



ASHESI UNIVERSITY

WATER QUALITY MONITORING

THESIS

CAPSTONE PROJECT

B.Sc. Electrical & Electronics Engineering

Deborah Date

2022

ASHESI UNIVERSITY

WATER QUALITY MONITORING

THESIS

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 & Electronics Engineering.


Deborah Date

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:



Candidate's Name:

Deborah Date

Date:

8/10/2021

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.

Supervisor's Signature:

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Supervisor's Name:

.....

Date:

.....

Acknowledgements

To God who saw me throughout this project. To Kofi Adu-Labi, my supervisor, and my parents, whose encouragement and academic advice helped me undertake this project.

Abstract

Water quality is one important factor considered in distributing potable water to the population. Bad water quality leads to the spread of diseases to people and livestock. Good water quality, however, promotes healthy living. At Ghana Water Company Limited, water quality is monitored every hour. Often, time is taken to cross-check the values recorded on the water quality parameters, for example pH, to ensure accuracy. Also, staff members have to be available daily to monitor the water quality. A system that monitors the water quality daily every hour ensuring accuracy in its measurement was designed for this project. The system has a database that stores all the parameters measured and a web dashboard to display the data. The web dashboard also displays the data on a graph to show the peaks at different times.

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Chapter 1: Introduction

Water is essential for the life of plants, animals, and humans. Clean water ensures healthy living. Unclean water may contract diseases such as cholera, diarrhoea, dysentery, and hepatitis A [1]. Water is also a good solvent for many substances. Therefore, it can dissolve many minerals or contain metals or poisonous substances harmful to humans and animals who drink the water and plants that use the water to grow. In Ghana, Ghana Water Company Limited is one of the major water supply companies set up to aid in the purification of water from the dam for human consumption. In Accra, for example, the Weija dam supplies approximately half of the city with water [2]. The river that is dammed at Weija is the Densu river. It flows 116km from the Atewa range, its source, to the Weija dam before entering the Gulf of Guinea [2]. Throughout the river's journey, it passes through many towns and villages, thereby picking up their waste along the way. The waste it picks up may be human waste, animal waste, or plastics. Some of the wastes dissolve in the water and breed lots of micro-organisms in the water that is harmful to human health. To provide potable water to the citizens, the water at the Weija dam goes through some purification processes before it is distributed to the public. Water quality monitoring plays an essential role in the purification process of the water. This project seeks to aid in the automation of the collection of real-time data during the water quality monitoring process using wireless sensor networks to improve efficiency and accuracy.

1.1 Background

Water is used for many things such as drinking, washing, cooking, flushing the toilet, washing our hands and irrigation. Ghana has improved with safe water access and improved water sources available to 80% of the population [3]. In Ghana, 37% of water is used in the municipality, 48% is used for agriculture, and 15% is used for agricultural purposes [4]. Water goes through four stages of purification: coagulation and flocculation, sedimentation, and filtration.

Before each stage, water parameters such as the pH value, turbidity, and TDS (Total Dissolved Solids) are recorded. During coagulation, chemicals like alum with a positive charge are added to the water to neutralize the negative charge of dissolved substances in the water [5]. A few minutes after the alum is added, the substances in the water get bound to the alum to create larger and heavier substances called flocs. These flocs settle in the base of the tanks during the process of sedimentation [5]. The water is passed through filters of different sizes to separate the flocs from the clean water after its settlement in the filtration stage. Next, the filtered water is disinfected using chlorine to kill the remaining micro-organisms left in the water. Nominal testing is usually done in a lab before the coagulation and flocculation stage, where small samples of raw water are tested on to know the amount of alum required to produce the best values of the water's parameters for consumption. After obtaining the best results, the amount of alum required is scaled up to the actual amount of water at the coagulation and flocculation stage. Workers are usually at the water company every day to check the water quality process.

1.2 Problem Definition

There are always workers in the lab to record the data by monitoring the water quality every hour. They measure each parameter one after the other and are sometimes inaccurate. This project seeks to aid in the automation of the collection of real-time data during the water quality monitoring process using wireless sensor networks to improve efficiency and accuracy.

1.3 Objectives of the Project Work

The objectives of this project are as follows:

1. To automate the recordings of the water quality monitoring process to facilitate the real-time monitoring of the system efficiently every hour.
2. To design a low-cost system that would also consume less power and would be easy to use.

3. To design a platform where the results can be easily accessible and displayed.

1.3 Motivation of the Project Topic

Having good water quality is essential and the workers who monitor it spend time recording the water parameters manually, whereas it can be done automatically to improve efficiency and accuracy.

1.4 Facilities Used for the Research

The following facilities were used that aided in the development of the project:

1. The fabrication laboratory at Ashesi University.
2. The internet services provided by Ashesi University.

1.5 Scope of Work

The project entails the use of sensors that would measure the water quality of raw water from the dam. A microcontroller is used to process the data it receives from the sensors. It involves the use of wireless communication technology for the transmission of the data to a database system. The database then stores the information received via wireless communication technology. A web dashboard is used to extract and display the information from the database.

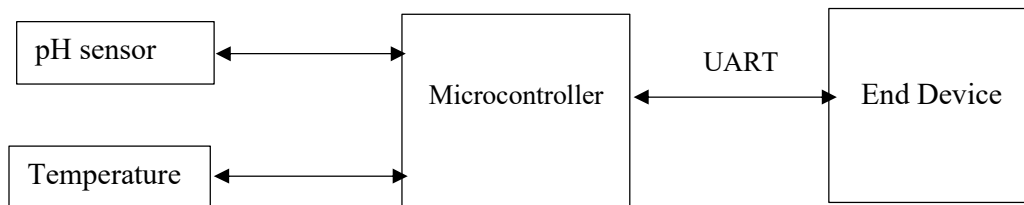
Chapter 2: Literature Review

2.1 Review of Existing Designs

Polluted water affects good water quality and our ecological environment [6]. Good water quality is needed for potable drinking water and irrigation in agriculture. The water quality monitoring system was designed to provide real-time monitoring of the water quality parameters [6]. This section describes a review of existing designs related to this project.

2.1.1 Sensor Nodes

The parameters usually measured are pH, temperature, and turbidity [7], [8]. At the sensor node, there exists three modules: sensor module, data processing module and data transmission module [7]. These modules work together to run a functional system. The sensor module consists of the temperature, turbidity, and pH value sensors [7], [8]. The sensor module is connected to the data processing module, for which an Arduino development board can be used [6]. The Arduino microcontroller is connected to the data transmission module for wireless communication. The data transmission module is made up of the communication device that transmits data from one device to another. The data can be transmitted wirelessly.



