ASHESI UNIVERSITY

MONITORING SYSTEM OF A PORTABLE HOUSEHOLD-SCALE BIODIGESTER

CAPSTONE PROJECT

B.Sc. Electrical and Electronic Engineering

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2022

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CAPSTONE PROJECT

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

Kuzivaishe Emmaculate Chibiso

2022

DECLARATION

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

Candidate's Signature:

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Candidate's Name: Kuzivaishe Emmaculate Chibiso

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Date: 25 April 2022

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

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Supervisor's Name:

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Date:

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Abstract

The ever-increasing amount of waste as the population grows prompted the primary concern of identifying various methods for reducing the growing amount of waste, in this case, biowaste. Anaerobic digestion methods, when applied to biomass waste, are a cost-effective approach to generating energy while also addressing environmental concerns. The few biodigesters that have been used on the African continent do not live up to their expected life-span. And this is because of lack of a control mechanism to monitor the degradation process in the biodigester. Biodigester monitoring systems that have been used mainly in the developed countries target large bio-energy generating plants. However, these monitoring solutions cannot be used with small house-hold scale biodigesters because of their complexity and high cost. In this project, a low-cost monitoring system of a household-scale biodigester is implemented to help improve the functionality of the biodigesters and in turn increase their life-span.

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Chapter 1: General Introduction

1.1 Background

In recent years, there has been a spike in interest in small-scale biogas systems across Africa. The socioeconomic and environmental benefits of biogas, which include reduced fossil fuel and firewood usage, lower greenhouse gas emissions, and the capacity to manage human, animal, and household waste efficiently, have fuelled the technology's adoption. Biogas technologies are considered to be sustainable, safe, and efficient biotechnologies, with the carbon footprint reduced significantly by CH4 capture and fossil fuel substitution. Methane, the biodigester's primary output, can be used for a variety of purposes, including cooking energy, renewable vehicle fuel, small-scale electricity or heat generating, and energy distribution grids.

The fermentation process that produces methane gas in the biodigester is very dynamic and consists of four primary processes: hydrolysis, acidogenesis, acetogenesis, and methanogenesis[1]. If one of these processes is disrupted, it may have a direct impact on the following phase, perhaps causing the biodigester to become unstable. The problems that could emerge in the biodigester if any of the biological processes is inhibited include, but are not limited to, inhibition of volatile fatty acids, hydraulic overload, organic overload, and ammonia inhibition. Process perturbations generated by digestion operational parameters and/or influent substrate characteristics create digester upsets[2], [3].

To avoid process upsets in the bio-digester, it is vital to configure the system properly and to monitor and manage all operational parameters closely in order to keep environmental variables stable and within acceptable ranges. Monitoring will assist in providing an overview of the biogas process and identifying any impending instabilities in the biodigesters before to their ultimate failure [2]. The entire cost of monitoring would be less than the expense of re-establishing the biodigester in the event it failed. The purpose of this project is to monitor the parameters that influence the stability of the anaerobic degradation process in the biodigester.

Any biogas digester generates its own process conditions for the target parameters; there is no universally accepted value for each process [1]. However, there is an optimal range of parameter values that must be maintained. It is critical to determine characteristics that characterize the degradation process in a biodigester, such as fermentation temperature, pH, alkalinity, volatile fatty acids, total ammonia-nitrogen, and gas composition. Monitoring these parameters throughout the life of the biodigester would enable rapid identification of deviations from 'normal' and the underlying causes of the process stability changes. It is critical to implement a real-time monitoring system that processes parameter data in real-time in order to increase efficiency, increase automation, and generate predictions about the digester's future performance [4], [5] .

Sensors connected to a network are capable of sensing and monitoring their environment, communicating with one another, and cooperating productively. Sensors generate enormous amounts of measurement data, which must be processed. To process this data, an appropriate communication protocol would be required to support data routing and message handling between sensor nodes, as well as from sensor nodes to optional gateways or centralized cloud computing. The biodigester's monitoring system is based on a sensor network. The sensor nodes are arranged in the biodigester to gather temperature, pH, and gas composition data in accordance with the specification of the data to be read. The collected data is analysed and uploaded to a cloud server, thereby establishing a data collection and early warning system. Users can access the database to obtain timely information on the biogas digester and to view the data visually via a dashboard.

1.2 Problem Definition

The increasing rate of waste material generation as the population grows has prompted the primary concern of identifying various methods for reducing the growing amount of waste, in this case, biowaste. Anaerobic digestion methods, when applied to biomass waste, are a cost-effective approach to generating energy while also addressing environmental concerns. They are believed to be sustainable, safe, and efficient biotechnologies that absorb CH_4 and thus help to mitigate global warming. However, the cost of importing ready-made biodigesters from countries such as India, China, and Israel is prohibitively costly, discouraging widespread use of this biogas technology in Sub-Saharan Africa [4]. And, of the few digesters utilized on the continent, the majority lack a control mechanism to monitor the degrading process; as a result, the digesters frequently become inefficient and have a life duration of only one or two years. The purpose of this project is to build and construct a low-cost system for controlling and monitoring a portable household-scale biodigester. The system should be capable of providing real-time information about the degradation process, which users can utilize to regulate the digester.

1.3 Motivation

The motivation of this project is to improve the life span of small-scale biodigesters through monitoring the operating conditions and make biodigester control and monitoring accessible and affordable to an average African, taking into consideration the future of green fuels as a source of energy.

1.4 Project Objectives

1. Design a Wi-Fi-based biodigester control and monitoring system.
2. Minimise the cost of the monitoring system.
3. Improve the lifespan of small-scale biodigesters.

1.5 Scope of Work

The main goal of this project is to create a monitoring system for a bio-digester in order to track parameters that could interfere with the biodigester's normal operation. Temperature and pH will be measured to determine the operational status of the biodigester, as well as methane gas concentration, which is a critical indicator of the biodigester's proper functioning. To successfully monitor the system, the user must be able to receive real-time reports on digester operations so that they can determine whether or not action is required in the event of a biodigester malfunction.

Chapter 2: Literature Review

Renewable and clean energy sources became the talk of the twenty-first century due to their ability to significantly cut greenhouse gas emissions while also reducing demand on the national grid. Nowadays, biomass is being used as a clean source of energy [8]. Biomass is converted into useful gas that can be used to heat or power other systems via the usage of biodigesters. The performance of these biodigesters is dependent on a variety of characteristics that affect the fermentation process, which is why past research has concentrated on developing methods for monitoring biodigesters. This chapter summarizes and synthesizes the study and work that has been conducted to develop various pre-existing solutions. The section reviews three research projects that were once carried out to monitor and/or understand the operating conditions of a biodigester. Lastly, the chapter will give an insight into what the project seeks to achieve and the improvement that it will make from previously built monitoring systems.

[6] presented a system for monitoring biodigesters. The created monitoring system was based on a sensor network. The authors intended to send data collected by the sensors to a cloud server through General Packet Radio Service (GPRS). GPRS is a legacy wireless data transfer protocol that is commonly referred to as 2G. GPRS employed packet-switched data rather than circuit-switched channels. Data transmissions through GPRS are quite sluggish. Today's high-speed data networks, such as 4G and 5G, are superior. With huge connectivity, the 5G network is projected to propel the Internet of Things to new heights. By 2023, it was anticipated that twenty billion gadgets would be connected. With the development of 5G networks, it will be feasible to link low-cost devices with extended battery life in order to send critical data without incurring any latency. However, the authors did not test the system with a genuine biodigester; instead, they created their own conditions and simulated them using the Arduino Simulator. They measured pH,

temperature, and pressure. In this project, the data values of the measured parameters, pH, temperature, and methane content will be measured directly from the biodigester and collected into a database for analysis.

In 2008, a group of ITCR researchers [7] collaborated on the development of a biodigester control system. Their primary objective was to explore innovative methods for optimizing biogas production. There are critical characteristics that affect the four primary processes that occur inside the digester during the biogas generation process. Hydrolysis, acidogenesis, acetogenesis, and methanogenesis are these processes. These processes are carried out by a diverse array of microorganisms that are extremely sensitive to environmental conditions. The authors constructed mathematical factors to quantify biogas productivity after determining how to monitor the environmental conditions affecting the microbial community. They next concentrated on the chemical and physical elements that affect biogas production. They focused on chemical parameters such as substrate compositions, substrate pairings with fat, and the presence of inhibitors. They investigated three physical factors: protein exclusion, solids removal, and phase separation.

