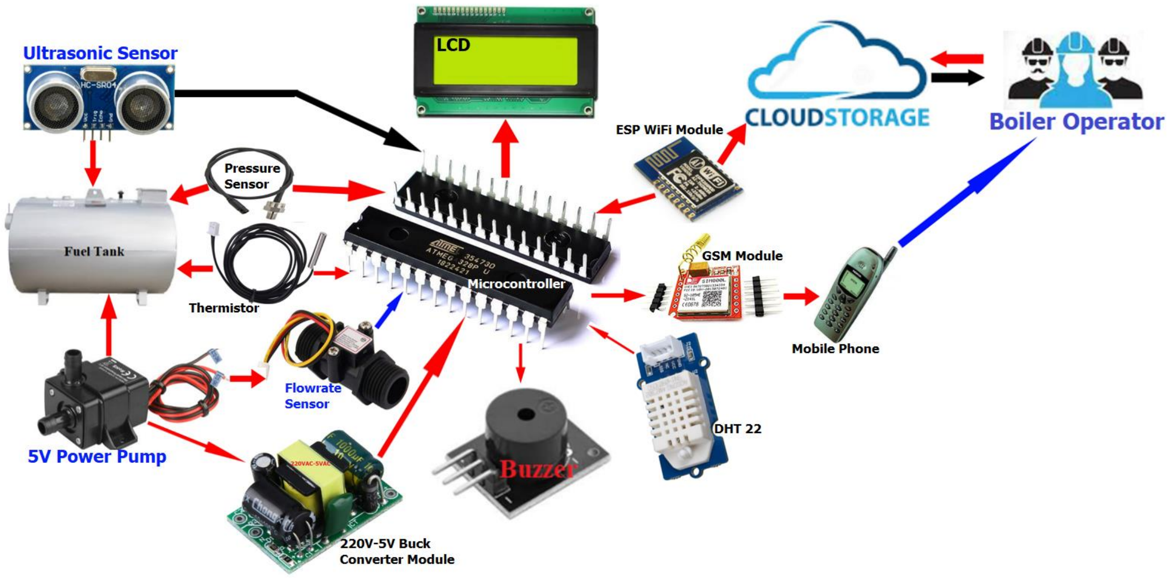


Figure 13: System conceptional design

3.10.2 Block Diagram

Figure 14 depicts the proposed system's block design, in which all sensing and actuating devices were connected to the microcontroller and activated. The 5 VDC submerged pump was powered to increase the speed of moving fuel to reach faster to the ignition point and gets ignited to the boiler. The sensed and actuated data were conducted and processed by microcontroller and sent to the cloud storage webpage via Wi-Fi module for data analysis, storage and visualization. The boiler operator was able to access the fuel data conditions using mobile phone via GSM module.

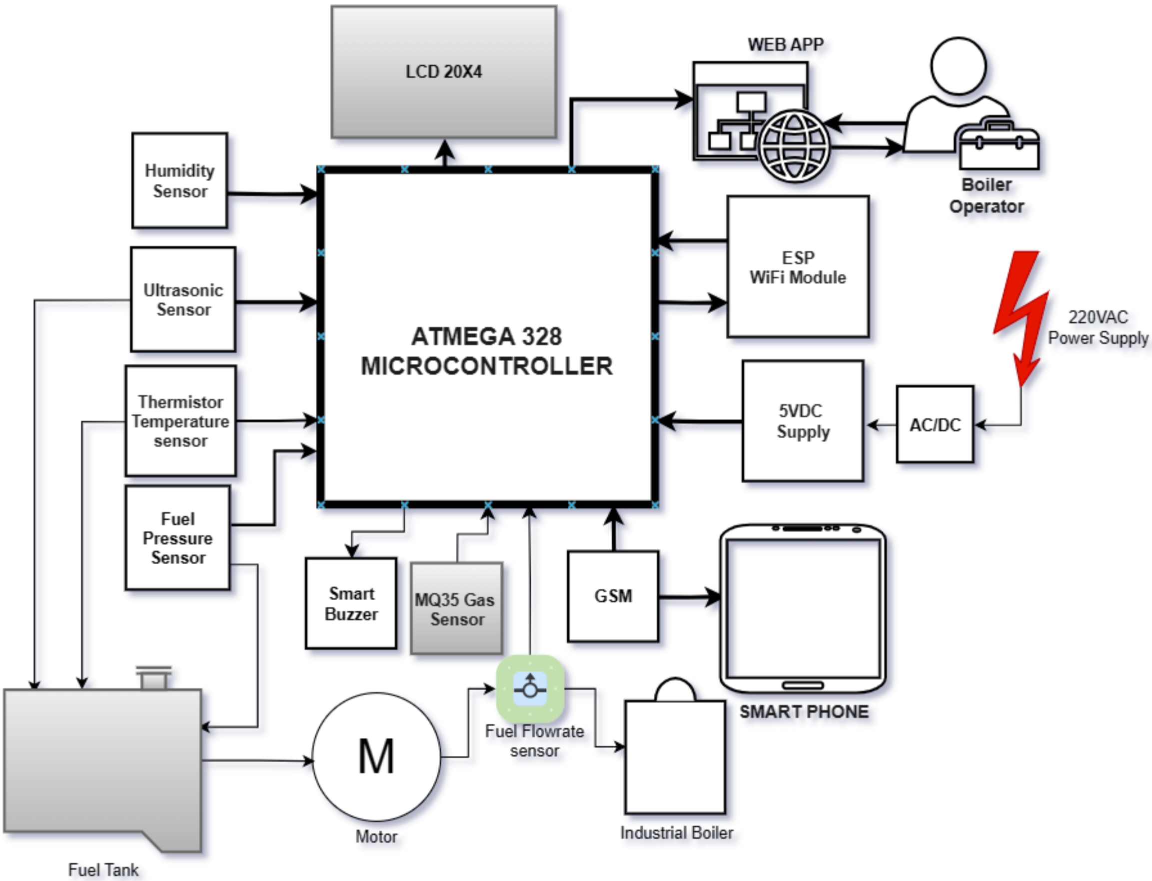


Figure 14: Block diagram of the proposed system

3.10.3 Circuit Diagram

Based on the block diagram, a circuit diagram was developed. This diagram was a design representation of the hardware system requirements electrically mounted and connected. The proteus design software was used to design this circuit diagram because all sensing and actuating units are well described in this software tool.

The microcontroller ATmega 328UP with 28 GPIO pins was selected to control all connected units and process all sensors and actuating units connected to the brain controller. The fuel flow rate sensor of 1~25 L/min for flow discharge, Operating Voltage: 4.5 V to 18 VDC, Maximum current of 15 mA at 5 V, the fuel thermistor sensor of -40℃-135℃ of operating temperature range, 5 VDC supply voltage, ≥ 25 milliseconds of response time, the fuel pressure sensor ranged between 4.75 to 5.25 V power supply, maximum current of 12 mA, operating and media temperature range of -40 to 130°C (140°C), pressure range of 0-600 bars, load capacity of 10 nF, output resistance of 10 Ohm, with maximum vibration of 210 m/s2 at 147 to 1,350 Hz, Full scale output UA of 10 to 90 % US of ratiometric were connected to microcontroller at 5VDC VCC pin, where all other GND pins of the sensing units were connected to GND pin of the processing unit called ATmega 328UP.

To ascertain the fuel level in the tank, an ultrasonic sensor with the following properties was used: DC voltage: 3.3 V – 5 V, operational current: 8mA, range: 2 cm – 400 cm, frequency of the ultrasound wave: 120 kHz, current draw: 20 mA (Max), Preciseness of 5% was connected to the microcontroller. This ultrasonic sensor contains a VCC pin that must be linked to the microcontroller's +5 V power source, as well as a TRIG pin that receives controlling signals from the ATmega board. This is the sensor's trigger input pin, ECHO pin, which helps to transmit signal pulses to the microcontroller board, where the microprocessor evaluates the period of the pulse to figure out the distance. This pin is linked to the sensor's ECHO output, the GND pin must be hooked up to the ground the target's reservoir tank height has been determined using an ultrasonic proximity sensor, and the sensor's output was sent to the signal conditioning section, and then processed using an ATmega 328UP microcontroller.

The Liquid Crystal Display (LCD) was connected to the microcontroller to the corresponding GPIO pins. The ESP Wi-Fi internet module was connected and configured to the microcontroller to provide internet where its VCC pin was hooked up to the VCC pin of the microcontroller, the GND pin to the module's GND pin, and the TX and RX pins were linked to each other.

The GPIO 16 and GPIO 17 of the module to the GPIO 8 and GPIO 9 pins of the microcontroller. GSM module was also connected to the relevant pins to provide message information. Figure 15 represents the developed system's entire system circuit.

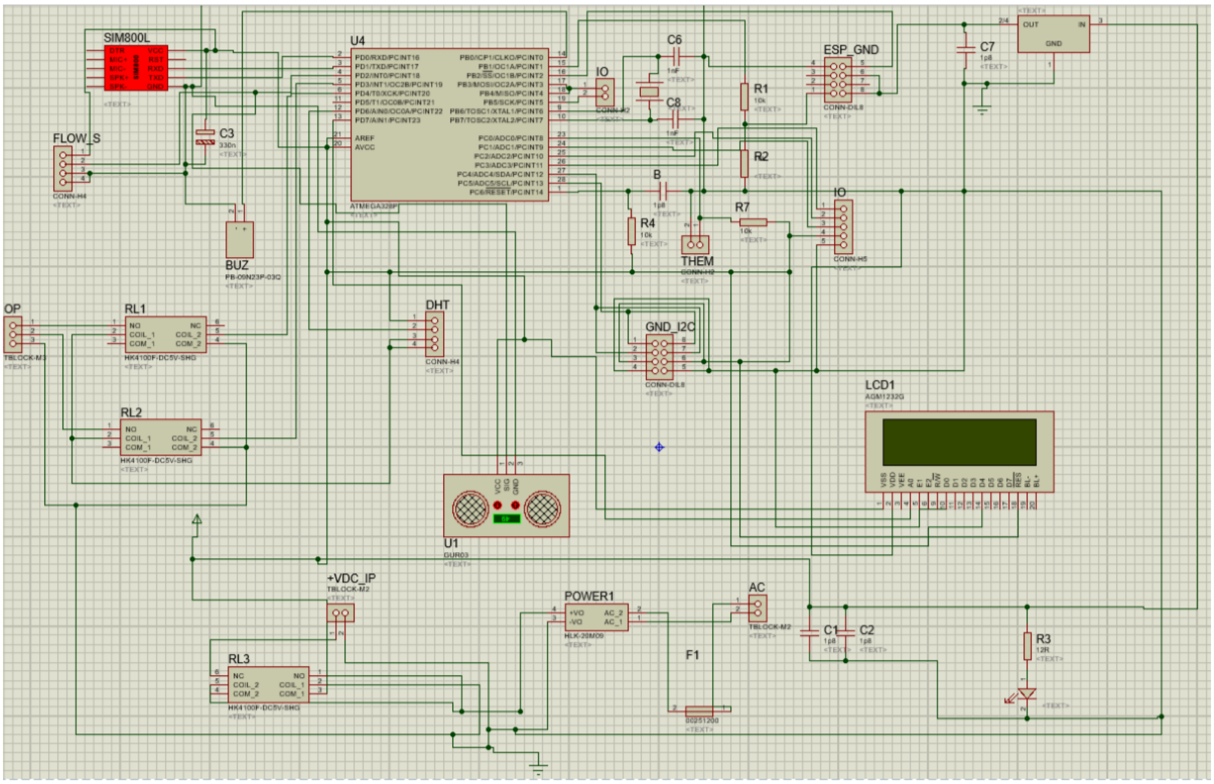


Figure 15.: The circuit diagram of the developed system

3.10.4 Use Case Diagram

The use case diagram is a schematic illustration of the way a user/actor could communicate with the developed system (Aleryani, 2021). The system starts by switching ON to power all connected sensing and actuating units. As fuel flows through the pipe from fuel tank to boiler, the motor pumped the fuel to increase the fuel flowrate.

The operation manager and boiler operator were assigned to observe fuel parametric conditions such as fuel temperature, fuel pressure, fuel level tank, fuel usage, fuel humidity, and environment temperature on LCD. In addition, any assigned operator/manager was able to login to ThingSpeak platform to access the fuel data in order to visualize, aggregate, and analyze these fuel data conditions. Then, the user was able to logout after all fuel observation activities from ThingSpeak platform. Figure 16 depicts the developed system's use case diagram, which outlines how the operator and operation manager interacted with the system and the respective duties of every actor.

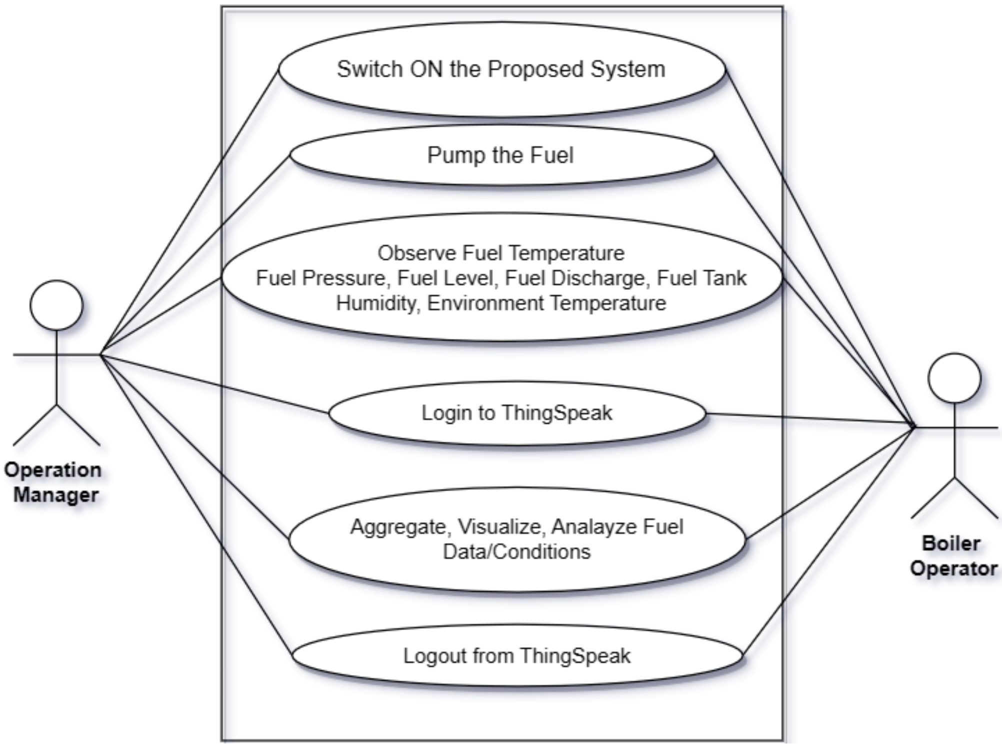


Figure 16: Use Case diagram of the developed system

3.10.5 Flowchart Diagram

The software design system is partially built in on the IoT ATmega 328UP microcontroller due to its great efficiency, compactness, impressive performance, and configurability. Firstly, this ATmega 328 microcontroller was powered by 5 VDC power supply and then all connected sensors (Flowrate sensor, DHT 22 sensor, ultrasonic sensor, pressure sensor, GSM module, thermistor sensor, MQ35 gas detection sensor, LCD), and ESP 32 Wi-Fi module got activated.

The DHT 22 sensor detects and measures any type of fuel tank humidity. The ultrasonic sensor transmits the signal to check the fuel level within the fuel tank and receiving the receiver signal, and then calculates the distance traveled based on the transmitting and receiving signals. The MQ35 sensor detects any form of gas that circulates around the boiler to prevent any hazardous and harmful fault. The flowrate sensor was used to calculate the amount of fuel going from the fuel container to the boiler in order to know the fuel usage by hourly and daily basis.

All sensed fuel information was processed and analyzed by microcontroller and transmitted to cloud storage through Wi-Fi module for visualization and analysis by a designated operator/manager. The operator's mobile phone receives fuel data message via GSM technology and then after, displayed on LCD. A boiler operator should be able to access these data through the ThingSpeak as webpage. If the amount of fuel in the tank is less than the predetermined amount, the buzzer sounds and an SMS is sent to any nominated boiler operator or operation manager through GSM module to refill the fuel tank with other alerting information messages.

Other conditions were set that if the pressure is higher than the threshold and the fuel temperature is greater than settable value, the system sent SMS to the operation manager for diagnosis alert and sent the corresponding values to the cloud. Figure 17 depicts a flowchart diagram of an IoT-based fuel monitoring system that was built and constructed to aid in the implementation of the system in this project.

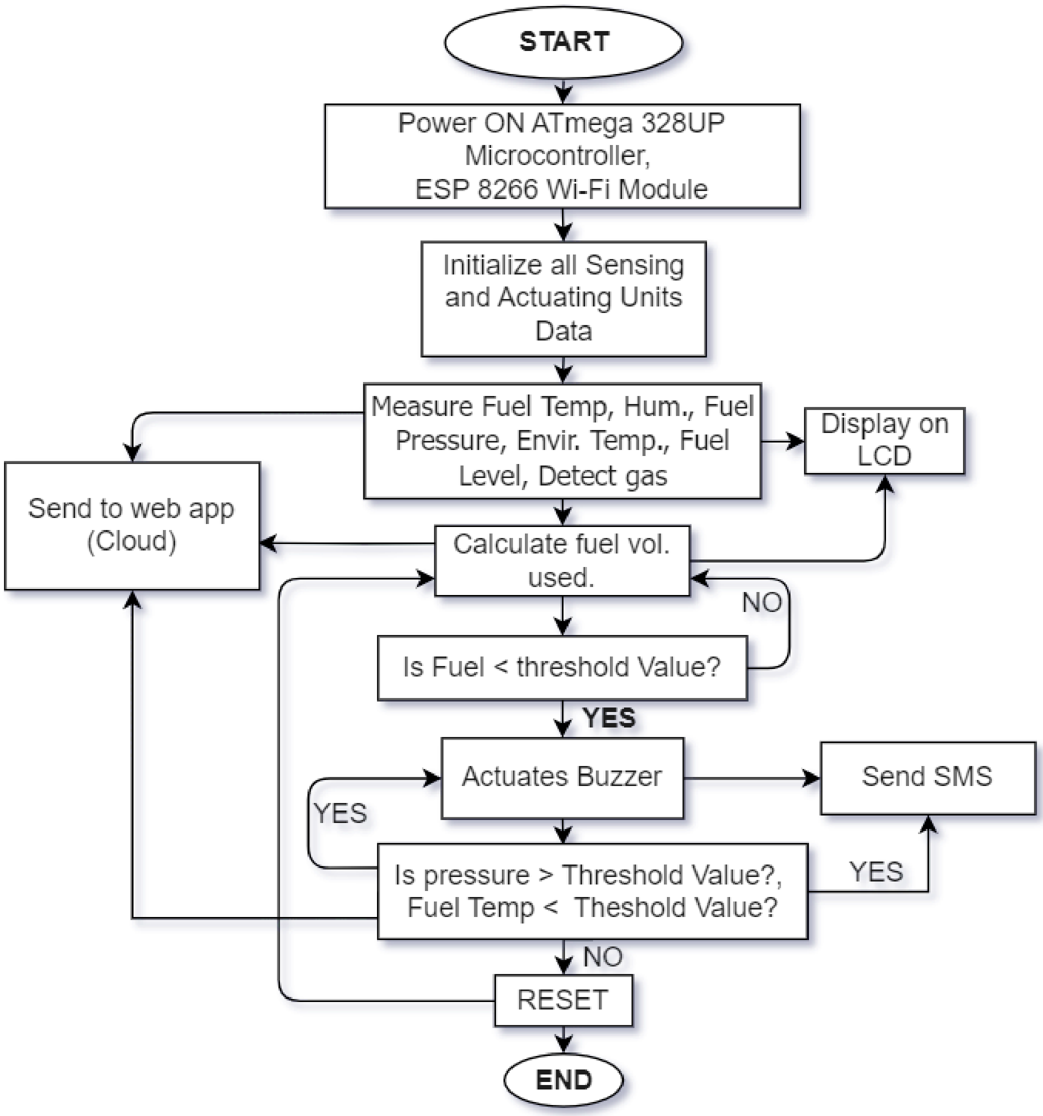


Figure 17: Flowchart of the IoT-based fuel monitoring

3.11 System Development

3.11.1 Hardware requirements

(i) ATmega 328UP Microcontroller

Figure 18 shows ATmega328, a microcontroller chip that was used in the implementation of this project. ATmega328 chips are usually found on Arduino Uno boards and have features such as processor speed of 20 MHZ, processor type of 8-bit Advanced Virtual RISC(AVR), electronically erasable programmable read-only memory (EEPROM) of 1024 bytes and 2 kB SRAM, and supports communication protocols of UART, SPI, and I2C (Shawn, 2020). This microcontroller is low-powered, low-cost and high-performance with GPIO 28-Pins and 32KB internal flash memory with very good instruction throughput compared to other processors. In this project, the ATmega 328 was used to process and analyze the sensing and actuating data during fuel monitoring system based on IoT technology with operating voltage of 5.5 VDC. Figure 19 shows the internal pin notations of the microcontroller in which each pin has its own functionality.