2.1.2 Communication Module

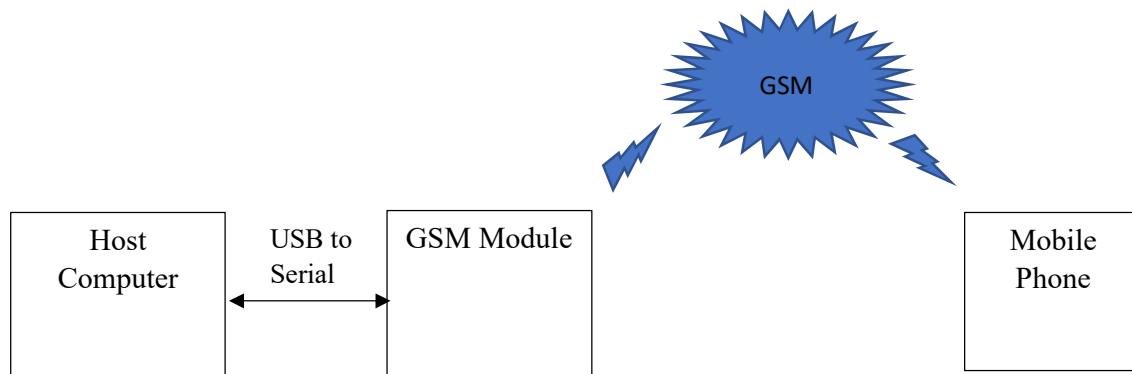
The data from the sensors have to be displayed in order to be computed. In order to prevent data from being distorted by interference in cables, data is often transmitted wirelessly. This can be done wirelessly using the ESP32 microcontroller which has an embedded Wi-Fi module [8]. The ESP32 can send sensor data to smartphones directly over Wi-Fi.

2.1.3 Host Computer and Data Storage

The host computer can be used to display the system's status in real-time. Engineers often use ThinkSpeak to display the data in real-time [9]. Engineers and developers also use the Blynk application to view the components involved in the system. It provides a web dashboard and can be used to store and display sensor data [10]. Other than the Blynk application, which can be used to store data, PHP and MySQL were used to create a database, which can also be used for web development [11].

2.1.4 The GSM module

The GSM enables the host computer to send SMS of the system's status to the mobile phone of users or staff members [7], [12]. In the field of distributed remote data acquisition and monitoring, the status terminal equipment can be received by SMS using the GSM anytime and anywhere [7], [12].



2.1.5 Mobile Terminal Module

Bluetooth is also a means by which data is shared with users or staff members. A Bluetooth module can be paired with a mobile phone or smartphone with enabled Bluetooth to view the data [6]. The host computer can send the processed data received by SMS to the mobile phone of some staff through the GSM module to view the status of the system in time [7].

Nevertheless, this type of system is not being used in Ghana to monitor water quality to provide potable and safe drinking water for humans, plants, and livestock. The water quality monitoring system enables less human interaction during the water monitoring duration and improves the system's accuracy.

Chapter 3: Design

3.1 Requirements Specifications

The requirements specifications describe how user-friendly the system could be and how the system should function as a whole.

3.1.1 User Requirements

The user requirements describe what the users expect from the system. The following outlines user expectations from the system.

- 1) It should be easy to use.
- 2) The user expects the system to be able to collect data automatically.
- 3) It should be less tedious than the existing methods.
- 4) The user expects the system to be safe to use.

3.1.2 System Requirements

The system requirements describe the technical aspect of the system. It details how the system should perform. The following outlines the requirements of the system:

- 1) To automate the recordings of the water quality monitoring process to facilitate the real-time monitoring of the system efficiently every hour.
- 2) To design a low-cost system that would also consume less power and be easy to use.
- 3) The system should have a platform where the results can be easily accessible and displayed.

3.2 Design Objective

The objective is to design a wireless sensor network that would obtain parameter values from raw water samples as signals using sensors and then be able to process the signals using a microcontroller. After the signal has been processed, it would be sent to a computer (base

station) via a communications module where the results would be displayed at every hour daily. The sensor will consist of pH, turbidity, and TDS sensors as they are the parameters to be measured.

3.3 Design Decisions

The design decisions would consider the kind of resources available for the design and the selection of the best out of the rest.

3.3.1 Types of communication modules

Different types of communication modules can be used in a wireless sensor network. They are Wi-Fi, Bluetooth Classic, BLE (Bluetooth Low Energy) and Zigbee.

3.3.1.1 Wi-Fi

Wi-Fi is a wireless networking technology that allows devices to interface with the internet [48]. Internet connectivity occurs through a wireless router [13]. Wi-Fi provides high-speed data connections between mobile data devices and nearby Wi-Fi access points [14]. It uses the 2.4GHz or 5GHz frequency bands [14]. The range that a Wi-Fi access point can cover indoors is up to 46m, and outdoors is 92m when operating on 2.4GHz [15]. The cost of Wi-Fi use is relatively high due to the use of Broadband and its relatively high-power consumption rate compared to Bluetooth, Bluetooth Low Energy and Zigbee [16]. The data rate for Wi-Fi is 11Mbps with a network join time of up to 3 seconds [17], [18]. It can support up to 250 devices [19].

3.3.1.2 Bluetooth Classic

Bluetooth Classic, or simply Bluetooth, is a wireless data protocol that uses radiofrequency for sharing data over short distances from fixed-mobile devices, creating personal area networks [20]. It uses the 2.4GHz ISM (Industrial, Scientific and Medical) frequency band [21]. The Bluetooth specification can be put into three power classes—class 1,

class 2 and class 3 with an output power of 1mW, 2.5mW and 100mW, respectively [22]. Each output power has a corresponding range the device would be able to cover. Thus, class 1 has a range of 100m and beyond; class 2 has a range of 10m; class 3 has a range of 1m [22]. Bluetooth has a low power consumption rate and has a data rate of 1 to 3 Mbps [23], [24]. It has 79 channels with 1MHz spacing [21]. It also has a network join time of up to 3 seconds [25]. It can support up to 7 devices [26].

3.3.1.3 Bluetooth Low Energy (BLE)

Bluetooth Low Energy (BLE) is a wireless data protocol that uses radiofrequency for sharing data over short distances from fixed-mobile devices, creating personal area networks [20]. It uses the 2.4GHz ISM (Industrial, Scientific and Medical) frequency band [21]. BLE has a lower power consumption than Bluetooth Classic over the same range but with lower bandwidth at a cheaper cost [27]. It covers a range of up to 100m and 400m for BLE 4.0 and BLE 5.0, respectively [28]. It also has a maximum range (outdoors) of around 100m and 1,000m for BLE 4.0 and BLE 5.0, respectively [28]. It has a data rate of 1Mbps and 2Mbps for BLE 4.0 and BLE 5.0, respectively [28]. BLE has 40 (3 for advertising, 37 for data) channels with 2MHz spacing [21]. It has a network join time of less than 7.5ms and can support up to 7 devices [29], [30].