The authors estimated methane productivity using a mathematical expression with the assumption that the organic waste is known and the time of the reaction to take place. The formula that they used was: $P_{CH4} = \frac{V_{CH4}}{V_{reactor} \times t}$, where V_{CH4} was the volume of the methane produced, $V_{reactor}$ was the volume of the matter placed in the fermentation chamber and t was the time for production. As mentioned earlier on, methane produced depends on the type of organic matter that is put into the digester system. A mathematical expression that they used to determine methane production for a certain type of organic matter was $M_{max} = \frac{V_{CH4}}{S_{org\ total}}$, where V_{CH4} is the methane produced and $S_{org\ total}$ is the amount of organic matter used in the fermentation process. The equations that they used give an estimate of the amount of gas produced based on the initial conditions approximated at the beginning of the process, the equations do not encompass the variations that happen in between the process. Environmental conditions fluctuate over time and have a direct impact on the fermentation process in the digester. Thus, this project is relevant in measuring real-time data of methane generation over time.

The last article that was considered in reviewing related work on monitoring the conditions of a biodigester had a design that is almost similar to what this project hopes to achieve. [8] designed a smart system that was made up of a sensor network, GPRS intelligent gateway, and cloud server. To relay data from the sensor nodes to the control center they used Zigbee. Zigbee was most suitable for their project because their sensor nodes were within a short distance, a few tens of meters, from the control center and management center which was an office that was within the farm where they were taking their measurements. Zigbee network is aimed at smart objects that have low bandwidth and low power needs. It has a communication range of ten to a hundred meters compared to Wi-Fi which has a range of 100 meters. They had an intelligent gateway that relayed data between the sensors and the cloud server. In this project, the data that is collected from the sensors will be communicated from the microcontroller directly to the database by the use of Wi-Fi. The objective of this project is to develop a low-cost monitoring system for a biodigester; thus, Wi-Fi would be suitable for the project because it is less expensive.

The review of the previous work that has been done to monitor biodigester conditions showed that there are a number of parameters that can be measured from the biodigester. The choice of which parameters to measure depends on the criterion that one would want to determine the proper functioning of the digester. In this paper, the parameters that will be measured are temperature and pH. pH is directly affected by the changes in temperature. Controlling the process temperature in the biogas digester is critical since a steady temperature is required for the microorganisms to work optimally. The ideal fermentation temperature is determined primarily by the bacteria involved and ranges between 36 and 43°C for mesophilic degradation and 50–65°C for thermophilic degradation. Additionally, fermentation temperature has an effect on other factors, such as ammonia dissociation and inhibitory action which in turn affect the pH level of the biodigester. As the concentration of the undissociated form of ammonia (NH3(aq)) increases with increasing temperature, thermophilic fermentation is unfavorable for decomposing protein-rich feedstocks [1],[2]

The pH value provides an approximation of the fermentation process's status. Due to the buffer capacity of biogas plants, which is dependent on dissolved CO2, carbonate, and ammonia, a pH change is visible only after the process becomes unstable. As a result, while measuring the pH value does not serve as an early indicator of process imbalance, it does provide critical information for process monitoring [1].

This project will also improve the work done in the reviewed projects by including a dashboard on which the user will be able to view and monitor the status of the fermentation process inside the biodigester. This will enable the user to act accordingly in the event that there is a biodigester malfunction.

Chapter 3: System Design and Component Selection

3.1 System Overview

The system is made of two main parts, namely; software and hardware. The hardware part of the system is made up of sensors, a microcontroller, and an LCD display. The software part of the system is made up of a MySQL database, a microcontroller program, and a dashboard for data visualization. Figure 3.1 shows the overall system in a block diagram.

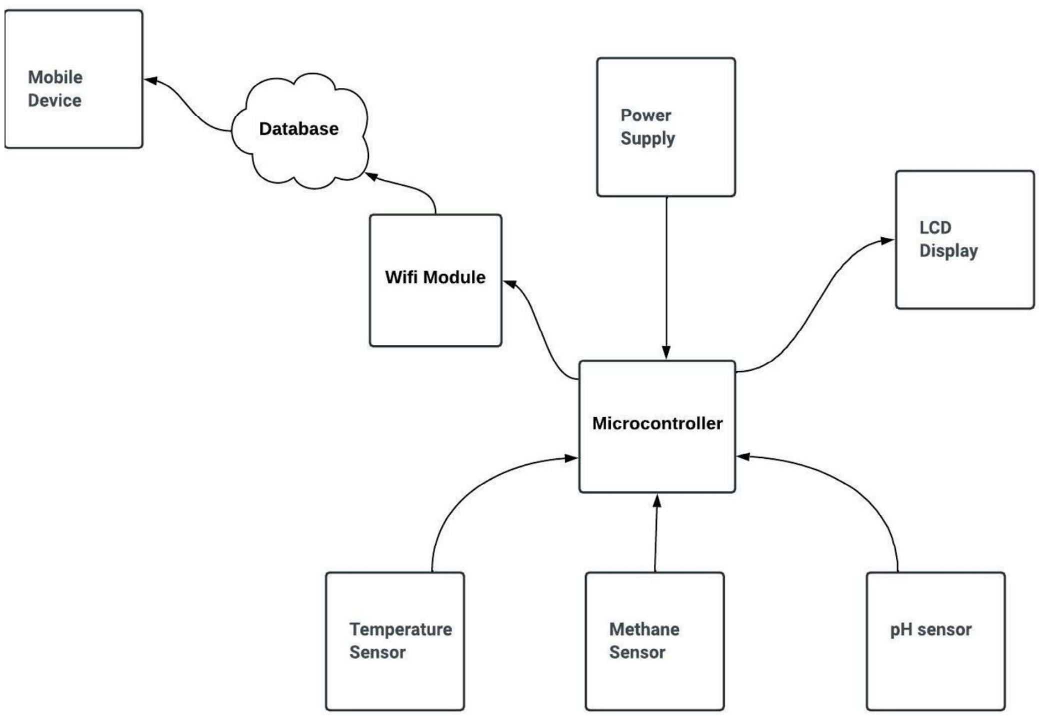


Figure 3. 1: Block diagram of the overall system

A sensor is a smart object that is capable of interacting with the physical world. The sensors collect data from the environment. The data captured from the environment, biodigester, are temperature, pH, and methane concentration. The microcontroller program processes the collected data and sends this data to the cloud database by means of a Wi-Fi module. The data is extracted from the database and processed to produce useful information for the user. The user will be able to view the status of the fermentation process in the biodigester through a dashboard that can be accessed using a mobile device or a computer. On the site of measurement, the readings of the parameters captured by the sensors are displayed on an LCD which is also controlled by the microcontroller. The user is also able to proactively check the status of the parameters using their mobile device.

3.2 Design Specifications

1. The system should accurately determine the condition of the parameters inside the biodigester.
2. The system should communicate information about the measured readings to the user wiressly
3. The system should be power self-sufficient.
4. The measurement of the parameters should be done in regular intervals.
5. The user must be able to view the status of the measured parameters via a dashboard.

3.3 Design Requirements

1. The system should be low-cost.
2. The system should have low power consumption.

3.4 Design Decisions

This section outlines the decisions that were made in selecting the different components that were used for the project.

3.4.1 Wireless Technology

A wireless technology that will be selected for this project will be used to communicate the data processed by the microcontroller to the database. This will require a stable wireless technology that is inexpensive.

Table 3. 1: Pugh chart for deciding which wireless technology to use

Criteria	Weight	Bluetooth	Zigbee	Wi-Fi	GSM (2G)
Communication Range	5	0	+1	+1	+1
Cost	5	0	-1	-1	-1
Mobile Device Integration	5	0	+1	+1	+1
Power Consumption	4	0	+1	-1	-2
Security	2	0	-1	-1	-1
Total		0	+7	-1	-5

Table 3.1 shows that Zigbee would be the best option for this project, however, Zigbee is a bit costly. Therefore, Wi-Fi will be used for this project, specifically the IEEE 802.11ah access technology. This wireless technology is a development of the IEEE 802.11 working group to define “industrial wifi.” IEEE 802.11ah provides adequate support for low-power devices and those that require sending data in smaller bursts at slower rates.

3.4.2 Microcontroller/Development Board

The microcontroller that will be used in this project must meet the following functional requirements:

- Should be low cost
- Should have a low power consumption
- Should have a Wi-Fi module

Table 3. 2: Pugh chart for deciding which development board to use

Criteria	ESP8266	Raspberry Pi Pico	ESP32	Arduino Nano 33 BLE
Clock Speed	0	+1	+1	-1
Cost (Development board)	0	+1	-1	-1
Power Consumption	0	+1	+1	+1
GPIO Architecture	0	+1	+1	+1
Connectivity	0	0	0	-1
Total	0	+4	+2	-1

The microcontroller that will be used for the project is the ESP32. Even though the Raspberry Pi Pico came out as the best option, it cannot be easily connected using wireless technologies. Thus, ESP32 was chosen because it can be easily connected using wireless technologies.

