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AQUABOTIX

AI BASED WATER QUALITY ASSESSMENT ROBOT

COLLEGE OF
ELECTRICAL AND MECHANICAL ENGINEERING
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COLLEGE OF ELECTRICAL AND MECHANICAL ENGINEERING

DE-42 EE
PROJECT REPORT

AQUABOTIX
AI BASED WATER QUALITY ASSESSMENT ROBOT

submitted to the Department of Electrical Engineering
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DEDICATION

This work is dedicated to our *parents*, whose love, support, and prayers have been our guiding light and unwavering strength throughout this journey.

ABSTRACT

The degradation of underwater ecosystems due to pollution and littering presents critical challenges to environmental sustainability. This project introduces AquaBotix, an underwater robot designed for water quality assessment, trash detection, and environmental monitoring. Traditional methods for these tasks are often labor-intensive and inefficient. AquaBotix leverages state-of-the-art robotics, sensor technology, and machine learning to enhance these processes, providing real-time, accurate data collection in aquatic environments.

AquaBotix is equipped with a variety of sensors, including those for pH, total dissolved solids (TDS), temperature, luminosity, and pressure, allowing for continuous monitoring of water quality parameters. Additionally, the robot features an object detection system integrated with machine learning algorithms to detect and locate underwater trash, aiding in precise cleanup operations. The robot's design ensures excellent maneuverability, enabling thorough exploration and inspection of underwater habitats, which is essential for environmental research and monitoring.

This project aims to greatly improve the conservation of underwater ecosystems. It demonstrates how robotics, sensor technology, and artificial intelligence can work together to address urgent environmental problems. By combining these technologies, an interdisciplinary approach is formulated to solving the complex challenges faced by the water bodies.

SUSTAINABLE DEVELOPMENT GOALS (SDGS)

The Sustainable Development Goals (SDGs) are a series of 17 goals fixed by the United Nations and adopted by 193 countries in 2015. Through sustainable (economic, environmental, and social) development, their overall objective is to create a better world, and a better life for all, by 2030.

Out of these 17 goals, AquaBotix aligns with five of them.

SDG	Goal	UN Statistics
	Good Health and Well-Being	9 million people die each year from air, water and soil pollution. It is three times more than tuberculosis, AIDS and malaria.
	Clean Water and Sanitation	2.2 billion people worldwide do not have access to safe drinking water
	Industry, Innovation and Infrastructure	34% of the world's population do not have access to the internet at home. 78% in least developed countries.
	Climate Action	+2.5°C is the increase in Earth temperature at the end of the century at the current rate of growth in carbon emissions. +1.5°C is the limit we must not exceed
	Life Below Water	34% of global fishery resources are fished at unsustainable levels

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CHAPTER 01 – INTRODUCTION

Water is among the planet's vital natural resources, enabling multiple ecosystems, human-environment services, and economic activities. Unfortunately, due to rapidly growing environmental pollution, the water in the seas, rivers, and lakes keeps deteriorating. This serious problem needs a creative solution. AquaBotix is a project designed to offer a technical edge in real-time monitoring systems on water quality and efforts to detect underwater trash, achievable through the ultimate advancements in robotic and sensor technology. AquaBotix aims to revolutionize how we investigate and manage our water bodies' overall well-being.

The growing amounts of water pollution and the problems they have caused served as inspiration for the creation of AquaBotix. The methods now in use to check the quality of the water and find waste are laborious, time-consuming, and have restricted accessibility. Developments in robotics, sensor technology, and machine learning offer a fantastic chance to build systems that can assess the quality of water in real time. AquaBotix combines various sensors and machine learning algorithms, which makes it a great solution for keeping the environment safe.

Pollution of water is a widespread problem that leads to serious health problems among people in a number of countries around the globe. The primary pollutants include plastics, chemicals, and organics chiefly found in rivers. This has led to contamination that compromises the safety of drinking-water supplies while also harming aquatic life. The AquaBotix project is significant because it deals with some major issues:

1. **Damage to Ecosystem:** Pollution harms our lakes and rivers, hurting the creatures that live there and messing up how they all depend on each other.
2. **Diseases:** People who drink dirty water are more susceptible to deadly illnesses like dysentery and cholera.
3. **Economic Damage:** Pollution hurts businesses like fishing and tourism, and it costs a lot to clean up dirty water. The UN Environment Programme estimates the global cost at a staggering $8.1 trillion per year, a figure that encompasses healthcare expenses, lost productivity, and ecosystem damage. **[1]**
4. **Global Warming:** Pollution isn't just bad for water; it also makes global warming worse.

Water quality assessment involves a thorough examination of several key parameters, each serving as crucial indicators of the overall health and integrity of aquatic environments. For example, pH levels provide important information about how acidic or alkaline the water is, and high or low pH levels can seriously jeopardize the delicate balance of aquatic ecosystems. In a similar manner, Total Dissolved Solids (TDS) measurement provides crucial details on the concentration of dissolved materials, which can significantly impact water's flavor and general quality. Furthermore, the temperature of the water has a significant impact on the metabolic processes of aquatic organisms and the solubility of oxygen, both of which are necessary for maintaining a robust and healthy aquatic environment.

Water pollution has many negative effects on the environment, including the loss of biodiversity and the deterioration of ecosystems. In addition to causing direct harm to marine life, pollutants also interfere with bioaccumulation and reproductive cycles, which amplifies their negative impacts all the way up the food chain. Furthermore, contaminated waterways increase greenhouse gas emissions, which exacerbates the worldwide problem of climate change. Water contamination is largely caused by human activity, which increases the risk of health issues for recreational activities like swimming and fishing. As a result, industries like tourism and commercial fishing that depend on clean water bodies for their operations suffer severe financial losses. **[2]**

It is imperative that everyone has access to clean, safe water for a number of reasons. From a public health standpoint, clean water is crucial for preventing waterborne infections and maintaining human health. In terms of the environment, clean water bodies support biodiversity and ecological resilience by serving as vital habitats for a range of aquatic organisms. **[3]** From an economic perspective, clean water is essential to sustaining tourism, industrial activity, and agricultural productivity. Furthermore, preserving healthy aquatic habitats is crucial to mitigating the consequences of climate change and enhancing environmental sustainability overall. **[4]**

Globally, states and organizations are investing heavily in the maintenance of water quality. Since the year's end, over $100 billion has been invested globally on water delivery and treatment facilities, according to Global Water Intelligence. **[5]** This invested money is utilized to create innovative concepts like AquaBotix, update water purifying facilities, and come up with pollution-reduction strategies.

AquaBotix has developed a comprehensive system for monitoring and improving water quality. Sensors have been utilized that measure pH, TDS, temperature, brightness, and pressure and employ artificial intelligence algorithms to deliver continuous real-time data on water quality. It comes with a camera that may be used alongside machine learning algorithms to detect and locate submerged waste.

CHAPTER 02 – BACKGROUND AND LITERATURE REVIEW

The development of underwater robots for purposes of environmental monitoring, more so in water quality assessment and trash detection, has changed immensely over the last several decades. People began this journey back in the 1970s when they realized that water pollution was impacting human health as well as aquatic environments leading to innovation in technology. The 1972 Stockholm United Nations Conference on the Human Environment was a historic occasion that brought environmental concerns, particularly water quality, to the forefront of public attention. **[6]**

Governments and environmental agencies began developing regulatory frameworks and monitoring systems. For example, in 1972, the United States Environmental Protection Agency (EPA) adopted the Clean Water Act, which attempted to minimize contaminants in water bodies and establish wastewater regulations. **[7]**

By the 1980s, it was clear that industrial discharges, untreated sewage, and agricultural runoff were major pollutants. The United Nations reported in 1982 that over 40% of the world's population lacked access to clean drinking water, highlighting the urgency of tackling water pollution. [8] Presently, the most common way to monitor water quality is by using labor-intensive, slow-moving laboratory analysis also referred to as manual sampling.

The burgeoning demand for increasingly comprehensive and efficient monitoring of water quality during the 21st century gave rise to significant advances in both automation as well as sensor technologies. Up until 2005, the global market for water quality sensors had surpassed $1 billion, signifying an increase in spending within this sector. **[9]**

The creation of the Remote Operated Vehicles (ROVs) was one of the first ways to use robotics for environmental monitoring. These are still used in underwater pipelines inspections and other marine structures especially for industry. [10] However, the environment is another area where they are currently used after being used industrially. For instance, the Monterey Bay Aquarium Research Institute (MBARI) developed AUVs that could collect a lot of data thanks to fitted sensors. The data collecting efficiency was increased by 50% thanks to these AUVs. **[11]**

The integration of Artificial Intelligence (AI) and machine learning into environmental monitoring systems marked a significant leap forward in the 2010s. AI programs boosted robots' ability to work with big data hence enhance precise identification and prediction of pollution incidents. In 2015 study, it was stated that AI based water quality monitoring systems could detect 95% accurately whereas traditionally operated ones were only doing 70% accurate detection. **[12]**

Currently, there is extensive work being done on water quality monitoring using state-of-the-art technologies. The market for underwater robots and drones is valued at an estimated (USD) $4.49 billion. A healthy CAGR of 14.5% is expected from 2023 to 2030. **[13]** Research continues to focus on improving the accuracy and efficiency of monitoring systems.

The table below lists the specifics of research articles along with their contributions:

S No.	Title of the Research Paper	Author(s)	Publishing Year	Main Contributions
1	Design and architecture of a slender and flexible underwater robot	Jia Lin Wang, Jia Lin Song, Jia Qiao Liang, Ai Rong Liu	2024	• Discusses the design and analysis of a biomimetic underwater snake-like robot, addressing the main limitations of current underwater robotic systems in terms of maneuverability and adaptability in complex environments • The specific advantages of this design include the robot's enhanced structural integrity, its ability to conform to irregular surfaces, and its adaptability to environmental variations
2	Design and Implementation of a Six-Degrees-of-Freedom Underwater Remotely Operated Vehicle	Khaled M. Salem, Mohammed Rady, Hesham Aly and Haitham Elshimy	2023	• Developed a control system for the ROV that allows it to move in all six directions • The ROV's navigation, position control, and path tracking were precise even in strong currents
3	Analysis of Underwater Robot Designs	M.A. Eladawy, Yury Karavaev	2023	• Considered a description and comparison of underwater mobile robots driven by screw propellers, de-pending on their number, location, and shape of the hull, is given, and the designs of robots implementing biosimilar motion in a liquid • The analysis made it possible to identify the strengths and weaknesses of the mechanisms used to

				implement biosimilar motion in a liquid
4	Review of research and control technology of underwater bionic robots	Khalaji et al	2023	• Reviews the current state of research on underwater robots inspired by biological designs (biomimetic robots) • Discusses the challenges of underwater control and navigation and explores potential solutions based on biomimicry.
5	A fundamental experiment on mobility of a wheeled underwater mobile robot on water-containing sand	Oefuchi et al	2023	• Explores the use of wheeled robots for underwater exploration • Presents the results of experiments on a wheeled robot designed to operate in sandy environments
6	Design of Autonomous Underwater Drone for Achieving the Efficiency in the Operation of the Sensor Package during Monitoring of Water Bodies	Muaz Abul-Muti	2022	• Developed a robust and autonomous prototype • Performed stress analysis at depth of 20m • Manufactured physical prototype using stainless steel and PLA material
7	Design and Construction of an ROV for Underwater Exploration	Oscar Adrian Aguirre-Castro, Everardo Inzunza-González, Enrique Efrén García-Guerrero	2020	• Reached depths of up to 100m • The ROV has an autonomy of up to 2 or 3 hours • Captured images of 800×640 px on video graphic array

8	Underwater Optical Wireless Communication	Hemani Kaushal, Georges Kaddoum	2016	• Discusses the feasibility and reliability of high data rate underwater optical links due to various propagation phenomena • Hybrid approach to an acousto-optic communication system

CHAPTER 03 – METHODOLOGY

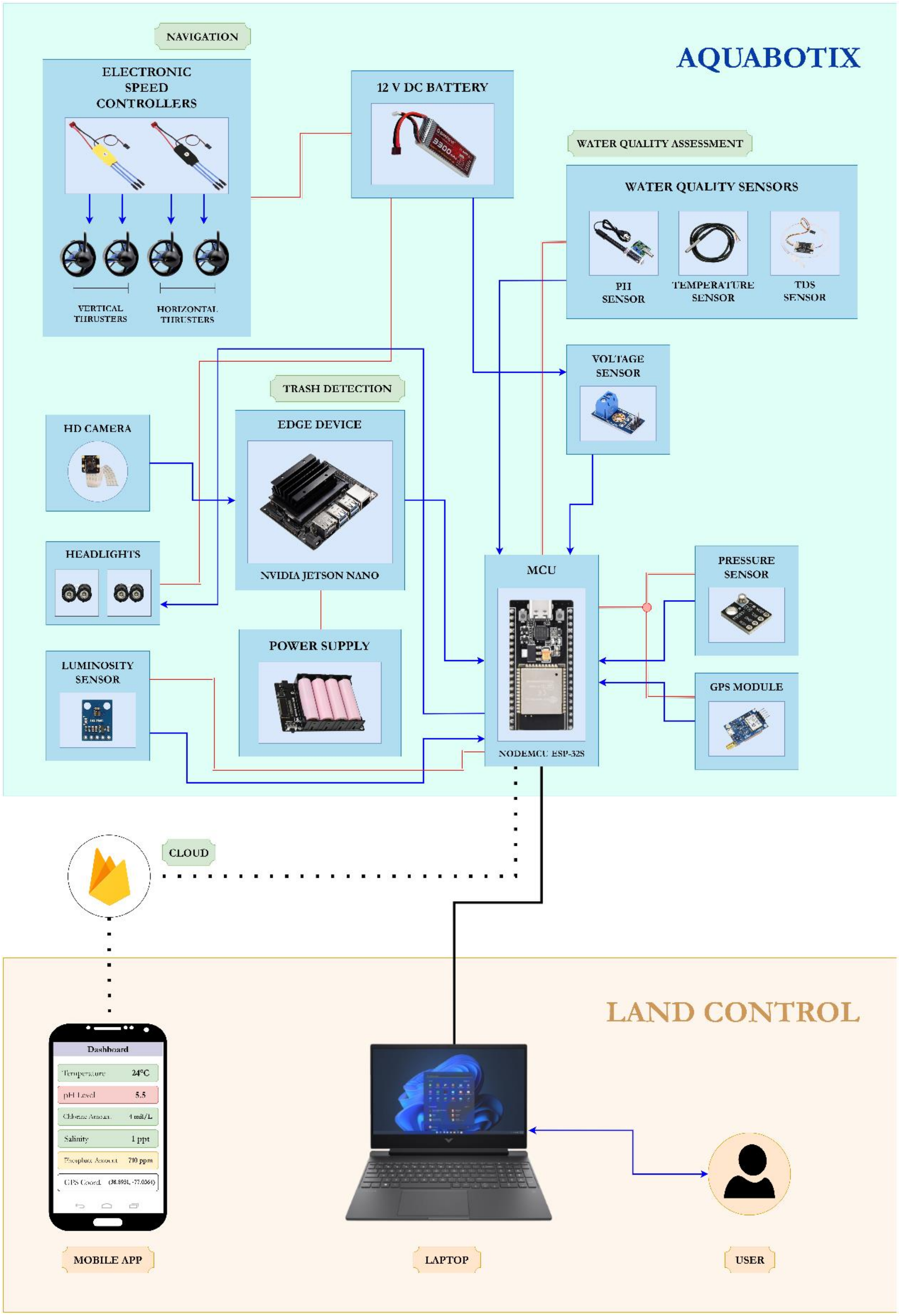

Figure 1. AquaBotix Flow Diagram

Four distinct domains are combined to form AquaBotix, and they are as follows:

1. Embedded Systems
2. Machine Learning
3. Mechanical Design
4. Mobile App Development

3.1 EMBEDDED SYSTEMS

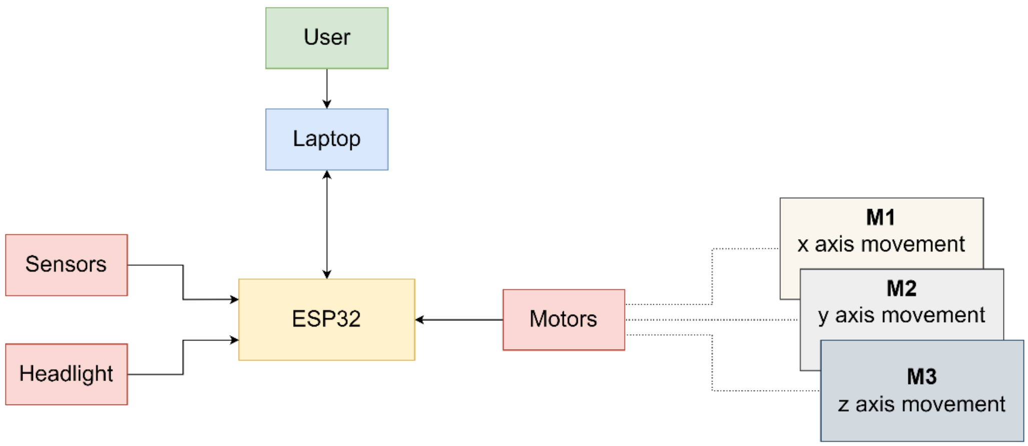

Figure 2. Embedded Systems Block Diagram

The electrical components used in this project are described in depth in this section and include the following:

1. Microcontroller
2. Sensors
3. Motors and ESCs
4. Leds and Led Drivers
5. Edge Device
6. Camera
7. Circuit Schematic and PCB

3.1.1 MICROCONTROLLER

We used the NODEMCU ESP-32S microcontroller in this project. It is a dual-core device with 32-bit LX6 CPU cores, which increases its speed and dependability for the tasks related to our project. Configuration registers allow for the adjustment of the operating frequency up to 240MHz.

The inclusion of Bluetooth (BLE) and Wi-Fi capabilities simplifies connecting wireless sensor networks, eliminating the need for additional components at different nodes. Another important thing is that its power consumption ranges from 2.2 to 3.6 volts. ESP32 fits well in many other types of projects like embedded systems and Internet of Things

(IoT) applications. Because it has several communication formats such as I2C, SPI, and UART, besides 4MB flash memory, which enable it to conduct many communications, it is compatible with numerous components.

Figure 3. NODEMCU ESP-32S

The algorithms and codes for the ESP32 were written in VS Code and built using the ESP-IDF (Espressif IoT Development Framework) v4.4 – an official framework for executing ESP projects by Espressif Systems. Version 4.4 of the ESP-IDF includes various tools and libraries necessary for developing and executing ESP32 projects.

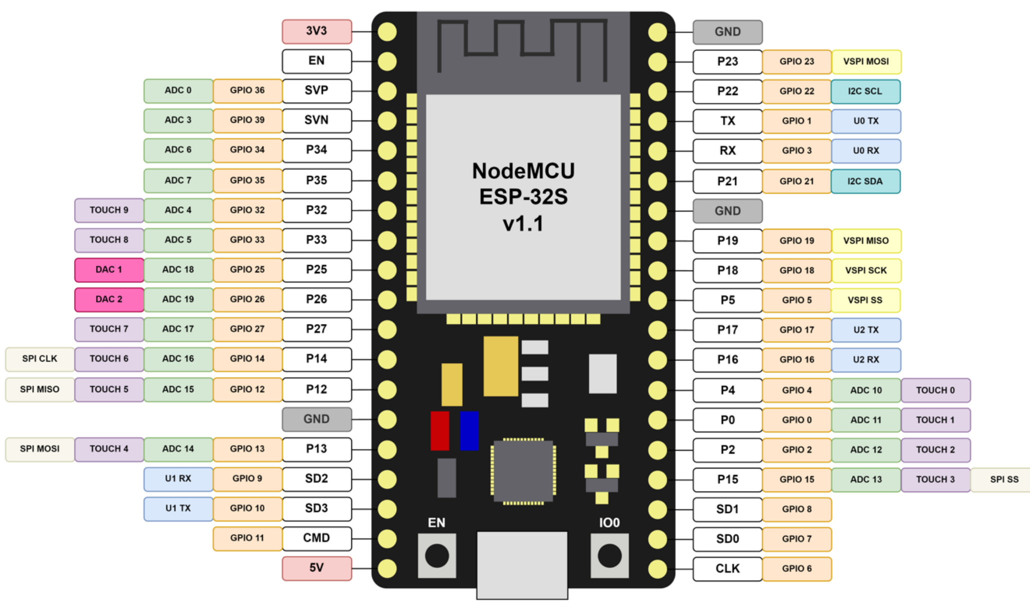

Figure 4. NODEMCU ESP-32S Pinout Diagram

3.1.1.1 DIRECTORY STRUCTURE

The projects created using ESP IDF have a specific directory structure. The directory structure for AquaBotix is as under:

```
├── CMakeLists.txt          <– Top-level CMake configuration file
├── main
│   ├── CMakeLists.txt      <– CMake config for the main application
│   ├── Kconfig.projbuild   <– Project build settings
│   └── main.c              <– Main application source code
├── components
│     └── component_01
│     ├── CMakeLists.txt    <– CMake config for component
│     ├── component_1.c     <– Component implementation file
│     ├── component_1.h     <– Component header file
│     ├── Datasheet.pdf     <– Technical details for component
│     └── Readme.md         <– Usage and setup for component
└── Readme.md               <– Project overview and setup instructions
```

A header file (.h) and an implementation file (.c) are included in every component folder. Functions are declared in header files and used in the implementation files of certain components. The functions declared in the matching header file are defined in an implementation file.

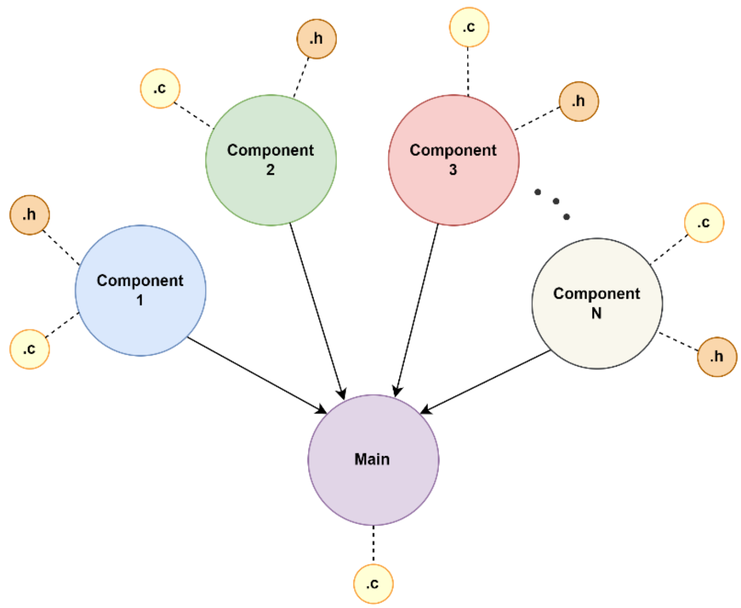

Figure 5. Embedded Systems Directory Structure

These component folders are connected with the "main" folder. For clarity, all sensors, motors, wireless protocols (e.g., WiFi or BLE) or other peripheral devices connected to the microcontroller are being referred as "components".

Following a directory structure helped us coding in an organized and modular manner by separating each component into its own folder. This modularity simplified code maintenance, debugging, and updates, as each component could be modified independently without affecting the others.

3.1.2 SENSORS

The following sensors are used in this project:

Water Quality Assessment Sensors	• pH Sensor • Total Dissolved Solids (TDS) Sensor • Temperature Sensor
Additional Sensors	• Pressure Sensor • Luminosity Sensor • GPS Sensor • Voltage Sensor

3.1.2.1 PH SENSOR

With a scale from 0 to 14, pH indicates how acidic or alkaline a solution is. pH has a significant impact on aquatic life health, chemical solubility, and the likelihood of corrosion or scale development in water systems, making it a crucial factor in water quality.

By measuring the concentration of hydrogen ions in water, the pH sensor produces a voltage from 0 to 5V that is mapped from 0 to 14. This helps monitor and maintain appropriate pH levels for various applications.

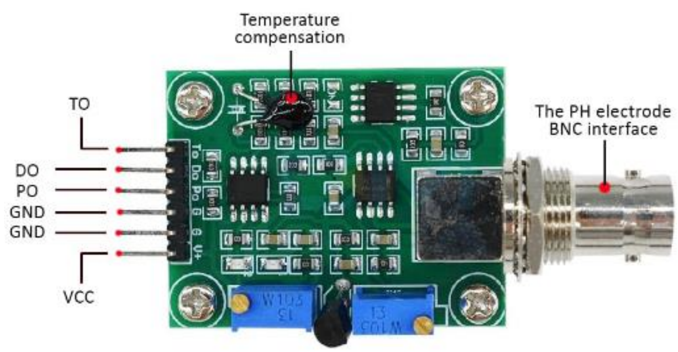

Figure 6. PH-4502C Module

Figure 7. E201-BNC Electrode

We have used the PH-4502C liquid pH sensor, which processes the signals coming from the electrode and is equipped with the E201-BNC electrode. The microcontroller can further process the module's output. The module has a potentiometer that can be used for calibration. The module has a 10K NTC thermistor installed for ideal calibration, and also features an output that indicates when the set acidity threshold is exceeded.

- **Mathematical Equation**

$$pH = -5.70 \times \left(\frac{ADC\ Value}{4096} \times 3.3 \right) + 0.75.$$

The pH value is calculated by converting the raw ADC value coming from pH module to the equivalent voltage value. It is then multiplied with the sensitivity factor. Finally, a calibration constant is added to compensate for the offset.

The specifications of sensor are mentioned below:

- **Pinout Table**

S No.	Pin Name	Description
1	To	Temperature Output
2	Do	3.3V Output (from pH limit POT 2)
3	Po	pH Value Output (Analog)
4	GND	Ground for pH Probe
5	GND	Ground for module

6	Vcc	Input Voltage (5 V)
7	POT 1 (near to BNC Connection)	Analog Reading Offset
8	POT 2 (near to module male-pins)	pH Limit Setting

Table 1. Pinout Table for pH Sensor

- **Nature & Range of Data Obtained from Sensor**

S No.	Pin	Data	Range	Usage
1	To	Temperature	0°C to 60°C	To measure the temperature of water
2	Do	Voltage	3.3V	To set alarms (turn on LED or buzzer) if the pH value exceeds a specific limit
3	Po	pH	0 to 14	To measure pH of water

Table 2. Nature and Range of Data Obtained from pH Sensor

With its great precision and dependability, the pH sensor provides accurate pH readings that are essential for evaluating the quality of the water. It also has a strong cost-effectiveness ratio, balancing price and performance.

3.1.2.2 TOTAL DISSOLVED SOLIDS (TDS) SENSOR

TDS, or Total Dissolved Solids, is basically the amount of all dissolved compounds in a liquid. As the number of solids that are dissolved in water increases, the conductivity of the fluid does rise and this is what allows TDS sensors to pick such changes instantly. Simply put, TDS shows us how many milligrams per liter there is of soluble solid matter present in that specific body of H_20.

This measurement assists in determining whether water can be considered suitable for drinking or other uses as it shows the presence of potential pollutants and impurities in it. When we determine TDS value we measure the total amount of various organic or inorganic substances dissolved in it using ppm or mg/l measurement standards.

Figure 8. TDS Meter v1.0 with TDS Probe

We used the TDS Meter V1.0 (PH2.0-3P interface) module for this project, which is paired with the TDS probe featuring the XH2.54-2P interface. Its electrode can measure conductive materials, such as suspended solids, heavy metals, and conductive ions in water.

- **Mathematical Equation**

$$TDS\ (in\ ppm) = 66.71(V_{comp})^3 - 127.93 \times (V_{comp})^2 + 428.7 \times V_{comp}$$

where

$$V_{comp} = \frac{V_{avg}}{Compensation\ Coefficient}$$

and

$$V_{avg} = ADC\ Value \times \frac{V_{ref}}{4096} \times ADC\ Compensation$$

$$Compensation\ Coefficient = 1 + 0.02\ (TDS\ Temperature - 25)$$

Initially, the average voltage is calculated by multiplying the raw ADC value with the reference voltage (1.18V). This is divided by 4096 which indicates the no. of levels in a 12-bit ADC conversion. Then the ADC compensation value is multiplied to give the final average voltage value.

Temperature compensation assumes adjusting of voltage for temperature by an average voltage division by the compensation factor, assuming a linear compensation factor of 2% per °C.

Lastly, the corrected voltage is transformed into a TDS value in parts per million (PPM) using a polynomial equation with empirically calculated coefficients.

The specifications of sensor are mentioned below:

- **Pinout Table**

S No.	Pin Name	Description
1	-	Ground (0V)
2	+	Input Voltage (3.3 – 5V)
3	A	Analog Signal Output (0 to 2.3 V)
4	TDS	TDS Probe Connector
5	LED	Power Indicator

Table 3. Pinout Table for TDS Sensor

TDS Meter V1.0 measures total dissolved solids in water with range of 1 to 1000ppm, with an accuracy of (10%) F.S. (25 °C).