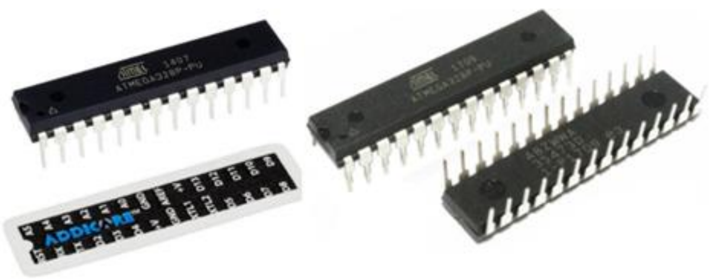


Figure 18: The ATmega328 microprocessor

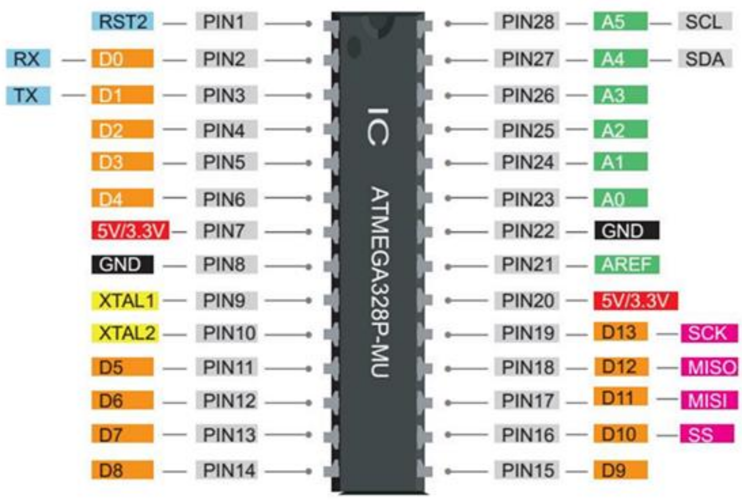


Figure 19: Internal pin specification of the ATmega 328P

(ii) Ultrasonic sensor

The ultrasonic sensor, with a rated 23-50 kHz and 1.8-12 VDC of frequency and voltage respectively, could offer precise measurement in a variety of detection, distance, and proximity applications. Ultrasonic sensors have the benefit of being unaffected by the color of the items being sensed, even translucent or clear substances such as water or glass. They are also adaptable in min-max ranges, extremely trustworthy, easy to interpret, and produce reliable outputs. They give very exact readings, with errors often falling below 1%, and even higher accuracy if necessary. Furthermore, they may provide rapid reset rates, and they are generally relatively inexpensive since they do not require uncommon elements (Arrow, 2021). Figure 20 depicts the HC SR04 ultrasonic sensor and its associated primary pieces, which were used in the system's development process.

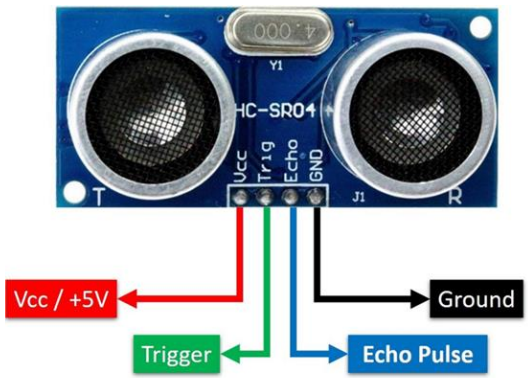


Figure 20: Ultrasonic sensor diagram

Table 2 indicates how the sensor was interfaced with microcontroller.

Table 2: Ultrasonic sensor with microcontroller interface

Ultrasonic Sensor	ATmega 328UP
VCC pin	5V pin
Trig pin	GPIO 7
Echo pin	GPIO 6
GND pin	GND pin

(iii) Fuel Pressure Sensor

This is the 5 VDC fuel pressure sensor that was mounted on the fuel tank. This sensor was specified by 2.0 milliseconds of response time, working temperature of 0-150℃, working current of 10 mA, pressure range of 0-1.2 MPa. The fuel pressure sensing element detects the internal fuel pressure within the fuel tank by measuring the tank's internal pressure. Then, sends an electronic message to the microcontroller notifying it precisely how much fuel needs to be released from the tank to the boiler. The fuel pressure sensor offers high accuracy, reliability, and durability with low-power consumption. Figure 21 shows the fuel pressure sensor that was used to detect the fuel pressure.

Figure 21: Fuel pressure sensor

(iv) GSM Module

This GSM comprises a SIM card that communicates by transmitting and receiving SMS via a network known as GSM. It can also make and receive phone calls and access the network via GPRS. SMS technology has grown in demand as a result of its convenience, low-cost, and ease of usage. AT instructions were utilized to instruct the microcontroller to run the GSM modem (Mohammed *et al.,* 2017). This GSM module was supplied by 3.4-5.0 VDC working voltage of the chip ranges. In this project, GSM technology was used to set up communications between an embedded system and the GSM cellular network. In addition, it was also used to send fuel data conditions both sensing and actuating units in form of short message services (SMS) to operator's mobile phone for easy fuel monitoring access. The GSM module was selected based on easy fuel data access in the case of poor internet connectivity within RABEC, being user friendly, possibility of poor network coverage, flexibility, reliable, and low-cost. Figure 22 demonstrates the SIM800L GSM module type that was utilized in this project to send fuel data from the system to the boiler operator's mobile phone.

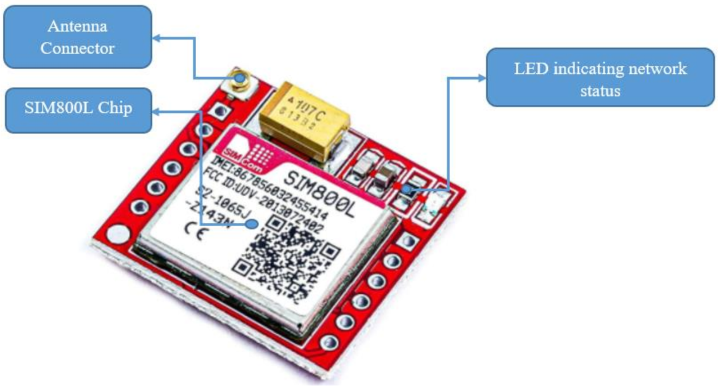


Figure 22: The SIM800L GSM Module

As illustrated in Fig. 22, LEDs on the upper right corner of the GSM indicate the network status, with variable blink speeds indicating different statuses. The LED illuminates once every one (1) second to indicate that the module is turned on but not yet linked to the cellular network. The basic GPRS connection is operational when the LED blinks every two seconds, and voice and SMS may be transferred and received when it blinks every three seconds. The SIM800L module is connected to the ATmega 328UP as shown in Table 3.

Table 3: Configuration of the GSM Module and ATmega 328UP

GSM Module	ATmega 328UP
TX	RX
RX	TX
GND	GND
VCC	5VDC

The anticipated AT commands for the proposed IoT based on fuel monitoring system are described in Table 4.

Table 4: List of AT commands

AT Commands	Response/Request
AT	To initialize the GSM
AT+CMGF	Setting GSM to text mode
AT+CMGS	Enter the receiver number

(v) Thermistor

A thermistor, or temperature probe, is basically a sophisticated sort of sensor that reacts appropriately to even tiny temperature fluctuations. Even at very low temperatures, it possesses a strong resilience. This implies that when the temperature rises, the resistance rapidly decreases. Due to the massive change in resistance per degree Celsius, this sensor efficiently detects even modest temperature changes. Because of the exponential operating principle, linearization is required (Rite, 2022). The fuel temperature sensor in this research was designed to detect fuel temperature and transfer it to the microcontroller for processing, allowing the air-fuel mix ratio to be tuned depending on the fuel temperature in relation to the air inlet air temperature. The cleaner the combustion process, the less pollutants are discharged through the boiler exhaust system (FTS, 2022). Temperature exactness of ±0.40°C at 25°C and ±1.45°C at 85°C, operational temperature range of -40°C to 250°C, storage temperature of -40°C to 250°C, responsiveness time of ≤25 seconds, and resistance of 200 Kelvin degrees are typical specifications for this sensor. This sensor was chosen in this project because its high accuracy, high precision, efficiency, reliable, low-powered and cost sensor. Figure 23 depicts a thermistor used as a fuel temperature device to sense the fuel temperature in the fuel tank.

Figure 23: Thermistor sensor for fuel temperature measurement

(vi) Resistor

The resistance is considered as passive element that was used to serve in reducing the flow of current and lowering voltage levels inside the circuit. The resistance was measured in Ohms, and the resistor color coding system kept track of both the resistance value and its tolerance (Demir *et al.*, 2018) or using a multimeter. Figure 24 depicts the interpretation of a resistor's color matching.

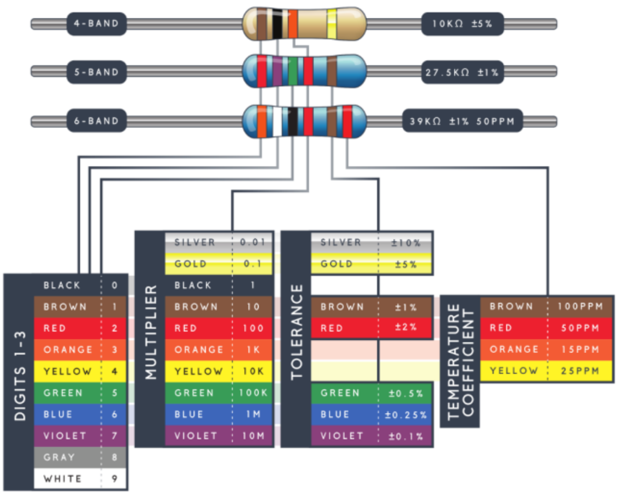


Figure 24: Resistance passive device with color description

(vii) Flow rate sensor

This sensor was employed in industrial fuel monitoring to determine the flow discharge of fuel/or fuel usage. It is made up of three primary parts: a rotor, a plastic, a Hall Effect sensor, and valve body. The pin wheel rotor rotates whenever fuel flows through the valve. This flow sensor module is simply interfaced with the Arduino ATmega 328, and its PWM outputs was generally attached to the microprocessor unit's interrupt pin. The fuel delivery rate is related to the number of pulses counted (CTS, 2022). Technically, the sensor was stated as Connection: G1/2" thread male, Flow rate: 1-30 L/min, working voltage: 3 V-12 VDC voltage, accuracy of 0.5%, output signal: pulse, signal: 2.5mL/P, maximum operating pressure: 1.2 Mpa at +20°C fluid temperature, ambient operating temperature: -10 to 70°C (freezing must be avoided). This fuel flow meter was selected due to its ability to conduct accurate flow measurements. Figure 25 shows the fuel flow sensor that was used in this project.

Figure 25: Fuel flowrate sensor

(viii) Power buck converter module

The 220VAC voltage was transformed to 12 V AC (12 V RMS value with a peak value of roughly 17 V), but the desired voltage was 5V DC. The 17 V AC power was first converted using a power electronics component known as a rectifier. With the bridge rectifier being the most often utilized to DC voltage power before being stepped down to 5 VDC voltage (Elprocus, 2022). In this project, the buck converter (Fig. 26) was used to convert 220 VAC power supply to 5 VDC voltage to power ON the whole developed system.

Figure 26: The 220VAC to 5VDC buck converter

(ix) Liquid Crystal Display (LCD)

This is a 20x4 optoelectronic screen that uses crystal display (LCD) to generate and show a visible image. It requires 8 digital pins and 2 power pins. In this study, the LCD was used to display fuel data conditions such as fuel usage, fuel temperature, fuel pressure, humidity, environmental temperature, fuel level percentage, high fuel temperature alerts, and gas detection states. Figure 27 depicts the external view of LCD that was used in implementation of the project.

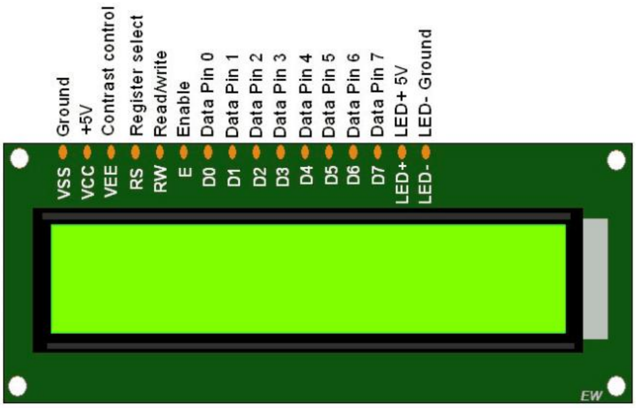


Figure 27: Liquid Crystal Display device

(x) Direct Current blushless submerged motor pump

A 12 VDC submerged brushless water pump was used in this project to increase the fuel speed from fuel tank to fuel boiler before fuel to air mixture for perfect combustion. This motorized pump had a long life, active noise cancellation, no commutation sparks, and other qualities that produced no electromagnetic interference. It is a design of a modern trend of micro-pumps that is guided by a high-sensitivity, reduced cost, and high-efficiency embedded system driver blended with the flowing fluid structural system, resulting in a comprehensive performance that is greater than traditional pump fuel efficiency and much more motionless.

The pump was characterized by 12 VDC working voltage, power 4.8 W, discharge of 240 L/H, and 400±20 mA (Grobotronics, 2022). Figure 28 indicates the DC submerged blushless pump physical view.

Figure 28: The 12VDC submerged blushless water pump

(xi) The DHT 22 humidity sensor

The sensor is pre-programmed and requires no extra components, enabling users to reliably determine relative temperatures and humidity. It is easy to use, but data collecting requires timeframe. It can only deliver information every two seconds. To monitor humidity, they use the humidity sensing element, which comprises two electrodes split by a moisture-holding substrate. The IC reads and interprets the resistance change before passing it on to a microcontroller (Aosong Electronics, 2022). This sensor is also low-powered by 3 to 5 V voltage with input/output of 2.5mA maximum. It gives accurate 0-100% humidity measurements with a 2-5% margin of error, accurate -40 to 80°C temperature readings with a 0.5°C margin of error, and a sample rate of no more than 0.5 Hz (once every 2 seconds). The DHT 22 sensor was applied in this project to sense and detect the humidity of the fuel tank and identify fuel moisture content, limiting potentially dangerous moistures. Figure 29 depicts the DHT 22 sensor utilized in the study.

Figure 29: The DHT 22 humidity sensor

(xii) The ESP8266 Wi-Fi Module

A SOC microprocessor such as the ESP8266 Wi-Fi module is commonly utilized in IoT applications. It is believed to be a standalone wireless transceiver and is quite inexpensive. It connects a variety of embedded system applications to the internet and offer TCP/IP capabilities as well as microcontroller access to any Wi-Fi network. It develops solutions that satisfy the cost, power, performance, and design requirements of the IoT industry (ElProcus, 2022). This module's on-board processing and memory features are robust enough for it to interface with sensors and other specific devices through its GPIOs with too little configuration and reloading throughout execution. Due to its top standard of on-chip coherence, it necessitates fewer peripheral circuits, such as the front-end module, which was developed to take up as little PCB area as feasible. The maximum input/output voltage is 3.6 volts with a current of 100 mA.

The integrated low-power 32-bit MCU runs at 80 MHz with flash memory capacity of 513 kb. It might be an access point, a station, or both. It allows for deep slumber at less than 10 micro-Amps. It enables serial transmission and is hence compatible with a variety of technology platforms such as Arduino AT commands, the Arduino IDE, or a Lua script are used to program it. It serves as a 2.4 GHz Wi-Fi module with WPA/WPA2 compatibility, WEP authenticity, and support for open networking. It has a 10-bit analog-to-digital conversion capability and employs two serial communication protocols (I2C and SPI). PWM encoding is employed, and UART is activated on dedicated communication pins. It includes a TR switch and corresponding networks, as well as 17 GPIO pins. Instruction RAM memory size of 32 KB, instruction cache RAM memory size of 32 KB, user-data RAM memory size of 80 KB. Figure 30 illustrates the ESP8266 Wi-Fi module utilized in Wi-Fi internet connectivity provision in this project to allow ThingSpeak platform be accessed.

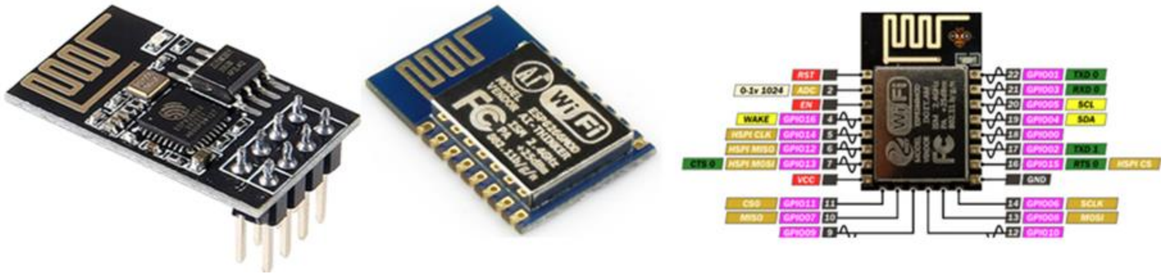


Figure 30: The ESP8366 Wi-Fi Module

(xiii) Piezoelectric Smart Buzzer

A piezo buzzer is essentially a smart speaker that can be plugged to any microcontroller. It emits a ringtone at a preset cadence and is supplied by a 5 VDC power supply. By inverting the piezoelectric operation. Regardless of the voltage changes supplied to it, the buzzer alarms sound waves and generates a same loud sound. The majority of buzzers emit a frequency range of 2-4 Khz (Ozeki, 2021). This buzzer was used in this project to inform the operator whenever the fuel in the fuel tank fell below the threshold value for refilling the tank. Figure 31 depicts the physical aspect of a buzzer.

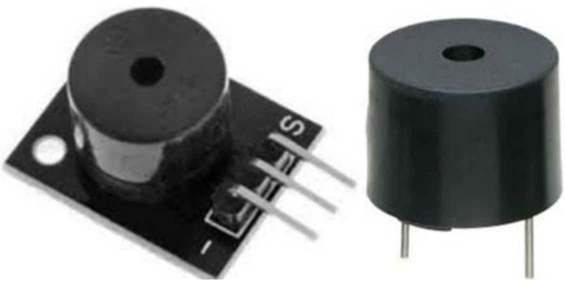


Figure 31: Piezoelectric Buzzer

(xiv) Fuel tank

The fuel tank was used in this project as fuel storage where fuel flows from the tank to the boiler in order to be burnt after mixture of air in combustion process perfection. Figure 32 shows the sampled tank to store the fuel.