Figure 3. 2: Development board (ESP32) [9]

The ESP32 is a dual-core CPU, which implies it contains two processors. The chip includes integrated Wi-Fi and Bluetooth. The development board is equipped with 30 pins and is capable of running 32-bit programs. The ESP32 development board features a diverse set of peripherals, including capacitive touch, ADCs, DACs, UART, SPI, and I2C [10].

3.4.3 Network Topology

For connecting IoT devices, three main topology schemes are available which are a star, mesh and peer to peer.

Table 3. 3: Pugh chart for designing which network technology to use

Criteria	Weight	Peer to peer	Star	Mesh
Range	4	0	+1	-1
Cost	5	0	-1	-1
Reliability	4	0	+1	+1
Security	3	0	+1	-2
Complexity	5	0	-1	-2
Total	-	0	+1	-21

Table 3.3 illustrates the criteria that were used to select the network topology that meets the design requirements. From comparative analysis, the star network topology was chosen over the mesh and peer-to-peer topology. The star network topology is simple and efficient. With the star network topology, you can also remove any of the sensor nodes without affecting the rest of the network. It also allows the use of a single microcontroller which becomes the central hub, this reduces the cost of implementing the network.

3.4.4 Sensors

The sensors that are to be used in this project have common functional requirements that they should all meet before they are considered for use. Some of these functional requirements include:

- The sensors should be able to read without mechanical interventions.

- The sensors should have the capability to be interfaced with a microcontroller
- The sensors should be sensitive and responsive to changes in the physical environment

3.4.4.1 Temperature Sensor

The temperature sensor should be able to measure temperature within a range of 20 - 70°C. Mesophilic anaerobic digestion temperatures can get as low as 25°C while thermophilic anaerobic digestion temperatures can get as high as 60°C [1].

Table 3. 4: Pugh chart for designing which temperature sensor to use

Criteria	AS PT-1000	DFRobot: DS18B20	Gikfun
Temperature range	0	0	0
Sensitivity	0	-1	-1
Interfacing	0	0	0
Immersion	0	+1	-1
Cost	0	+1	+1
Accuracy	0	+1	+1
Total	0	+2	0

Table 3. 5: Full definition of short form names used in Table 3.4.

Short form in Table 3.4	**Full name**
AS PT-1000	Atlas Scientific PT-1000 Temperature Kit
DFRobot: DS18B20	DFRobot: Waterproof DS18B20 Digital temperature sensor for Arduino
Gikfun	Gikfun Digital temperature sensor for Arduino
Interfacing	Ability to be interfaced with a microcontroller
Immersion	Ability to be submerged in the solution

The temperature sensor that will be used for this project is the DS18B20 temperature sensor. The sensor can measure temperatures within a range of -55°C - 125°C. The sensor has an accuracy of +/- 0.5°C and requires only one digital pin for communication. The sensor has a 1m cable which gives room for immersion into the biodigester [11].

3.4.4.2 pH Sensor

The pH sensor that should be selected for this project should be able to measure pH within a range of pH0-14, although biodigester pH does not normally fall to a value below 4.5 [7].

Table 3.5: Pugh chart for deciding which pH sensor to use.

Criteria	Effluent ltd	DFROBOT: Pro V2	4502C pH sensor
pH range	0	0	0
Sensitivity	0	+1	+1
Interfacing	0	0	0
Immersion	0	+1	0
Accuracy	0	+1	-1
Cost	0	-1	+1
Total	0	+2	+1

Table 3. 6: Full definition of short form names used in Table 3.5.

Short form in Table 3.5	**Full name**
AS PT-1000	DFROBOT: Analog pH meter Pro V2 Professional pH sensor
DFRobot: DS18B20	DIY More PH-4502C pH sensor
Gikfun	pH probe (Automated Water and Effluent ltd)
Interfacing	Ability to be interfaced with a microcontroller
Immersion	Ability to be submerged in the solution

The pH sensor that will be used in this project is the DIY More pH sensor. Table 3.5 shows that the DFrobot pH sensor would have been the best option for this project, however, the sensor is way more expensive than the DIY More pH sensor. The accuracy of the DIY more pH sensor can be improved by calibrating it well, the DFrobot pH sensor is factory calibrated. The DIY More pH sensor is made up of a sensitive glass membrane with low impedance measurements with fast response and excellent thermal stability. The sensor has a 1m long cable which makes it suitable for continuous submersion. It measures pH values within a range of pH0 – 14 and temperature conditions of 0-60°C [12].

3.4.4.3 Methane Sensor

The methane sensor that will be used for this project must be able to detect and measure methane gas concentration in parts per million. The methane sensor that will be used for the project is the MQ-4 gas sensor. It has low power consumption, and can be powered using a microcontroller. MQ-4 methane gas sensor is the only school-project worth sensor that is available on the market [13].

3.4.5 Power Supply

In IoT, there are powered nodes and battery-powered nodes. A powered node is one that has a direct connection to the power source and normally the communications are not limited by power consumption. However, the deployment of powered nodes is limited by the availability of a power source, which makes mobility more complex. Battery-powered nodes offer more flexibility to IoT devices. IoT wireless technologies address the needs of low power consumption and connectivity for battery-powered nodes. This has led to the evolution of a new wireless environment known as Low-Power Wide Area (LPWA). It is possible to run any wireless technology on batteries. However, no operational deployment would be acceptable if hundreds of batteries have to be changed every now and again [14].

The devices that will be used in this project are constrained devices which span across all the three classes of constrained devices. The main aspect of this project that would consume the most power is the communication between the microcontroller and the database. The wireless access technology that was chosen for this project to handle the communication is well suited for connecting the constrained devices. The power supply that will be used for this project is the battery power supply, for the reasons that are mentioned above.

3.4.6 Sampling Frequency

When it comes to choosing the monitoring frequency for a biodigester monitoring network, there are two primary approaches: low frequency and high frequency. The low-frequency technique may be advantageous when the monitoring network's objective is to characterize the performance of big biodigesters over an extended period of time in order to discover seasonal fluctuation or long-term trends. In these instances, sampling frequency recommendations range from monthly to tri-monthly or even half-yearly. A low-frequency technique is not appropriate in small study areas or biodigesters, as discharges and atmospheric events induce more abrupt changes in biodigester functioning. Continuous high-frequency monitoring procedures are suggested in the literature for small research areas [15].

When choosing the sampling frequency, there are two parameters that should be taken into consideration namely: sampling rate and the number of samples or data points required. The sampling rate refers to the frequency at which data samples will be captured from the sensor devices [16]. The aim of this project is to monitor the operation of the biodigester in relation to the key operators that might inhibit the fermentation process inside the digester. A total of ten sample values would be collected at equal intervals within this four-hour period and the average value calculated. The average value of these ten recorded values is the one that would be communicated to the database. In a day this would result in six data values being communicated to the database for each of the three parameters under consideration. There is a need to keep the power consumption used for communication at minimal levels thus the frequency of sending data to the database should take this into account.

Chapter 4: Implementation and Testing

4.1 Chapter Overview

This chapter outline the key steps that were taken in implementing the project from calibrating the sensors to integrating the components to the circuit. It gives a detailed overview of how each experiment was set up.

4.2 Sensor Calibration

Calibrating is a term that refers to the process of determining the accuracy of an instrument (in this case, a sensor) in comparison to predefined standards [17]. The primary goal of calibration is to reduce measurement uncertainty and to assure both precision and consistency. Calibrating sensors ensures that they operate at their best rate and give the maximum possible accurate performance.

4.2.1 pH sensor: DIY More PH-4502C

Figure 4.0 1: pH sensor DIY More PH-4502C

The pH-sensitive element in the case of glass electrodes is the glass bulb fused to the end of the glass electrode. The glass electrode is filled with a potassium chloride buffer solution with a pH of 7 and is connected with a silver chloride wire. When the pH sensor is immersed in a solution, the solution's hydrogen ions penetrate the glass bulb's outer membrane. The same process occurs within the sensor, using a neutral solution buffered to pH 7 and containing a constant concentration of hydrogen ions. Additionally, the hydrogen ions permeate the glass bulb's inner membrane. When the pH concentration within is different than the pH concentration on the outside, a detectable potential difference is generated. When the hydrogen concentration on the outside is less than the pH inside the glass bulb, a pH less than 7 is recorded; conversely, when the hydrogen concentration on the outside is greater than the pH inside the glass bulb, a pH more than 7 is recorded [12].

4.2.1.1 Calibration of DIY More PH-4502C

The pH sensor board outputs a voltage signal, which must be mapped to a pH value. Ideally, with a 5V analog output, a 0V output indicates a PH 0 and a 5V output represents a PH 14. PH 7 on the sensor board is set to 0V by default. Calibration is required since, in the presence of an acidic PH, the output voltage will be negative, which cannot be read by the analog channels on the NodeMCU. It is also important to note that the maximum analog output voltage that can be read from an ADC pin on the NodeMCU is 3.3V. Thus, there is need to step down the 5V output from the pH sensor to 3.3V so that the analog voltage can be mapped correctly on the NodeMCU. This is achieved by making use of a voltage divider in this case a series of 1K ohm and 2K ohm resistors were used. The offset port is used to calibrate the probe such that it reads 1.65V on the NodeMCU analog channel when connected to a PH 7. To establish the offset, the outside of the BNC connector is shorted to the inside, as illustrated in figure 4.02.