3.1.2.3 TEMPERATURE SENSOR

Temperature is a measure of heat or cold, expressed in Kelvin (K), Fahrenheit (°F), or degrees Celsius (°C). It has an impact on chemical reactions, dissolved oxygen levels, and biological activity, making it essential for water quality. Elevated temperatures have the potential to accelerate chemical processes, decrease oxygen solubility, and affect aquatic life's metabolism and reproduction.

We have used the DS18B20 sensor in this project for measuring the temperature of water. This sensor operates using the One-Wire communication protocol, allowing it to communicate with a microcontroller using a single data line. The sensor has an internal diode that is used to measure the temperature. This measurement is converted into a digital signal. The sensor's built-in analog-to-digital converter (ADC) processes the temperature reading and stores it in a scratchpad memory. The ESP32 can then request the stored temperature reading from the DS18B20.

Figure 9. DS18B20 Temperature Sensor

- **Mathematical Equation**

$$Temperature = \frac{Temp_{LSB} + (Temp_{MSB} \times 256)}{16}$$

Two bytes are used to store the temperature: $Temp_{LSB}$ and the $Temp_{MSB}$. By moving the MSB eight bits to the left (multiplying by 256) and adding it to the LSB, the two bytes are combined into a single value. To convert the whole value to Celsius, it is lastly divided by 16.

The specifications of sensor are mentioned below:

- **Pinout Table**

S No.	Pin Name	Description
1	Vcc	Input Voltage (3.3V – 5V)
2	DQ	Analog Signal Output
3	GND	Ground (0V)

Table 4. Pinout Table for Temperature Sensor

- **Sensor Response Time**

S No.	Medium	Response Time (seconds)
1	Water	1
2	Air (still)	6
3	Air (moving)	3
4	Metal	0.5

Table 5. Response Time of Temperature Sensor

The response time depends on the following factors:

1. The temperature resolution
2. The thermal conductivity of the medium in which the sensor is placed
3. The air flow around the sensor

The DS18B20 measures temperatures from -55°C to +127°C with ±0.5°C accuracy.

3.1.2.4 PRESSURE SENSOR

Precise pressure measurement is important for safe processes, accurate data gathering as well as equipment operation.

We have utilized the MS5837-30BA pressure sensor in our project. It is a high-resolution sensor designed for both air and water pressure measurement. The sensor communicates with the ESP32 via the I2C interface. The MS5837 sensor is well-suited for underwater applications due to its ability to withstand high pressures and provide accurate readings.

Figure 10. MS5837-30BA Pressure Sensor

- **Mathematical Equation**

$$Pressure = \frac{(D_o \times SENS_2)}{2^{15}\,(2^{21} - OFF_2)} + 6480$$

Initially, the raw pressure data is multiplied by the second order adjusted sensitivity. The value is divided by a scaling factor of 2^{15}. Subtracting second order offset adjustment from another scaling factor of 2^{21} scales the result according to the sensor's resolution. 6480 is added as a final offset to align the calculated pressure with the actual sensor output.

The specifications of sensor are mentioned below:

- **Pinout Table**

S No.	Pin Name	Description
1	Vcc	Input Voltage (3.3V – 5V)
2	GND	Ground (0V)
3	SCL	Serial Clock
4	SDA	Serial Data

Table 6. Pinout Table for Pressure Sensor

3.1.2.5 LUMINOSITY SENSOR

Luminosity is defined as the intensity of light passing through a given area. In deep-sea environment, luminosity is a considerable aspect for camera operation since water scatters light at all angles making visibility decrease as you go deeper into the water body. With proper lightning for the camera, we can detect underwater waste materials.

Given its high sensitivity and accuracy in monitoring ambient light levels, the TSL2561 light sensor is a great fit for this project. It has two photodiodes that can detect visible and infrared light. This feature is useful for exploring underwater, where turbidity and depth can cause light intensity to shift quickly. The sensor can measure light at very low to very high levels due to its large dynamic range.

Figure 11. TSL-2561 Luminosity Sensor

- **Mathematical Equation**

$$Luminosity = \frac{402\ (CH_0 - CH_1)}{Gain\ \times T_{integration}}$$

The problem of silicon detectors to respond strongly to infrared light is overcome in the TSL2561 through the use of two photodiodes. One of the photodiodes (channel 0) is sensitive to both visible and infrared light, while the second photodiode (channel 1) is sensitive primarily to infrared light. An integrating ADC converts the photodiode currents to digital outputs. Channel 1 digital output is used to compensate for the effect of the infrared component of light on the channel 0 digital output. The ADC digital outputs from the two channels are used in a formula to obtain a value that approximates the human eye.

The specifications of sensor are mentioned below:

- **Pinout Table**

S No.	Pin Name	Description
1	Vcc	Input Voltage (3.3V – 5V)
2	GND	Ground (0V)
3	SCL	Serial Clock
4	SDA	Serial Data
5	INT	Interrupt

Table 7. Pinout Table for Luminosity Sensor

- **Data Obtained from Sensor**

S No.	Criteria	Value
1	Range	0.1 – 40000 lux
2	Resolution	0.1 lux
3	Sensitivity	(0.038 - 4.0) lx / digit
4	Error	± 0.5%
5	Precision	0.1 lux
6	Response Time	13.7 – 402 ms

Table 8. Data Obtained from Luminosity Sensor

3.1.2.6 GPS SENSOR

The GPS, or Global Positioning System, is a satellite-based navigation system that provides location and time information anywhere on or near the Earth's surface. It consists of a network of satellites that orbit the Earth, emitting signals that are received by GPS receivers to determine their precise location.

It aids in precise geotagging of images or videos, allowing for the identification of underwater trash locations with latitude and longitude coordinates. GPS aids in navigation to specific cleanup sites, facilitating targeted efforts.

Figure 12. NEO-M8M GPS Sensor

The NEO-M8M GPS module uses trilateration in finding latitude and longitude details. It picks incoming signals from multiple Global Navigation Satellite System (GNSS) satellites including BeiDou, GPS and GLONASS and Galileo.

Every satellite sends out a signal with its unique position and exact timing information on it. These signals are received by the NEO-M8M GPS sensor, which calculates the time it takes for the signals to reach the sensor. The sensor determines the separations between itself and each satellite by analyzing the timing discrepancies between signals from various satellites.

In trilateration, spheres centered on each satellite are intersected; the distance between the sensor and the satellite is represented by the radius of each sphere. The exact latitude and longitude coordinates of the sensor are obtained from the intersection of these spheres.

The specifications of sensor are mentioned below:

- **Pinout Table**

S No.	Pin Name	Description
1	Vcc	Input Voltage (3.3V – 5V)
2	GND	Ground (0V)
3	TXD	Data Transmitted from GPS Sensor
4	RXD	Data Received by the GPS Sensor
5	PPS	Pulse Per Second

Table 9. Pinout Table for GPS Sensor

- **Data Obtained from Sensor**

S No.	Criteria	Value
1	Baud Rate	9600 Hz (configurable from 4800 Hz to 115200 Hz)
2	Resolution	1 – 5 Hz
3	Warmup Time	27 seconds (fastest)

Table 10. Data Obtained from GPS Sensor

A challenge faced with the GPS sensor is its inability to function underwater. To make use of GPS, the robot must remain above the water surface.

3.1.2.7 VOLTAGE SENSOR

A voltage sensor is used to measure the voltage of a battery by connecting its input terminals to the positive and negative terminals of the battery.

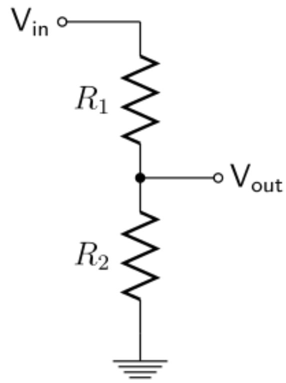

Figure 13. Voltage Divider Circuit (VDR)

An analog voltage sensor, such as a voltage divider or a voltage divider circuit connected to an analog-to-digital converter (ADC), is used to measure the voltage of a battery. Two resistors linked in series, one to the battery's positive terminal and the other to its negative terminal (ground), make up a voltage divider circuit. The voltage sensor taps into the junction between these resistors to detect the voltage across one resistor, which is proportional to the battery voltage. For the sensor utilized in this project, the values of resistors are:

R1 = 30k Ω R2 = 7.5k Ω

The input battery voltage is scaled down by a factor of 5 before it is fed to the ADC of the ESP32 for further processing.

Figure 14. Voltage Sensor

- **Mathematical Equation**

$$Battery\ Voltage = \left[\left(\frac{Raw\ ADC\ Value}{4096} \times 3.3\right) \times \left(\frac{R1 + R2}{R2}\right)\right] + Calibration\ Value$$

The calculation of battery voltage involves converting the ADC value into its equivalent voltage value. This value is then multiplied with the voltage divider factor. Finally, to compensate the voltage value, a calibration value of 0.75 is added.

3.1.3 MOTORS AND ESCS

The motors used for robot navigation are as follows:

Motors for Vertical Motion	Brushless DC Motor A2212 930KV
Motors for Horizontal Motion	Brushless DC Motor X2212 980KV

These motors are controlled with Electronic Speed Controllers (ESCs). The ones used in our project are:

Uni-directional ESCs	Supports only clockwise or anti-clockwise rotation
Bi-directional ESCs	Supports both clockwise and anti-clockwise rotation

3.1.3.1 MOTORS FOR VERTICAL MOTION

Three A2212 930KV brushless DC motors have been used for the vertical motion. Even at their highest RPM, these motors' well-balanced rotor ensures remarkably smooth and dependable performance. Brushless motors have a much longer lifespan and a greater power-to-weight ratio than brushed motors.

Figure 15. 930KV A2212 Brushless DC Motor

- **Electrical Specifications**

S No.	Specification	Value
1	KV	930
2	No load speed	980 RPM/V

3	No load current	10 V @ 0.5A
4	Free load current	2.5A
5	Current capacity	12A/60s
6	Max Efficiency	80%

Table 11. Electrical Specifications for A2212 BLDC Motor

- **Mechanical Specifications**

S No.	Specification	Value
1	Length	43.5mm (with shaft)
2	Diameter	28.5mm
3	Shaft Diameter	3.17mm

Table 12. Mechanical Specifications for A2212 BLDC Motor

3.1.3.2 MOTORS FOR HORIZONTAL MOTION

Two X2212 980KV brushless DC motors have been used for the horizontal motion. These motors were chosen due to their exceptional performance and efficiency. The motors' 980KV rating means that, under no-load situations, they can accomplish 980 revolutions per minute (RPM) per volt of applied voltage, which is the required speed and power for efficient vertical movement.

Brushless DC motors like the X2212 are famous for their dependability, lifespan, and durability when compared to brushed motors.

Figure 16. 980KV X2212 Brushless DC Motor

- **Electrical Specifications**

S No.	Specification	Value
1	KV	980
2	Internal Resistance	92m Ω
3	No load current	10V @ 0.6A
4	Max Continuous Power	385W
5	Max Continuous Current	26A/30S

Table 13. Electrical Specifications for X2212 BLDC Motor

- **Mechanical Specifications**

S No.	Specification	Value
1	Length	46.0mm (with shaft)
2	Diameter	27.5mm
3	Shaft Diameter	3.175mm

Table 14. Mechanical Specifications for X2212 BLDC Motor

3.1.3.3 UNI-DIRECTIONAL ESC

The Electronic Speed Controller (ESC) is a device meant to control electric motors' force and speed specifically for cases where it's necessary for the motor to rotate in one direction only. In drones, electric cars and robots, this type of ESC is frequently employed when accurate and effective regulation of the motor velocity is vital. Uni-directional ESCs maintain motor power through modifications in pulse width modulation (PWM) signals. This leads to an increase in speed without jerks or sudden stops. For particular applications, they help in improving system performance and dependability through limiting movement in one side only.

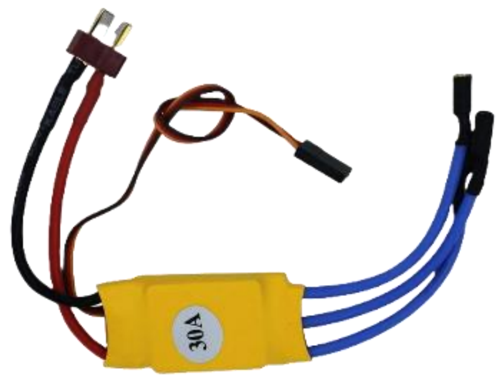

Figure 17. Uni-directional Electronic Speed Controller

A pulse width of 1ms indicates the minimum throttle position for a unidirectional ESC, which usually indicates that the motor is halted or operating at its slowest speed. Half throttle or a moderate speed is typically represented by the middle. Whereas the maximum throttle position, which denotes the motor's maximum operating speed, is often represented by 2ms. It is important to mention that these speeds only apply to one direction: clockwise or counterclockwise.

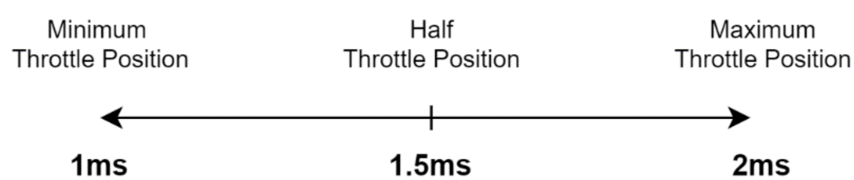

Figure 18. PWM and Speed Relation for a Uni-directional ESC

The specifications of an electronic speed controller are mentioned as:

- **Pinout Table**

S No.	Pin Name	Description
1	BAT+	The positive pin connected to battery (usually between 3.7V to 22.2V)
2	BAT-	The ground pin connected to battery
3	Vcc	Output voltage for ESP32
4	PWM	Pulse Width Modulation (PWM) signal from the ESP32
5	GND	Ground connected to ESP32 (0V)

Table 15. Pinout Table for Uni-directional ESC

An ESC has three wires on its output, which is connected to the three phases of a brushless DC motor. It provides controlled power to the motor that, in turn, spins at the intended rate.

3.1.3.4 BI-DIRECTIONAL ESC

A bi-directional electronic speed controller is able to change the direction of movement of electric motors both ways, forward and backward, without any problem. It is particularly used in cases like robot arms, cars, or other machines requiring careful, uninterrupted two-directional motion. The algorithms utilized in bi-directional ESC functioning and the way pulse width modulation (PWM) is employed to regulate the speed and direction of motors set them apart from uni-directional ESCs. Quick direction changes and precise, steady motion are made possible by this combination, which also improves output quality and versatility.

Figure 19. Bi-directional Electronic Speed Controller

With a bi-directional ESC, the same pulse widths have different meanings. Here, the 1ms pulse represents full reverse throttle, making the motor spin fastest in the reverse direction; while 2ms stands for full forward throttle resulting in the same happening but this time at its maximum speed in forward direction. And the midway point signifies zero throttle.