Figure 32: The fuel tank

(xv) Mobile Phone

This is a device that communicates with to a network to transmit and receive message other data in terms of short message services (SMS). There exist two options for cellphones to interface with the public switched telephone network (PSTN): Global satellite telephony (GST) or cellular phone networks (CPN) (Britanica, 2022). During system development and testing, the operator utilized a mobile phone to receive fuel data parameters in form of SMS from GSM module, which allowed the boiler operator to obtain fuel data conditions. Figure 33 depicts the cell phone used by the assigned operator to receive fuel data condition signals.

Figure 33: Mobile Phone

(xvi) The VDC rechargeable Lithium (Li) battery

The developed system's circuit consisted of a powered 3.7 V-12 VDC rechargeable Lithium (Li) battery voltage range and maximum current of 3700mA. The microcontroller with all sensing and actuating units were powered by a filtered 5VDC voltage. In addition, this DC voltage was converted from 220VAC which uses buck converter but alternatively, the DC power backup of a rechargeable battery was able to power the system as long as it is required. The duration of the battery ranged from 3 to 5 years. To fully recharge this battery, would take approximately 4.5 hours. For this fuel monitoring system, the included battery can last 6 months to 1 year before the next recharging (Sunder, 2022). This rechargeable battery was chosen as backup power supply for continuous power supply to developed system in the case of power failure. The Figure 34 shows a 12 V, 4.5 AH rechargeable battery

Figure 34: Rechargeable Lithium battery

3.11.2 Software Requirement

This project's software requirements comprise coding and hardware languages necessary to create a quality software prerequisite. The application instructions were written using C and assembled by Arduino IDE which is a software technology development platform.

(i) Integrated Development Environment (IDE)

IDE is an accessible technology platform through which concepts for various Arduino boards are produced, as seen in Fig. 35. The IDE incorporates a code editor, a messaging box, a textual interface, and a dashboard with basic operation icons. To upload the code and allow communication, a link was established within the device. This program includes a toolkit for compiling the hexadecimal file (Veerasamy, 2015). After creating a program on the Arduino board, as illustrated in Appendix 4, it is checked for bugs and then uploaded to the ATMEGA 328UP chip.

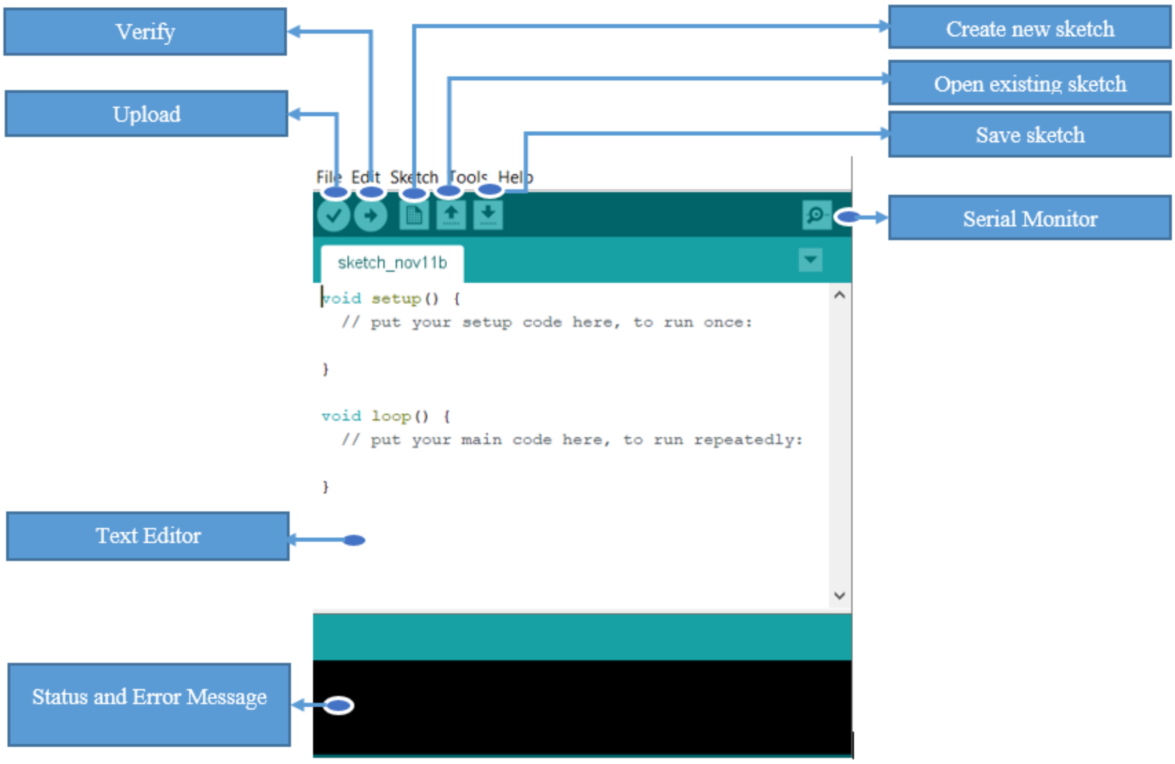


Figure 35: Arduino IDE

(ii) Proteus Design software

This is a proprietary software application that is mostly used for electrical design automation. It serves as windows program for virtual prototyping, simulation, and PCB layout designs. It is available in a range of shapes and sizes, based on the size of the models being made and the necessity for microcontroller simulator. The goal of this post is to help you understand the importance of a good design. The proteus PCB design package integrates the circuit simulation and PCB layout modules to provide a cost-effective, sophisticated, and convenient set of professional PCB development tools (NIT Warrangal, 2021). In this project, an IoT based boiler fuel monitoring system was designed, tested, and debugged in the proteus electronics simulator and printed in 3D PCB layout as shown in Appendix 5.

Figure 36 depicts the proteus platform page, which includes a schematic diagram and PCB layout from the proteus simulator. All linked sensors and actuators, peripheral interface controllers (PICs), and Arduino boards were supported as libraries and embedded devices. With the exception of a few devices, such as the GSM module, which must be acquired from other sources. The programs are authored, built, and emulated in this simulator using the Arduino IDE. Just as in real life, the hexadecimal code is uploaded to the microcontroller (Derouich, 2020).

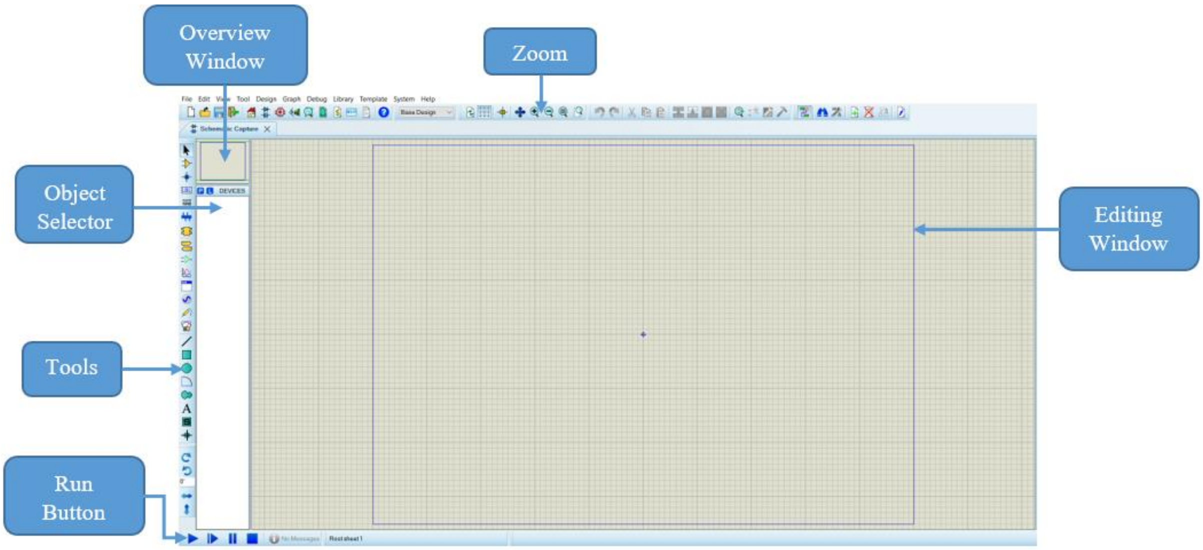


Figure 36: Screenshot of the Proteus simulation software

(iii) IoT ThingSpeak Platform

ThingSpeak can receive data from devices, produce quick graphics of real time data, and deliver alarms via web services. Engineers and researchers may use ThingSpeak to design and deploy Embedded technology without demand for servers or web programming (Foltin, 2022). ThingSpeak as an IoT platform, was used in this project to monitor and analyze live fuel temperature, fuel pressure, fuel tank humidity, fuel flow discharge, and boiler ambient temperature data streams from sensor devices in the cloud.

This platform also enables for real-time data analysis on fuel data acquired from remote devices by sign up and start creating channels on the platform. As illustrated in Fig. 37, these channels are set by written codes to connect with the required sensors.

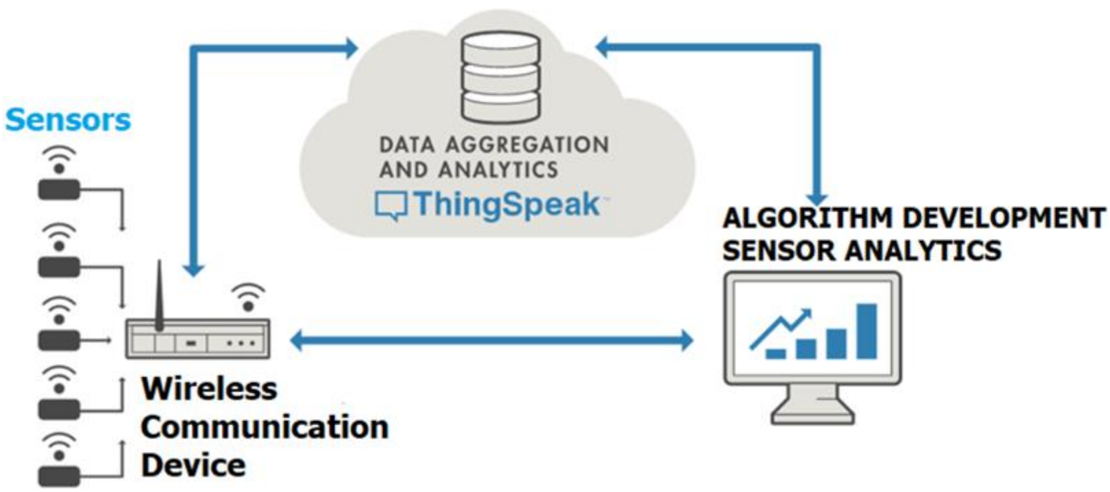


Figure 37: ThingSpeak IoT platform

3.12 System Development and Testing

The developed and proposed system ordered the XP Agile methodology phases as follow:

3.12.1 Planning Phase

In this project, the duration and period were determined, requirement analysis tackled by the customer with the functionality, would be checked in this developed fuel monitoring system.

3.12.2 Designing Phase

The system of this proposed project has been designed in certain manner that it is extremely simple to understand and easy to manage once tiny stages were joined and integrated. The system was created using system design, circuit design, block diagram, use case diagram, and flowchart diagram.

3.12.3 Coding Phase

The coding process was divided in set of actions by coding of each individual component that was connected to the microcontroller as processor like fuel pressure sensor, DHT22 sensor, fuel temperature, LCD, buzzer, IoT ThingSpeak, fuel flowrate sensor, and relays. Then, the coding was done, there was an integration of all components codes for working together.

3.12.4 System testing Phase

Testing is the process of putting the produced system into the environment to see how well it performs in relation to its intended goals. There were no assumptions of error-free performance in the proposed and developed system at this stage until it was tested and approved. As illustrated in Fig. 38.

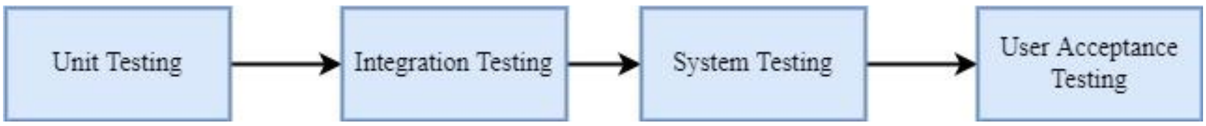


Figure 38: System testing phases

(i) Unit Testing

The unit testing was done by testing individual units of both software and hardware. This unit testing aimed to validate the performance of each unit of the software during the development phase in this project.

(ii) Integration Testing

The integration testing was also done during the period of interfacing two or more units. The purpose was to expose the faults which would occur between the integrated units. Once the modules were tested individually, the integration testing was carried out then performed.

(iii) System Testing

To establish compliance with the applicable standards, system testing was performed on a fully integrated system. This testing identifies faults in integrated units as well as the complete system. The outcome of system testing allows the operator to observe the system's performance.

(iv) User Acceptance Testing

Before deploying the software and hardware application to the production environment, user acceptance testing was also done at the end-user to validate or accept the software system.

3.13 System Validation

The system prototype has been developed and tested at RABEC for confirmation that it meets the company's standards and needs. The test was conducted into boiler room where there is fuel flowing from fuel tank to boiler before fuel to air mixture. The data were delivery to the microcontroller where pressure sensor, thermistor, DHT 22 sensor, flow sensor, environment sensor, and other sensing and actuating units communicate with the microcontroller. The fuel data were processed by the microcontroller before being transferred to the web and the operator's cell phone, with the IoT ThingSpeak platform used to aggregate, display, and analyze the fuel data.

3.14 System Implementation

The system was implemented after its validation and RABEC agreement where the operator and operation manager observed the fuel condition monitoring based on IoT system, and overcome all challenging issues regarding the fuel monitoring system, and the developed system was successfully accepted. This developed system encountered the RABEC's requirements and standards where the company started involving in the system implementation use.

3.15 Ethical Consideration

The following are the parts that were considered and abided by during this study:

(i) Participants were given consent and agreement to participate after providing informed approval. The essence of written authorization demands scientists to offer adequate data and security assurances concerning actively participating so as for respondents to fully understand the implications of involvement while making an up-to-date intentional, readily delivered action whether or not to participate, free of oppression or persuasion.

(ii) Offensive, discriminatory, or other undesired terminology was avoided in the development of Questionnaire/Interview/Focused group questions.

(iii) The utmost level of objectivity was maintained in talks and assessments throughout the study (Bell, 2012).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 The User's Responses Analysis in Improvement of Fuel Monitoring System

The multiple methods were intertwined in data gathering techniques which resulted in improving the current fuel monitoring system to monitor the fuel in RABEC remotely. Strongly, a substantial response of 96% of respondents have willingly agreed and suggested to utilize the IoT developed system that makes a system to be deployed in RABEC while 4% of respondents were agreed. Figure 39 shows a comparison of the respondents' perspective and percentage about the willingness and adaption of new fuel monitoring technological integration.

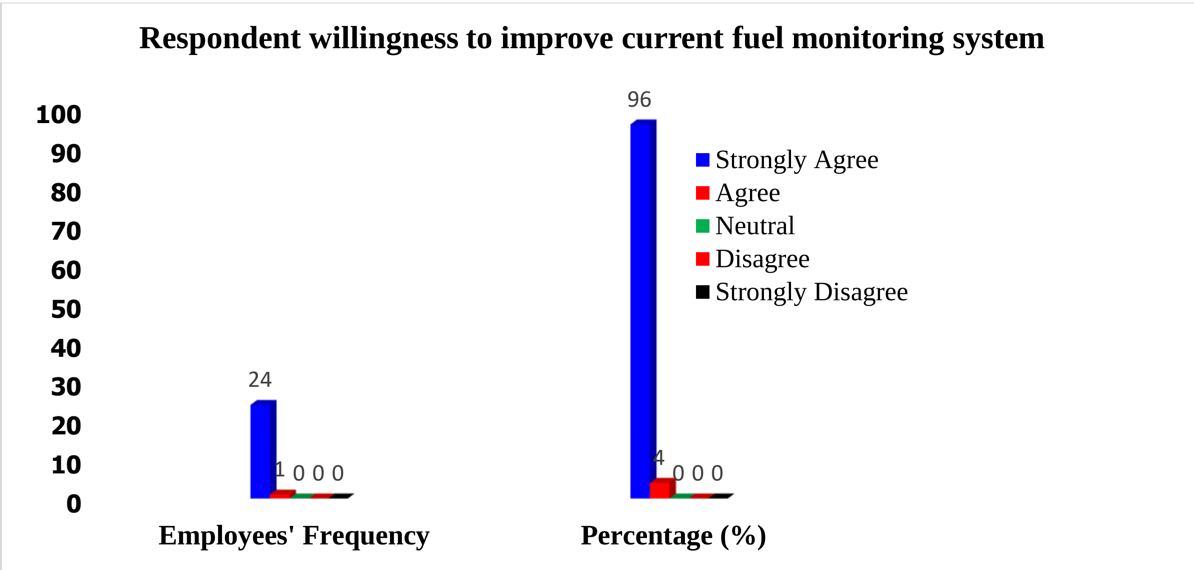


Figure 39: Respondent's perception and willingness percentage in current system improvement

The proposed system has met with RABEC's requirements and benefit the company as the respondents were responded. A considerable 84% of the respondents were strongly agreed that the suggested system shall deliver the company's benefits of its usefulness. Furthermore, as indicated in Fig. 40, a sizable 8% of respondents agreed with the anticipated system advantage to the organization, while the remainder remained indifferent.

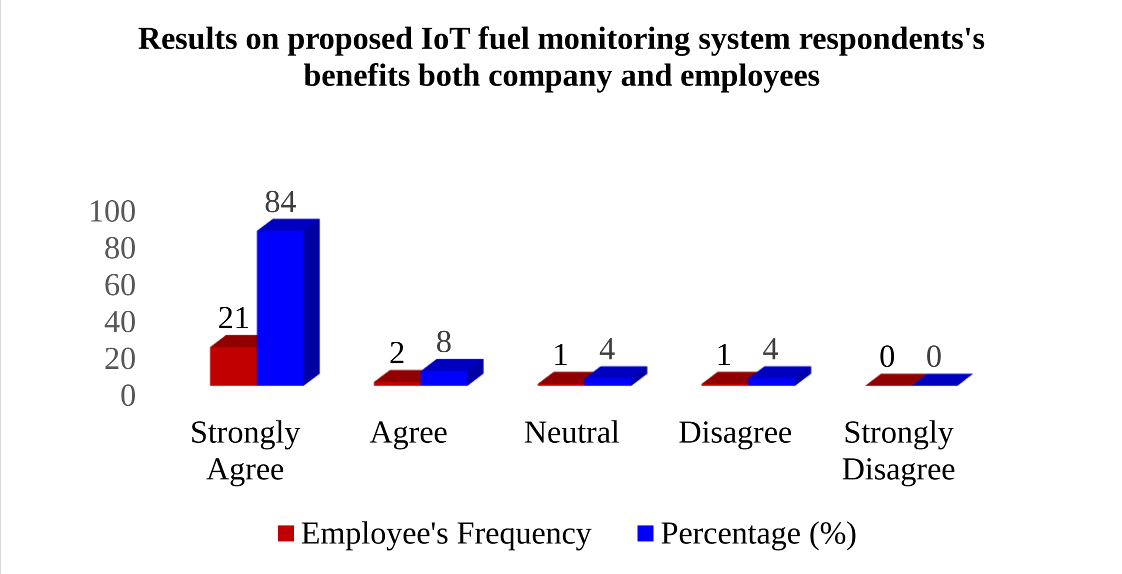


Figure 40: Response on proposed IoT fuel monitoring system benefits

4.2 Awareness Existence of a Remote/Digital Fuel Monitoring System

In this project, the awareness of current fuel monitoring technique was taken into account to verify how the employees are aware of this remote fuel monitoring method. A substant 47.5% of the respondents were neutral/not sure if RABEC knows that there is a remote fuel monitoring system. On the other side, a substantial 32% of respondents strongly disagreed, while 10.5% of respondents only disagreed and 5% of respondents strongly agreed, while the remaining 5% of respondents agreed. Figure 41 demonstrates the overall different percentages of respondents regarding to the awareness of existing digital system to monitor fuel during steam production process and how this manual monitoring system can be replaced by the digital technology.