3.3.1.4 Zigbee

Zigbee is a standards-based wireless technology built for control and sensor networks on the Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 standard for Wireless Personal Area Networks (WPANs) [25]. Zigbee operates on 2.4GHz, 900MHz and 868GHz. It is used for low-data, low-cost and low-power applications [31]. It has data rates of 250kbps, 100kbps, 40kbps and 20kbps [32]. The range of a Zigbee radio is approximately 30m indoors [32]. The network join time for a Zigbee module is approximately 30m seconds [25]. It can connect to a maximum of 240 devices in practice [33].

Table 3.1: Pugh matrix for the wireless communication technologies

Criteria	Baseline	Wi-Fi	Bluetooth Classic	BLE	Zigbee
Power Consumption	0	-1	2	3	3
Data Rate	0	3	2	2	1
Network Join Time	0	1	1	2	3
Range	0	3	1	2	3
Number of supported devices	0	3	1	2	3
Cost of product	0	1	2	3	3
Total	0	10	9	14	16

From Table 3.1, Zigbee has the highest matrix value. However, Wi-Fi was chosen due to its higher data rate as compared to Zigbee.

3.3.2 Wireless Network Topologies

There are three types of network topologies that will be discussed in this paper: star topology, tree topology and mesh topology.

3.3.2.1 Star Topology

Star topology is one of the simplest topologies. It consists of a central node and other peripheral nodes [34]. The peripheral nodes cannot communicate directly with one another but can only communicate with the central node [34]. However, the peripheral nodes can communicate with one another via the central node [34]. The advantages are that star topology is simple and direct [34]. It also has the lowest latency of the networks [34]. For the disadvantage, it has a minimal network coverage due to the limited number of peripheral nodes that can be connected to the network [34].

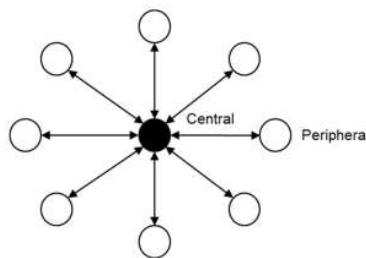


Figure 3.1: Star topology [34]

3.3.2.2 Mesh Topology

Mesh topology is used to connect many-to-many device communications [34]. It enables the creation of large-scale device networks and is suitable for control, monitoring, and automation systems where many devices need to be securely connected [34].

The advantages are that every node is connected to the neighbouring node except for the end devices [34]; a message hops from one device to another in order to reach its destination [34]; data can be re-routed using another path if one node fails (self-healing process) [34]; the range of the network can be increased by adding more devices to the network [34]; can eliminate dead zones [34]; adding or removing a device is easy [34].

For the disadvantages, more complex routing protocol [34]; it is not power and latency efficient compared to star networks [34].

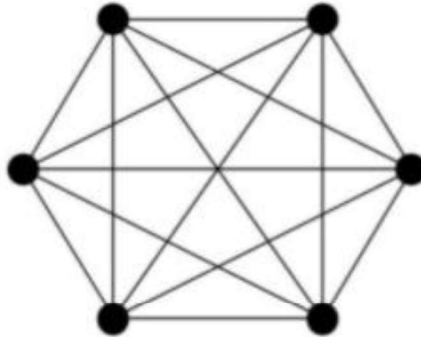


Figure 3.2: Mesh topology [34]

3.3.2.3 Tree Structure Topology

The tree structure topology is made up of a grandpa node, father nodes and child nodes. The grandpa node communicates with the father nodes [34]. The father nodes then communicate with the child nodes [34]. However, the child and father nodes cannot communicate directly amongst themselves [34]. They can do so by only message forwarding [34].

The advantages are routing rules are more straightforward as compared to the mesh routing rules [34]; it can connect more nodes as compared to star topology [34]; it has more extensive network coverage as compared to star topology due to having more than one level connection distance [34].

The disadvantages are higher latency due to too many layers [34]; it has a vulnerable network when any father node is down [34].

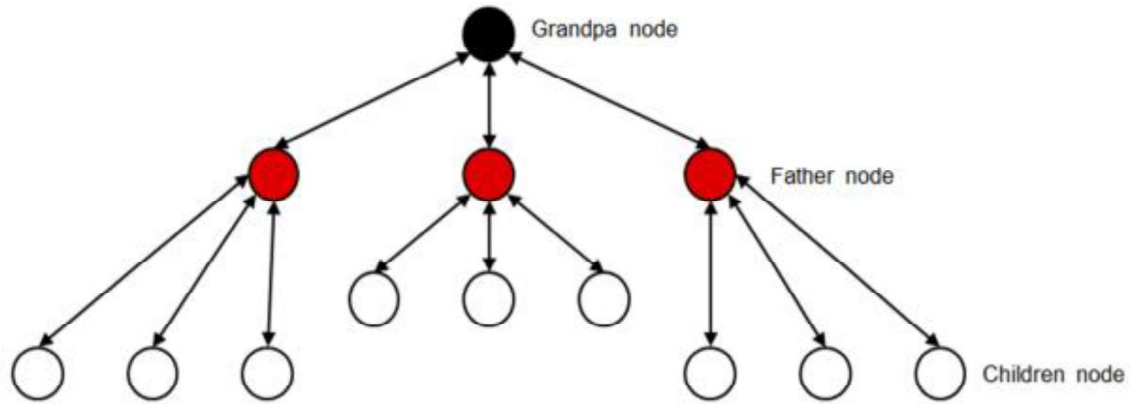


Figure 3.3: Tree structure network [34]

Table 3.2: Pugh matrix for the network topologies

Criteria	Baseline	Star Topology	Mesh Topology	Tree Structure Topology
Size of Network	0	1	3	3
Ease of Implementation	0	3	1	2
Compatibility of Hardware Resources	0	3	3	2
Cost	0	3	1	2
Reliability	0	1	3	2
Total	0	11	11	12

From Table 3.2, tree structure topology has the highest value. However, star topology is more applicable for this project. It has the most compatibility with the hardware resources. In the

sense that it also requires the least number of cables for connecting the peripherals. In addition to that, it is the most uncomplicated topology to implement.

3.3.3 Intelligence Module

Intelligence modules that could be applied for this project are STM32F103C8, ATmega328P, and PIC18F4550. These microcontrollers are used to obtain and process the information obtained from the sensors to the BLE for transmission.