Figure 4.0 2: Short-circuiting pH sensor board

The short circuit simulates a neutral pH. The code in fig 4.03 below reads the output voltage from the analog pin of the sensor. The offset pot (trimmer) on the sensor board is adjusted until the voltage output reads 1.65V.

```
float Voltage;
int potPin= 34;

void setup() {
 Serial.begin(115200);
 pinMode(potPin, INPUT);
}

void loop() {
  float potValue = analogRead(potPin);
  Voltage = potValue*(3.3/4095.0);
  Serial.println(Voltage);
  delay(500);

}
```

```
COM8

1.66
1.65
1.65
1.66
1.65
1.65
1.66
1.65
1.65
1.66
1.65
1.65
1.66
1.65
1.65
1.66
1.65
1.65
```

Figure 4.0 3: Short-circuiting pH sensor board Arduino code

The code prints the analog pin's voltage value to the serial monitor. In the main loop, a variable (pH pot) must be created to store the potentiometer's resistance value (which is a number between 0 and 4095). To convert the values from the 0-4095 range to the analog pin's voltage range, create another variable (Voltage) that stores scaled values between 0.0V and 3.3V.

4.2.1.2 Connecting the pH Probe

There was a need to test and see if the pH probe would read accurate pH values. Ideally, it would be preferable to use buffer solutions with known pH values. Due to the lack of these buffer solutions, simple liquids such as distilled water, lemon juice, and water with washing powder were used to test the accuracy of the pH probe. It was important to keep the conditions for all the test experiments the same. For example, the level of the solution, placement of the pH probe, and the time of measurement. The tests were carried out as shown in figure 4.04 below.

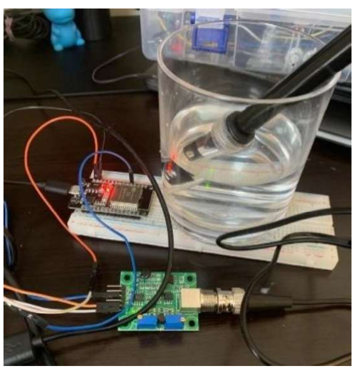


Figure 4.0 4a: Water

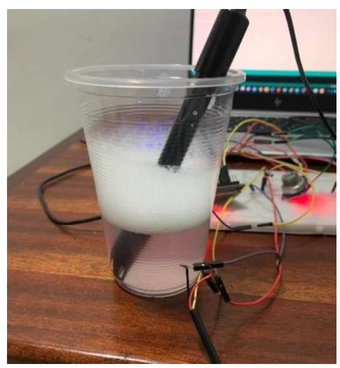


Fig 4.0 4b: Washing detergent

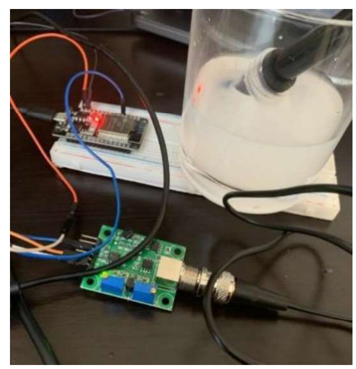


Fig 4.0 4c: Lemon juice

The volume of the water that was used in each of the pH test experiments was measured using a small cup used in the kitchen to ensure that the same volume was attained for all three experiments. For each experiment, the pH probe was left in the solution for 2 minutes before the pH was read from the serial monitor. A set of ten recordings were made for each experiment. In transitioning the pH probe from one solution to the other, the pH sensor was cleaned using distilled water.

The pH values for the three liquids were recorded in table 4.1 below. The ideal pH of distilled water is 7. However, any pH between a pH of 5.5 and 6.9 is acceptable depending on how long it stays open in the air. The pH of water with a washing powder is estimated to be 10 and that of lemon juice is between pH 2 and 3. Thus we can conclude that the pH sensor is accurate with an error rate of +/-7%.

Table 4. 1: Results of pH sensor calibration

	Distilled water	**Washing powder solution**	**Lemon juice**
Average	6.57	10.24	2.09
Error rate (%)	5.84	2.40	7.2
Accuracy (%)	94.1	97.6	92.8

4.2.2 Temperature Sensor: DS18B20

Figure 4.0 5: Temperature sensor [18]

To calibrate a temperature sensor, something with a known temperature must be measured. Additionally, a calibrated sensor could be utilized as the control experiment to validate the sensor's accuracy. The temperature of the probe was determined in this experiment using boiling water and a triple-point bath. The boiling temperature of boiling water is known to be 100°C at atmospheric pressure and that of triple point bath to be 0°C. By comparing the value that the sensor reads to the value that it should read, we may convert the value read by the DS18B20 temperature sensor to a more accurate result.

4.2.2.1 Boiling Water

In a kettle, water was heated until gas bubbles formed and the water agitated itself. The temperature sensor was immersed completely inside the kettle, ensuring that the probe makes no contact with anything other than the water. The DS18B20 temperature sensor used in this project required at least one and a half minutes of immersion in water before readings could be taken. The measured boiling temperature was recorded as High Raw. At the same time, the temperature values of the boiling water were recoded using a lab thermometer.

Figure 4.0 6: Temperature sensor immersed in boiling water

4.2.2.2 Triple Point Bath

Small ice cubes were added into a ceramic cup, small cubes were used in order to increase the surface area of the ice in contact with the temperature sensor. The cup was filled to 80% with cold water. The temperature sensor was immersed and left for one and a half minutes before readings were taken. The measured melting temperature was recorded as Low Raw. At the same time, the temperature values of the triple point bath were recoded using a lab thermometer.

Figure 4.0 7: Temperature sensor immersed in ice bath

The measured temperature values were compared with the reference values that were measured using the lab thermometer. Range values were calculated using the known values using the formulas:

- $Range\ Raw = High\ Raw - Low\ Raw$
- $Range\ Reference = High\ Reference - Low\ Reference$

The values that were obtained were recorded in table 4.2 below.

Table 4. 2: Results of temperature sensor calibration

	Triple point lab thermometer	**Triple point bath DS18B20**	**Boiling water lab thermometer**	**Boiling water DS18B20**
Average (°C)	0.0208	0.0558	99.8	98.5
Error rate (°C)	-	(+/-) 0.0351	-	(+/-) 1.29

The temperature values for the boiling water and the triple-point bath were recorded in table 2 above. The ideal boiling temperature of water at atmospheric pressure is 100°C and the triple point bath is 0°C. From the experimental test that was carried out, it was proven that the temperature sensor is accurate with an error rate of +/-1.3

4.2.3 Methane Sensor

The gas sensor detects methane gas in the surrounding atmosphere. The sensor detects a potential difference in response to the gas concentration, which alters the resistance of the chemiresistor material inside the sensor. Tin Dioxide is the sensitive material contained within the gas sensor (SnO_2). The current conducted is determined by the fact that this material is an n-type semiconductor with free electrons. Pure air has more oxygen than methane, a flammable gas. The oxygen atoms attract the free electrons in SnO_2, which remain on the oxide's surface [13].

Figure 4.0 8: Methane sensor

At this point, there is no current flow. When the sensor is placed in methane gas, the methane gas breaks the bond between the free electrons and the oxygen atoms. As the free electrons are released, the current is conducted. As the methane gas increases, the free electrons increase, and more current is conducted. Fig 4.09 below illustrates the behavior of the electrons.

The MQ4 gas sensor is normally used to detect gases only. However, the scope of this project requires finding the concentration of methane gas produced from the biodigester.

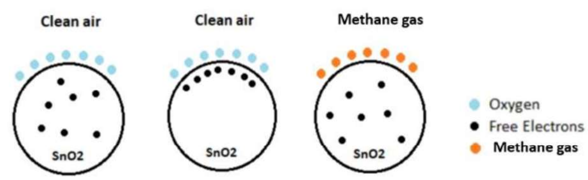


Figure 4.0 9: Illustration of electrons behavior in SnO_2 in the sensor [19]

The gas sensor's working principle is built on a variable resistor, its resistance value changes depending on the concentration of the gas. The resistance reduces as the concentration rises and the resistance rises when concentration is low. Besides the variable resistor, the sensor also has a load resistor, the purpose of this resistor is to adjust the sensitivity and accuracy of the sensor.