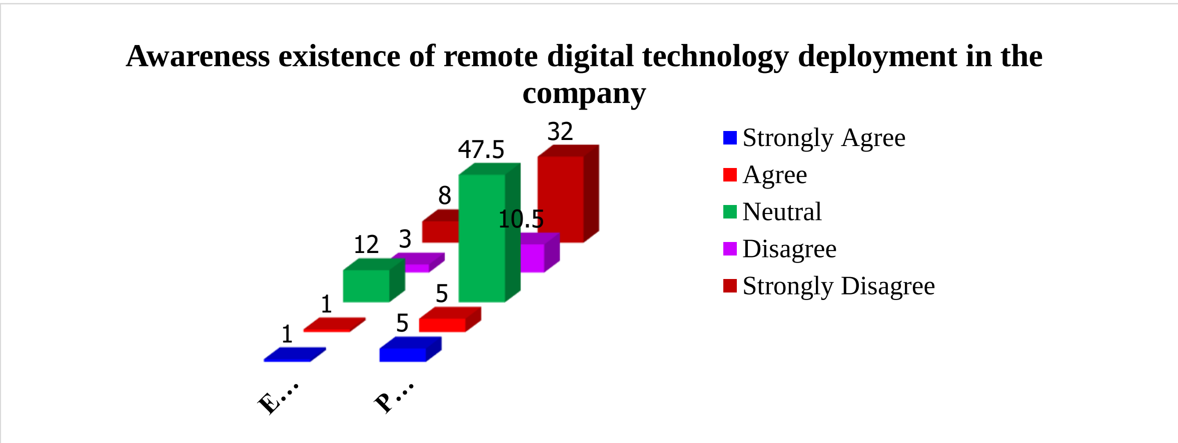


Figure 41: Response to the awareness regarding IoT fuel monitoring system

4.3 Willingness To Have A Digital Technology For Fuel Monitoring System

The deployment of a proposed remote technology for fuel monitoring system was willingly surveyed and considered. A 68% of respondents were strongly agreed, while 20% have agreed. Among the surveyed participants, only 7% of the respondents were neutral to have the proposed system and another 5% of the respondents were completely disagreed with none who strongly disagreed. The digital technology that remotely monitors fuel was highly important to be adopted and implemented in RABEC, according to the larger number of respondents who have strongly agreed. Figure 42 illustrates the overall willingness diagram to deploy this new remote technology to monitor fuel.

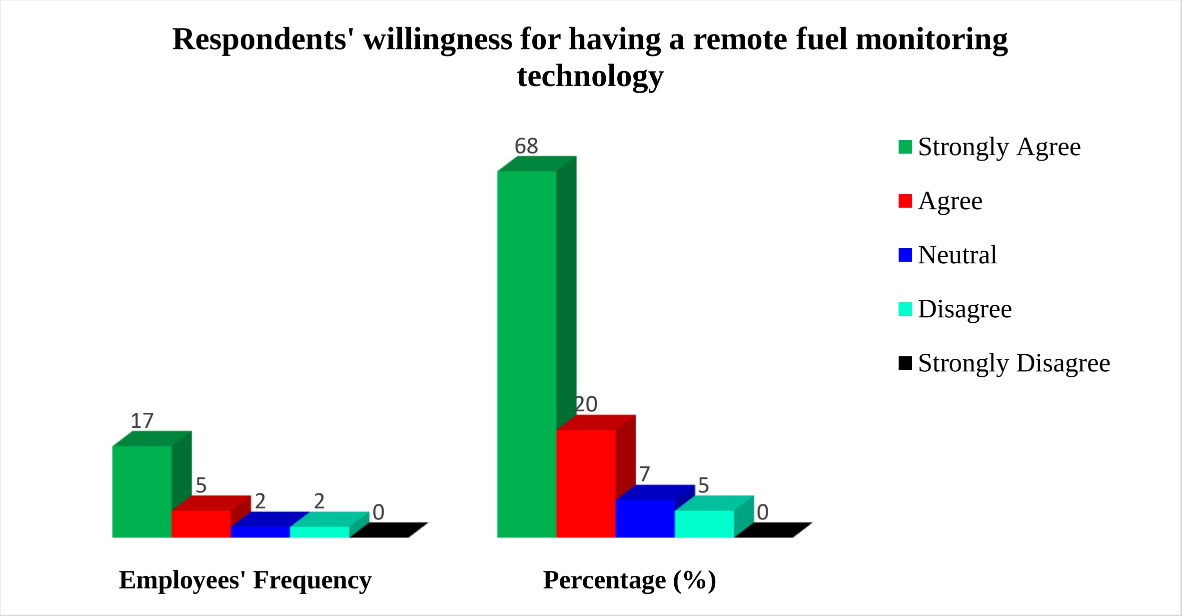


Figure 42: Response to the willingness to have and use remote technological system for fuel monitoring system

4.4 The Influence and Applicability Results of the Proposed System

The IoT based on boiler fuel monitoring system has proved the applicability in RABEC and influences positively the industry in the prevalent views dropped sideways by utilizing this remote fuel monitoring technology. Reasonably, the use of IoT technology that communicates with GSM module to release and identify the fuel data conditions, limits and mitigates the manual fuel monitoring risks (accidents, death,…) when using graduated metal stick and tap measure (Mohamed, 2021). Among the respondents who were interviewed (Appendix 1), a substant 50% of responses have proved to develop an efficient and effective remote fuel monitoring technology, while 10% of respondents were challenged and stressed by using current fuel monitoring method that may cause poor production. A significant 25% of respondents have confirmed that the proposed system can mitigate inconveniencies and risks due to plant breakdown. In addition, 5% of respondents also confirmed that it was hard to manage the accuracy and the efficiency whenever using current fuel monitoring method, while 10% of respondents have agreed that IoT based fuel monitoring system can improve company production with inefficient reduction.

Figure 43 shows the respondents that have participated in the interview process with their correspondence percentages regarding the proposed system influence and applicability as novel remote fuel monitoring technology in the RABEC.

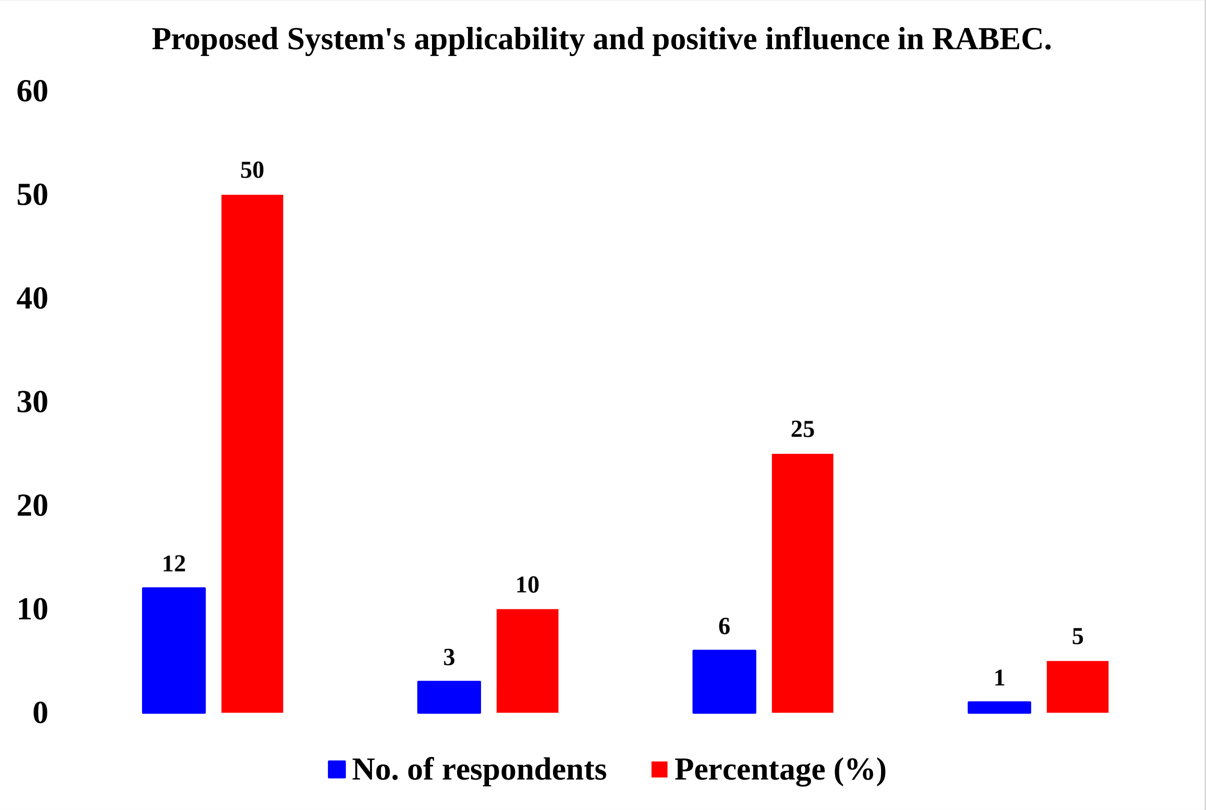


Figure 43: Proposed system influence and applicability in the industry

4.5 Identified Project System Requirements

4.5.1 System Functional Requirements

The functional requirements of the system were determined based on what they do and how they should respond to a certain input with the way in which the system should operate in a given environment. Table 5 depicts the functional requirements results of a developed IoT fuel monitoring system.

Table 5: Functional requirements of the proposed and developed system

S/N	Requirements	Description
1.	The system shall monitor the amount of fuel usage.	The system should be able to monitor fuel used within the fuel tank using flow rate sensor.
2.	The system shall monitor the fuel level within the tank.	The system should be able to monitor fuel level using ultrasonic sensor.
3.	The system shall monitor and display the fuel parameters like temperature and pressure of the fuel, fuel tank humidity, and fuel flow discharge.	LCD should continuously display all of these fuel parameters during the boiler steam production process.
4.	The system shall produce noise when fuel is below the threshold value.	The system should generate noise to alert on duty operator whenever the fuel reached to the threshold value or when the fuel level within the tank is low.
5.	The system shall send SMS to the operator and operation manager's phone	The system should be able to send SMS via GSM technology containing the fuel parameters.
6.	The system shall visualize and analyze fuel data through IoT ThingSpeak Platform.	The system should send fuel parameters data to the cloud (ThingSpeak) to be visualized and timely analyzed.
7.	Detect any gas around the Boiler	The system should be able to identify any type of gas in the boiler environment utilizing the MQ35 sensor in order to reduce the plant's risk.

4.6.1 System Non-Functional Requirements

In this project, non-functional requirements included system performance, system usability, efficiency, and efficacy of the total produced system. Table 6 displays a summary of the requirements met by the system.

Table 6: Non-Functional Requirements of the developed system

S/N	Requirements	Description
1.	Efficiency	The system should demonstrate efficiency on real-time and accurate fuel data condition providences
2.	Effectiveness	The system should perform effectively as it meets remote operational requirements
3.	Power Consumption	The system should be a low power consumption.
4.	Real Time	The system should reply on time.
5.	Security	The system should be ensured by any assigned user and by securing it to the safe installation place.
6.	Reliability	The system should be reliable
7.	Flexibility	The system should be simpler to use for boiler operators and operations managers.
8.	Maintainability	The system should be maintainable whenever any fault occurred

4.6 System Design Results

A developed system was designed to monitor fuel as well as manage it from fuel tank to the boiler before combustion process starts in order to produce a perfect combustion. This proposed system consists of a microcontroller that serves as processor to process the fuel data like fuel temperature sensed by thermistor, fuel pressure sensed by pressure sensor, fuel discharge from flowrate sensor, fuel tank humidity, fuel tank level captured by ultrasonic sensor and surrounding gas using MQ35 sensor. These fuel data are then analyzed and visualized in ThingSpeak, then plotted in the web-based application where the assigned operator can have access.

Whenever there is no or poor internet connectivity, the developed system sends SMS to the operator's mobile phone via the GSM module that handles communication networks. To facilitate an operator in easy way of monitoring, LCD was used to display and visualize fuel data conditions. The system also alerts an operator/or an operation manager if fuel temperature is higher than the threshold value and whenever fuel tank level is low comparing to the threshold value and beeps/or sounds using a connected buzzer.

Figure 44 depicts the proposed system's system design diagram, which was conceived and developed during hardware design development.

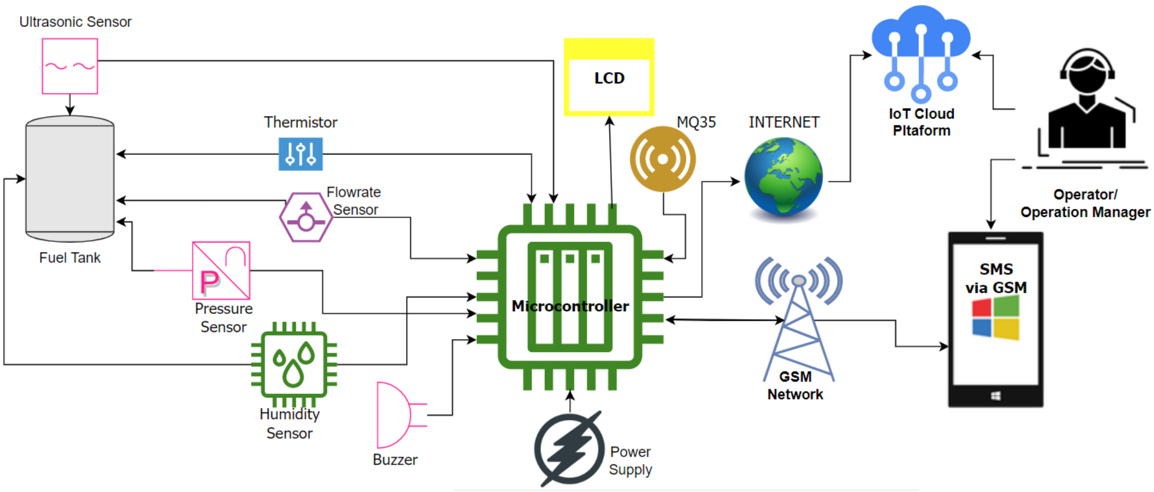


Figure 44: Developed System Design Architecture

4.7 System Development Results

The IoT based fuel monitoring system was developed. The communication between sensing and actuating units was done perfectly. The sensing and actuating data were processed by ATmega 328 microcontroller and sent to the display unit to be visualized. The development stage started by connecting all sensors to the PCB board at the designed places. The LCD was attached for displaying fuel sensed data conditions. The pressure and thermistor (temperature measurer) sensors were assembled to the board to give the pressure and temperature data as the main fuel data that were considered during this system development process. A whole system was powered by 5 VDC after being converted from 220 VAC by using buck converter which was filter by capacitor (nF).

The RTC sensor provides the real time in which the fuel data were sensed and actuated. Figure 45 depicts the whole system assembled and developed during implementation process of this proposed fuel monitoring system.

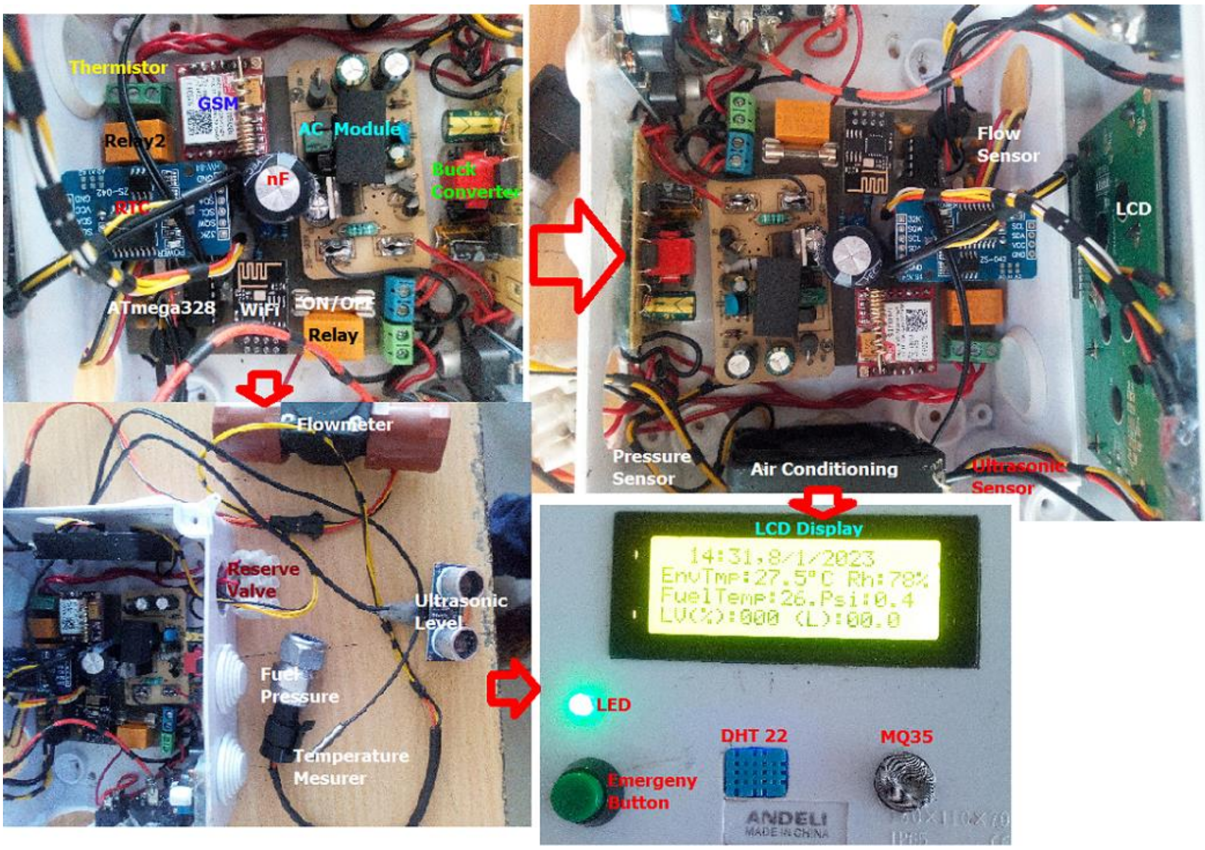


Figure 45: Proposed system development during Lab assembling stage

4.8 Web-Based Application System Results

The proposed web-based application includes the login and dashboard pages. This web-based application was created to allow data to be transferred from the developed system. Boiler operator/or operation manager was assigned with login credentials where these users can change the password for both security and preferences reasons where it demonstrates a sense of easiness of the developed system.

4.8.1 Login Page

To proceed to the main interface, the assigned users must provide their credentials for login, which includes their email address and password. Figure 46 shows login page by entering email address for the web-based application which all assigned boiler operators and managers can login and Fig. 47 shows the assigned operator entering password.