3.3.3.1 STM32F103C8

STM32F103C8 is a 32bit microcontroller which incorporates the ARM Cortex-M3 RISC core from STMicroelectronics [35]. It operates on the 72MHz frequency, high speed embedded memories [35]. It has a flash memory 64Kbytes and SRAM (Static Random Access Memory) up to 20Kbytes [35]. STM32F103C8 has two 12bit ADCs (Analog to Digital Converters), three general-purpose 16bit timers and one PWM (Pulse Width Modulation) timer [35]. In addition to that, it has up to two I²Cs (Inter-Integrated Circuits) and SPIs (Serial Peripheral Interface), three USARTs (Universal Synchronous Asynchronous Receiver Transmitter), a USB and a CAN (Controller Area Network) [35]. It also has 37 I/O ports [35]. It operates from a 2.0V to 3.6V power supply [35]. It has a power-saving mode that allows the design of low-power applications [35]. It costs \$7.49 [36].

3.3.3.2 ATmega328P

ATmega328P is a high performance, low power controller from Microchip [37]. It is an 8bit microcontroller based on the AVR RISC architecture [37]. It has 2Kbytes of internal SRAM, 1Kbytes of EEPROM with 32Kbytes of flash memory and 1MHz of CPU speed [37]. It has 28 pins with 23 programmable I/O lines [37]. It has three pins that can be used as SPI Serial Interfaces, two pins that can be used as Programmable Serial USART and two pins that can be used as Two-wire Serial Interfaces [37]. ATmega328P has 6 channels and 10bit

resolution ADC for the ADC module [37]. It has an 8bit counter and one 16bit counter [37]. It has two pins to be used as Analog Comparators and six PWM channels [37]. It has an external oscillator with the following features: 0-4MHz @ 1.8V to 5.5V; 0-10MHz @ 2.7V to 5.5V; 0-20MHz @ 4.5V to 5.5V [37]. Its operating voltage is from 1.8V to 5.5V [37]. It has six power save modes [37]. It costs \$4.50 [36].

3.3.3.3 PIC18F4550

PIC18F4550 is a high performance, enhanced flash, USB microcontroller with nano-Watt Technology [38]. It is a 40 pin 8bit microcontroller from Microchip Technology Inc, of which 35 of them are programmable I/O pins [38]. Two pins can be used as a USB Serial Interface; four pins can be used as Master/Slave SPI Serial Interface; two pins can be used as Programmable Serial UART; two pins can be used as a Two-wire Serial Interface [38]. It has 13 channels and 10bit resolution ADC for the ADC module [38]. PIC18F4550 has one 8bit counter and three 16bit counters [38]. In addition to that, it has two Analog Comparators and four PWM channels [38]. It also has an external oscillator of up to 48MHz and an internal oscillator from 32KHz to 8MHz [38]. It has a flash memory of 32Kbytes, and 12 MIPS of CPU speed [38]. It has 2Kbytes of RAM and 256Bytes of EEPROM [38]. Its operating voltage is from 4.0V to 5.5V [38]. It costs \$7.00 [36].

3.3.3.4 ESP32

ESP32 is a microcontroller made by Espressif Systems embedded with Wi-Fi and Bluetooth [39]. It has a single or dual-core LX6 microprocessor which is 32 bits with a maximum clock frequency of 240MHz [39]. It has SRAM of 520KB, RTC SRAM of 16KB, and ROM of 448KB [39]. It facilitates the 802.11 b/g/n, Bluetooth Classic and BLE [39]. Its Wi-Fi speed has a maximum of 150Mbps [39]. The ESP32 has up to 34 programmable GPIOs [39]. It has up to 18 channels of 12bit SAR ADC and 2 channels of 8bit DAC [39]. Its serial

connection consists of 4 x SPI, 2 x I²C, 2 x I²S and 3 x UART [39]. Its operating voltage is from 2.3V to 3.6V [40]. It costs \$1.35 [36].

Table 3.3: Pugh matrix for the intelligence modules

Criteria	Baseline	STM32F103C8	ATMega328P	PIC18F4550	ESP32
Responsiveness	0	3	2	2	2
Power Consumption	0	3	3	3	3
Cost	0	1	3	-1	3
Memory	0	3	1	2	3
Ease of Use	0	-1	3	2	3
Processing Power	0	3	1	2	3
Total	0	14	14	10	17

From Table 3.3, ESP32 has the highest Pugh matrix value. It is low cost, has low power consumption together with embedded Wi-Fi and Bluetooth.

3.3.4 Sensors

The sensors used in this project are all analogue. They are used to measure the water quality properties such as the pH level, the TDS, and the turbidity.

3.3.4.1 Analog pH Sensor

An analogue pH sensor is used to measure the acidity or alkalinity of the water [41]. It has a scale that ranges from 0 to 14. When water has a pH value of seven, it is neutral. When it has a value less than seven, it is acidic. When it has a value greater than seven, it is alkaline.

Figure 3.3 shows the image of an analogue pH sensor.



Figure 3.3: Analog pH sensor

3.3.4.2 Analog TDS Sensor

A TDS sensor measures the total dissolved solids in water [42]. Figure 3.4 shows the image of an analogue TDS sensor.

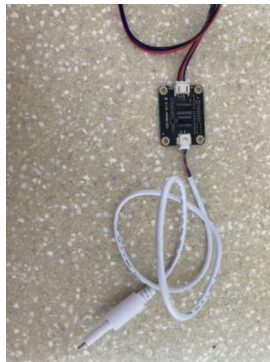


Figure 3.4: Analog TDS sensor

3.3.4.3 Analog Turbidity sensor

A turbidity sensor measures the amount of light scattered by the suspended solids in the water [43]. Figure 3.5 shows the image of an analogue turbidity sensor.



Figure 3.5: Analog turbidity sensor

3.3.4.4 Breadboard Power Supply and Adapter

The breadboard power supply is used to supply 5V, 3.3V and ground. Figure 3.6 shows the image of a breadboard power supply. The adapter is used to supply the breadboard power supply with power from the mains.

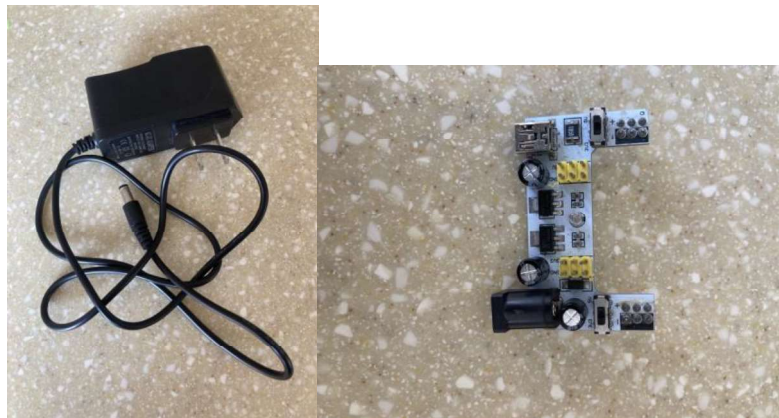


Figure 3.6: Adapter (left) and breadboard power supply (right)

3.3.4.5 ADS1115

ADS1115 is an Analog to Digital Converter. It can perform operations up to 860 samples per second [44]. The figure below shows an image of the ADS1115.