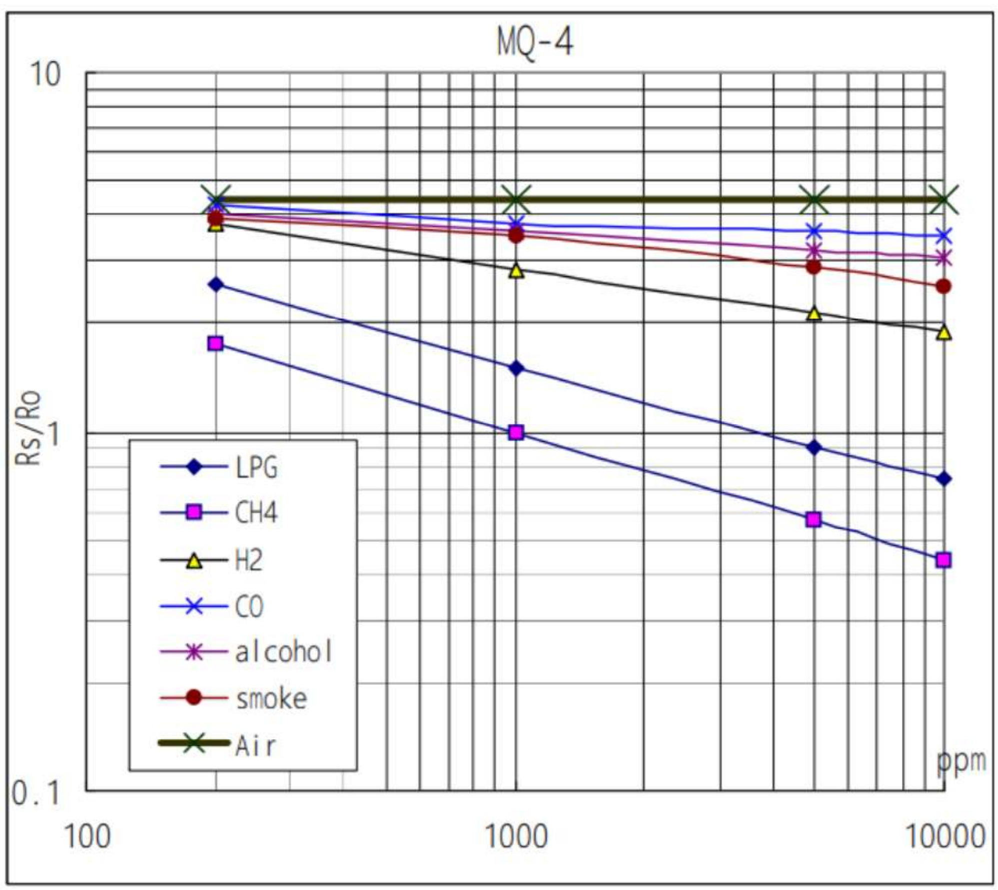


Figure 4.1 1: MQ-4 sensitivity characteristics [13]

The graph in figure 4.09 above was obtained for the MQ4 sensor datasheet. The graph shows the sensitivity of the sensor to various gases. The graph shows that the sensor is most sensitive to methane followed by LPG gas. The concentrations of the gases were recorded in parts per million (ppm) based on the sensor's resistance ration (RS/R0). R0 is the resistance of the sensor in clean air, and RS is the resistance of the sensor in the presence of the target gas.

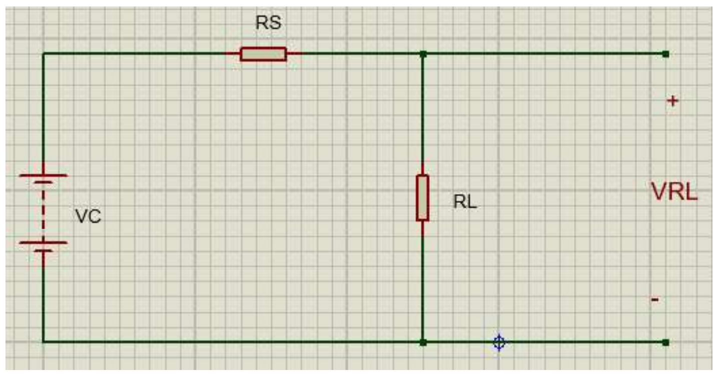


Figure 4.1 2: MQ-4 Resistance

The Ohms law was used to calculate the value of RS using the circuit diagram of the sensor that was provided in the datasheet. The circuit was simplified as shown in figure 4.12 to show the connection between RS and R0.

$$V = I \times R$$

$$VRL = \frac{VC}{RS + RL} \times RL$$

$$VRL = \frac{VC \times RL}{RS + RL}$$

$$\boldsymbol{RS = \frac{VC \times RL}{VRL} - RL}$$

In order to calculate the value of R0, the value of RS in clean air was required. This was accomplished by reading the analog signals from the sensor and changing them to voltage. Equation was then used calculate the calculate R0.

The curve shown in figure 4.11 was plotted on a log-log scale. This suggests that on a linear scale, the relationship between gas concentration and resistance ratio is exponential. The graph shows that the ratio RS/R0 in clean air is 4.4ppm. The curves on the graph were assumed to be linear. This way, it is possible to use a single formula to relate the resistance ratio and the concentration linearly. It also becomes possible to extrapolate the concentration of the gas at any resistance ratio. The formula that was used is:

$$\log(y) = mlog(x) + b$$

Two points were picked from the graph of LPG to solve for *m* and *b*. The two points that were used are (1000,1.6) and (5000,0.9). LPG was used because it is the one that was readily available for testing.

$$m = \frac{\log(y) - \log(y0)}{\log(x) - \log(x0)}$$

$$m = \frac{log\frac{y}{y0}}{log\frac{x}{x0}}$$

$$m = \frac{\log\left(\frac{0.9}{1.6}\right)}{\log\left(\frac{5000}{1000}\right)}$$

$$m = -0.357$$

To solve for *b*, a third point was chosen from the LPG graph; (200,2.6).

$$b = \log(y) - mlog(x)$$

$$b = \log(2.6) - (-0.357)\log(200)$$

$$b = 1.275$$

With the value of *m* and *b*, the concentration of the LPG gas can be found for any ratio using the formula:

$$\log(x) = \frac{\log(y) - b}{m}$$

$$x = 10^{\frac{\log(y)-b}{m}}$$

$$x = 10^{\frac{\log(y)-1.275}{-0.357}}$$

The above equations were implemented in Arduino IDE to calculate the concentration of LPG gas.

4.2.3.1 Testing the Accuracy of the pH Sensor

Gas analysis is one of the most challenging experiments to carry out because gas is very volatile. A lot of work went in to brainstorming how best the accuracy of the methane sensor could be measured. The viable solution that was then implemented made use of helium balloons; beach ball balloons could have done a better job than the helium balloons because they have a self-sealing cap, however, they were not readily available in the shops.

LPG gas was used in this experiment to test the accuracy of the methane sensor. The MQ-4 sensor is sensitive to methane, LPG and hydrogen among other gases as shown in figure 4.11. Two helium balloons were used at a time in this test. Each experiment was set up as shown in figure 4.13 below. One balloon was filled with LPG gas and the other balloon was filled with mouth blown air. The two balloons were blown to the same size. The volumes of the balloons were recorded.

The reasoning behind using this experiment was that mixing 1 balloon filled with pure LPG with 1 balloon of the same volume filled with air would yield a mixture that is 50% LPG and 50% air (i.e., 1 volume LPG distributed in 2 volumes of total gas, a 1:2 dilution). This would represent a 500,000 ppm (500,000 LPG/1,000,000 total). This is one end of the range of concentrations that would actually be needed, since a functional digester should produce gas that is >50% methane. If the experiment was repeated with the 50% LPG balloon and another balloon full of air, this would present 25% LPG, 250 000 ppm. If it was repeated again for the third time, then the concentration would be 12.5% LPG or 125 000ppm.

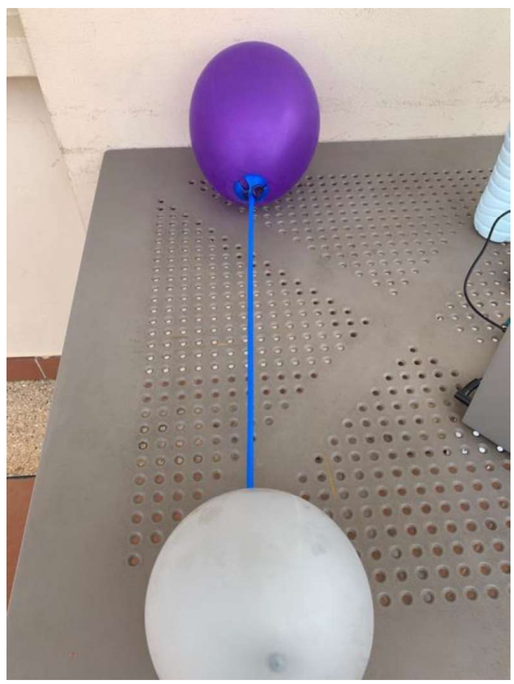


Figure 4.1 3: Experiment to determine accuracy of pH sensor

Three experiments were carried out in this test. For the first experiment, one balloon was filled with LPG gas and other balloon was filled with mouth blown. The balloons were allowed to sit for a while to allow for the gases to mix. The concentration of the balloon that initially contained air was then measured by venting the gas out of the balloon onto the sensor. The experiment was repeated but this time the LPG balloon that was used in experiment 1 is the same LPG balloon that was used in experiment 2. The experiment was also repeated for the third time.