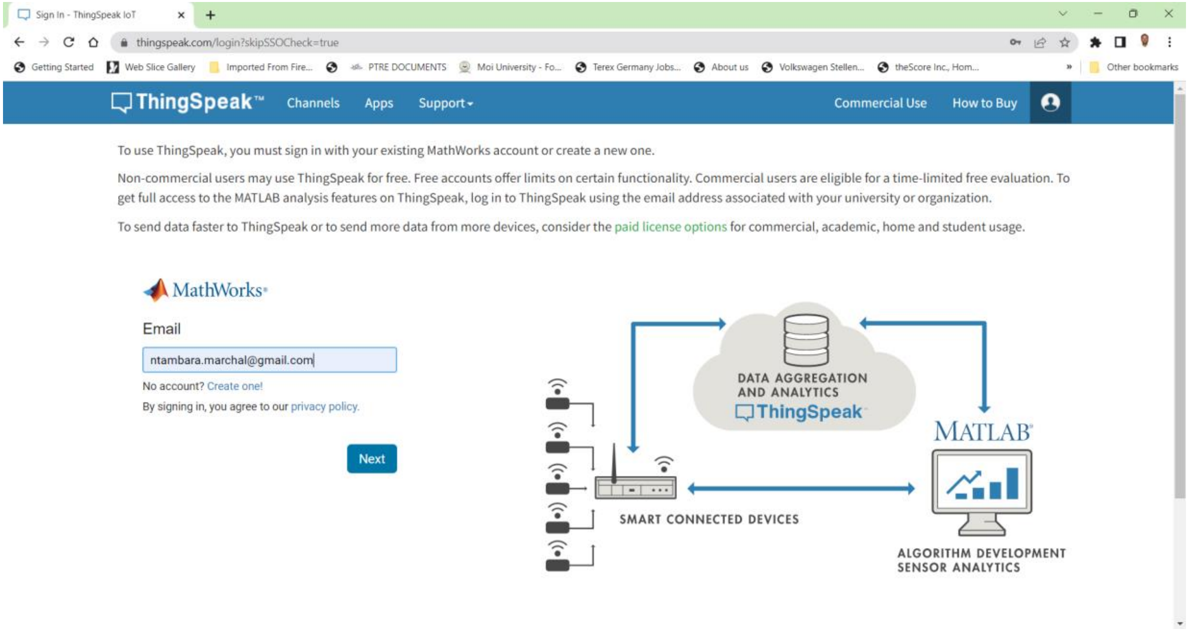


Figure 46: Entering email address and click next

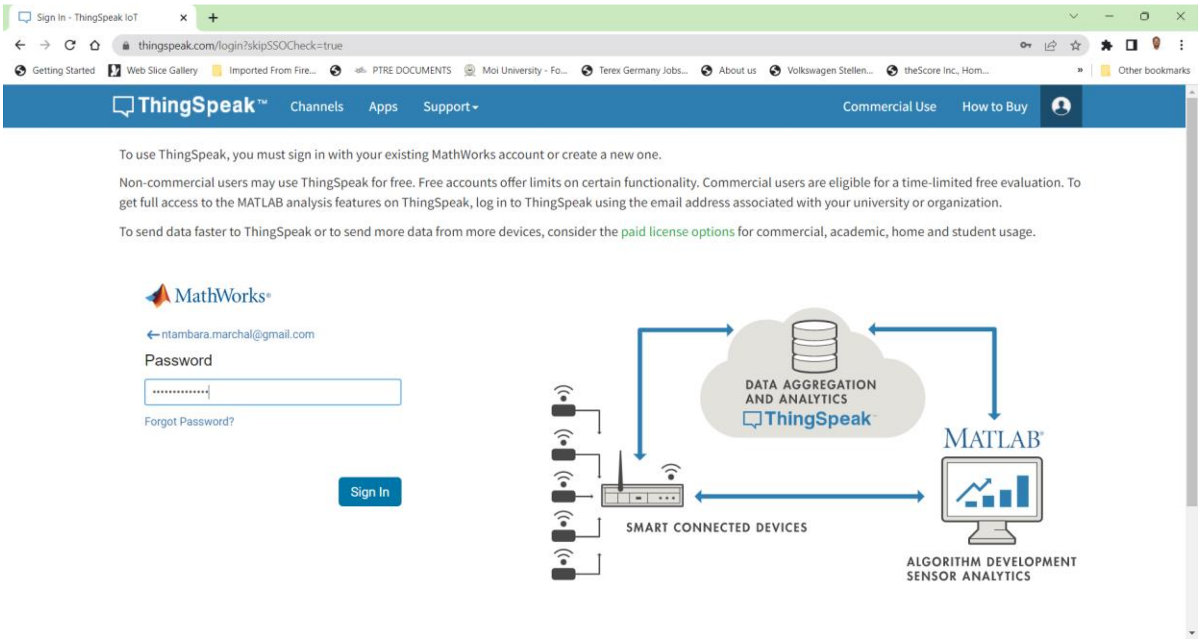


Figure 47: Entering Password then click Sign In

4.8.2 Dashboard Page

Figure 48 shows that the Signing In was successfully done. The user was able to observe and visualize the fuel monitoring data on IoT ThingSpeak.

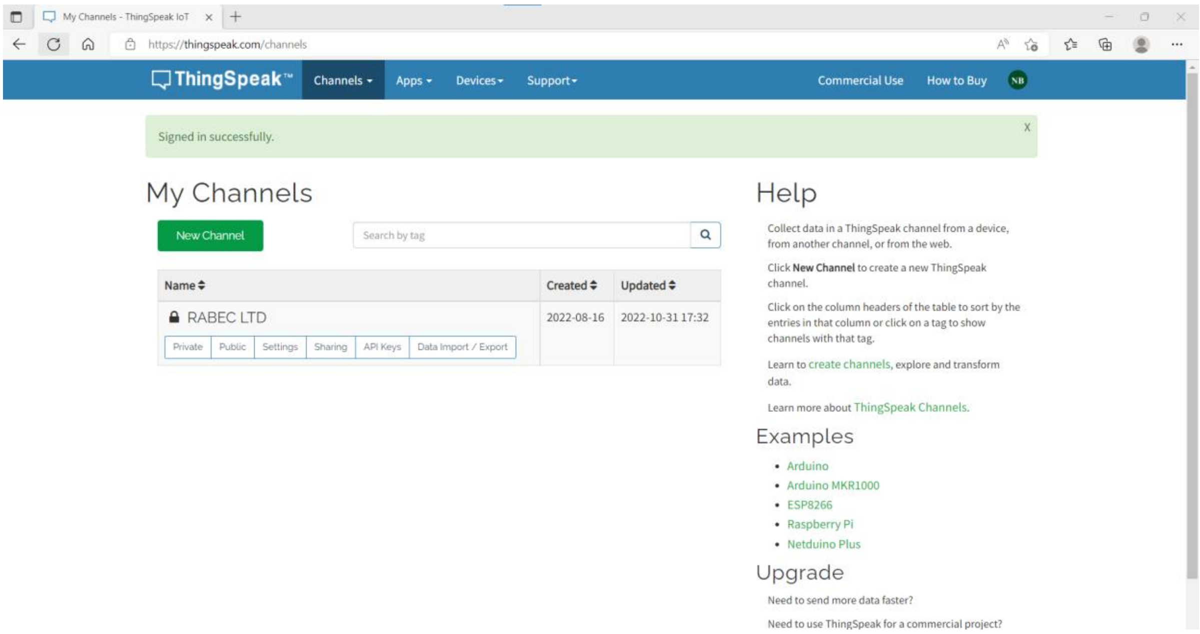


Figure 48: Operator signed successfully

Figure 49 shows that an operator was able to access fuel temperature, fuel pressure, fuel tank humidity, gas detection, and fuel tank level monitoring system on the ThingSpeak.

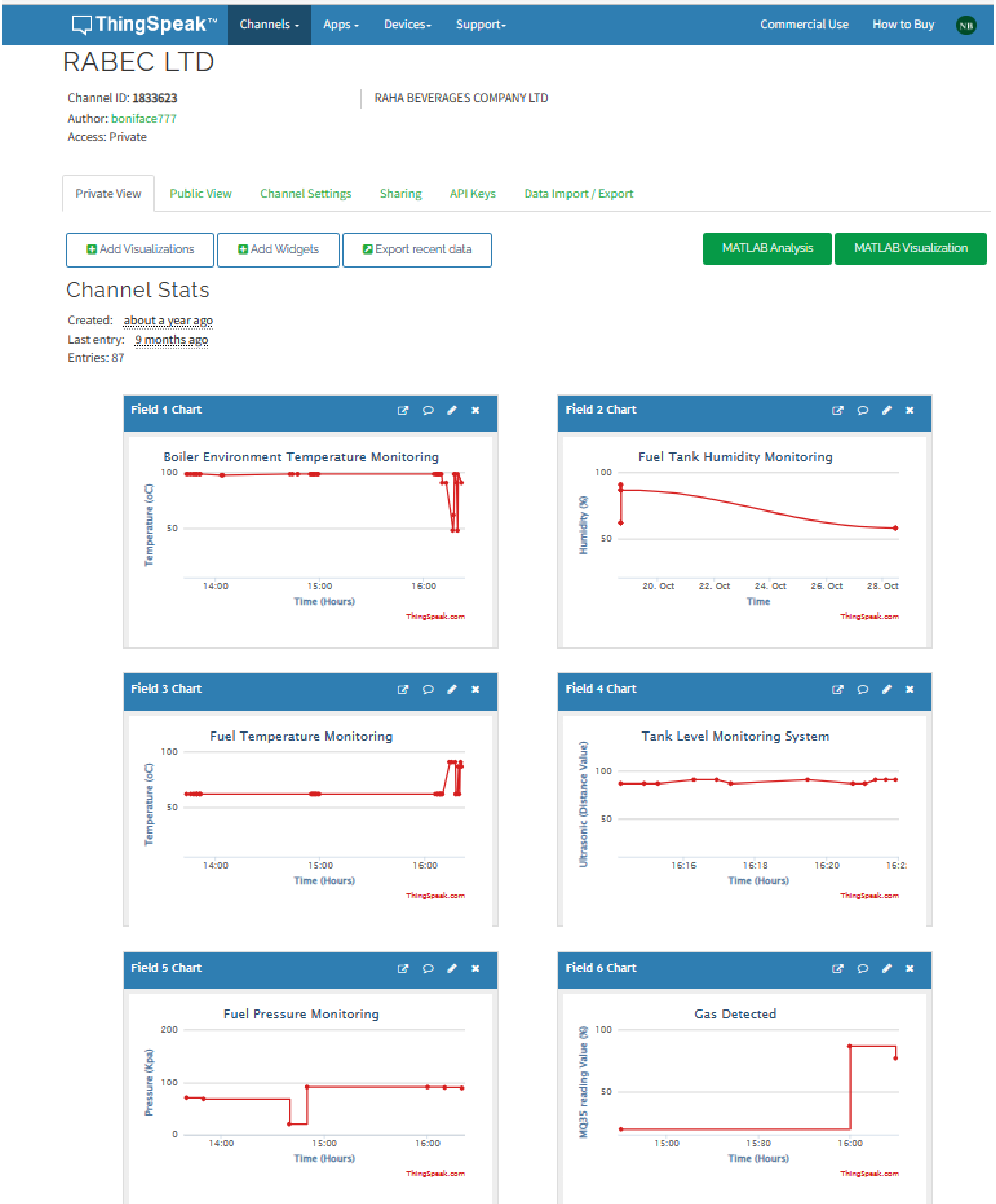


Figure 49: Fuel data condition visualization

4.8.3 Logout page

The developed system has a sign out/logout page where an assigned either boiler operator/and or operation manager can sign out successfully after fuel data observation, visualization, and analysis in the ThingSpeak platform as shown in Fig. 50.

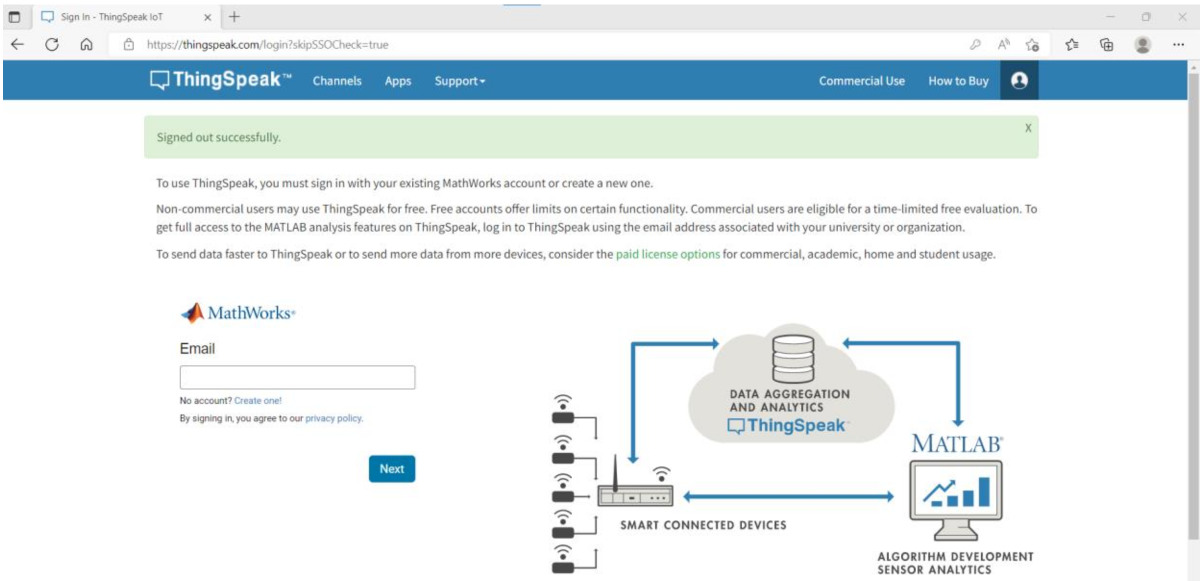


Figure 50: The operator signed out successfully

4.9 Unit Testing Results

4.9.1 Liquid Crystal Display (LCD) I2C testing results

The LCD was able to display the environment temperature (℃) where the boiler is installed, fuel temperature (℃), fuel pressure (Psi), humidity (%), fuel remaining (L), and display also if there is gas leakage or not. From the test experiments the environment temperature (EnvTemp) was 31.8℃ while fuel temperature (Fuel Temp) was 29℃ and the humidity (Rh) was 38%. The fuel level resealed by the ultrasonic unit (LV) was 52cm as unit tank length while the remain fuel in the tank (L) was 127.7 Liters. This fuel test indicates that the fuel pressure was 0.2 Psi. In addition, the system proved that there was no gas detected with normal range temperature while the fuel level was good. The fuel air mixture was perfect. Figure 51 shows all fuel parameters as sensed by the connected sensing units and displayed in LCD where the fuel monitoring conditions is properly fine.

Figure 52 indicates when the system demonstrates the abnormal fuel temperature of 105℃, gas detected, and poor fuel pressure of -0.1Psi.

Figure 51: The LCD testing results (a) fuel data and (b) fuel condition updates display

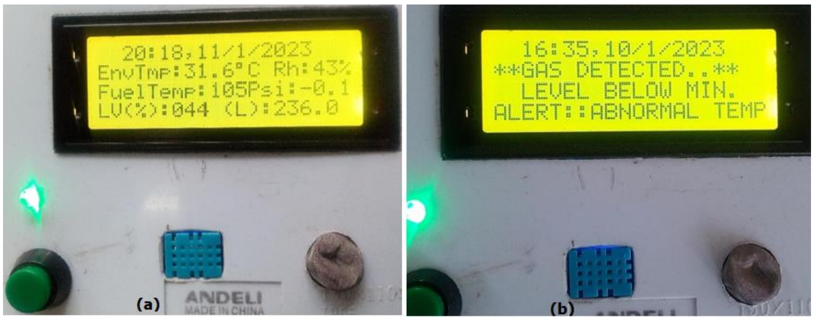


Figure 52: The LCD with (a) abnormal fuel conditions (b) Alert notification display

4.9.2 Ultrasonic Sensor Testing Results

The ultrasonic sensor detected any changes in fuel level within the fuel tank and relayed the percentage amount to ThingSpeak at every change that occurred where 79.5% of fuel tank level was sensed. Furthermore, short-range ultrasonic sensors perform best at higher frequencies because sound waves transmit for progressively shorter distances as the frequency increases. In this study, higher frequency ultrasonic was used as short-range proximity detection in fuel tank. Figure 53 depicts the ultrasonic sensor output in distance value in relation to the fuel level in the fuel tank.

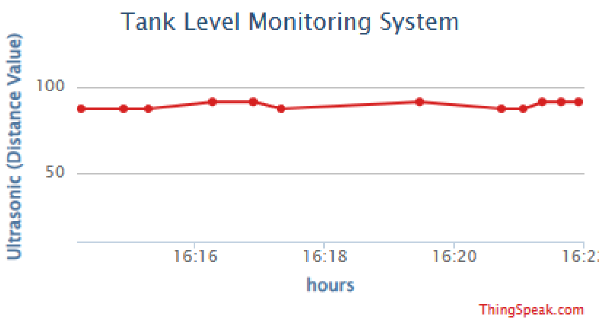


Figure 53*:* Visualization of ultrasonic sensed fuel level values

4.9.3 Thermistor sensor calibration and testing results

The thermistor was calibrated in order to sense accurate and correct fuel temperature outputs as shown in Fig. 54. As, fuel temperature plays an important role in fuel combustion during steam production process, the fuel temperature was sensed in this scenario using thermistor sensor and send the information to the ThingSpeak. The operator was enabled to check the fuel temperature conditions according to the any change of fuel pressure.

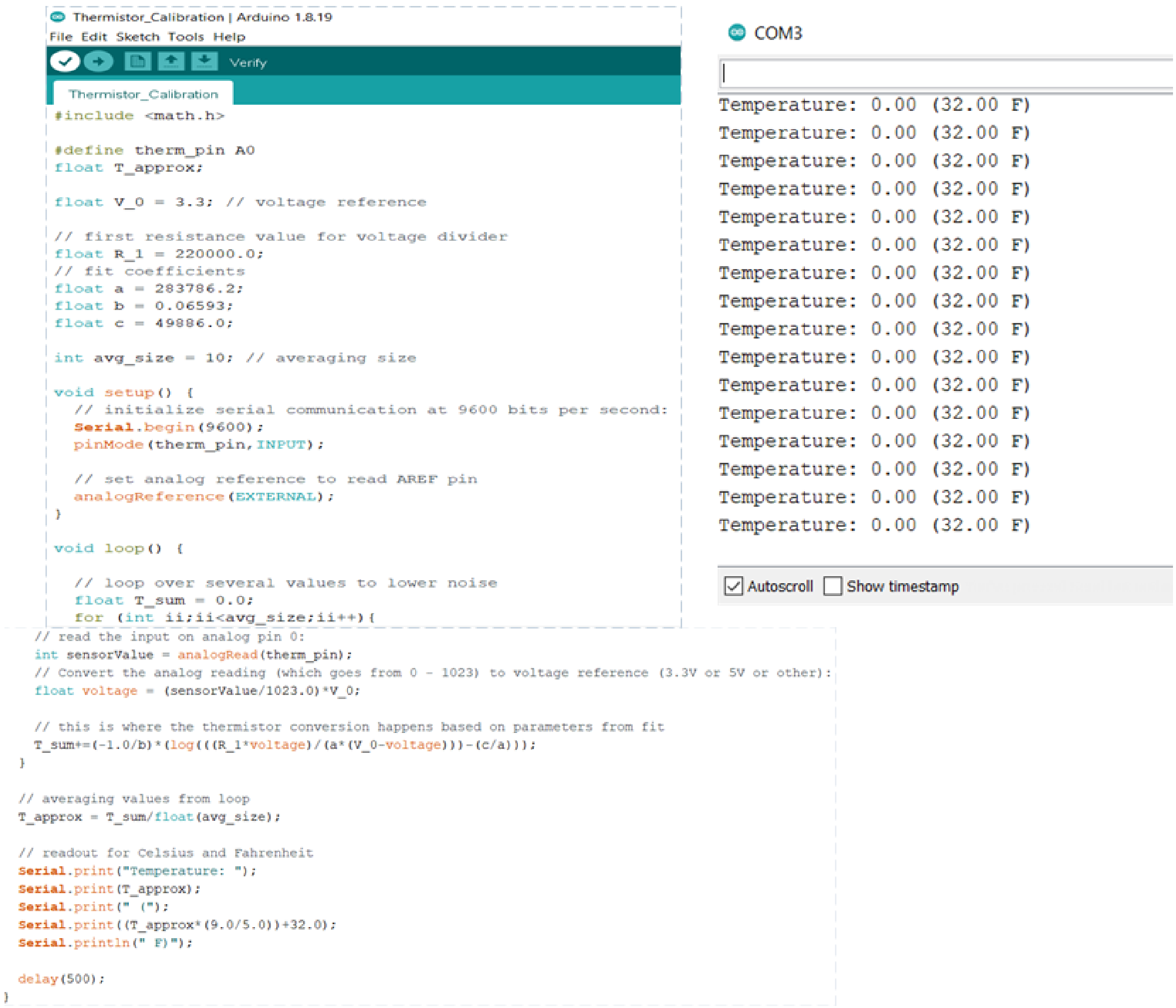


Figure 54: Thermistor calibration results

Figure 55 demonstrates the thermistor reading of the sensed temperature of the fuel during the testing process where the fuel temperature raised up to 98°C and diminished to 62°C.