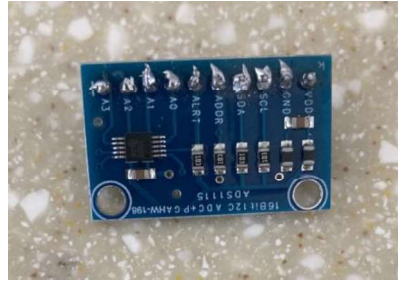


Figure 3.7: ADS1115

3.3.4.6 OLED Module

An OLED is a display module. The figure below shows the image of the OLED module.

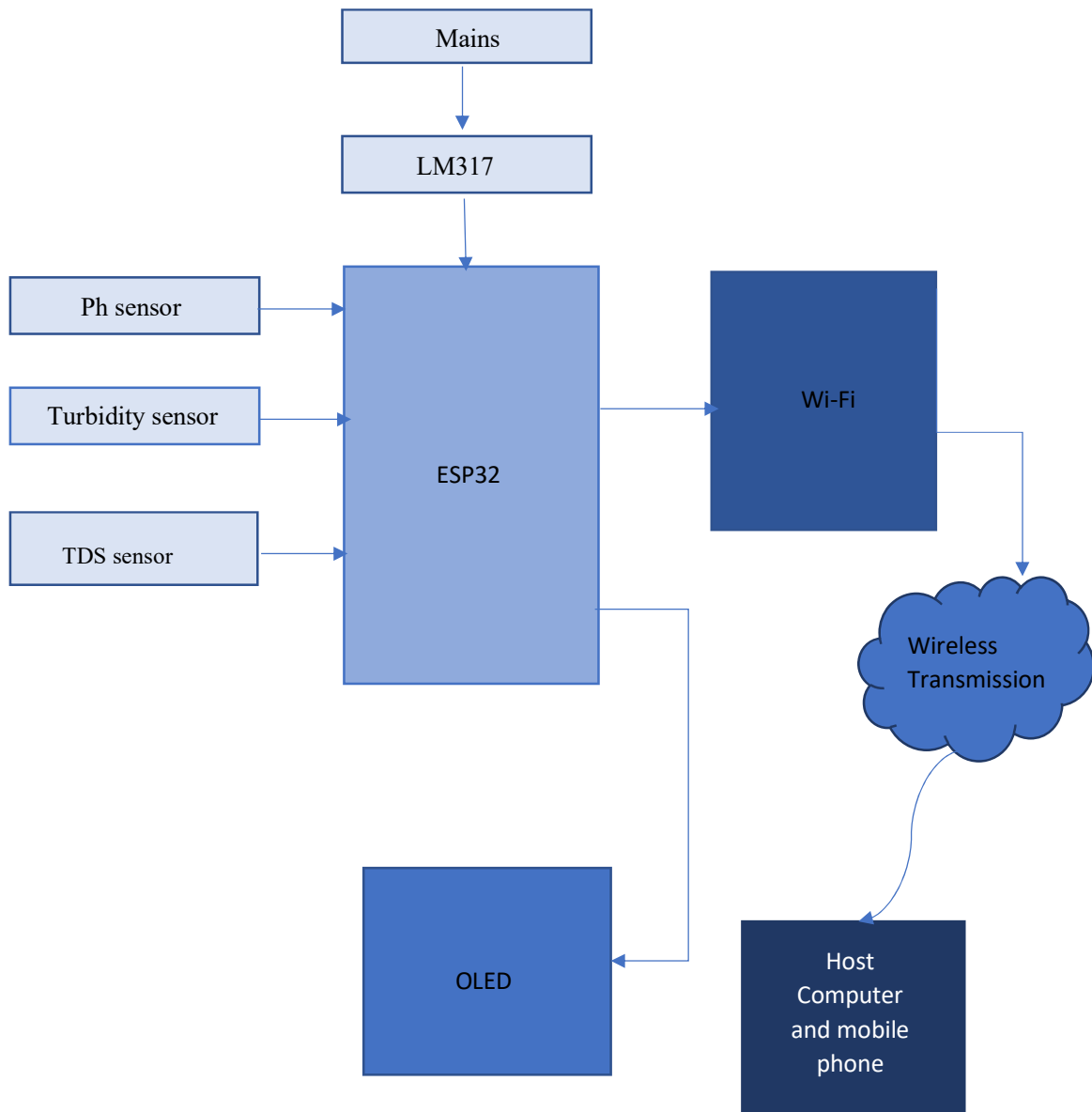


Figure 3.8: OLED

3.3.5 Display of Data

The data collected from the microcontroller is displayed via a web dashboard that is developed using HTML, CSS and JavaScript. The dashboard displays the hourly transmitted data from the database. The dashboard can display graphs for the data accumulated over a particular day or month. An OLED would also be connected to the microcontroller to view the readings near the setup.

3.2.6 Block Diagram of Design



3.2.7 Circuit Diagram

The circuit diagram was designed using EasyEDA. The circuit diagram is divided into two parts, the power circuit diagram and the main circuit diagram. Figures 3.7 and 3.8 show the power circuit and main circuit, respectively.