Table 4. 3: Results of methane sensor calibration

	Experiment 1	Experiment 2	Experiment 3
Initial volume of LPG balloon (cm^3)	4 849	4 315	3 942
Initial volume of air balloon (cm^3)	4 188	4 577	5 575
Concentration (ppm)	641 567	117 349	83 289
Percentage error	28.3	53.1	33.4

The results obtained from the three experiments are shown in table 4.3 above. The average sensor values that were recorded for the three experiments differed so much from the expected concentrations in each experiment. A percentage errors are too large and such a sensor cannot be used to measure the concentration of methane gas produced from a biodigester because it would give inaccurate readings. However, the error in these readings could be attributed to the fact that the experiments that were carried out were not the best option for carrying out gas analysis. Some gas leaked into the air during the process of opening and closing the balloons and the slightly different balloon sizes that were used. Also, the MQ-4 sensor functionality is intended for gas detection, so using the sensor for finding concentration could also result in inaccurate readings.

4.3 Circuit Implementation

Figure 4.14 below shows the design of the circuit that was done in proteus. The power supply system was the 12V battery. Three voltage regulators were used to regulate the amount of power as per the needs of each of the circuit components. The voltage regulators that were used are LM317K, LM7805 and LM7809. The LM7805 is a voltage regulator that gives an output of 5V. The minimum voltage that can be supplied to the voltage regulator is 7V and the maximum voltage is 25V. It was used to regulate the 12V power supply to 5V which was required to power the microcontroller and the MQ-4 sensor. LM317K voltage regulator is a three terminal positive regulator with a 1.2V to 37V adjustable output voltage. This voltage regulator was used to regulate the 5V produced from the LM7805-voltage regulator to 3.3V which was required to power the temperature sensor. Lastly, the LM7809-voltage regulator gives an output voltage of 9V. The input voltage can range from 11-35VDC. It was used to regulate the 12V voltage supply to 9V which is required to power the pH sensor.

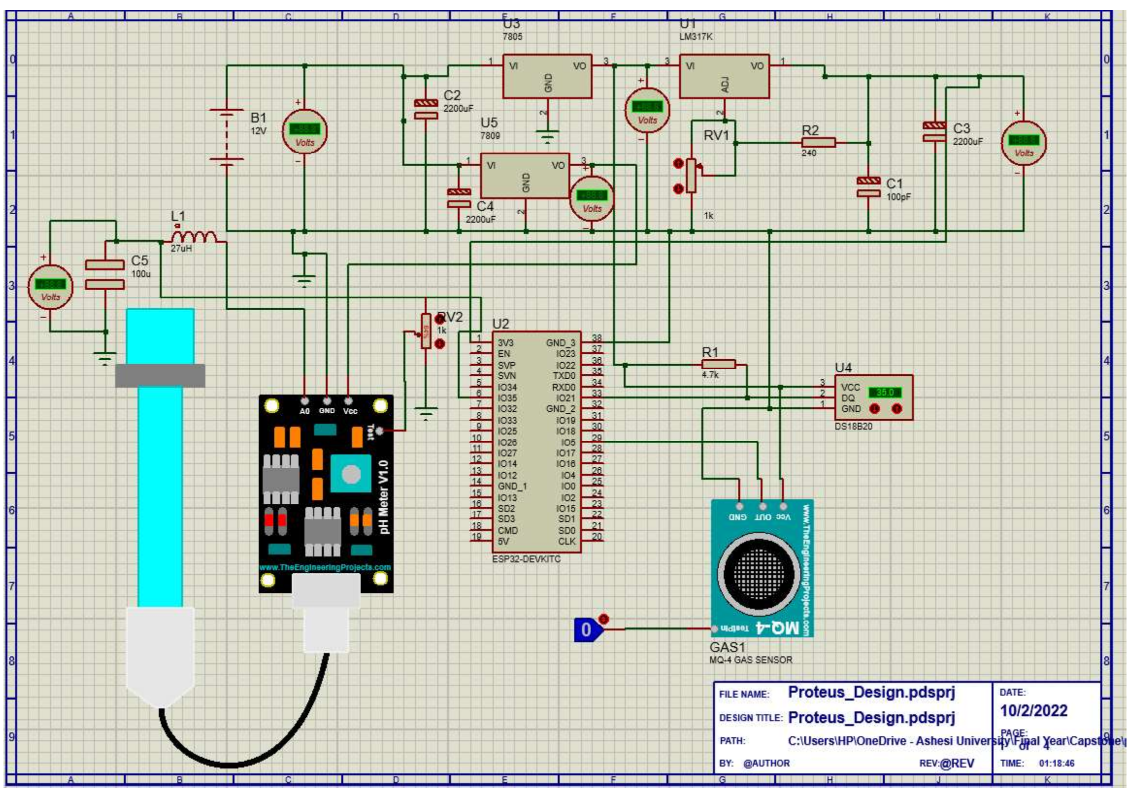


Figure 4.1 4: Proteus circuit design

The temperature sensor with an external 4.7kΩ pull up resistor between the data line of the sensor and the 5V power supply was used. Ground, Data, and Power are the three pins/wires visible on a common DS18B20 sensor. One advantage of the 1-wire protocol is that it eliminates the need for a dedicated power cable, allowing the chip to be powered directly from the 'data' line. This works because the 1-wire protocol requires that the 'data' line be set to logic 1 when the device is idle, and the DS18B20 has a small capacitor that stores enough energy to allow it to operate even when the data line is low during transmission. As a result, there is need for a pull-up resistor to either 'pull up' the power pin voltage near the voltage of the data line (when you don't want to connect a 'power' wire) or to pull up the data line voltage near the voltage of the power pin.

4.3.1 System Integration

The components were soldered onto a perforated board and packaged. The packaging was designed in solidworks and a laser cutter was used to produce the packaging. Figure 4.15 below shows the integrated system.

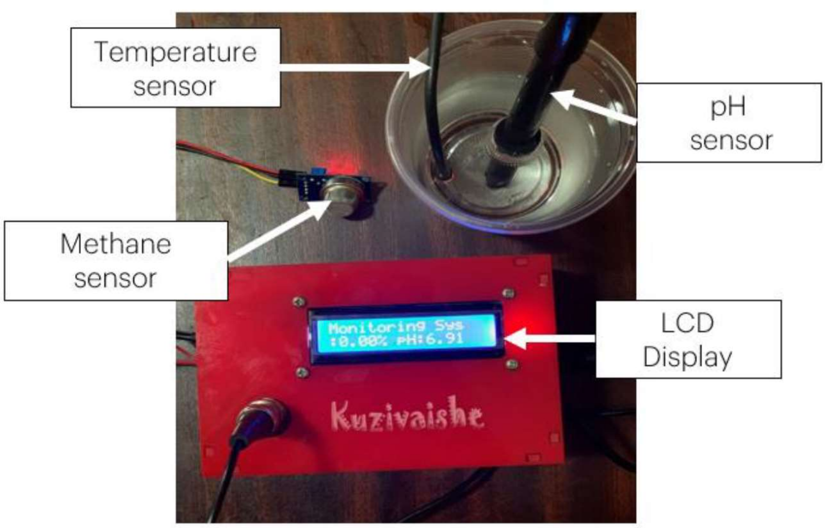


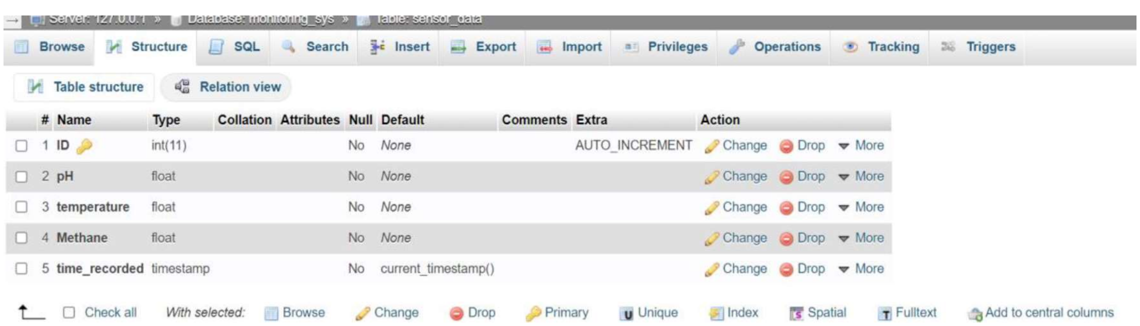
Figure 4.1 5: System Integration

4.4 Implementation of the Software Sub-system

The true value of IoT is not in connecting 'things,' but in the data generated by those 'things, in the new services enabled by those connected things, and in the insights revealed by the data. To be useful, data needs to be handled in a way that is organized and controlled. This section details the software that was implemented in handling the data that was produced by the sensors [14].