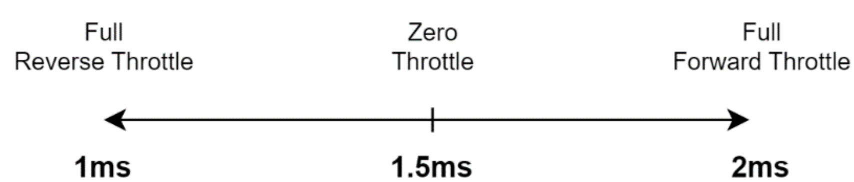

Figure 20. PWM and Speed Relation for a Bi-directional ESC

The specifications of an electronic speed controller are mentioned as:

- **Pinout Table**

S No.	Pin Name	Description
1	BAT+	The positive pin connected to battery (usually between 3.7V to 22.2V)
2	BAT-	The ground pin connected to battery
3	Vcc	Output Voltage for ESP32
4	PWM	Pulse Width Modulation (PWM) signal from the ESP32
5	GND	Ground connected to ESP32 (0V)

Table 16. Pinout Table for Bi-directional ESC

While the pinouts of a bi-directional ESC are same as those of a uni-directional, the main difference lies in their construction and operation principle. The range of PWM signal for both ESCs is from 1ms to 2ms.

3.1.4 LEDS AND LED DRIVERS

3.1.4.1 LEDS

The leds are a part of the sight for the robot. Some of the key points that should be considered while choosing leds include the brightness, size, current requirements, etc. After much research, the 3W CREE leds were finalized. While the led itself is not waterproof, but it offers controllable brightness (using PWM signal from ESP32).

Figure 21. CREE Led

3.1.4.2 LED DRIVERS

A led driver is an important electronic device that modifies the power supply to a led. It makes sure that the led gets the same and proper amount of power that it requires at all times, irrespective of any fluctuations in the voltage or current coming from the power source. For the CREE 3W leds, a 5 – 35V, 700mA driver has been used to make sure it receives the accurate current and voltage necessary for optimal performance.

Figure 22. Led Driver

3.1.5 EDGE DEVICE

Edge computing is becoming more crucial in the current computing environment. It is about processing data at or close to the source, which reduces latency and therefore improves processing. At the innermost layer of this principle is the edge device, a vital element in network computing.

3.1.5.1 WHAT IS AN EDGE DEVICE?

A computing device that is located at the terminal of a network, often situated right next to the user end or the data center itself, is commonly referred to as an edge device. The main function of an edge device is to process data at its point of origin (user or data center), hence eradicating the need for constant connection to any cloud or central server. Edge devices find importance in several uses, such as the IoT, robotics, or autonomously functioning systems, because they help in real-time data handling with faster response rates as well as better protection.

3.1.5.2 NVIDIA JETSON NANO

Jetson Nano is a small but powerful edge computing device specifically meant for AI (artificial intelligence) and machine learning applications, as designed by NVIDIA. It has impressive processing ability in just a tiny package, thanks to the powerful GPU and quad-core ARM Cortex-A57 CPU that it comes with. It is also built-in with local storage, several connectivity options, and an array of software, which makes it perfect for any developer.

Figure 23. Nvidia Jetson Nano

- **Key Features**

Feature	Description
Processor	Quad-core ARM Cortex-A57 CPU
GPU	NVIDIA Maxwell 128-core GPU
Memory	4GB LPDDR4
Storage	MicroSD card slot
Driving Voltage	5V DC
Camera Connection	MIPI CSI-2 Camera Connector
Header	40 Pin GPIO Header

Table 17. Key Features of Nvidia Jetson Nano

3.1.5.3 ADVANTAGES OVER RASPBERRY PI

Jetson Nano offers several advantages over Raspberry Pi, making it a preferred choice for AI and edge computing projects. Following table shows the comparison:

Feature	Nvidia Jetson Nano	Raspberry Pi 4
CPU	Quad-Core ARM Cortex-A57 64-bit @ 1.42 GHz	Quad-Core ARM Cortex-A72 64-bit @ 1.5 GHz
GPU	Nvidia Maxwell w/ 128 CUDA cores @ 921 MHz	Broadcom VideoCore VI (32-bit)
Memory	4 GB LPDDR4	4 GB LPDDR4
Networking	Gigabit Ethernet / M.2 Key E (for WiFi support)	Gigabit Ethernet / WiFi 802.11ac

Display	HDMI 2.0 and eDP 1.4	2x micro-HDMI (up to 4Kp60)
USB	3x USB 3.0, USB 2.0 Micro-B	2x USB 3.0, 2x USB 2.0
GPIO	40-pin GPIO	40-pin GPIO
Video Encode	H.264/H.265 (4Kp30)	H264(1080p30)
Video Decode	H.264/H.265 (4Kp60, 2x 4Kp30)	H.265(4Kp60), H.264(1080p60)
Camera	MIPI CSI port	MIPI CSI port
Storage	Micro-SD	Micro-SD

Table 18. Comparison of Nvidia Jetson Nano with Raspberry Pi 4

- Having a dedicated GPU and an optimized software stack, Jetson Nano performs better than Raspberry Pi in AI tasks involving inference, thus facilitating the deployment of more advanced machine learning algorithms.
- Jetson Nano supports different power source options, including barrel jack, micro-USB, and GPIO pins in different deployment scenarios which is flexible and convenient.
- With support for Gigabit Ethernet, Jetson Nano presents improved networking capabilities making it possible for faster operations involving transfer of large data amounts and engaging in two-ways communication with other devices connected to the Internet.

3.1.6 CAMERA

The robot sees through a camera which gives useful sight during trash detection. For precise detection which might be needed under particular conditions, it is important to have an HD camera. In conjunction with Jetson Nano module for cameras, there are two highly recognized options: Raspberry Pi Camera Module v2.1 and Arducam IMX219 lens. These modules pride in high-definition imaging capabilities enabling the robot to perceive its surroundings with clarity and detail.

However, the choice of the right camera becomes very necessary when operating in water, which can be quite tricky because of water visibility and lighting. During such occasions, the most appropriate option is the Raspberry Pi Camera Module V2.1. Moreover, trash detection and other similar activities are facilitated thanks to the device’s ability to take pictures with fine details courtesy of an 8 Megapixel Sony IMX219 sensor module.

Raspberry Pi Camera Module V2.1 additionally makes it perfect in water bodies due to its small design. It is also possible to record videos on it, even though it supports up to 1080p resolution and can take photos at a speed of 30 frames per second.

Figure 24. Raspberry Pi Camera v2.1

3.1.7 CIRCUIT SCHEMATIC AND PCB

The complete circuitry for AquaBotix involves a combination of different sensors, motors, electronic speed controllers, edge device, etc. that aid in the objectives of water quality assessment, trash detection, and underwater navigation. The schematic and PCB have been developed on Altium, which is industry-level software.

3.1.7.1 CIRCUIT SCHEMATIC

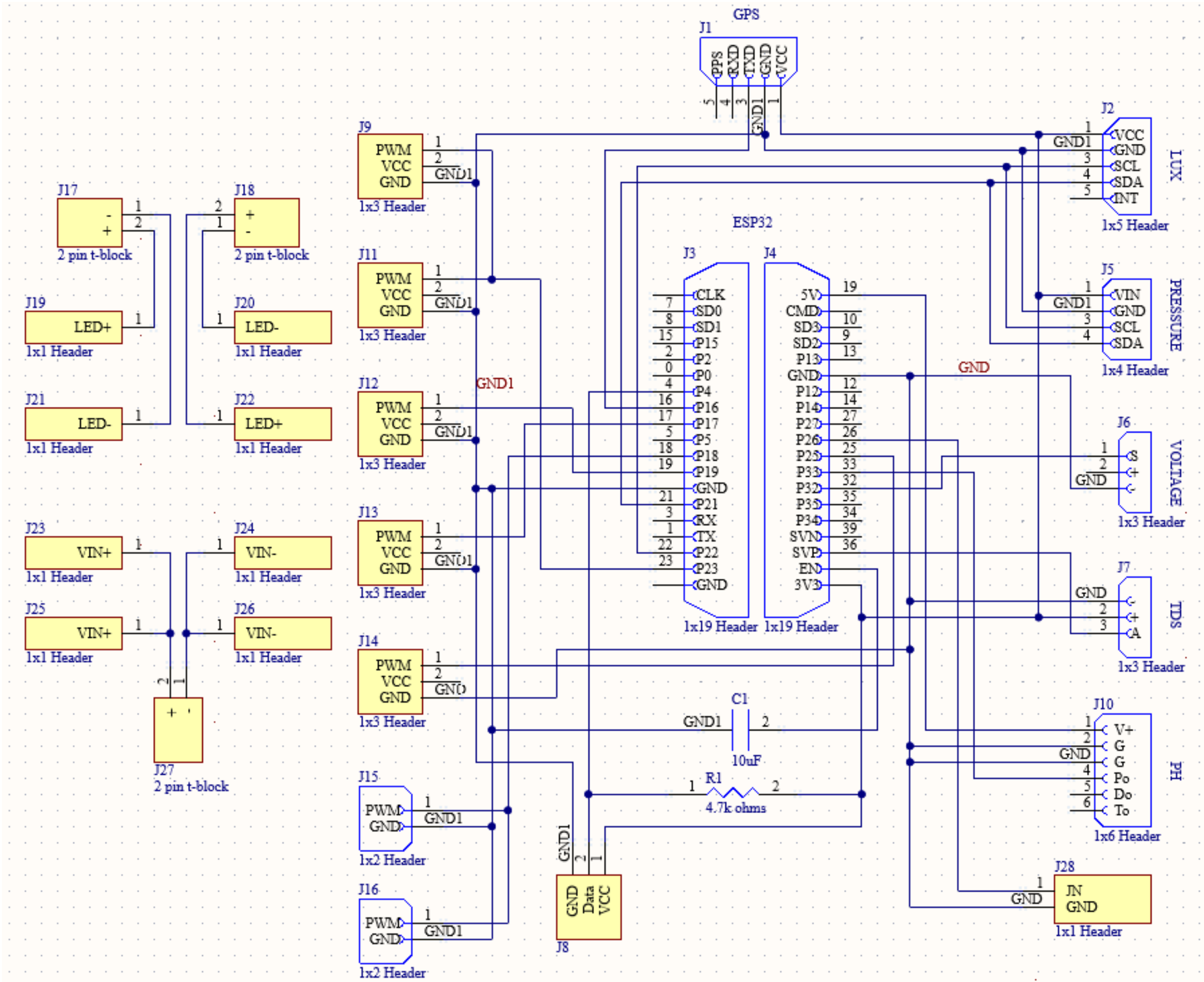

Figure 25. AquaBotix Circuit Schematic

3.1.7.2 PRINTED CIRCUIT BOARD

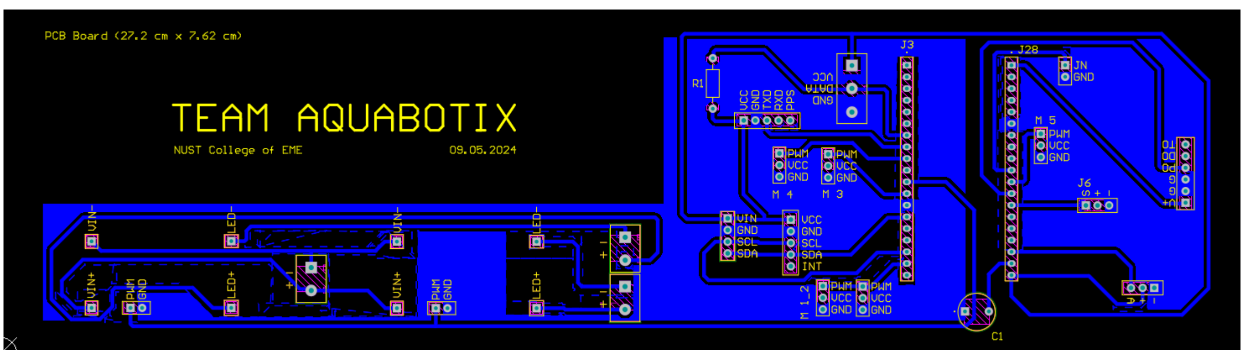

Figure 26 (a). AquaBotix PCB 2-D Model

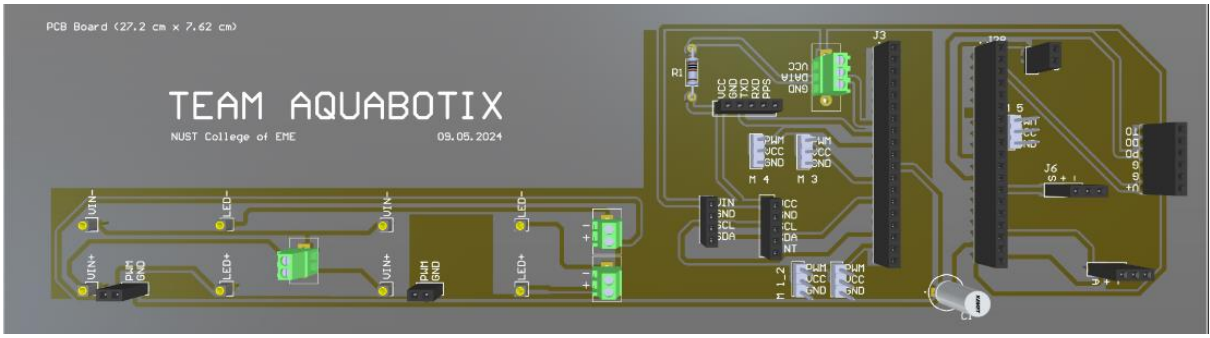

Figure 26 (b). AquaBotix PCB 3-D Model

3.2 MACHINE LEARNING

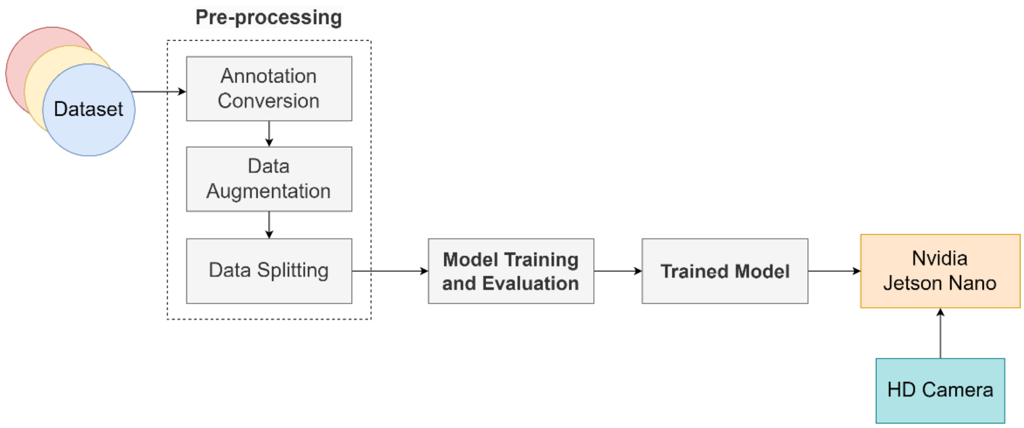

Figure 27. Machine Learning Block Diagram

Building an efficient machine learning model that can efficiently detect underwater trash is one of the main aims of this project. The key concern was to ensure high levels of accuracy when distinguishing between a scenario with only one object in it or none whatsoever, and other cases with different items within it. This would help protect marine life through aquatic trash identification.