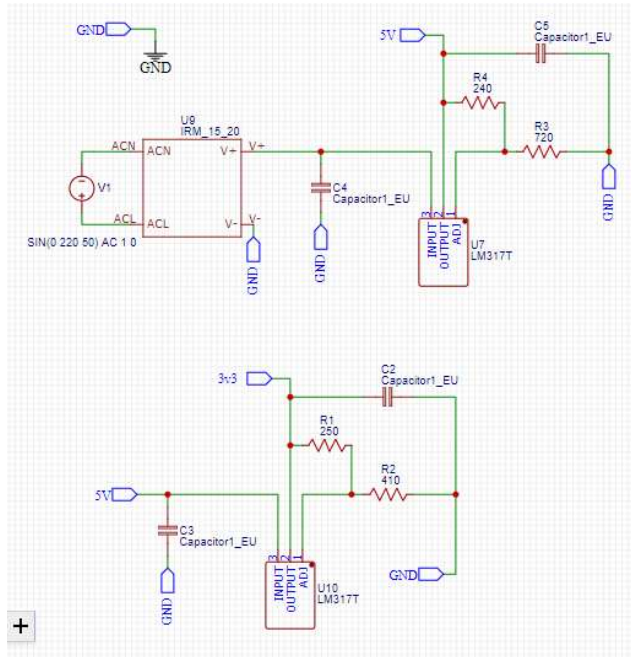


Figure 3.9: Power Circuit

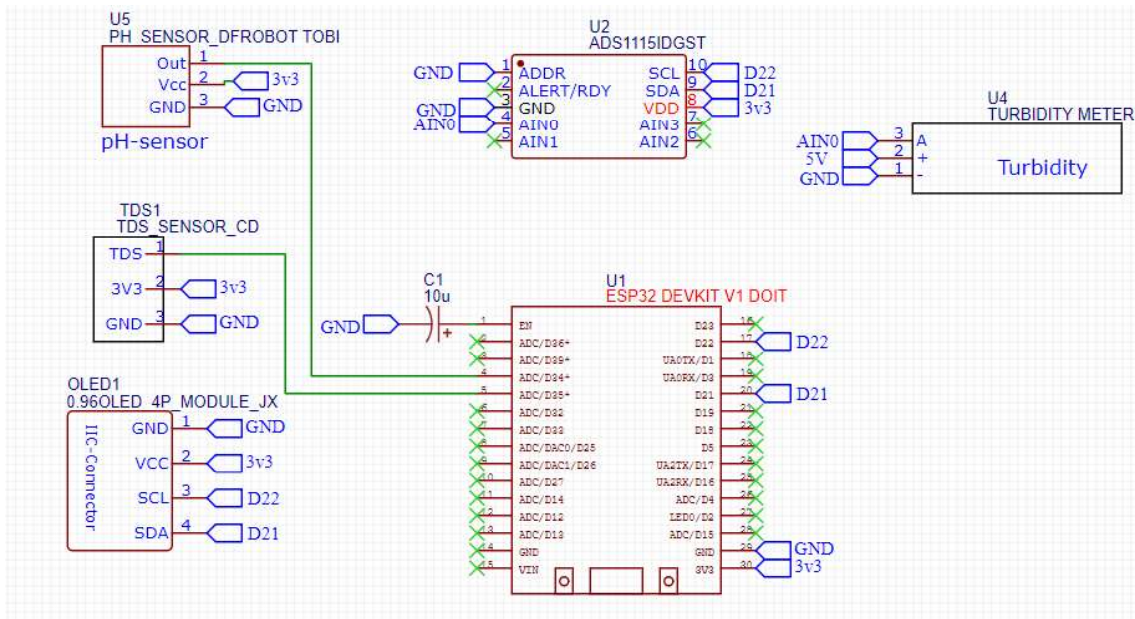


Figure 3.10: Main Circuit

3.3 Cost of Materials

The components used for the project were easy to find. Most of the components were locally sourced.

Table 3.4: The cost of materials.

Component	Model Name	Ratings/Specifications	Quantity	Price (\$)
Voltage Regulator	LM317T	1.25V-37V, >1.5A	2	N/A
AC-DC Adapter	N/A	9V, 1A	1	N/A
Breadboard	IRM 15-20	5V, 3.3V	1	12.30
Power Supply				
Microcontroller	ESP32	2.3V-3.6V	1	2.82
Analog pH sensor	SKU: SEN0161	3.3V-5V	1	28.38
Analog TDS sensor	SKU: DFR0244	3.3V-5V	1	72.13
Analog turbidity sensor	TS-300B	3.3V-5V	1	19.80
ADC converter	ADS1115	2.0V-5.5V	1	5.23
Capacitor	N/A	0.1 μ F, 1 μ F, 10 μ F,	2 (0.1 μ F), 2 (1 μ F), 1 (10 μ F),	N/A
Resistors	N/A	240 Ω , 250 Ω , 410 Ω , 720 Ω	1 (240 Ω), 1 (410 Ω), 1 (250 Ω), 1 (720 Ω)	N/A

Chapter 4: Implementation

4.1 Hardware Implementation

The hardware aspect of this project includes the sensors, the power supply system, a 10 μ F capacitor and the ESP32. All these components work together to ensure the capturing and analyzing of data. This section describes how the design is implemented and how all the hardware components function together.

4.1.1 The Power Supply System

The power supply system consists of the breadboard power supply and an AC-DC adapter. The adapter gets power from the mains. The mains produces about 220V AC at 50Hz. The adapter converts the 220V AC voltage to 9V DC with a current of 1A. This is connected to the breadboard power supply. The breadboard power supply has two output terminals. Each terminal can provide either 3.3V and ground or 5V and ground. The breadboard power supply is used in the circuit to power the electronic components that use 5V. Those components are the pH sensor, the TDS sensor, the turbidity sensor and the ADS1115 analogue to digital converter.

4.1.2 Sensor Configuration

The turbidity sensor probe is made up of an infrared transmitter LED and receiver LED. The sensor's behaviour is based on the Tyndall effect: light scattering in a medium due to suspended particles [45]. The infrared receiver receives some amount of radiation from the transceiver based on the cloudiness of the water. The clearer the water, the higher the radiation received by the infrared receiver [46]. The controller board of the turbidity sensor has three pins: ground, VCC and analogue pin. The ground pin was connected to the ground of the breadboard power supply. The VCC pin was connected to the 5V terminal of the breadboard power supply. The analogue pin was connected to the A0 pin of the ADS1115 ADC converter.

The unit for turbidity is NTU (Nephelometric Turbidity Units). The turbidity sensor was configured with the ADS1115 such that NTU was converted to Volts (V), from 0 to 3.3V. The result will be such that the clearer the water, the higher the voltage.

The ADS1115 has 10 pins: VDD, GND, SCL, SDA, ADDR, ALRT, A0, A1, A2 and A3. The VDD pin was connected to the 5V terminal of the breadboard power supply. The GND pin was connected to the ground terminal of the breadboard power supply. The SCL pin was connected to the D22 pin on the ESP32. The SDA pin was connected to the D21 pin of the ESP32. The ADDR pin was connected to the ground terminal of the breadboard power supply to use the I²C address 0x48 on the ESP32. The ADS1115 was configured with the highest resolution of 187.5 μ V to ensure high accuracy.

The pH sensor has two parts: the probe and the controller board. The probe contains pH electrodes which senses the hydrogen ion concentration in the solution to create a potential difference to generate a signal [47]. The controller board has three pins: GND, VCC and Analog pin. The GND pin was connected to the ground terminal of the breadboard power supply. The VCC pin was connected to the 5V terminal of the breadboard power supply. The Analog pin was connected to D15, an ADC channel, of the ESP32.