4.4.1 Database Design and Implementation

The data that is produced from IoT sensors is structured data. This means that the data follows a model or schema that defined how the data is represented or organized. The temperature, pH and methane content values are all structured values that are sent in a known format. Structured data can be easily formatted, stored, queried and processed. Because of the highly organizational format of structured data, a wide array of data analytics tools are available for processing this type of data [14]. In this project custom scripts in PHP were used to process the data that was collected from the sensors. To implement the database for the sensor data, phpMyAdmin was used to create the database named “monitoring_sys”. The table was created named “sensor_data” and PHP scripts with MySQL commands were written to insert data into the table. The scripts establish a connection to the MySQL server. If the connection is successful, the scripts have commands to insert data from the esp32 into the database. Figure 4.15 below is a snapshot of the database created in phpMyAdmin.



#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
1	ID	int(11)			No	None		AUTO_INCREMENT	Change Drop More
2	pH	float			No	None			Change Drop More
3	temperature	float			No	None			Change Drop More
4	Methane	float			No	None			Change Drop More
5	time_recorded	timestamp			No	current_timestamp()			Change Drop More

Figure 4.1 6: Database implementation

4.4.2 Dashboard Implementation

Data produced from IoT devices is considered data in motion because it passes through the network en route to its final destination. Often, the data generated by these sensors is analyzed at the edge or through fog computing. Fog computing will be used to process the data in this project, and in this case, a local server, XAMPP, will be used. A benefit of this structure is that it enables data analytics and control from the closest possible point, resulting in improved performance over constrained networks. Analyzing data close to where it is collected minimizes latency and keeps data inside the local network. Additionally, critical fog-related applications rely on real-time interactions rather than batch processing.

The requirement of this project is that the user must be able to access the status of the fermentation process in the biodigester in real time. To achieve this goal, chart.js was used to give the user real time graphical visualization of the data collected from the biodigester. The type of data analysis that would be achieved with chart.js is descriptive data analysis. The user is able to open the dashboard at any moment to gain insight into the operation of the biodigester. If any of the parameter values are not within the required range, then there could be a problem with the biodigester.

Chart.js is an open-source JavaScript library that allows data visualization. It is well suited for creating responsive bar charts, pie charts, line plots, donut plots, and scatter plots, among other types of graphs. All that it requires is specifying the location of the graph on your page, the type of graph we want to produce, and then supply Chart.js with data, labels, and other settings. To use chart.js, one needs to have knowledge in HTML5 and JavaScript.

Chapter 5: Results and Analysis

5.1 Chapter Overview

This chapter discusses the results that were obtained from testing the integrated system. The goal of this project was to monitor the three key parameters of a biodigester, namely; temperature, pH and methane concentration. However, the biodigester was not ready for testing at the time of writing this report. For the purpose of testing the system, fresh milk was used as the biodigester solution. If unpasteurized milk is not refrigerated, it ferments naturally, and the fermentation involves microorganisms present in the raw milk and surrounding air. The fermentation takes 1 to 2 days depending on the ambient temperature [20]. The process that the milk goes through was a good alternative to represent the fermentation process that takes place in the biodigester.

5.2 Integrated System

Milk was placed in a 1.5 litre bottle. Holes were made on the walls of the bottle to allow immersion of the temperature and pH sensors. The experiment set up was left for 36 hours, of which by then the milk had become sour. Data values were collected every one hour. The sampling frequency was low here because the time within which the sample values were taken was also small, it only takes between one to two days for milk to ferment. Ten recordings were recorded at regular intervals (6 minutes) within the one-hour sampling period, the average was calculated and this is what was sent to the database. In this experiment, the methane gas content was not tested because methane gas is not produced in the fermentation process of milk. The system was set up as shown in figure 5.1 below and left in one of the hostel rooms to ferment naturally.

Figure 5. 1: Integrated monitoring system

Figure 5.1 shows the set-up of the monitoring system. The system hardware components were mounted onto a perforated PCB copper board. Soldering was used to connect the components on the perforated board. The system was powered by an eternal power supply, a 9V DC power supply adapter. The adapter works by converting AC wall power into DC. The adapter was used in place of the battery because a 9V battery could not be outsourced. The LCD displayed all the readings that were recorded at 6-minute intervals. The packaging of the system was designed in solid works and laser cut.

5.3 Database

The values that were recorded were sent to MySQL database at one-hour intervals. Below in figure 5.2 is a snap of the values were recorded in the database for the three parameters, pH, temperature and methane concentration. The database had 5 fields, an ID filed to identify each of the records, pH field, temperature field, Methane field and time recorded field which showed the exact time at which the readings were taken from the sensors. The records in the database show that the sampling time, the time at which the average value was communicated to the database, was interrupted because there was a power outage which cut power supply to the monitoring system. And this is one main advantage that power self-sufficient/battery powered nodes have over eternally powered nodes.

Browse | Structure | SQL | Search | Insert | Export | Impor

←T→				ID	pH	temperature	Methane	time_recorded
☐	Edit	Copy	Delete	160	5.28	32.94	0	2022-04-22 19:31:28
☐	Edit	Copy	Delete	161	5.92	32.4	0	2022-04-22 20:31:43
☐	Edit	Copy	Delete	162	5.48	32.3	0	2022-04-22 21:30:35
☐	Edit	Copy	Delete	163	5.83	32.17	0	2022-04-22 22:31:08
☐	Edit	Copy	Delete	164	5.74	31.73	0	2022-04-22 23:31:15
☐	Edit	Copy	Delete	165	5.28	29.78	0	2022-04-23 00:32:32
☐	Edit	Copy	Delete	166	5.29	28.49	0	2022-04-23 01:56:05
☐	Edit	Copy	Delete	167	5.13	27.45	0	2022-04-23 03:56:11
☐	Edit	Copy	Delete	168	5.16	26.93	0	2022-04-23 03:55:11
☐	Edit	Copy	Delete	169	5.64	26.36	0	2022-04-23 04:56:44
☐	Edit	Copy	Delete	170	5.55	27.38	0	2022-04-23 05:55:17
☐	Edit	Copy	Delete	171	4.29	28.99	0	2022-04-23 06:56:50
☐	Edit	Copy	Delete	172	4.96	29.93	0	2022-04-23 07:56:23
☐	Edit	Copy	Delete	173	3.25	30.04	0	2022-04-23 08:56:56
☐	Edit	Copy	Delete	174	5.28	31.83	0	2022-04-23 09:55:29

Figure 5. 2: Data collection in the database

5.4 Dashboard

The dashboard was created in such a way that as the data values were sent to the database, they would be processed into graphical representation in a real-time manner using chart.js. This means that at any time, the user can access the dashboard and gain insight into the operation of the biodigester. Figure 5.3 below shows the visual representation of the data.