3.2.1 YOU ONLY LOOK ONCE (YOLO V7) MODEL

YOLO v7 is an object detection model for real-time computer vision tasks that are both fast and accurate. It cuts down on the parameters by approximately 40% and computation by up to 50% comparing it with other models while maintaining better performance metrics in terms of speed or accuracy. It differs from other leading object detection algorithms by processing frames at 155 fps speed. Even the original baseline YOLO model was capable of processing at a maximum rate of 45 frames per second.

3.2.1.1 ARCHITECTURE

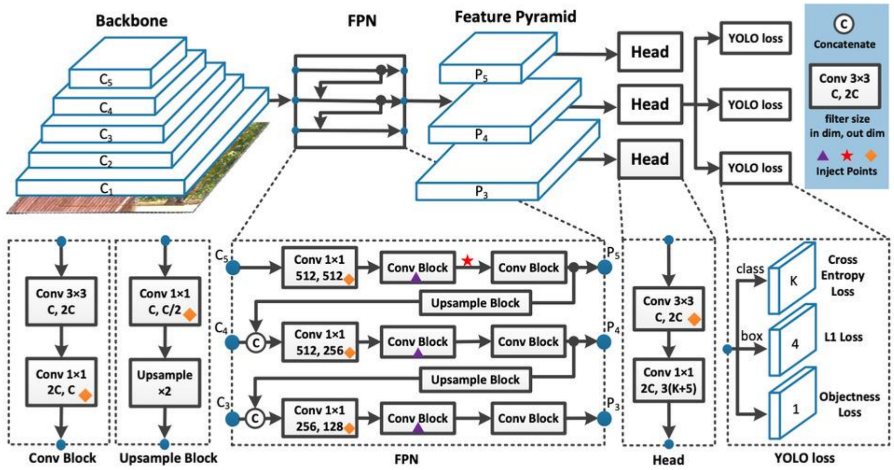

Figure 28. YOLO Network Architecture

- **Backbone**

  The backbone of YOLOv7 extracts features from the input image. It adopts a modified version of the CSP Darknet (Cross Stage Partial) which is well known for its effectiveness and efficiency in feature extraction by YOLOv7. Various convolutional layers, batch normalization, and Leaky ReLU activations are used in the backbone.

- **Neck**

  YOLOv7's neck is composed of multiple feature pyramid networks (FPN) and path aggregation networks (PAN) that merge characteristics coming from multiple scales allowing more effective object detection various sizes.

- **Head**

  The head of the network is in charge of predicting the bounding boxes, objectness scores, and class probabilities. YOLOv7 exploits anchor boxes (predefined bounding boxes in various shapes and sizes) to make the final detections.

3.2.2 DIRECTORY STRUCTURE

The directory structure for machine learning, inspired by Cookie Cutter, is shown below:

```
├── dataset
│   ├── raw                        <– The original dataset (images)
│   └── processed                  <– Final dataset for model training
│       ├── train                  <– Training images and their labels
│       │   ├── images
│       │   └── labels
│       └── val                    <– Validation images and their labels
│           ├── images
│           └── labels
├── models                         <– Trained and serialized models
│
├── reports                        <– Analysis reports
│   └── figures                    <– Generated graphs and figures
│
├── src                            <– Source code for this project
│   ├── _init_.py
│   │
│   ├── preprocessing              <– Scripts to preprocess data
│   │   ├── task_01.py
│   │   ├── task_02.py
│   │   ├── ...
│   │   └── task_n.py
│   ├── models                     <– Scripts to train and validate model
│   │   ├── model_val.py
│   │   └── model_train.py
│   ├── testing                    <– Scripts to train and test model
│   │   └── model_test.py
│   └── visualization              <– Scripts to create exploratory visualizations
│       ├── report_gen.py
│       └── figure_gen.py
│
└── Readme.md                      <– Top-level Readme file
```

3.2.3 DATASET

The dataset we used were from following two sources:

1. Taco Dataset
2. MJU Waste v1.0 Dataset

3.2.3.1 TACO DATASET

This dataset comprises of around 1500 garbage photos obtained in the outdoors. The photos are annotated and stored in JSON (COCO) format. It comprises over 60 classifications that represent various forms of waste, such as plastic bags, tin cans, etc.

Figure 29. Taco Dataset Sample

3.2.3.2 MJU WASTE V1.0 DATASET

This dataset consists of 2475 trash images taken against a plain background (indoor). The images are labeled and available in JSON (COCO) format. It has only one class, "0" to show if the trash has been detected or not.

3.2.4 DATA PREPROCESSING

After combining the above two datasets, we had collectively around 3975 images. However, before partitioning the set into training and validation subsets, some things were resolved:

1. Conversion needed to be done from JSON annotations into the YOLO format. The YOLO annotation style requires the classification number, the box start point and the box height and width as indicated below:

YOLO Annotation Format

0	0.540664	0.591264	0.152245	0.115666

2. Ensuring that every annotation corresponds to only one class is crucial. The TACO dataset has around 60 classes hence for all annotated images, their class numbers were uniformly assigned to be “0”.
3. Before merging the two datasets, each image was checked to have a distinct name.
4. To expand the dataset to around 8000 images, data augmentation was performed.
5. When these activities are done, 80 percent of this information goes for training, while the rest (20%) goes for validation.

3.2.5 MODEL TRAINING

Training included several loops through the dataset, where model weights were changed to reduce errors in detection.

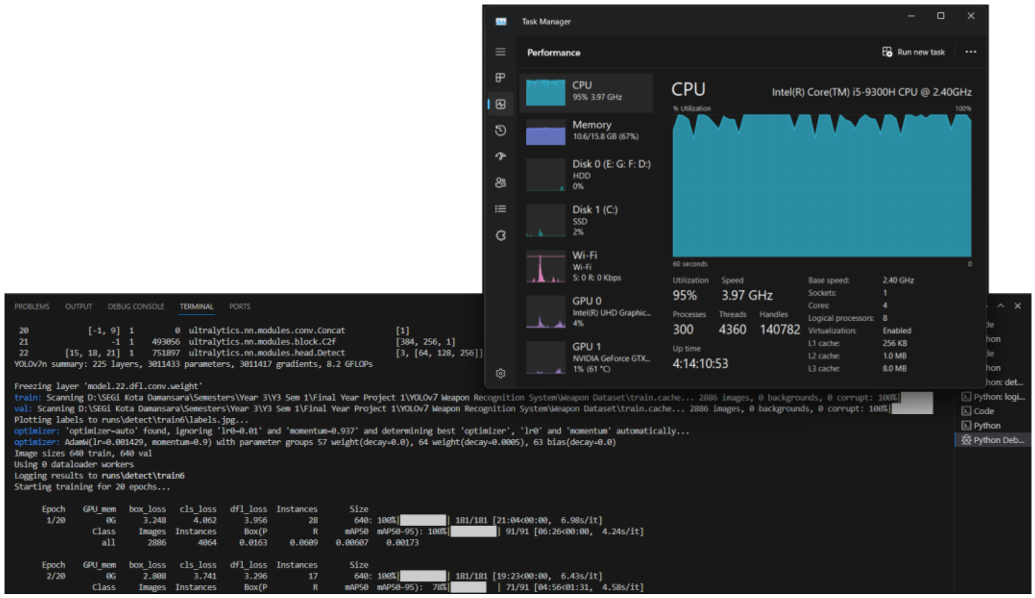

Figure 30. Yolo v7 Model Training on Custom Dataset

3.2.6 YOLO V7 CONFIGURATION STEPS ON JETSON NANO

In order to configure yolo v7 model on Jetson Nano, we followed the following steps:

3.2.6.1 SWAP MEMORY

Building the complete OpenCV package requires more than 4 GBs of RAM and the 2 GBs of swap space delivered by ZRAM, usually found on Jetson Nano. Temporarily, the *dphys-swapfile* was installed to get the additional room from the SD card.

After the compilation, we removed the mechanism, eliminating swapping to the SD card.

 # Check for updates
$ sudo apt-get update
$ sudo apt-get upgrade

 # Install nano
$ sudo apt-get install nano

 # Install dphys-swapfile

$ sudo apt-get install dphys-swapfile

 # Enlarge the boundary (4.5.2 and higher)
$ sudo nano /sbin/dphys-swapfile

 # Give the required memory size
$ sudo nano /etc/dphys-swapfile

 # Reboot
$ sudo reboot

3.2.6.2 INSTALLING OPENCV WITH CUDA SUPPORT

 # Check memory first
$ free -m

 # We need at least a total of 8.5 GB
 # If not, enlarge the swap space as explained in the guide
$ wget https://github.com/Qengineering/Install-OpenCV-Jetson-Nano/raw/main/OpenCV-4-8-0.sh
$ sudo chmod 755 ./OpenCV-4-8-0.sh
$ ./OpenCV-4-8-0.sh

 # Once installation is done
$ rm OpenCV-4-8-0.sh

 # Remove the dphys-swapfile now
$ sudo /etc/init.d/dphys-swapfile stop
$ sudo apt-get remove --purge dphys-swapfile

 # Just a tip to save an additional 275 MB
$ sudo rm -rf ~/opencv
$ sudo rm -rf ~/opencv_contrib

3.2.6.3 INSTALLING YOLOV7

 # First create a folder for the YOLO project and clone Yolov7 repo
mkdir yolo
cd yolo
git clone https://github.com/WongKinYiu/yolov7

All necessary packages were installed. However, we encountered a problem here. *pip install matplotlib* did not work for us to install the matplotlib library. Installing matplotlib on Jetson Nano will require a few extra steps. Execute these two commands first:

sudo apt install libfreetype6-dev
sudo apt-get install python3-dev

 # It is best to install *numpy* and *matplotlib* first
pip3 install --upgrade pip setuptools wheel
pip3 install numpy==1.19.4
pip3 install matplotlib

We have to comment out two packages that we installed manually (PyToch and TorchVision). Change the requirements using the nano editor. We installed all required packages from requirements.txt. We did this in a Yolov7 cloned repository where requirements.txt file is located.

pip install -r requirements.txt

3.2.6.4 INSTALLING PYTORCH AND TORCHVISION

We installed PyTorch version 1.8, because it was officially provided by Nvidia

pip3 install -U future psutil dataclasses typing-extensions pyyaml tqdm seaborn
pip3 install Cython
wget
https://nvidia.box.com/shared/static/p57jwntv436lfrd78inwl7iml6p13fzh.whl -O
torch-1.8.0-cp36-cp36m-linux_aarch64.whl
pip3 install torch-1.8.0-cp36-cp36m-linux_aarch64.whl

Now came the tricky part. Because there is no pre-built wheel for torchvision for Jetson Nano, we have to clone it from GitHub. Then we build the right version. After this we installed it in our virtual environment. TorchVision version needs to be compatible with PyTorch. We used PyTorch version 1.8.0, so we will choose TorchVision version 0.9.0

sudo apt install libjpeg-dev zlib1g-dev libpython3-dev libavcodec-dev
libavformat-dev libswscale-dev
pip3 install --upgrade pillow
git clone --branch v0.9.0 https://github.com/pytorch/vision torchvision
cd torchvision
export BUILD_VERSION=0.9.0
python3 setup.py bdist_wheel
cd dist/
pip3 install torchvision-0.9.0-cp36-cp36m-linux_aarch64.whl

```
cd ..
cd ..
sudo rm -r torchvision
```

3.2.6.5 RUNNING YOLO V7 ON JETSON NANO

Before we ran YOLOv7 on Jetson Nano for the first time, we had to download trained weights first. We had to choose between normal and tiny version. So, we used the tiny version for this project, because it's optimized for edge devices like Nano.

 # Download tiny weights
wget https://github.com/WongKinYiu/yolov7/releases/download/v0.1/yolov7-tiny.pt

 # Download regular weights
wget https://github.com/WongKinYiu/yolov7/releases/download/v0.1/yolov7.pt

 # Installing package for using jetson gpios
sudo apt install Jetson.GPIO

Finally, we implemented the python code with object detection using yolo v7 in order to accomplish the desirable outcomes.

3.3 MECHANICAL DESIGN

The outer cover design is the most crucial part in developing an underwater robot; it must be waterproof, lightweight, small, and appropriate in size.

All of the electrical components in our design are housed in a single pipe. While one end of the pipe is sufficiently open to allow all the wires to reach the corresponding motors and sensors outside the pipe, the other end of the pipe is entirely shut. In front of the design is a small acrylic pipe. This pipe, which serves as the robot's eyes, has an 8 MP Raspberry Pi v2.1 camera and a luminosity sensor.

Below is a view of the design from several perspectives:

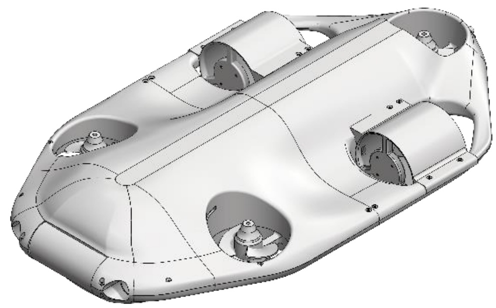

Figure 31 (a). Isometric View

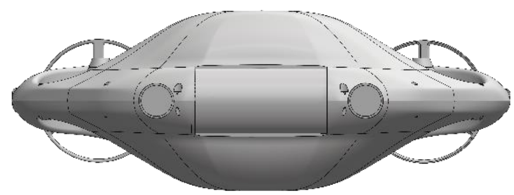

Figure 31 (b). Front View

Figure 31 (c). Side View

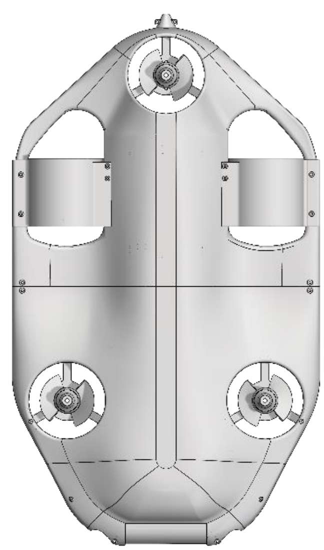

Figure 31 (d). Top View

The detail of mechanical components is as under:

1. Front top body
2. Front bottom body
3. Main back body
4. Front-back connector
5. Main pipe open lid
6. Main pipe close lid
7. Main pipe compartment
8. Acrylic pipe lid
9. Acrylic pipe compartment
10. Led holders
11. Pressure sensor holder
12. Thruster hubs
13. Vertical propellers
14. Horizontal propellers
15. Tether cable holder

3.3.1 FRONT TOP BODY

One of AquaBotix's four primary parts is the front top body. Overall hydrodynamic efficiency is maintained by this section, which is aerodynamically designed to decrease drag and smoothly merges with the rest of the body.