The TDS sensor has two parts: the probe and the controller board. The probe has two pins at its tip that are used to detect the amount of dissolved minerals in the water. The controller board has three pins: GND, VCC and Analog pin. The GND pin was connected to the ground terminal of the breadboard power supply. The VCC pin was connected to the 5V terminal of the breadboard power supply. The Analog pin was connected to D27, an ADC channel, of the ESP32.

The ESP32 reads the analog signals it receives from the sensors and transfers the information wirelessly through the embedded Wi-Fi module over to the database. The OLED

is used to display on-site the information processed by the ESP32. The OLED has four pins: GND, VDD, SCK and SDA. The GND pin was connected to the ground terminal of the breadboard power supply. The VCC pin was connected to the 5V terminal of the breadboard power supply. The GND pin was connected to the ground terminal of the breadboard power supply. The VCC pin was connected to the 3.3V terminal of the breadboard power supply. The SCK pin was connected to the D22 pin on the ESP32. The SDA pin was connected to the D21 pin of the ESP32. The I²C address of the OLED could not be found at 0x3C. Therefore, it was configured to work at any address apart from 0x3C. The figure below shows the system setup.

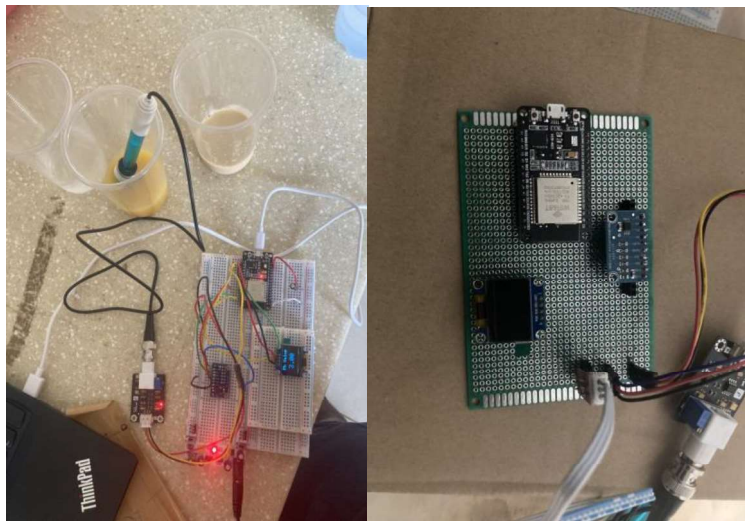


Figure 4.1: The system setup: breadboard setup (left), Figure 4.2: Perforated board (right)

4.2 Software Implementation

This section describes how the code was implemented to coordinate the functionality of the system. The Arduino IDE was used for the coding of the ESP32.

The Adafruit_ADS1X15 library was downloaded to facilitate the use of the ADS1115. The Adafruit_GFX and Adafruit_SSD1306 libraries were downloaded to facilitate the use of the OLED. The pH sensor pin, TDS sensor pins were defined at pins 15 (D15) and 27 (D27)

respectively. The OLED reset pin was defined at -1. The TDS sensor pin was declared as an input. The gain of the ADS1115 was set at two-thirds ($187.5\mu\text{V}$). The OLED's I²C address was specified at any address apart from 0x3C. This is because the OLED's I²C address could not be found at 0x3C. The serial monitor was initialized at a baud rate of 115200. The signals read from the ADC channels on the ESP32 were converted into voltages using the expression, $sensorSignal*(3.3/4096)$ before being converted into their respective units. However, the data from the pH sensor was outside the expected range of values so the *map()* function was used to map the values with the expected range of values. The figure below shows the software used for the programming of the system.



Figure 4.3: Arduino Software

4.3 Communication Module

Wi-Fi embedded on the ESP32 was used as a communication medium. It was used to send the data processed by the ESP32 over to the database.

4.4 Database

The database was created using MySQL. Xampp was used as a virtual host for the local host of the web server. PhpMyAdmin was used to run the MySQL on the web server. Tables were created with IDs based on the water quality parameters measured: pH, turbidity and TDS. The tables on the database get updated when the data is transmitted over Wi-Fi. The figure below shows the updated database.

	ID	TDS	pH	Turbidity	Date
<input type="checkbox"/> Edit Copy Delete	4	0.00	7	2.83	2022-04-22 00:39:10
<input type="checkbox"/> Edit Copy Delete	5	0.00	6	2.74	2022-04-24 00:40:10
<input type="checkbox"/> Edit Copy Delete	6	718	9	2.63	2022-04-24 00:41:10
<input type="checkbox"/> Edit Copy Delete	7	726	10	2.70	2022-04-24 00:42:10

Figure 4.4: The database table

4.5 Display

A web dashboard was created to view the data from the database. The template was used for the design of the web dashboard. The template was written in HTML, CSS and JavaScript. The frontend of the template was edited using the HTML and CSS tools to suit the kind of display required for the project. JavaScript was used as the backend of the template. Php was used as a server-side language. It is used to connect the web dashboard to the database. The figure below shows the readings on the web dashboard.

TDS	PH	Turbidity	Date
726	10	2.70	2022-04-24 00:42:10
718	9	2.63	2022-04-24 00:41:10
0.00	6	2.74	2022-04-24 00:40:10
0.00	7	2.83	2022-04-22 00:39:10

Figure 4.5: The web dashboard interface

Chapter 5: Results

5.1 Results

Four solutions were used for the testing of the system: orange juice sample, milk solution, tap water and muddy water. The pH sensor kept recording values outside the pH scale of 0-14. As such, the values of different kinds of solutions were sampled and mapped to fit the range of the pH scale. The map function on the Arduino IDE deals with integers. That gives an explanation to why the pH values were recorded as integers for all the different solutions. The turbidity values can be converted into NTU (Nephelometric Turbidity Unit) by using the equation:

$$\text{NTU} = -1120.4 * (\text{turbidity value_volt})^2 + 5742.3 * (\text{turbidity value_volt}) - 4352.9 \text{ -----(1)}$$

The values from each solution were recorded in the tables below.

Table 5.1: Results from the orange juice sample

Turbidity Value/V	pH Value	TDS Value/ppm
2.53	4.00	689
2.60	4.00	696
2.35	4.00	696
2.63	4.00	698
2.35	4.00	702
2.69	4.00	705
2.42	4.00	707

Using equation (1), the turbidity values range from 2982 NTU to 3003 NTU.

Table 5.2: Results from the milk solution

Turbidity Value/V	pH Value	TDS Value/ppm
2.55	8.00	710
2.57	8.00	710
2.64	8.00	710
2.55	8.00	710
2.51	8.00	710
2.44	8.00	710
2.46	8.00	710

Using equation (1), the turbidity values range from 2988 NTU to 3005 NTU.