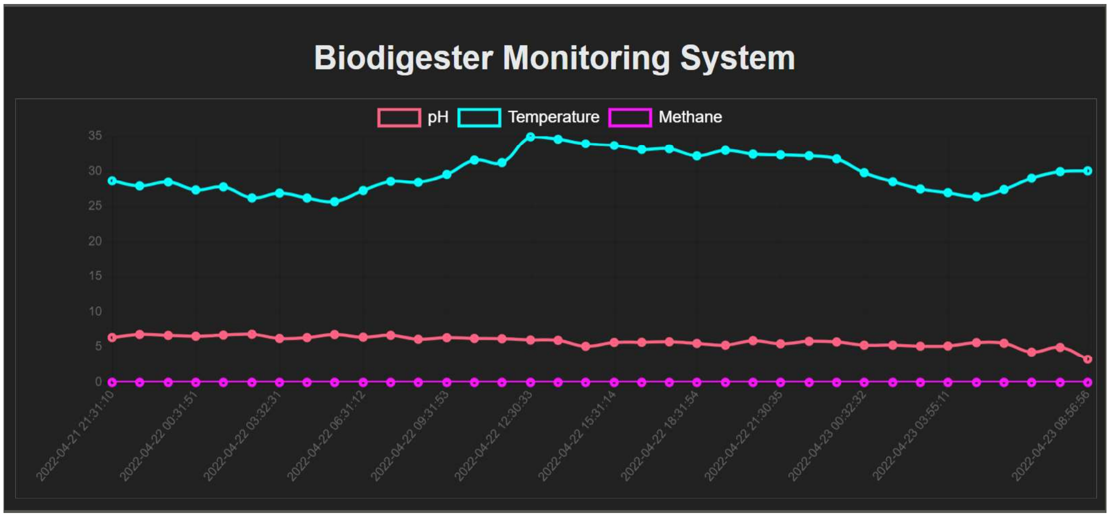


Figure 5. 3: Dashboard data visualization using chart.js

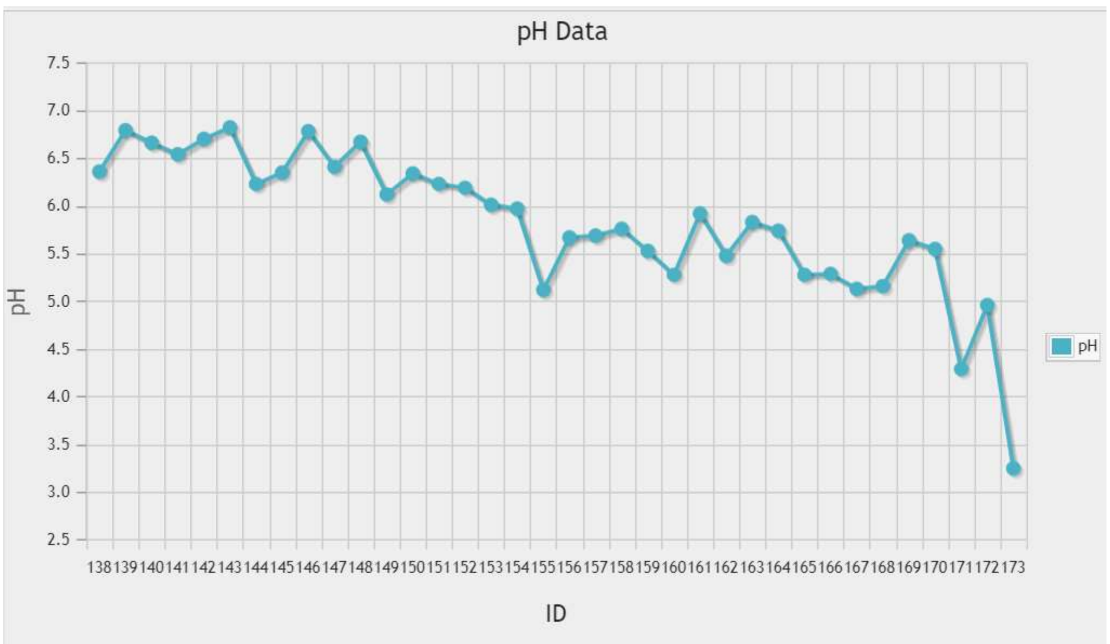


Figure 5. 4: Line plot of pH data plotted in MySQL database

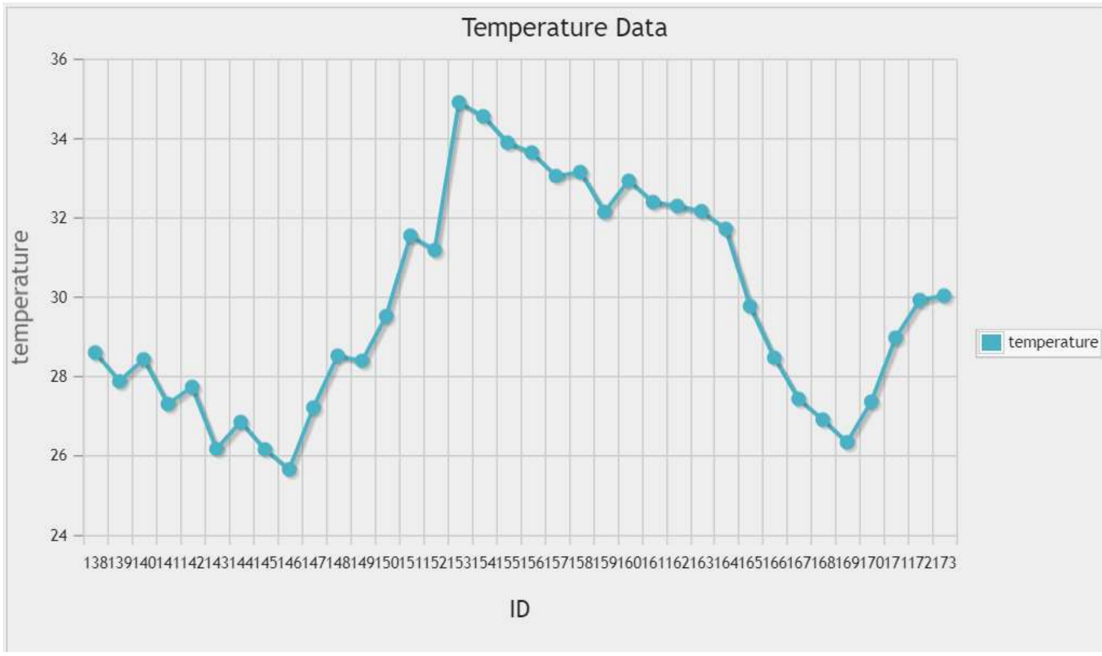


Figure 5. 5: Line plot of temperature data plotted in MySQL database

When the testing experiment was first set up, the pH of the milk was 6.84 at 28.69°C. With time, the pH values dropped to a value around 5.3. It was also observed that the pH of the milk started to decrease after 17 hours, during the day when the temperature was high. When the temperature was high during the day, the pH of the milk decreased as was expected and by the end of the experiment, the pH was was acidic which is expected of any sour milk.

5.6 Analysis

The test experiment was carried out to test four main aspects of the system which are, the positioning of the sensors, the ability of the sensors to capture data, the ability of the microprocessor to communicate the measured data values to a database and the ability of the system to display this information for the user. The results obtained from this experiment proved that the sensors were positioned well to capture the environmental data, except for the methane sensor which was not tested in this experiment. The microprocessor communicated well the measured values to MySQL database. The only problem that could potentially affect the communication system is the power supply in the event that there is a power outage as was seen in the way it affected the sampling time of the experiment. The display of the sensor values onto the dashboard did not function well to meet the expectations of the user. Another limitation that the dashboard offers is that it can only be accessed on the same machine on which the server is hosted since a local server was used in this project.

Chapter 6: Limitations, Future Works and Conclusion

6.1 Chapter Overview

This chapter summarizes the project, restates the goal and gives a summary of how the project was carried out to achieve this goal. It also highlights some of the challenges that were faced in executing the project, the limitations of the project and the improvements that can be made by future works.

6.2 Limitations and Challenges

As mentioned earlier, the methane sensor that was used in this project did not read accurate values, and also it was not included in measuring gas concentration values in the experiment that was done to test the integrated system. The challenge with the methane sensor emanated from the fact that there was no gas analysis equipment that was readily available to accurately collect gas and carry out some tests with it. The other issue with the sensor is that it is intended to detect the presence of gas in the environment around it and not necessarily measure the concentration of a gas. The method that was employed to find the concentration of the gas made use of estimated values that were read from the sensitivity graph obtained from the datasheet of the sensor. So even when gas concentration values are read from the sensor, it is difficult to tell whether they are accurate or not.

The other limitation of the project is that the user can only access information about the biodigester on the same machine that the server is hosted. This could be solved by making use of a remote server that can be accessed from anywhere. Also, the x-axis of the graphs could be programmed to show the time at which the data was recorded instead of showing the identity numbers of the records using expert knowledge in java script.

Furthermore, a challenge that was faced in implementing this project is that the methane sensor and pH sensor that were used in this project are designed for Arduino boards, so mapping the analogue output values onto an esp32 channel required extra work.

6.3 Future Work

To help improve the system, further works should focus on developing a system that uses a methane sensor that can accurately measure the concentration of methane gas. An improvement could also be made on the hardware sub-system so that it is power self-sufficient so that it is possible to deploy the system without a power constraint.

6.4 Conclusion

The goal of this project was to develop a monitoring system for a portable household-scale biodigester. The system was designed to improve the performance of the biodigester and in turn increase its lifespan. This was achieved by monitoring key parameters that affect the fermentation process that takes place in the biodigester which are namely: temperature, pH. Methane concentration could have also been measured to measure the amount of combustible gas that is produced from the biodigester. The system is made of two main parts, namely; software and hardware. The hardware part of the system is made up of sensors, a microcontroller, and an LCD display. The software part of the system is made up of a MySQL database, a microcontroller program, and a dashboard for data visualization. The development of the monitoring system will help improve the life span of small-scale biodigesters through monitoring the operating conditions and make biodigester control and monitoring accessible and affordable to an average African, taking into consideration the future of green fuels as a source of energy.

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