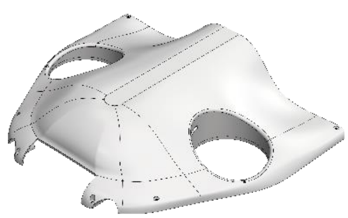

Figure 32 (a). Isometric View

Figure 32 (b). Front View

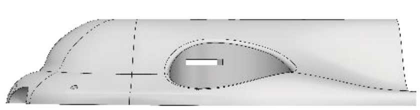

Figure 32 (c). Side View

Figure 32 (d). Top View

3.3.2 FRONT BOTTOM BODY

The front top half is complemented by the front bottom part through holding sensors and giving upright support. Here are placed TDS and temperature probes for water quality values monitoring at all times. This keeps those sensors in check so they can identify contaminants right away when the robot goes on in water.

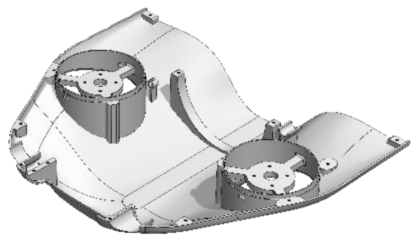

Figure 33 (a). Isometric View

Figure 33 (b). Front View

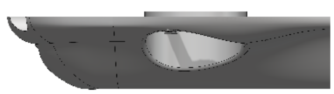

Figure 33 (c). Side View

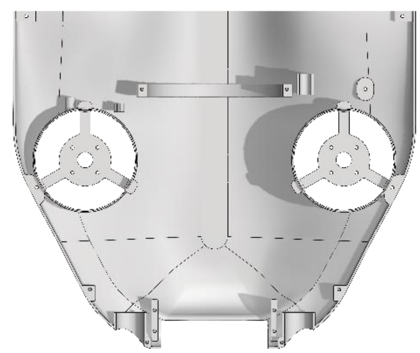

Figure 33 (d). Top View

3.3.3 MAIN BACK BODY

The pH sensor and the sealed end of the main acrylic pipe are located within the main back body. Horizontal thruster hubs can be connected via mounting positions on the outside. An opening at the back-back end of this body which acts as the cable's entry point.

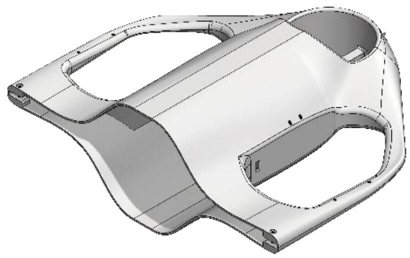

Figure 34 (a). Isometric View

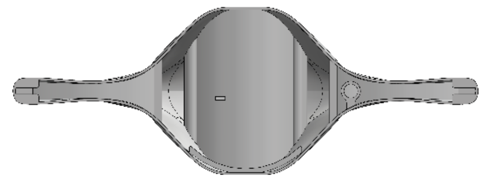

Figure 34 (b). Front View

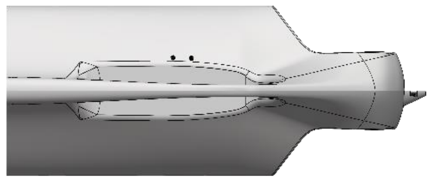

Figure 34 (c). Side View

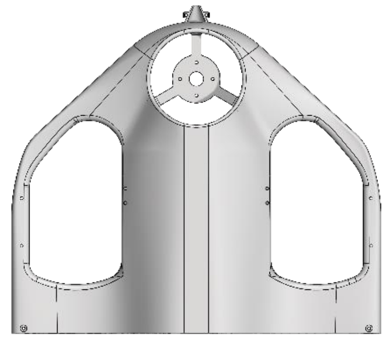

Figure 34 (d). Top View

3.3.4 FRONT-BACK CONNECTOR

The most crucial part of AquaBotix is the connection that links the front and back sections of its body. It serves to keep the entire system in place so that the internal parts do not shift around during operation. It is made up of elements which are strong and flexible making it possible to integrate either of the two major segments smoothly.

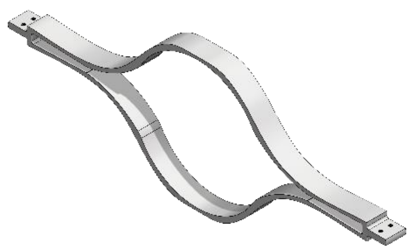

Figure 35 (a). Isometric View

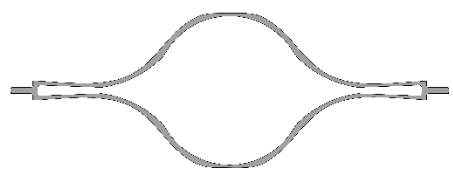

Figure 35 (b). Front View

Figure 35 (c). Side View

Figure 35 (d). Top View

3.3.5 MAIN PIPE OPEN LID

This is one of the two lids of the main pipe. This has four holes for passing the wires of sensors and motors through them. One of the holes has been specially designed to accommodate the large diameter of the BNC connector of the pH sensor. Once the wires have been passed, the base of the lid is filled with epoxy to make sure water does not sweep into the pipe. An O-ring seal has also been placed over the lid to aid in waterproofing.

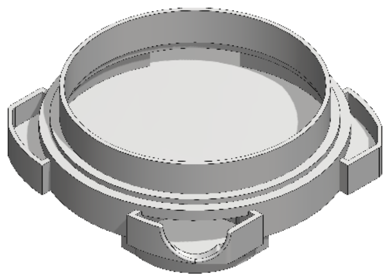

Figure 36 (a). Isometric View

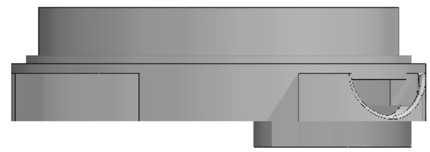

Figure 36 (b). Front View

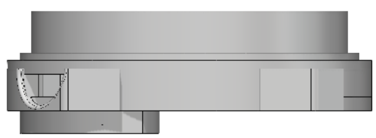

Figure 36 (c). Side View

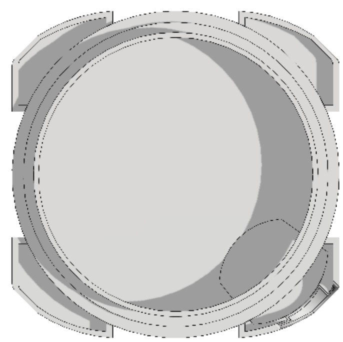

Figure 36 (d). Top View

3.3.6 MAIN PIPE CLOSED LID

This main pipe lid is totally closed, as the name suggests. This cover does not allow any cabling or sensor cable to pass through. By doing this, the main pipe's entry points are kept as few as possible. The pipe is once more waterproofed with an O-ring seal.

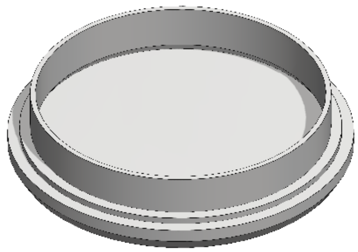

Figure 37 (a). Isometric View

Figure 37 (b). Front View

Figure 37 (c). Side View

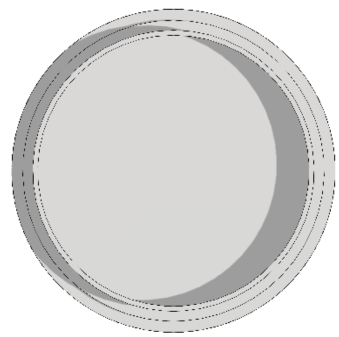

Figure 37 (d). Top View

3.3.7 MAIN PIPE COMPARTMENT

This compartment is divided into three parts:

3.3.7.1 COMPARTMENT FOR JETSON NANO

This compartment provides a base for the Jetson Nano which is placed on top of its charging module.

3.3.7.2 COMPARTMENT FOR PCB

This component makes sure the PCB fits between the main pipe's closed cover and the Jetson Nano chamber. This aids in maintaining the PCB's position.

3.3.7.3 COMPARTMENT FOR BATTERY AND ESCS

The compartment is made up of three separate parts. There is a battery compartment at the bottom. A compartment housing the power distribution board and two electronic speed controllers is situated atop it. On top of that are positioned the final three ESCs. To accommodate the pipe's curvature, the compartment's ends are shaped like a circle.

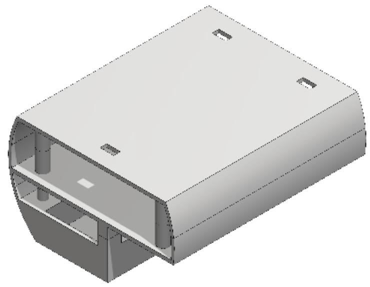

Figure 38 (a). Isometric View

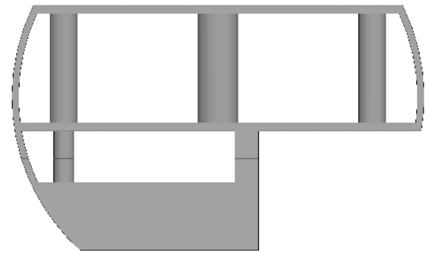

Figure 38 (b). Front View

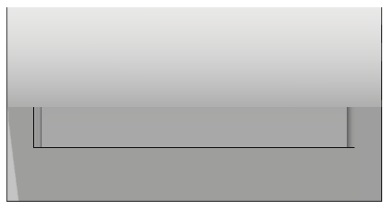

Figure 38 (c). Side View

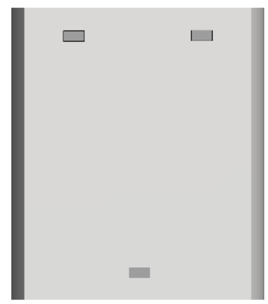

Figure 38 (d). Top View

3.3.8 ACRYLIC PIPE LID

For the smaller acrylic pipe, there are two lids, each having a single opening, one for the CSI cable and the other for jumper wires of the luminosity sensor.

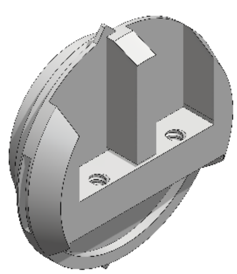

Figure 39 (a). Isometric View

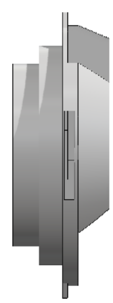

Figure 39 (b). Front View

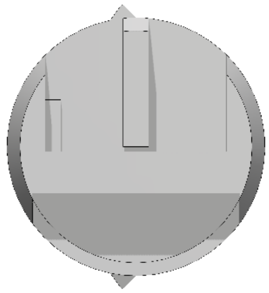

Figure 39 (c). Side View

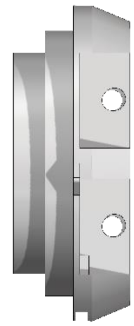

Figure 39 (d). Top View

3.3.9 ACRYLIC PIPE COMPARTMENT

This compartment is a solid component that fits into the acrylic pipe. This piece has places etched to hold the camera and luminosity sensor with screws. This helps to keep the camera secure and in place.

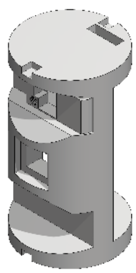

Figure 40 (a). Isometric View

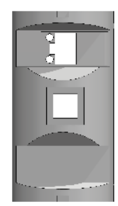

Figure 40 (b). Front View

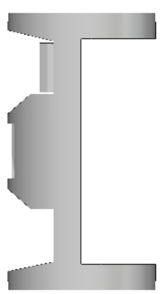

Figure 40 (c). Side View

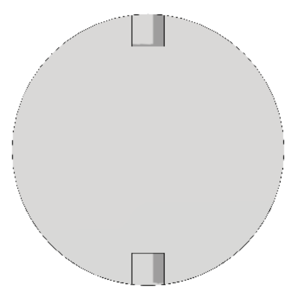

Figure 40 (d). Top View

3.3.10 LED HOLDERS

The led holders are responsible for providing a place for putting the led lights along with the lens. Once the led is placed inside the holder, the remaining space is filled with epoxy to provide strength and prevent the water from reaching the led. The led holder has two openings for two wires (positive and ground) to illuminate the led. This holder connects with the front top body at one point and with the front bottom body at the other point, which potentially helps in keeping the two parts together.

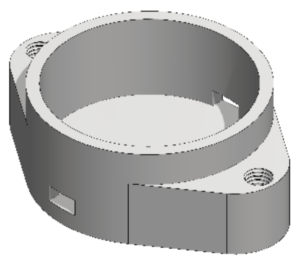

Figure 41 (a). Isometric View

Figure 41 (b). Front View

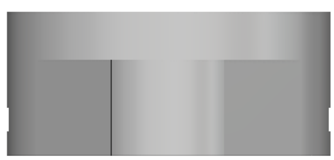

Figure 41 (c). Side View

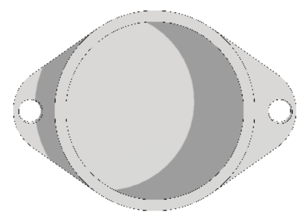

Figure 41 (d). Top View

3.3.11 PRESSURE SENSOR HOLDER

This component is mounted outside the main pipe to hold the pressure sensor in place. This provides a compact place for the sensor to measure the pressure and depth of water. Since it has no lid and the sensor itself is not waterproof, after mounting, an adequate amount of epoxy is carefully poured onto the sensor to protect the electric board.