Table 5.3: Results from the tap water

Turbidity Value/V	pH Value	TDS Value/ppm
2.42	7.00	0
2.35	6.00	0
2.38	7.00	0
2.33	7.00	0
2.38	7.00	0
2.37	7.00	0
2.40	7.00	0

Using equation (1), the turbidity values range from 2954 NTU to 2967 NTU.

Table 5.4: Results from the muddy water

Turbidity Value/V	pH Value	TDS Value/ppm
2.72	8.00	191
2.63	8.00	191
2.62	8.00	191
2.60	8.00	191
2.59	8.00	191
2.51	8.00	191
2.45	8.00	191

Using equation (1), the turbidity values range from 2977 NTU to 3004 NTU.

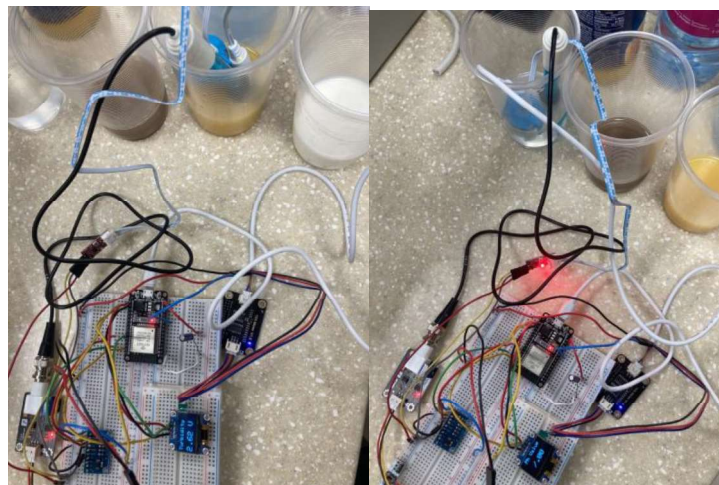


Figure 5.1: Sensors measuring the water quality in the orange juice sample (left), Figure 5.2: and tap water (right)

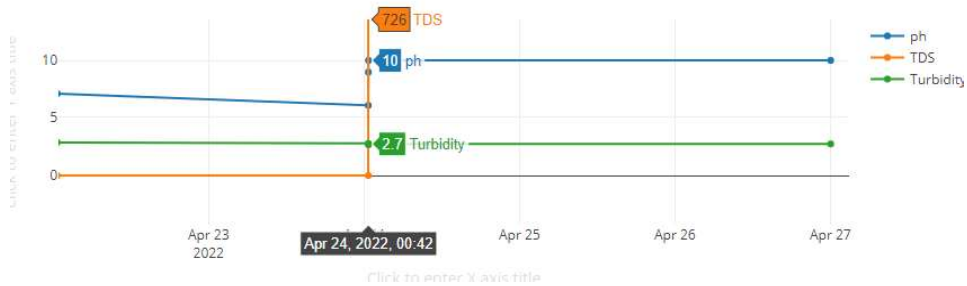


Figure 5.3: Graph of data from the dashboard at one time

5.2 Statistical Analysis

The Vernier pH and turbidity sensors were used to measure the pH and turbidity of the four solutions: orange juice sample, milk solution, tap water and muddy water. The results were compared to the values from the system's pH and turbidity values in order to test for accuracy. A t test was performed with both parameters on all the solutions using MATLAB. The t test was to return an h and p value. The h value represents the result of the null hypothesis. The p value represents the probability that hypothesis is true. The null hypothesis for this test is that the pH and turbidity values that the system provides are accurate.

5.2.1 Turbidity Values

The h values obtained from all the solutions indicate that the null hypothesis of the accuracy has to be rejected. The p-values obtained from each solution were less than 0.05 which meant that the null hypothesis was false.


```

capstone_stats.m  X +
17 [H,P] = ttest(ntu_o,ntu_o1)
18 [H,P] = ttest(ntu_w,ntu_w1)
19 [H,P] = ttest(ntu_m,ntu_m1)
20 [H,P] = ttest(ntu_md,ntu_md1)

Command Window
>> capstone_stats

H =

     1

P =

 1.2920e-13

H =

     1

P =

 1.1865e-15

```

Figure 5.4: T test for the turbidity values

5.2.2 PH Values

The h values obtained from all the solutions indicate that the null hypothesis of the accuracy has to be rejected. The p-values obtained from each solution were less than 0.05 which meant that the null hypothesis was false.

```

capstone_stats.m  X +
34
35 [H,P] = ttest(pH_o,pH_o1)
36 [H,P] = ttest(pH_w,pH_w1)
37 [H,P] = ttest(pH_m,pH_m1)
38 [H,P] = ttest(pH_md,pH_md1)

Command Window
H =

     1

P =

 1.0772e-15

H =

     1

P =

 0.0015

```

Figure 5.5: T test for the pH values

5.4 Responsiveness

The sensors were not able to read the water quality parameters on time. There was usually a lag in the display of the sensor readings. A timer was used to record the delay before

the readings were displayed. After the time lag, the sensors displayed stable readings. The table below shows the lag time in the sensor readings.

Table 5.5: Time lag for the sensors

Time Lag	Turbidity sensor	pH sensor	TDS sensor
1	3s	44s	80s
2	2s	42s	79s
3	2s	43s	81s
4	1s	44	81s
5	2s	42	80s
Average Time Lag	2s	43s	80.2s

From Table 5.5, the TDS sensor has the longest time lag followed by the pH sensor then the turbidity sensor. This shows that the system is not responsive enough. This can affect the efficiency of the system in terms of timely readings.

Chapter 6: Conclusion

6.1 Conclusion

This water quality monitoring system is designed to monitor the parameters of the water automatically every hour into a database to be displayed on a web dashboard. The user has the ability to see on the values displayed every hour on the web dashboard with the current reading displayed first. The database was designed with MySQL and phpMyAdmin to store the data received.

There were some limitations which affected the efficiency of the system. These limitations bring help bring about some improvements in the system design in the future to improve upon the efficiency and accuracy of the system.

6.2 Project Limitation

Due to the application of the database and the web dashboard, there was a level of knowledge required to help build the display system. It took quite some time learning concepts and languages that contributed to the storage and display system. This slowed down the progress of the project.

6.3 Future Works

Other parameters such as conductivity, sodium and oxygen could be monitored during the water quality monitoring process. This will gradually integrate all the other water monitoring parameters to the system to be monitored gradually.

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Appendix

Arduino Code: <https://github.com/adjoadd/codes.git>