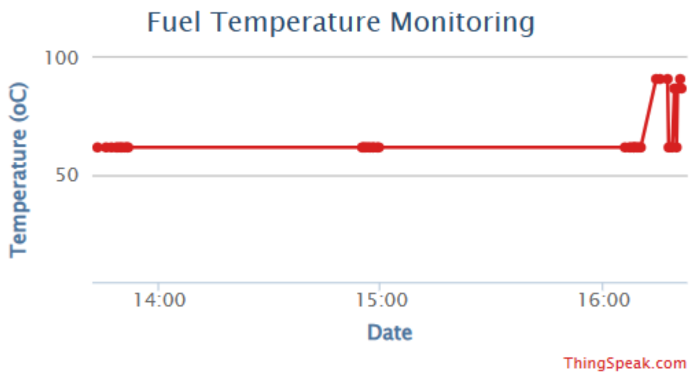


Figure 55: Thermistor sensor value for raised fuel temperature

4.9.4 Pressure Sensor Testing Results

The fuel pressure is the essential parameter that was very interested when monitoring was being conducted during in this study. The fuel pressure was increased during day-shift where the industry was required to produce high amount of banana wine production where it reached up to 99 Kpa while in the night shift the production was lower because of small production that the industry had to produce. In this case, the pressure was decreased up to 25.5 Kpa. Figure 56 shows the pressure increase (day-shift) where the amount of fuel consumption was high and pressure decrease (night-shift) during fuel pressure test performances.

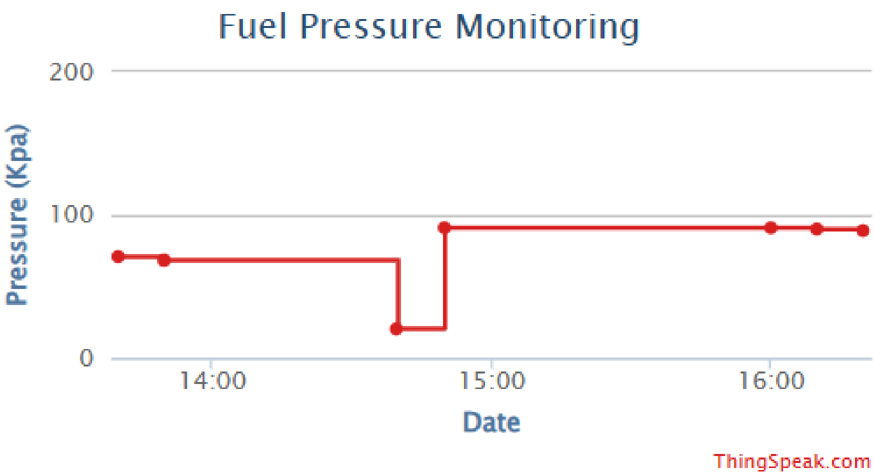


Figure 56: Fuel pressure readings high pressure and low pressure

4.9.5 The DHT22 Sensor Testing Results for Humidity Monitoring

The DHT22 sensed the humidity percentage of fuel tank in order to illustrates the moisture percentage during steam production process. As fuel temperature may change, the humidity can also change which should affect the fuel combustion performance. During the experiment, the humidity was equally to 91% which made fuel combustion more efficient during day-shift and in some case, the humidity was decreased to 58% which made fuel combustion moderate in night shift operation in RABEC. Figure 57 shows the humidity observation on ThingSpeak platform during test performance.

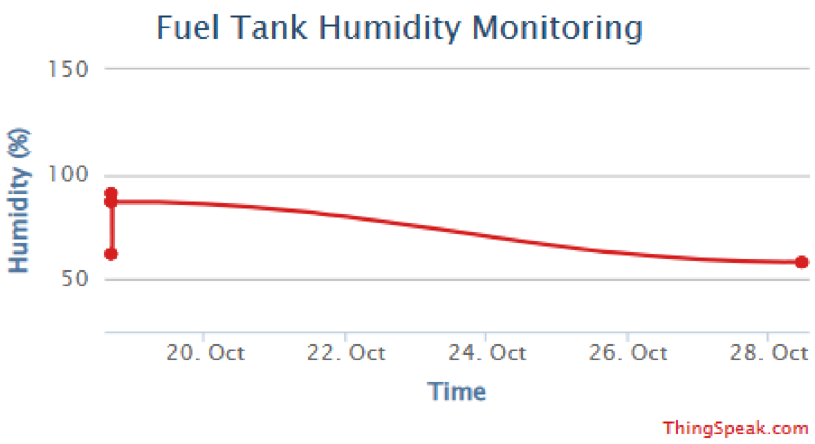


Figure 57: Sensed fuel tank humidity percentage

4.9.6 The DHT22 Sensor Testing Results for Environment Temperature Monitoring Within Boiler Installation Area

The boiler installation temperature area was detected. This temperature was considered as environment temperature. In addition, the higher environmental temperature of 46℃ was observed and the system alerted the plant operator to be alerted. The system also detects the normal temperature of 22.6℃ during plant operation. Figure 58 depicts the environmental temperature in the boiler installation area within RABEC.

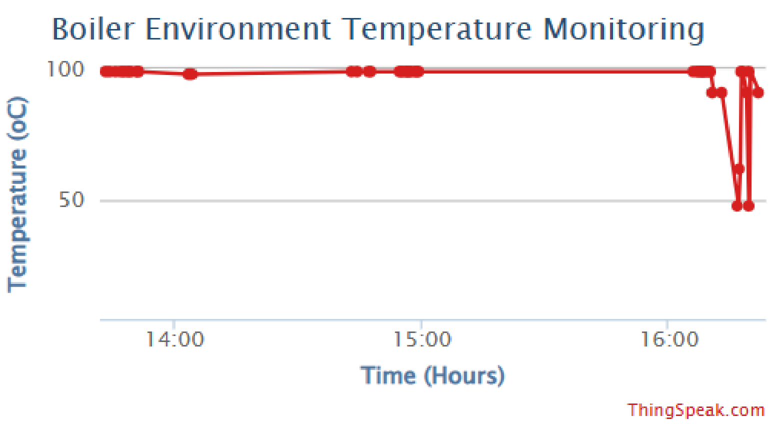


Figure 58: Boiler installation environment temperature conditions

4.9.7 The MQ35 sensor testing results

The developed system detects if the boiler surrounding exists the inflammable gas which can provoke the plant incident/or plant fire occurrence. In testing experiment, the MQ35 sensor read 87% value of gas detected. If the gas was not detected, the system reads 0% value. Figure 59 illustrates the gas detection condition or no gas detected in the fuel monitoring process.

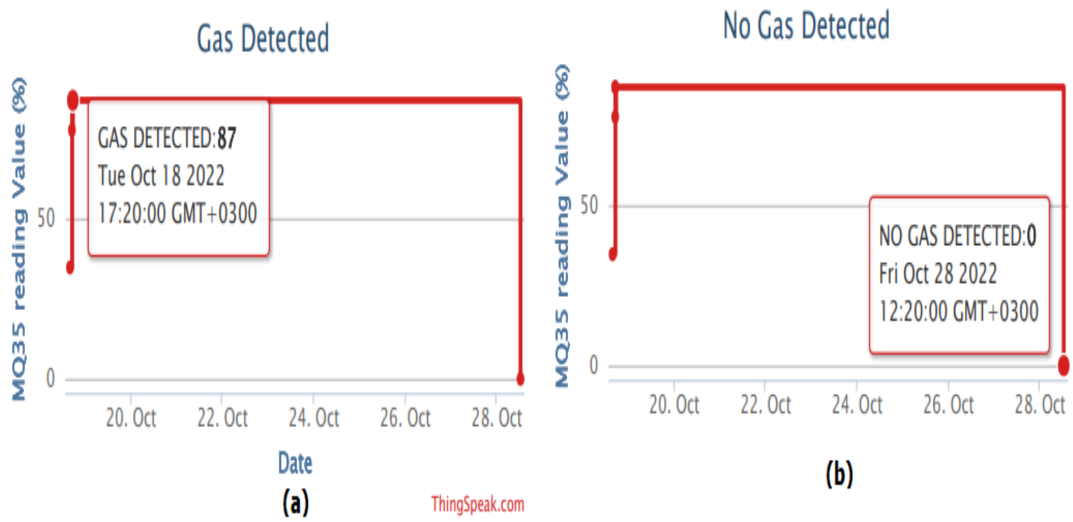


Figure 59: Gas condition results around the boiler (a) Gas detected (b) No gas detected

4.9.8 Global System for Mobile Communication (GSM) testing results

The developed system sent the short message service (SMS) via GSM module to the assigned operator's mobile phone in every one (1) hour of plant operation. The SMS includes the fuel level in the tank if it falls below the minimum specified, the humidity state if it is abnormal, fuel pressure, the fuel temperature if it is also abnormal, and the gas detection states. The system also has shown the other fuel data such as fuel pressure, fuel temperature, humidity percentage, and environmental temperature as shown in Fig. 60.

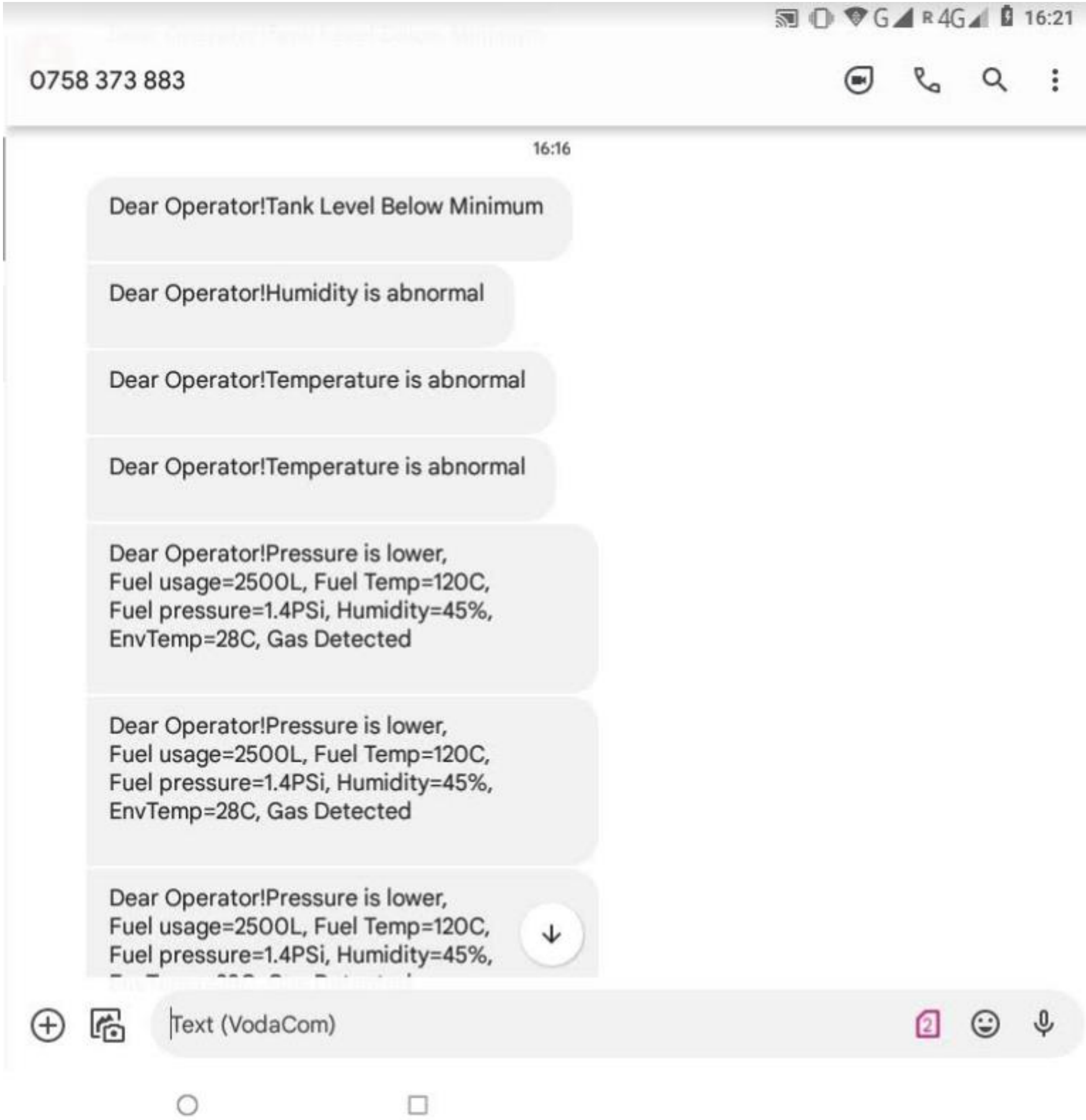


Figure 60: The GSM test results of fuel data monitoring and fuel conditions

The developed system also sent other SMS indicating that fuel data are in good conditions in every one (1) period in order to secure the plant operation without any abrupt plant shutdown occurrences/or disturbances.

Figure 61 shows the message arrived to the operator indicating the state of pressure, fuel usage, fuel pressure of 2.0Psi, humidity of 80% (abnormal), normal environmental temperature of 25℃ with no detected gas.

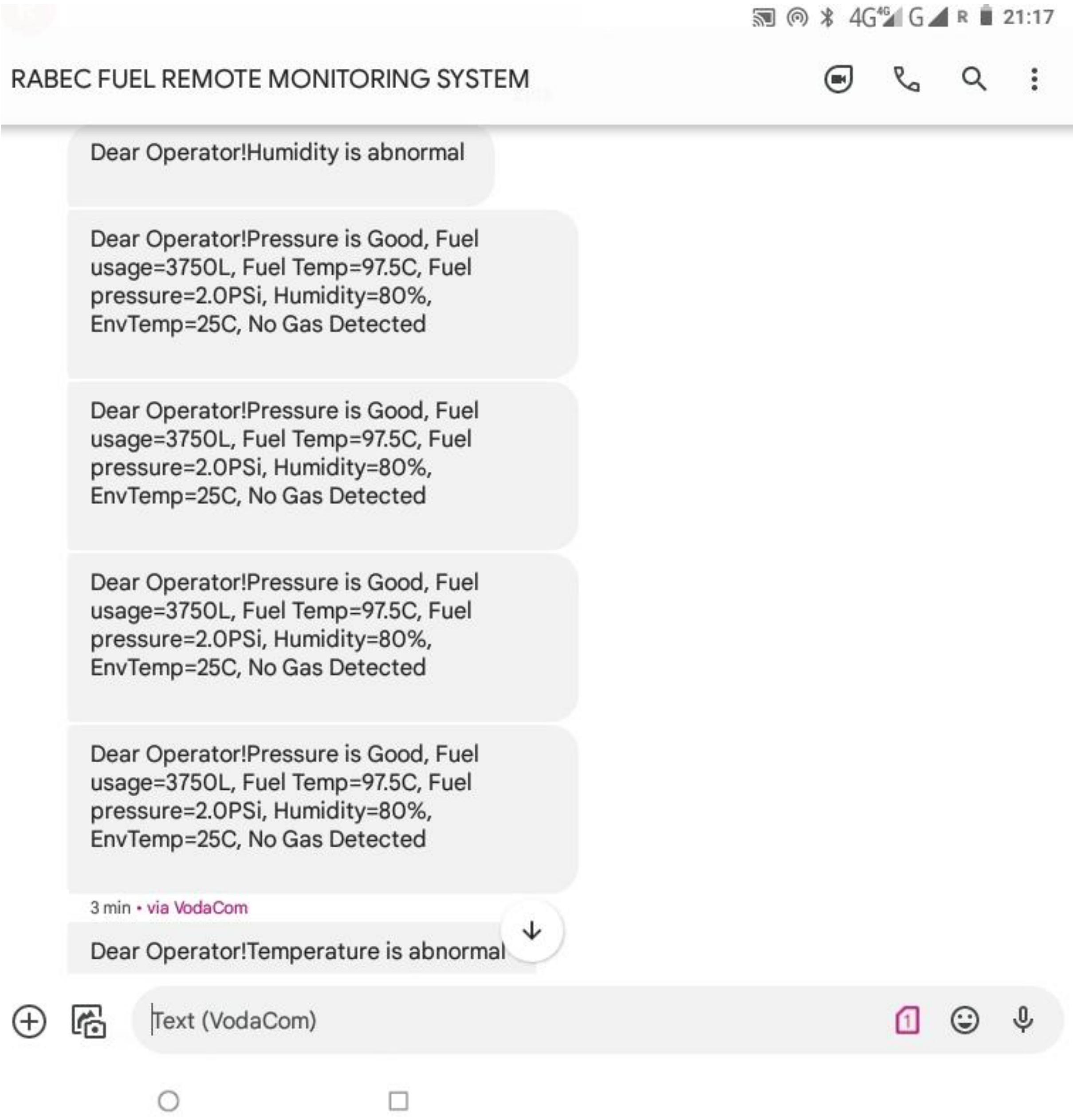


Figure 61: The SMS notification regarding fuel conditions

Suddenly, the fuel temperature increased to 120℃ while the fuel pressure is lower and reached to -0.1Psi. The fuel temperature was detected abnormal. At this point, the operator was alerted whenever any inconvenience occurred about fuel data condition while the humidity remained at 80%, and EnvTemp at 25℃.

Figure 62 indicates also the message notification sent to operator for alert purpose of the fuel data status during steam boiler production process.

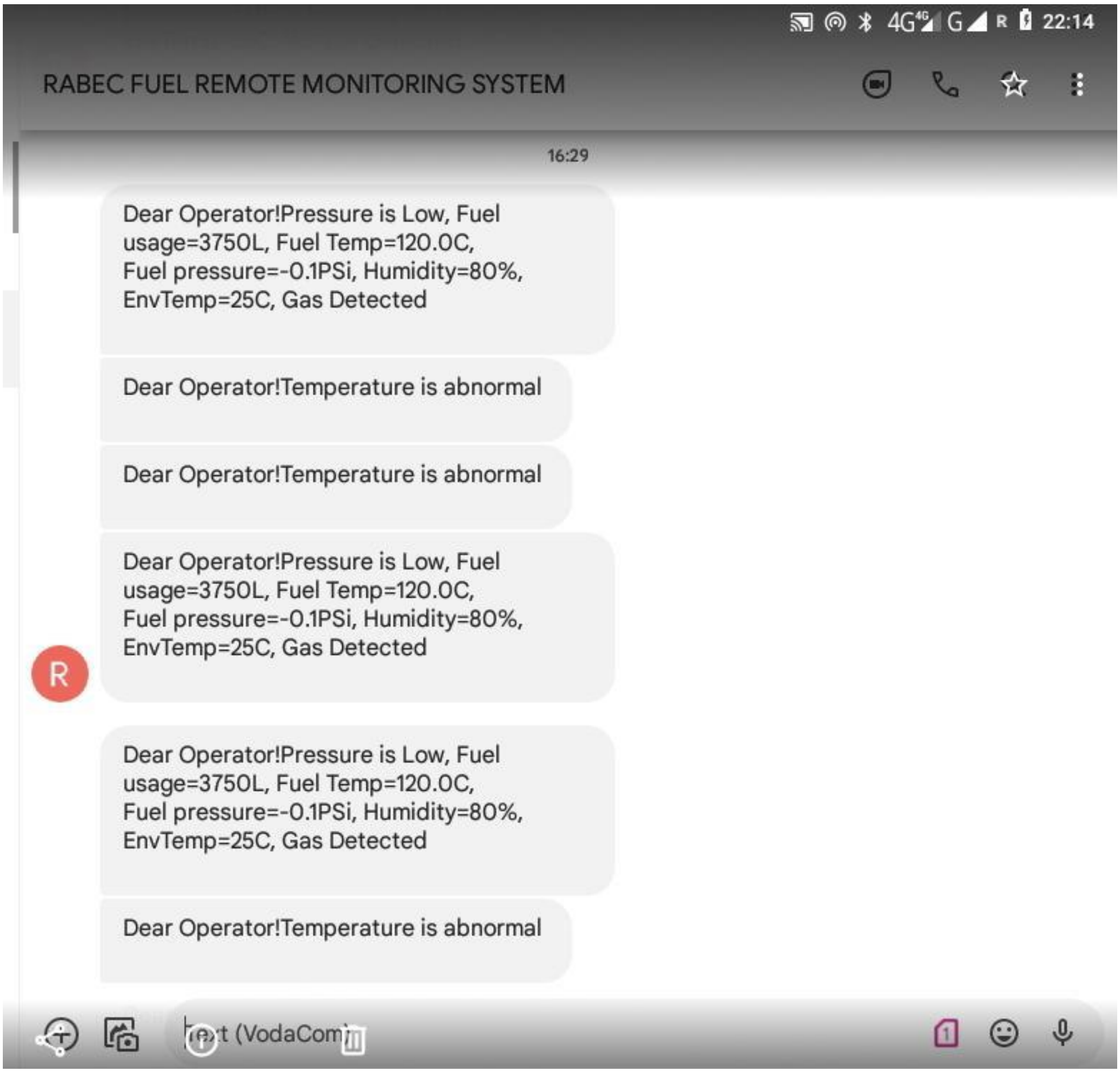


Figure 62: Fuel data sent to operator mobile phone regarding fuel conditions

4.10 Integration Testing Results

The proposed system units both sensing and actuating units were integrated and incorporated each other. Appendix 5 shows the entire final prototype's codes that were used and integrated with individual unit codes and declarations. The fuel data were sent to the cloud and SMS was sent to the operator mobile phone via GSM module. The assigned person either boiler operator or operational manager visualized the fuel conditions that were aggregated and analyzed via IoT platform as form of webpage.

The system was able to sense the fuel temperature, fuel tank level, fuel pressure, fuel usage, detect gas that might surround the boiler, fuel tank humidity, and environment temperature where the boiler is installed. These fuel parameters were sensed at any condition happened and displayed on LCD. The operator was able to monitor the fuel flowrate on daily basis and check the fuel tank level once the fuel level reached at 25% of the total amount of fuel volume remotely.

4.12 System Testing Results

The entire proposed system was developed and tested to review and check its functionality and performance. The functional and non-functional requirements were verified to observe how individual unit responds regarding the RABEC's performance requirements. Table 7 illustrate non-functional requirements system testing results.

Table 7: The system non-functional requirement testing results

S/N	System Non-Functional Test results	Assessment
1.	Efficiency	Pass
2.	Effectiveness	Pass
3.	Power Consumption.	Pass
4.	Real Time	Pass
5.	Cost	Pass
6.	Security	Pass
7.	Reliability	Pass
8.	Flexibility	Pass
9.	Maintainability	Pass

Table 8 shows functional requirement system testing for the developed system.

Table 8: The system functional requirement testing results

S/N	Test Results	Assessment
1.	Monitor amount of fuel usage	Pass
2.	Monitor fuel level within the tank	Pass
3.	Monitor and display the fuel parameters like temperature and pressure of the fuel, fuel tank humidity, and fuel flow discharge on LCD.	Pass
4.	Produce noise when fuel is below the threshold value.	Pass
5.	Send SMS to the operator and operation manager's phone of fuel conditions	Pass
6.	Aggregate, Analyze, and Visualize Fuel Data through IoT ThingSpeak Platform.	Pass
7.	Detect any gas around the Boiler	Pass
8.	Log In to check fuel conditions on ThingSpeak	Pass
9.	Log Out after fuel data check	Pass

4.13 System Prototyping

The developed system components were connected and assembled in proper manner. The sensing and actuating units included thermistor, fuel pressure, MQ35 gas detection sensor, DHT22 sensor for fuel tank humidity and environment temperature detection and sensing, LCD, GSM module, and YF-S201 fuel flow sensor were communicating together before assembled and printed to PCB and was verified for performance checks. Figure 63 shows the developed system prototype where all units were communicated after sensing and actuating all related fuel data before and after sending them to the IoT ThingSpeak platform.

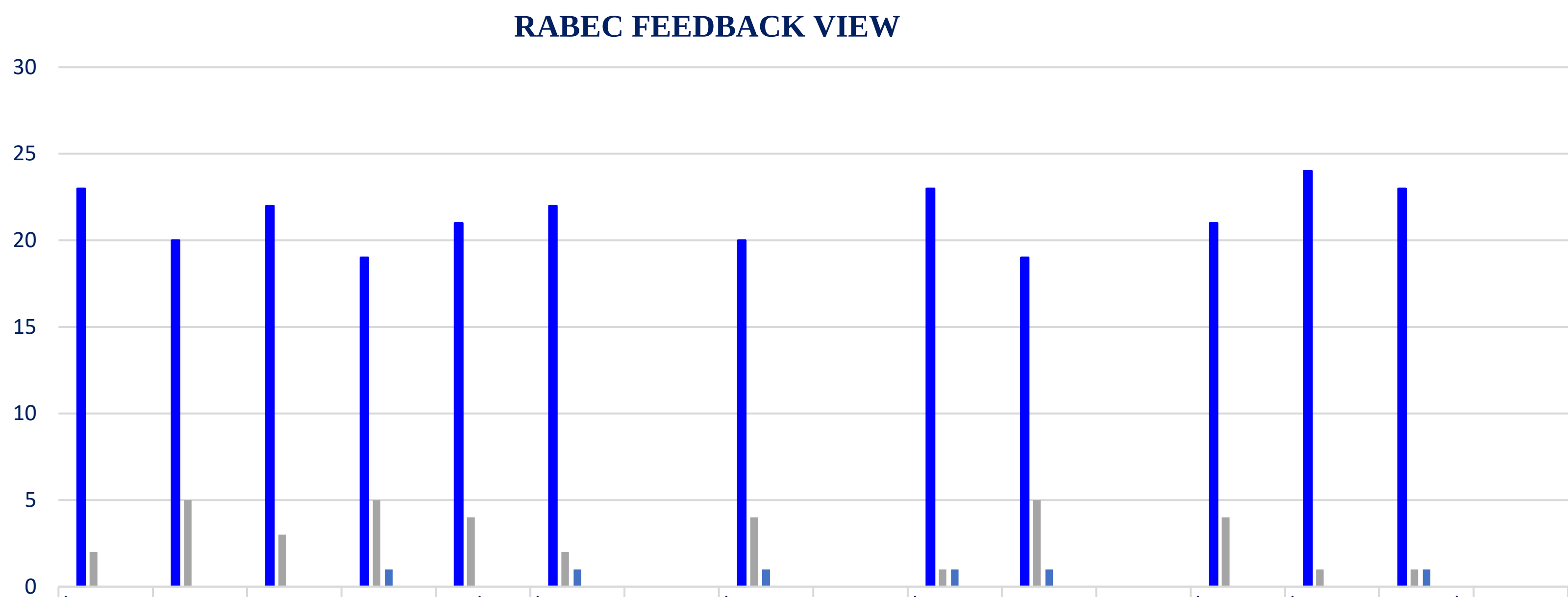
Figure 63: Final developed prototype that was implemented to monitor fuel IoT based system

4.14 System Validation Results

The system was validated using a questionnaire as shown in Appendix 2.

4.14.1 Developed System Validation to Users

To validate the developed IoT based fuel monitoring system, a questionnaire based on a Likert Scale with five (5) points of Strongly Agree, Agree, Neural, Disagree, and Strongly Disagree was established, and 25 workers observed the validation of the generated prototype. Furthermore, utilizing a systematic questionnaire, the constructed system was evaluated and validated to RABEC/engineering department (Appendix 4). The system was also presented to the one (1) operation manager, one (1) production manager, two (2) boiler operators, and one (1) electrical engineer of the RABEC as leading management and engineering team. The developed system was also scalable verified with effective responsive checks in 7 days consecutively. The hardware and software functionalities, and combination of all individual units were included during system validation and communicated together to provide the whole working system. Figure 64 demonstrates the feedback from the user (RABEC) where the user selected either strongly agree if the developed system provide a sustainable solution to the fuel monitoring problem at 100% success rate, agree if the developed system solves the fuel monitoring problem at good rate. The neutral, disagree, and strongly disagree were also the perception of the user where RABEC was able to accept/or reject the system functionalities according to its requirements.



	The system displays the fuel data at any change	The system is easy to use	The system is most interactive	The system is affordable	The developed system is innovative	The system is responsivne ss		The system is simple and friendly user		The system performs work in real-time	The system is fully automatic		The system facilitates in fuel data monitoring	The system touches on the user curiosity	Persuade the business to use system	
Strongly Agree	23	20	22	19	21	22		20		23	19		21	24	23	
Agree	2	5	3	5	4	2		4		1	5		4	1	1	
Neutral	0	0	0	1	0	1		1		1	1		0	0	1	
Disagree	0	0	0	0	0	0		0		0	0		0	0	0	
Strongly Disagree	0	0	0	0	0	0		0		0	0		0	0	0	

Figure 64: User feedback view during system validation

4.14.2 System Requirements Validation

(i) Functional system verification

This includes testing using RABEC fuel data to ensure that the system fits the company's requirements, as well as involving potential customers or users of the built fuel monitoring system. The engineering department was required to test the IoT system based on the fuel monitoring system to assess whether or not it was ready for usage in the fuel monitoring system to alleviate the fuel consumption difficulties. The system impressed the responders and had the potential to produce excellent results. Table 9 shows the system functional requirements that were observed and achieved after developed system test performance.

Table 9: The functional system requirements verification

S/N	Requirements	System verification
1.	Monitor amount of fuel usage	The system was able to monitor fuel used within the fuel tank using flow rate sensor.
2.	Monitor fuel level within the tank.	The ultrasonic sensor was able to sense the fuel level and communicate with display.
3.	Monitor and display the fuel parameters like temperature and pressure of the fuel, fuel tank humidity, and fuel flow discharge on LCD.	The system was able to display fuel parameters during the boiler steam production process according to the fuel consumption.
4.	Generate noise	The system was able to generate noise whenever the fuel reached below the threshold value.
5.	Send SMS	The system was able to send SMS containing the fuel parameters to the on-duty engineer/or operator.
6.	Visualize and Analyze fuel Data	The system was able to send fuel data to the ThingSpeak to be visualized and timely analyzed.
7.	Detect any gas around the Boiler	The system was able to detect any gas around the boiler environment using MQ35 sensor to mitigate the harmful dangers to the plant.

(ii) Non-functional system requirement verification

The developed system prototype was tested with different usability factors of operations of RABEC and performed as expected, as shown in Table 10.

Table 10: The operational user acceptance test of the developed system

S/N	Usability Factors	Usability Features	Remarks
1.	System Quality	Satisfaction	Excellent
		Responsiveness	Very Good
2.	Service Quality	Ease of use	Very good
		Efficiency and Reliable	Excellent
3.	Technical Quality	Navigation	Excellent
		Interaction	Very Good
4.	Information Quality	Learnability	Very good
		Memorability	Good

4.15 Discussion

The tests and experiments performed during system prototype development has shown that the components were communicated each other as demonstrated in Fig. 45. The developed system was able to communicate with ThingSpeak as IoT platform and provides the real-time fuel data during steam production process on the system itself as well as webpage as shown in Figs. 46 to 49. The fuel level change, fuel temperature, fuel pressure, fuel usage, fuel tank humidity, and boiler environment temperature were sensed by ultrasonic sensor, thermistor sensor, pressure sensor, flowmeter sensor, and DHT22 sensor respectively and automatically displayed on LCD as indicated in Figs. 51 to 52. The fuel parametric data were sent to the cloud (ThingSpeak) for remote storage, visualization, and analysis at each fuel condition as shown in Figs. 53 to 59. The developed prototype also proposed another alternative of SMS communication via GSM technology to send fuel data to the boiler operator/ or operation manager to assist and support easiness of fuel data condition accesses in the case of poor internet connectivity and or poor network coverage in the assigned time wherever they are as shown in Figs. 60 to 62. Figure 63 shows the final developed prototype and Fig. 64 indicates the RABEC’s views after validating and test performance of developed system. RABEC strongly appreciated and satisfied with the developed and prototyped system. The developed IoT fuel monitoring system provides a safe operational aspect with a remote fuel parameter monitoring. In addition, the system is costly effective, efficient with user friendly interactive and provides higher performance to any assigned engineer. Users must have internet access and login using the username and password created during the registration process. Rendering to the study, the developed system has successfully operated to provide the real time fuel data.

Furthermore, all of these mentioned features demonstrate its uniqueness and innovative in comparison with the current and existing fuel monitoring systems. The comparison made in the previous proposed fuel monitoring technologies can monitor only one fuel parameter but other important parameters have missed. For instance, RABEC uses graduated stick to check only fuel level but this method requires much time, it is risky with poorest accuracy fuel level data while this developed fuel monitoring system is based on IoT systems which is more accurate, reliable, efficient, and affordable. Thorough the tests that were conducted to validate the system, it was appeared that the objectives of the system satisfactorily met with company’s standards and requirements. As the result, it is believed that the project has been satisfactorily accomplished with all IoT based on fuel monitoring system's functional and non-functional requirements.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The industrial process remote monitoring makes tasks simpler, diminish humanoid contribution and errors, and promote the industrial awareness in the processes. Raha Beverages Company Limited is one of such industry that rapidly wanted to adapt remote fuel monitoring process. In the related works, it has demonstrated that the similar systems were designed to provide only fuel level monitoring. The IoT-based fuel level monitoring system was developed and tested to determine if the sensing units like thermistor sensor, pressure sensor, DHT22 sensor, MQ35 sensor, flow-rate sensor and actuating unit such LCD can be communicated with the microcontroller in order to provide the accurate fuel data in real time. Likewise, to the GSM module, it was tested to see if it could send SMS messages providing fuel parameters to the operator's mobile phone. Aside from eliminating mistakes, the proposed system may also help to enhance fuel combustion efficiency whenever needed in fuel pressure rise at fuel temperature reduction to an ideal fuel-air combination and save these fuel data to the cloud.

Finally, the developed system was able to monitor fuel parameters such as fuel temperature, fuel pressure, fuel tank humidity, fuel level, boiler environment temperature, gas detection around boiler, and fuel flow discharge at any fuel conditions, send the fuel data to LCD and to the IoT ThingSpeak platform for aggregation, visualization and analysis with system's user usefulness, friendliness, maintainable and safety that predicts and prove the better performance than the existing manual fuel monitoring system.

5.2 Recommendations

5.2.1 Implication to Policymakers

Policymakers should push the beverage sectors, particularly RABEC, to apply the established system to enable real-time fuel monitoring. They may also devise methods to automate the majority of industrial operations in the beverage industries at a reasonable cost in order to shorten work, manage time, and resources in beverage factories.

5.2.2 Implication to Practitioners

Although the developed fuel monitoring technique is projected to have a substantial influence on the beverage industry sectors, there are numerous other businesses that require distant systematic techniques to monitoring fuel at real-time at affordable price in order to get benefits from the system. The designed method aims to reduce human mistakes that contribute to accidents within RABEC in the engineering sector alone; however, automation enhancement in other parts such as the manufacturing section is highly encouraged.

5.2.3 Scientific Contribution

The developed system utilized the remote technology that makes it to be at low-cost that eliminate the economic barriers caused by the high-cost systems that were premeditated and used in the developed industries only.

5.2.4 Future Work

From the prototype system to the real working environment, the designed system must be implemented. The system only monitors the fuel consumption because limited funds but the system can also control and reduce fuel consumption. The prediction and early detection of fault diagnosis of the fuel oxygen, viscosity, and density can be added for further studies.

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APPENDICES

Appendix 1: Interview Guide

IoT BASED ON BOILER FUEL MONITORING SYSTEM: A CASE STUDY OF RAHA BEVERAGES COMPANY LIMITED, ARUSHA-TANZANIA

Dear Participant,

I am Boniface NTAMBARA, a final year Master's student in Embedded and Mobile Systems (Embedded Systems Option) at The Nelson Mandela African Institution of Science and Technology in Arusha, Tanzania, and I would like to welcome you to take part in this interview guide.

The purpose of this interview is to define needs and offer user satisfaction throughout the construction of an IoT-based boiler fuel monitoring system: a case study of Raha Beverages in Arusha, Tanzania.

You have been identified as a potential key participant in this survey because of your role and experience in in fuel monitoring matters a lot. This interview will be timed between 10 to 15 minutes. The participation of this interview is voluntary. Your responses will be kept confidential in a secured database and only be used for academic purposes. The findings of this study will be published in regional academic journals.

If you have any questions about this interview guide, please contact me at the embedded and mobile systems, the School of Computational, Communication Science and Engineering (COCSE), The Nelson Mandela African Institution of Science and Technology, Arusha-Tanzania, via email: bonifacen@nm-aist.ac.tz , or by phone: +255 758034053

Instructions: This interview guide is divided into four sections. Section A covers general opening questions, where the respondent can answer easily, Section B includes information on critical procedures and strategies used for fuel monitoring approach in RABEC. Section C covers the technical skills regarding on fuel monitoring systems. Section D covers the general conclusion regarding IoT fuel monitoring views on interviewee side (respondent).

Note: Deadline to receive your response is August 30, 2022.

Thank you for your valuable time and participation!

Section A. Opening Questions

(1) Would you mind if we can conduct this interview in your office or you have a perception of other place which is most comfortable?
(2) May I know little about yourself and what is the name of your section/or department?
(3) How long have you been working in this beverage industry?
(4) Do you have any question or suggestion for me before we continue with our interview?

Section B. Introductory Questions

(1) What is your experience of working in this section/or department?
(2) What are the procedures of monitoring fuel from fuel tank to ignition point before fuel-air mixture?
(3) What strategy do you utilize to know fuel parameters like pressure, temperature, fuel usage, fuel tank humidity, boiler environment temperature, and gas leake around boiler?

Section C. Key Questions

(1) Have you ever used a remote technology to monitor fuel during boiler steam production process?
(2) Do you think that digging stick method and tap measure to monitor fuel level and assumption of fuel usage are accurate and efficient method?
(3) Have you ever challenged by your current method to monitor fuel that you are using nowadays?
(4) What is the most typical way for determining whether fuel has run out in the fuel supply tank?
(5) What do you think should be done to enhance the present methods for smart fuel monitoring?
(6) Do you think a new technological fuel monitoring system will aid with efficiency and accuracy?
(7) Do you think a remote fuel monitoring approach can improve production related to the fuel consumed?
(8) Which additional features do you think the gasoline monitoring system should have?
(9) Do you think a remote fuel monitoring technology can be benefit your company?

Section D. Concluding Questions

(1) Do you think IoT based Fuel Monitoring System can be useful in your industry?
(2) What would be the benefits of employing an IoT based Fuel Monitoring System in your company?
(3) Any interesting and important issues missed in our today's discussion?

Appendix 2: Survey Questionnaire

IoT BASED ON BOILER FUEL MONITORING SYSTEM:cA CASE STUDY OF RAHA BEVERAGES COMPANY LIMITED, ARUSHA-TANZANIA

Dear Participant,

I'm Boniface NTAMBARA, a final-year Master's student in Embedded and Mobile Systems (Embedded Systems Option) at The Nelson Mandela African Institution of Science and Technology in Arusha, Tanzania, and I'd like to encourage you to fill out this survey questionnaire form.

The purpose of this survey is to define needs and offer user satisfaction throughout the development of an IoT-based boiler fuel monitoring system: Raha Beverages case, Arusha, Tanzania.

Because of your position and experience in fuel monitoring, you have been selected as a prospective significant participant in this survey. This survey will take you around 10 to 15 minutes to complete. The participation of this survey is voluntary. Your responses will be kept confidential in a secured database and only be used for academic purposes. The findings of this study will be published in regional academic journals.

If you have any questions about this survey, please contact me at the embedded and mobile systems, the School of Computational, Communication Science and Engineering (COCSE), The Nelson Mandela African Institution of Science and Technology, Arusha-Tanzania, via email: bonifacen@nm-aist.ac.tz or by phone: +255 758034053. Note:

Deadline to receive your response is **August 30, 2022.**

Consent:

By clicking Yes, you consent that you are willing to answer the questions in this survey.

Yes ☐ No ☐

Instruction: Fill the following fo √ y check and honestly rate yourself on the situation of existing fuel monitoring system by applying the following scales.

5-Always 4-Often 3-Sometimes 2-Rarely 1-Never

S/N	Existing Monitoring System	5	4	3	2	1
1.	Fuel monitoring is totally manual					
2.	Accident happens operators are going to check fuel level					
3.	Fuel level checks use a graduated digging stick					
4.	Fuel data visualization is accurate and efficient					
5.	Current methods of fuel monitoring system, monitor also other fuel data such as pressure, temperature, humidity…					
6.	There are human errors during fuel level checks					
7.	To climb fuel tank is the way utilized to observe the fuel level within tank					
8.	During fuel level and other fuel parameter checks require serious and special attention					
9.	The industry proposed other alternative fuel monitoring strategy instead of manual way					
10.	There are more than 3 people involved in fuel monitoring process					

Appendix 3: System Validation Questionnaire

5-Strongly Agree 4-Agree 3-Neutral 2- Strongly Disagree 1-Disagree

S/N	Existing Monitoring System	5	4	3	2	1
1.	In the fuel monitoring process, the developed system meets with the industry needs and standards					
2.	The developed system is easy to use					
3.	The developed system is interactive with the operators					
4.	Coming from manual fuel monitoring to remote/smart fuel monitoring, the proposed system evolved					
5.	The developed system provides automatic fuel monitoring system					
6.	The developed system is cost-effective with no pricey					
7.	The developed system piqued and touches with the industry curiosity					
8.	The developed system will require engineering instruction on how to use it					
9.	The designed and developed system prevents/mitigate hazards by providing real-time fuel data monitoring					
10.	The developed system monitors other fuel conditions like pressure, temperature, humidity, detect surround gases, and send the fuel data to ThingSpeak for visualization and send SMS containing the fuel data					
11.	The developed system can be persuaded into businesses					

Appendix 4: ThingSpeak codes

```
#include <ESP8266WiFi.h>
#include <WiFiClient.h>
#include <ESP8266WebServer.h>
#include <ESP8266HTTPClient.h>
#include "ThingSpeak.h"
char ssid[] = "Boniface";
char pass[] = "Michaella777!@";
unsigned long Channel_ID = 1833623; // Your Channel ID
const char * myWriteAPIKey = "DT2H64SV18JI891D";
WiFiClient client;
char *Msg[7],*msgExtract = NULL;
char mine[100],Rx;
bool Read=false;
int i=0;
void setup(){
  Serial.begin(115200);
  WiFi.mode(WIFI_STA);
  ThingSpeak.begin(client);
  WiFi.begin(ssid, pass);
  Serial.println("");
  Serial.print("Connecting");
  while (WiFi.status() != WL_CONNECTED){
    Serial.print(".");
    digitalWrite(LED_BUILTIN, HIGH);
    delay(250);
    digitalWrite(LED_BUILTIN, LOW);
    delay(250);
  }
```

```
  Serial.println("");
}
void loop(){
  internet();
  while( Serial.available()){
    char Rx=char(Serial.read());
    if(Rx=='#'){
      i=0;
      Read=true;
      break;
    }
else
      Read=false;
    mine[i++]=Rx;
   }
   if(Read){
     msgExtract = strtok(mine, ",");
     int index = 0;
     while (msgExtract != NULL){
       Msg[index++]=msgExtract;
       msgExtract = strtok(NULL, ",");
     }
     String dataRead1 = String(Msg[0]);
     String dataRead2 = String(Msg[1]);
     String dataRead3 = String(Msg[2]);
     String dataRead4 = String(Msg[3]);
     String dataRead5 = String(Msg[4]);
     String dataRead6 = String(Msg[5]);
     Serial.println("dataRead1: " + dataRead1);
     Serial.println("dataRead2: " + dataRead2);
```

```
      Serial.println("dataRead3: " + dataRead3);
      Serial.println("dataRead4: " + dataRead4);
      Serial.println("dataRead5: " + dataRead5);
      Serial.println("dataRead6: " + dataRead6);
      ThingSpeak.setField(1, dataRead1);
      ThingSpeak.setField(2, dataRead2);
      ThingSpeak.setField(3, dataRead3);
      ThingSpeak.setField(4, dataRead4);
      ThingSpeak.setField(5, dataRead5);
      ThingSpeak.setField(6, dataRead6);
      ThingSpeak.writeFields(Channel_ID,myWriteAPIKey);
      Read=false;
      delay(15000);
  }
}
void internet(){
  if (WiFi.status() != WL_CONNECTED){
    while (WiFi.status() != WL_CONNECTED){
      WiFi.begin(ssid, pass);
      delay(500);
      Serial.print(".");
    }
  }
}
```

Appendix 5: Final Prototype codes

```
#include <LiquidCrystal_I2C.h>
#include <SoftwareSerial.h>
#include <Wire.h>
#include "DHT.h"
#include <TimeLib.h>
#include <RTClib.h>
#define flowValve 4
#define spareValve 3
#define flowSensor 2
#define Alarm 8
#define DHTPIN 6
#define ThermistorS A0
#define MQ A1
#define pressureSensor A2
#define Echo A3
#define Trig 13
#define LEDR 5
#define LEDB 7
#define DEBUG true
#define dataLog 15000
#define beepTime 15000
#define flowCalculation 1000
#define DHTTYPE DHT11

float Temp,Total=0,Average,R,fuelTemp,Volume = 0.0,ltMinute,
pressurePascal=0.0,pressureBar=0.0,pressurePsi=0.0,voltRead=0.0;
int i,Hum,tankLevel=0,sCrn=0,sClr=0,disp[3],Distance,TankLevel;
volatile int count=0;
double duration;
```

```
unsigned long previousTime=0,previousTime1=0,previousTimeBeep,currentTime;
String myAPI = "DT2H64SV18JI891D",Date,
myHOST = "api.thingspeak.com", myPORT = "80";
bool
smsLevel=true,gasLeakage,smsTemp=true,smsPsi=true,smsHum=true,smsGas=true,smsFlow
=true;
LiquidCrystal_I2C lcd(0x27, 20, 4);// LCD I2C
RTC_DS1307 Rtc;
DHT dht(DHTPIN, DHTTYPE);
SoftwareSerial Esp(10,9);
void setup() {
//configuration
  pinMode(flowValve, OUTPUT);    pinMode(spareValve, OUTPUT);
  pinMode(flowSensor, INPUT);   pinMode(Alarm, OUTPUT);
  pinMode(MQ, INPUT);  pinMode(ThermistorS,INPUT);
  pinMode(pressureSensor, INPUT);
  pinMode(Trig, OUTPUT);   pinMode(Echo, INPUT);
  pinMode(LEDR, OUTPUT);   pinMode(LEDB, OUTPUT);
  attachInterrupt(digitalPinToInterrupt(flowSensor), flowCount, RISING);
//Initiallization
  Rtc.begin();   dht.begin();
  Wire.begin();
  lcd.begin();
  Esp.begin(115200);
  Serial.begin(9600);
  lcd.setCursor(0,0);
  lcd.print(">>WELCOME TO...");
  delay(3000);
  for(char col=0;col<19;col++)
{
    lcd.setCursor(col,1);
```

```
    lcd.print('.');
    delay(500);
  }
delay(4000);
  lcd.setCursor(4,2);
  lcd.print("_RABEC FUEL_");
  lcd.setCursor(1,3);
  lcd.print("MONITORING SYSTEM.");
  delay(3000);
  Beep();Beep();
  digitalWrite(flowValve,HIGH);
}
```

//main cycle

```
void loop()
{
//Sensor read and quantization
  currentTime=millis();
  DateTime now = Rtc.now();
  Date=String(now.hour()) + ':' + String(now.minute()) + ',' + String(now.day()) + '/' +
String(now.month())+ '/' + String(now.year());
  Hum = dht.readHumidity();
  Temp = dht.readTemperature();
  if(analogRead(MQ)>500)
    gasLeakage=true;
  else
    gasLeakage=false;
  for(char i=0;i<20;i++)
{
    Total=Total + analogRead(ThermistorS) * (5.0 / 1023.0);
    delay(1);
  }
```

```
Average=Total/20;
  Total=0;
  R = (Average * 15) / (5 - Average);
  fuelTemp = ( 1 / ((1 / 298.15) + ((log(R / 15)) / 3950)));
  fuelTemp = fuelTemp - 274.15;
//Pressure calculation
  voltRead=(analogRead(pressureSensor)*5.0)/1024;
  pressurePascal=(3.0*(voltRead-0.475))*1000000.0;
  pressureBar=pressurePascal/10e5;
  pressurePsi=pressureBar*14.5038;
//Fuel flowmeter
  if(currentTime - previousTime1 > flowCalculation)
{
    previousTime1 = currentTime;
    if(count!=0)
{
      ltMinute = (count / 7.5);
      ltMinute=ltMinute/60;
      if(ltMinute>0)
        Volume= Volume + ltMinute;
    }
  }
//Ultrasonic sensor readings
  digitalWrite(Trig,HIGH);
  delayMicroseconds(10);
  digitalWrite(Trig,LOW);
  duration=pulseIn(Echo,HIGH);
  Distance=0.017*duration;
  if(Distance>=25)   Distance=25;
  if(Distance<=0)    Distance=0;
```

```
  duration=0;
  TankLevel=map(Distance,0,25,100,0);
  disp[0]=(TankLevel/100)%10;
  disp[1]=(TankLevel/10)%10;
  disp[2]=TankLevel%10; //Sensor read and quantization
//Display
  if(sCrn<10)
{
    if(sClr!=1)
      lcd.clear();
    sClr=1;
    lcd.setCursor(2,0);
    lcd.print(Date);
    lcd.setCursor(0,1);
    lcd.print("EnvTmp:");
    lcd.print(Temp,1);
    lcd.print(char(223));
    lcd.print('C');
    lcd.setCursor(14,1);
    lcd.print("Rh:");
    lcd.print(Hum);
    lcd.print('%');
    lcd.setCursor(0,2);
    lcd.print("TANK:");
    lcd.print(fuelTemp,1);
    lcd.print(char(223));
    lcd.print('C');
    lcd.setCursor(12,2);
    lcd.print("Psi:");
    lcd.print(pressurePsi,1);
```

```
      lcd.setCursor(0,3);
      lcd.print("LV(%):");
      lcd.print(disp[0]);
      lcd.print(disp[1]);
      lcd.print(disp[2]);
      lcd.setCursor(10,3);
      lcd.print("(L):");
      lcd.setCursor(14,3);
      if(Volume<10)   lcd.print('0');
      lcd.print(Volume,1);
   }
else
{
      if(sClr!=2)
         lcd.clear();
      sClr=2;
      lcd.setCursor(2,0);
      lcd.print(Date);
      lcd.setCursor(0,1);
      if(gasLeakage)
         lcd.print("!!! GAS LEAKAGE. !!!");
      else
         lcd.print("**No_GAS LEAKAGE..**");
      lcd.setCursor(2,2);
      if(tankLevel<20)
         lcd.print("LEVEL BELOW MIN.");
      else
         lcd.print("LEVEL OK....");
      lcd.setCursor(0,3);
      if(fuelTemp>40||Temp>50)
```

```
      lcd.print("ALERT::ABNORMAL TEMP");
    else
      lcd.print("NORMAL TEMP. RANGE");
  }sCrn++;
  if(sCrn>15)
    sCrn=0;
//Alarm
  if(fuelTemp>40||Temp>50||tankLevel<20||gasLeakage){
    if(currentTime - previousTimeBeep > beepTime){
      previousTimeBeep=currentTime;
      Beep();   Beep();
    }
digitalWrite(LEDR,LOW);
    digitalWrite(LEDB,HIGH);
  }
else
{
    digitalWrite(Alarm,LOW);
    digitalWrite(LEDR,HIGH);
    digitalWrite(LEDB,LOW);
  }
//Communication
  if(currentTime-previousTime>dataLog){
    dataSent();
    previousTime=currentTime;
  }
//SMS
  if(tankLevel<20){
   if(smsLevel)
     SendSms("Tank Level Below Minimum");
```

```
    smsLevel=false;
   }
else
     smsLevel=true;
  if(pressurePsi<0.5){
    if(smsPsi)
      SendSms("Pressure is lower");
    smsPsi=false;
   }else
     smsPsi=true;
   if(fuelTemp<50||fuelTemp>120){
    if(smsTemp)
      SendSms("Temperature is abnormal");
    smsTemp=false;
   }else
     smsTemp=true;
   if(Hum<50||Hum>80){
    if(smsHum)
      SendSms("Humidity is abnormal");
    smsHum=false;
   }
else
     smsHum=true;
   if(gasLeakage){
    if(smsGas)
      SendSms("Gas leakage detected");
    smsGas=false;
   }
else
     smsGas=true;
```

```
  delay(500);
}

//Flow interrupt
void flowCount(){
  count++;
}
//Beeping
void Beep(){
  digitalWrite(Alarm,HIGH);
  delay(70);
  digitalWrite(Alarm,LOW);
  delay(70);
}
//GSM SMS
void SendSms(String message){
  Serial.println("AT+CMGF=1");    //To send SMS in Text Mode
  delay(200);
  Serial.println("AT+CMGS=\"+255758034053\"\r");
  delay(200);
  Serial.print("Dear Operator!");
  Serial.println(message);
  delay(300);
  Serial.println((char)26);//the stopping character
  delay(500);
}//SMS
void dataSent(){
  Esp.print(Temp); Esp.print(',');
  Esp.print(Hum); Esp.print(',');
  Esp.print(fuelTemp); Esp.print(',');
```

```
  Esp.print(TankLevel); Esp.print(',');
  Esp.print(pressurePsi); Esp.print(',');
  Esp.print(gasLeakage); Esp.print(',');
  Esp.print('#');
}
```

Appendix 6: Final Developed Prototype

(i) Final Developed Prototype for Fuel Monitoring System

(ii) Project Demonstration within the RABEC

(iii) Developed System Testing within RABEC

(iv) Developed Prototype Operational working explanation

RESEARCH OUTPUTS

(i) Research Paper

Ntambara, B., Nyambo, D., & Solsbach, A. (2023). Iot-Based on Boiler Fuel Monitoring System: A Case of Raha Beverages Company Limited, Arusha-Tanzania.

(ii) Poster Presentation

Appendix 7: Poster Presentation

IoT-BASED ON BOILER FUEL MONITORING SYSTEM: A CASE OF RAHA BEVERAGES COMPANY LIMITED, ARUSHA-TANZANIA

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ABSTRACT

The RAHA Beverages Company (RABEC) in Arusha-Tanzania is implementing an IoT-based fuel monitoring system to improve fuel usage and conditions. The current system, which uses a dropping stick, is time-consuming, inaccurate, and inefficient. The study aimed to develop an IoT-based system that provides real-time fuel conditions to prevent plant breakdowns and accidents. The system uses flow meter, ultrasonic, fuel temperature, humidity, and pressure sensors to gather data. GSM technology was used to send fuel data messages to the operator's phone, while an AT mega 328 microcontroller processed and analyzed the data. The Thing Speak IoT platform was used to visualize and aggregate fuel data using Wi-Fi connectivity. The system alerts operators when fuel level is below the threshold value, and at 0.1Psi pressure, 120°C temperature, and 80% humidity, it notifies operators to check injector pressure and fuel-air mixture. The system demonstrated high accuracy, security, and efficiency compared to the current system.

INTRODUCTION

Fuel as one of the most significant consumables is highly considered in beverage industries to be monitored remotely [1]. The IoT-based fuel monitoring system serves as a remote solution to track real-time fuel conditions from the storage tank to the boiler within production plant [2]. Through the insertion of sensors, the real-time state parameters of the fueling system in RABEC can be collected and transmitted to the remote management platform or webpage using an IoT web server platform like ThingSpeak [3].

SYSTEM DESIGN ARCHITECTURE

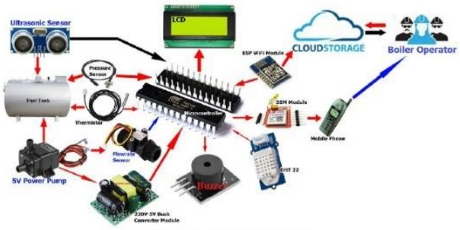

Figure 1. System Design

FLOWCHART DIAGRAM

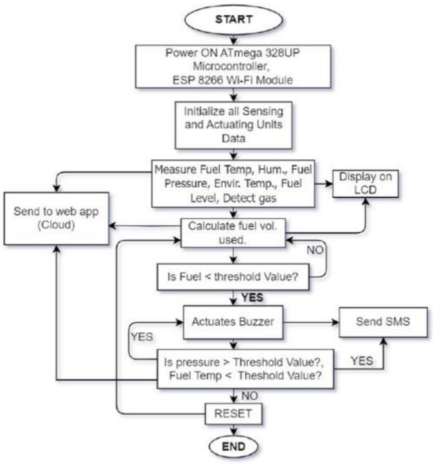

Figure 2. Flowchart of the developed system

HARDWARE PROTOTYPE

Figure 3. Prototype

DASHBOARD PAGE

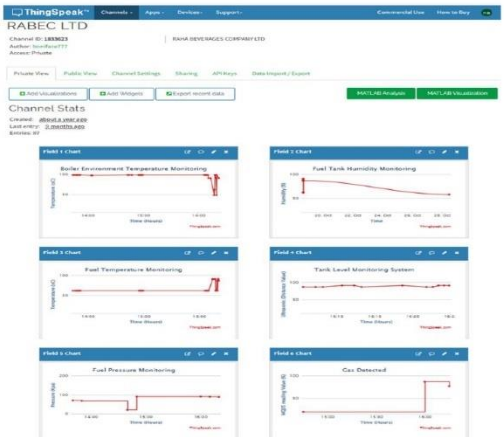

Figure 4. Dashboard page.

CONCLUSION

The IoT fuel Monitoring system wad developed, tested, and validated. The sensing and actuating units that attached to microcontroller were communicated. The fuel data were accessed via phone and displayed on LCD. The operator was able to access fuel data via ThingSpeak platform by login credentials. The developed system has proved efficient, reliable, and accurate compared to the current system.

REFERENCES

[1] G. Promise E., "Automation of Fuel Tank Level Monitoring and Measurement," International Journal of Engineering Science Invention (IJESI), vol. IX, no. 8, pp. 43-49, 2020.

[2] G. P.Geethabai ME., "Design and Implementation of GSM Based Digital Fuel Meter and Fuel Theft Detection Using PIC Microcontroller," IOSR Journal of Electronics and Communication Engineering, pp. 11-14, 2020.

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