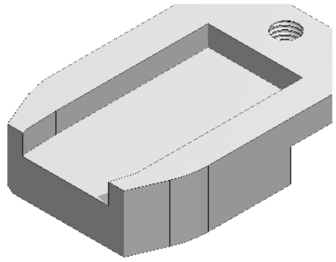

Figure 42 (a). Isometric View

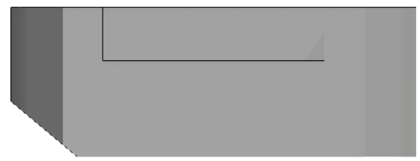

Figure 42 (b). Front View

Figure 42 (c). Side View

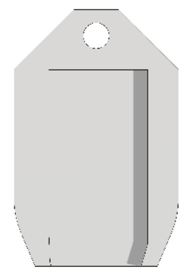

Figure 42 (d). Top View

3.3.12 THRUSTER HUBS

These act as casing for the brushless DC motors and propellers. At the bottom is a mounting place for the motors with four holes. Motors can be mounted on this structure using screws. The design also aids in streamlining the flow of water, thus reducing water resistance as well.

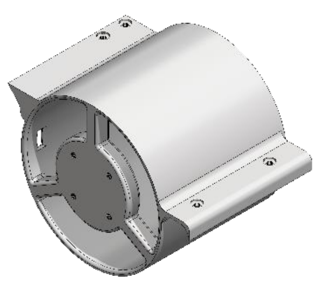

Figure 43 (a). Isometric View

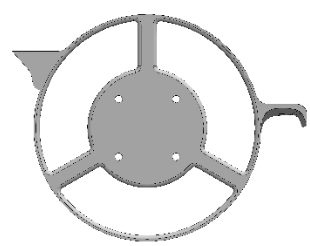

Figure 43 (b). Front View

Figure 43 (c). Side View

Figure 43 (d). Top View

3.3.13 VETICAL PROPELLERS

These propellers are responsible for the upward and downward motion of the robot. These blades are mounted on the shafts of brushless DC motors that rotate at high speed. The vertical propellers are of two types: the right propeller and the left propeller. Since the motion of the propeller is circular, the overall robot can rotate in one direction if there is no opposing force.

In a specific direction, the right propeller produces clockwise torque and the left propeller produces anti-clockwise torque, overall resulting in a stable linear upward/downward motion.

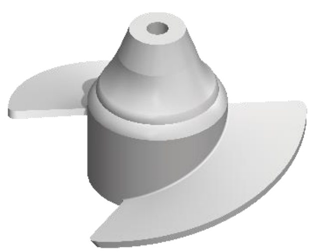

Figure 44 (a). Isometric View

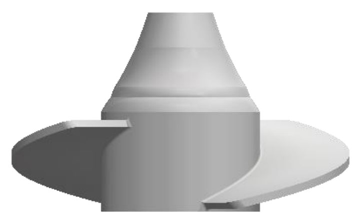

Figure 44 (b). Front View

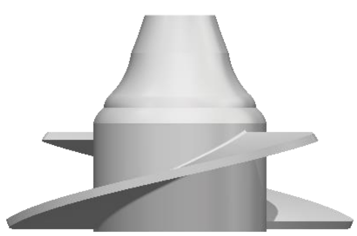

Figure 44 (c). Side View

Figure 44 (d). Top View

3.3.14 HORIZONTAL PROPELLERS

These propellers are responsible for the forward and backward motions of the robot. The propellers are of two types: the right propeller and the left propeller. Using two motors, four types of motion can be produced. The following table explains it effectively:

	Motor 4	**Motor 5**	**Motion in water**
State	Anti-clockwise	OFF	Right
	OFF	Anti-clockwise	Left
	Anti-clockwise	Anti-clockwise	Forward
	Clockwise	Clockwise	Backward

Table 19. Horizontal Motors Propeller Motions

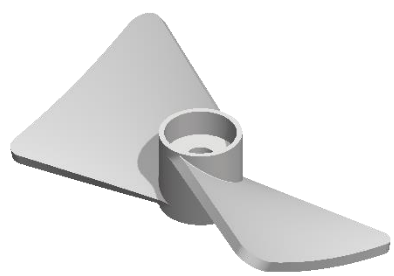

Figure 45 (a). Isometric View

Figure 45 (b). Front View

Figure 45 (c). Side View

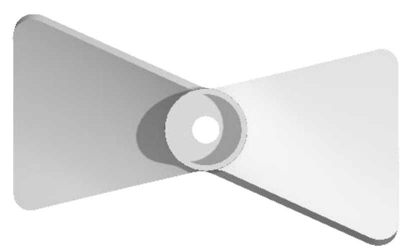

Figure 45 (d). Top View

3.3.15 TETHER CABLE HOLDER

This little component is crucial for keeping the tether cable in place. This element, located at the rear end of the main back body, guarantees that the tether wire is securely packed and that water does not pass through the back hole.

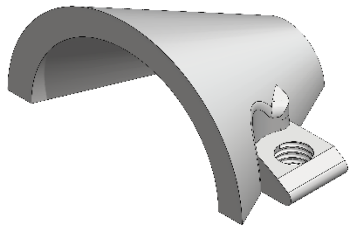

Figure 46 (a). Isometric View

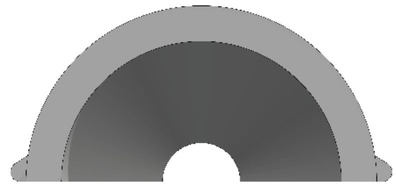

Figure 46 (b). Front View

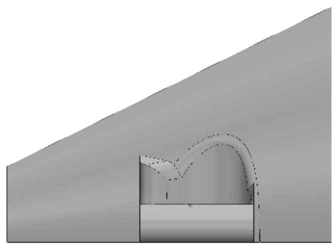

Figure 46 (c). Side View

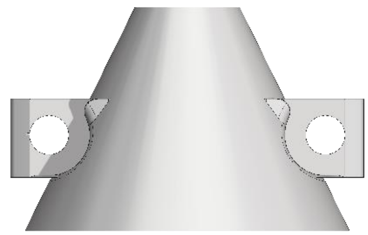

Figure 46 (d). Top View

3.4 MOBILE APP DEVELOPMENT

A mobile application has been developed for AquaBotix to provide the user with real-time water quality updates and essential system information. Flutter was employed in the designing process.

Flutter is an open-source UI toolkit made by Google for mobile (iOS, Android), web, and desktop natively executed apps in one place.

3.4.1 WHY FLUTTER?

Flutter has been chosen over its competitor Kotlin, due to the following reasons:

1. With Flutter, one can build native compiled android and IOS applications using one single code, instead of using two code bases, one for Android (in Kotlin) and another for iOS (in Swift). Therefore, it becomes cost-effective by saving time which would be spent in developing these applications.
2. For both Android and iOS, Flutter applications are compiled into native ARM codes assuring performance and animations simplicity. Moreover, there is advanced compilation in Dart, which makes its performance comparable to that of native language apps.
3. Flutter equips developers with a wide range of built-in widgets and resources that make design of responsive layouts quite easy. These widgets and tools are especially helpful when it comes to developing apps that require displaying intricate data alongside interactive features.
4. Hot reload feature of Flutter is such that developers can view immediately changes they have made to their code without restarting any application. This helps in reducing development time significantly as well as simplifying user interface design and software functionality.

3.4.2 APP FEATURES

1. Sign up and Login

For the sake of security, we have incorporated user authentication services such as secure password protected login form for protecting user data from unauthorized access.

2. Real-time Data Visualization

The app displays real-time data from various sensors (pH, temperature, TDS, pressure, depth, luminosity) in an easy to understand format. It also maintains the count of all detected trash items with GPS coordinates, shows the remaining battery life and the system up-time.

3. Alerts and Notifications

Sends real-time alerts to the user when trash is detected, specifying the location of the trash. It also notifies the user about battery life of robot that is when it’s the time to turn off the robot and get it charged.

3.4.3 APP FUNCTIONALITIES

1. Data Transmission:

The robot uploads sensor data and alerts to the Firebase database as soon as trash is detected in the water body. This data is stored in structured JSON format. The mobile application subscribes to changes in the Firebase database. Whenever new data is uploaded by the robot, it is immediately synchronized with the mobile app, ensuring real-time updates.

2. Communication Method:

The robot uses Wi-Fi to connect to the internet and upload data to Firebase. This is the primary method for data transmission due to its stable connection.

3. Updates and Notifications:

Real-time triggers supported by Firebase alert the mobile application to any database changes. This guarantees that the user gets real-time information on garbage detection and water quality metrics.

Push notifications are sent to the mobile application via Firebase Cloud Messaging (FCM) to notify the user of important updates, including garbage identified or notable changes in water quality.

3.4.4 APP PROTOTYPE

Prototype of AquaBotix app is shared below:

3.4.4.1 SPLASH SCREEN

Figure 47. App Splash Screen with AquaBotix Logo

3.4.4.2 GETTING STARTED SCREEN

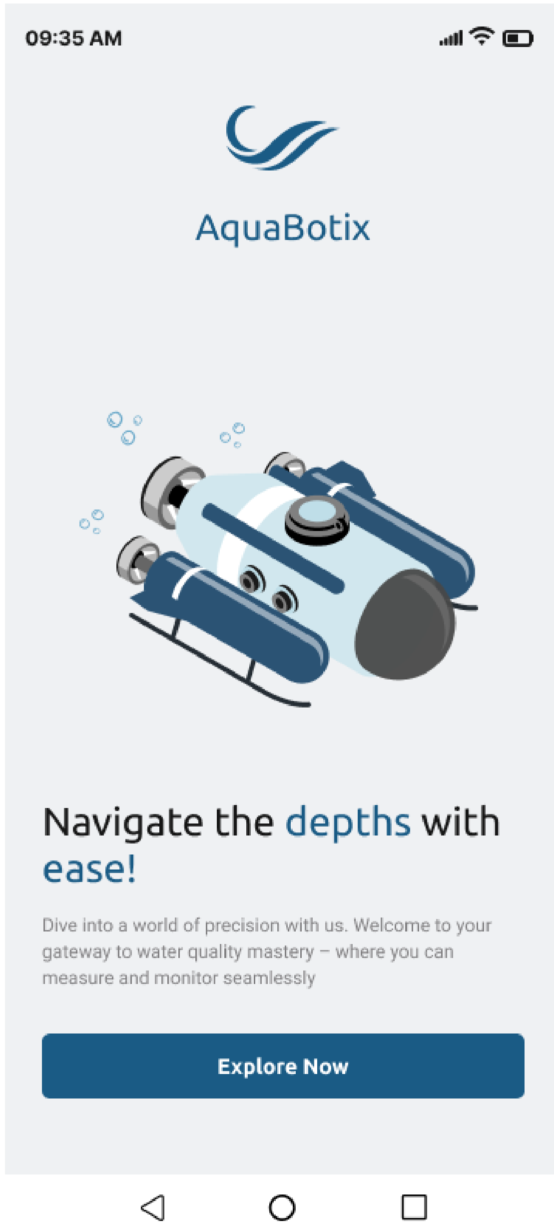

Figure 48. Getting Started Screen

3.4.4.3 SIGN UP SCREEN

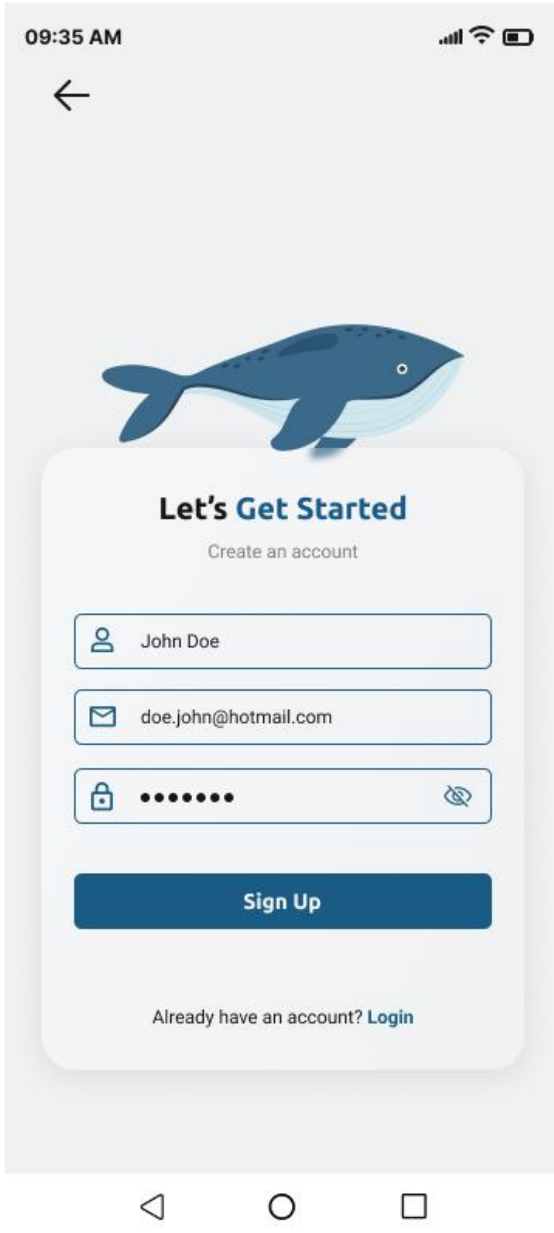

Figure 49. Sign Up Screen

3.4.4.4 LOGIN SCREEN

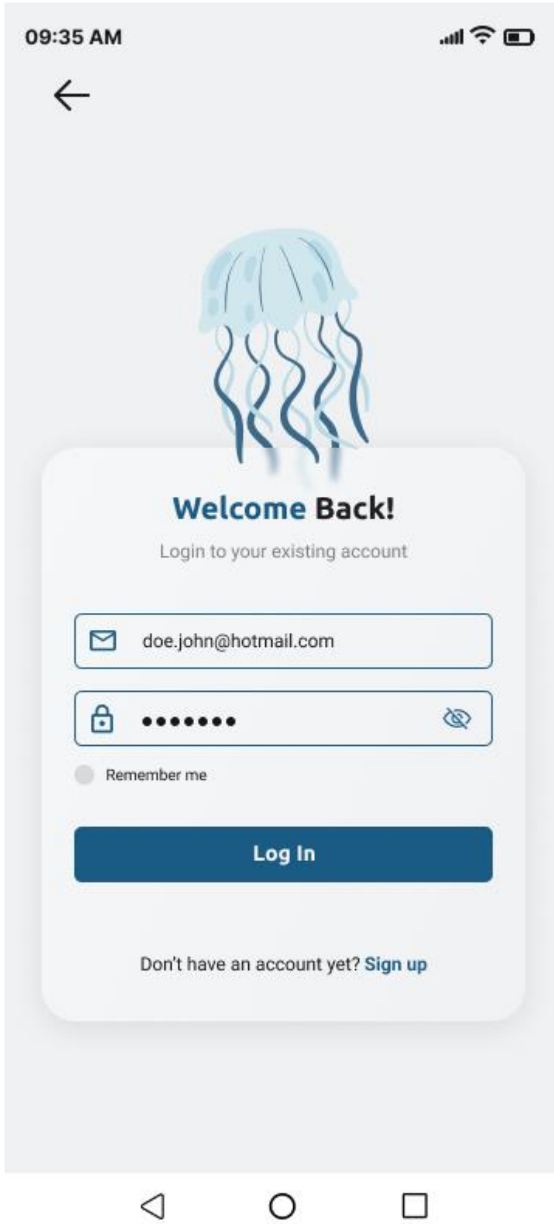

Figure 50. Login Screen

3.4.4.5 CONNECTION SCREEN

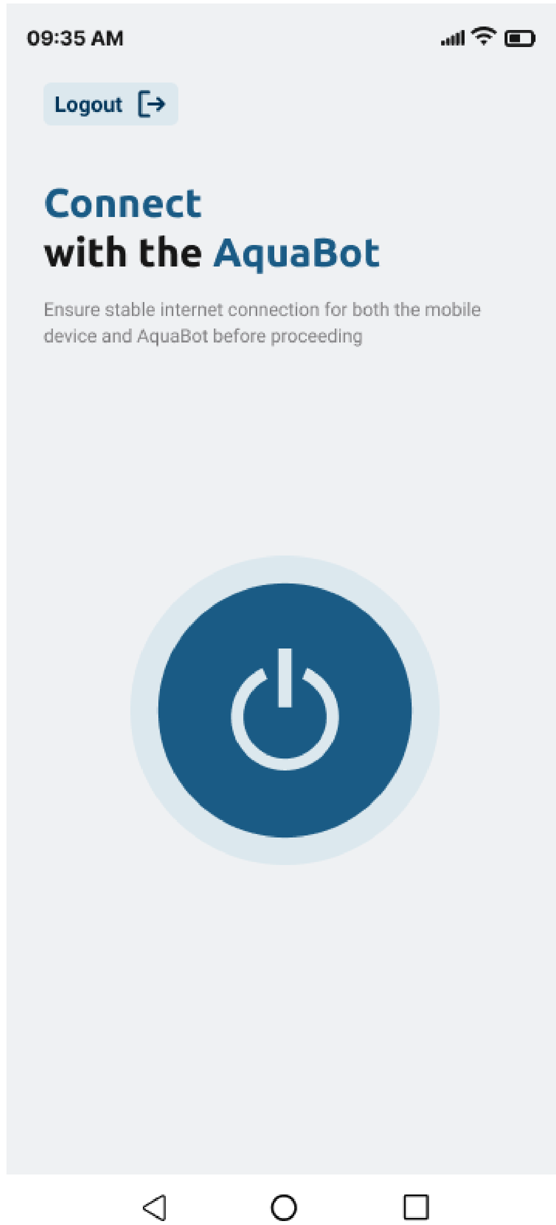

Figure 51. Connection Screen

3.4.4.6 WATER QUALTIY SCREEN

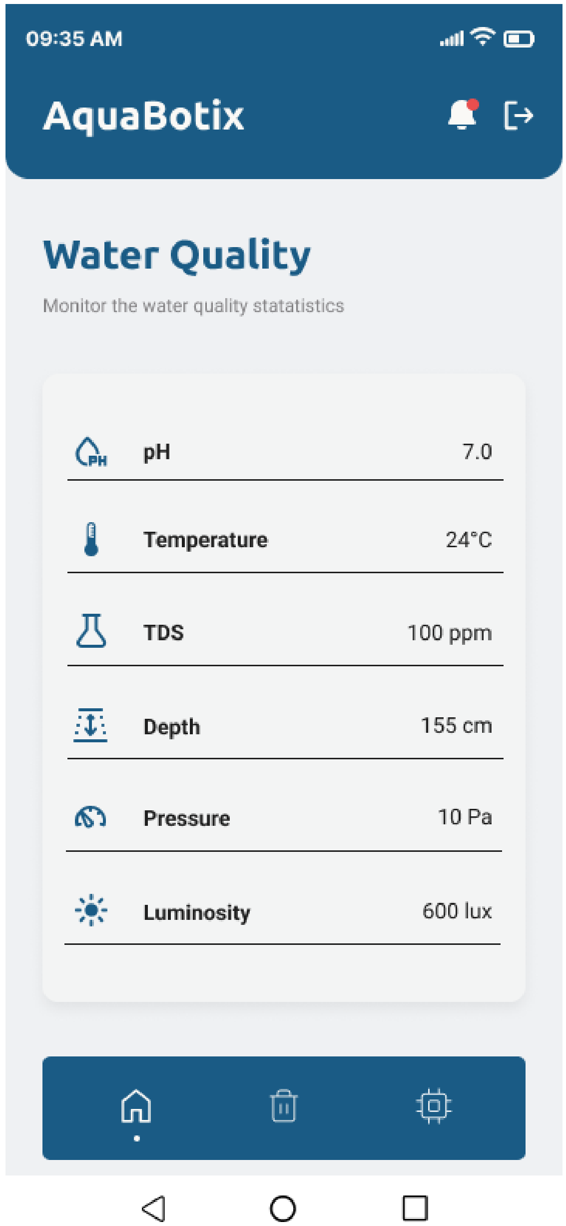

Figure 52. Water Quality Parameters Screen

3.4.4.7 TRASH UPDATES SCREEN

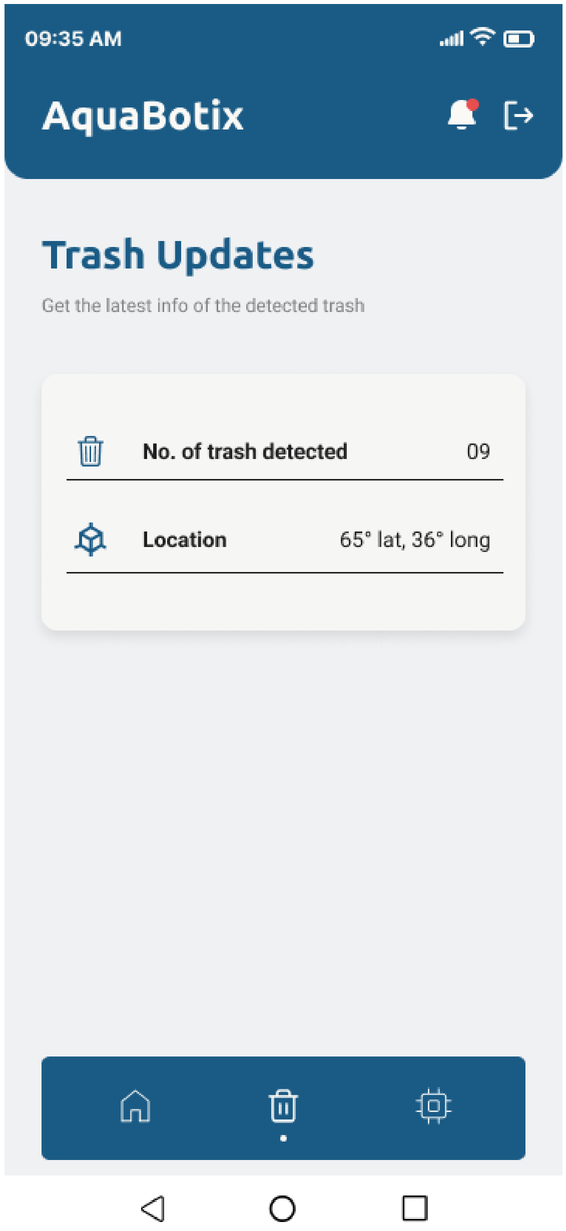

Figure 53. Trash Updates Screen

3.4.4.8 ABOUT AQUABOTIX SCREEN

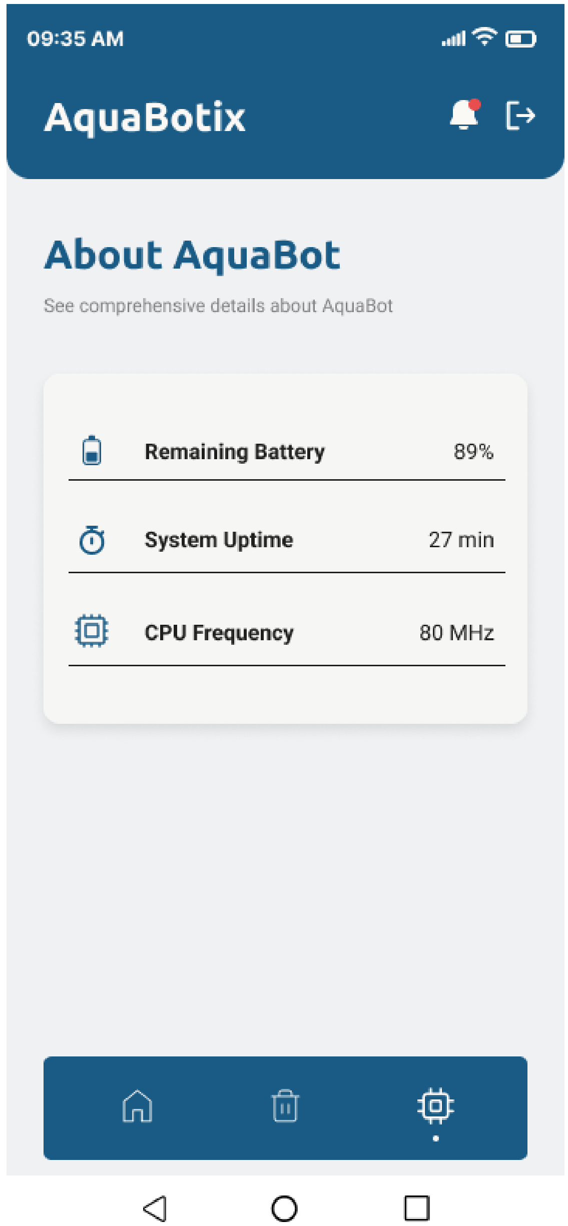

Figure 54. About AquaBotix Screen

3.4.4.9 NOTIFICATIONS SCREEN

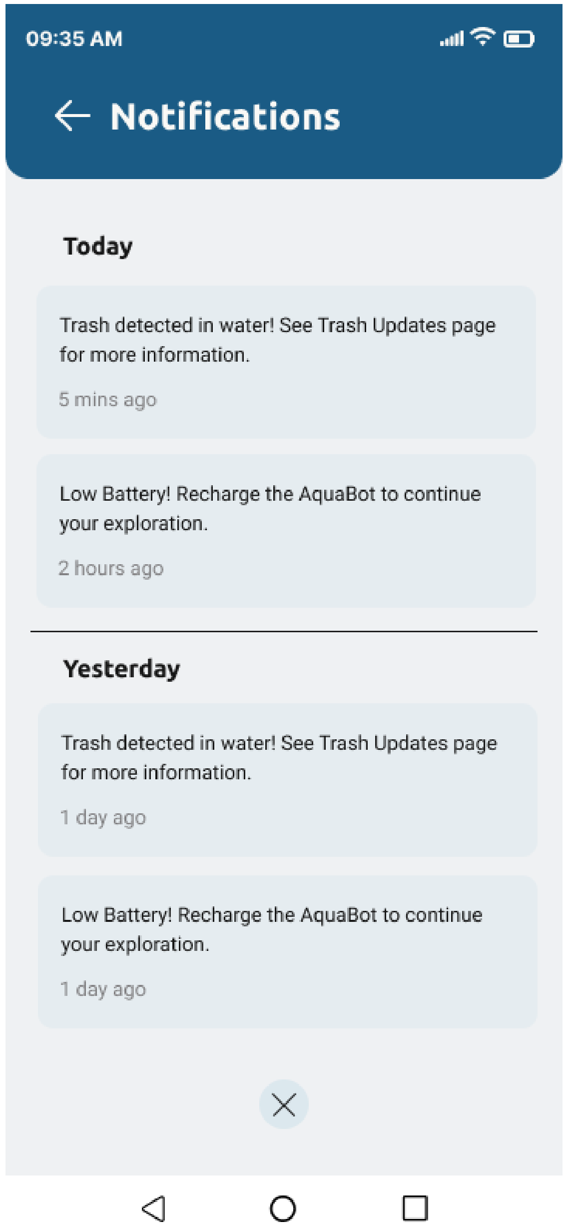

Figure 55. Notifications Screen

CHAPTER 04 – RESULTS

4.1 EMBEDDED SYSTEMS RESULTS

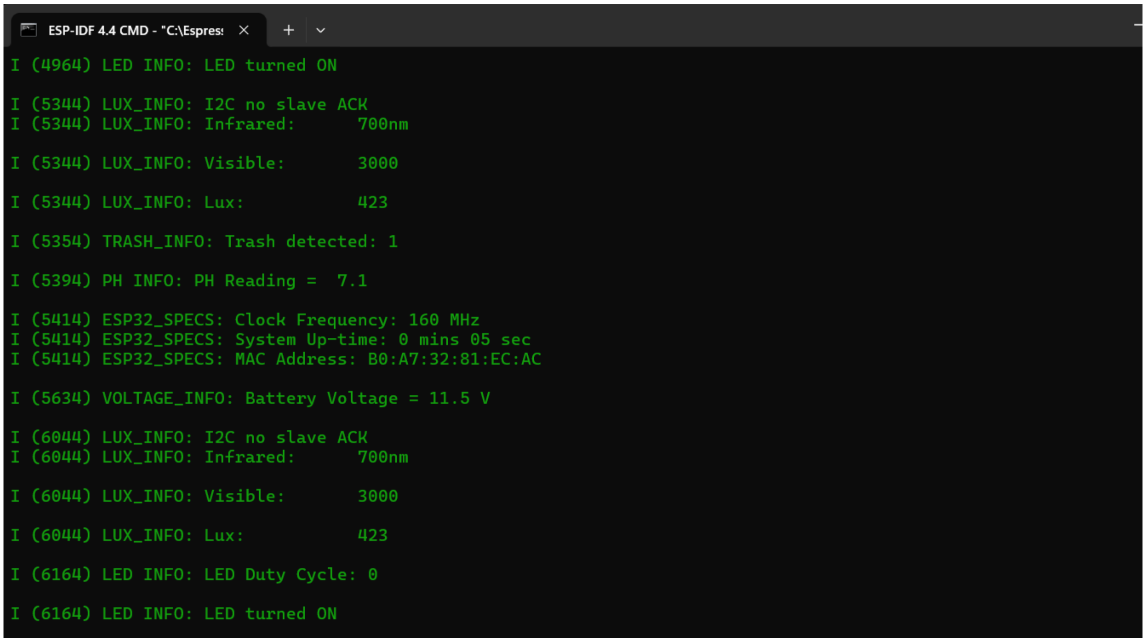

Figure 56. ESP IDF Sensor Results

4.2 OBJECT DETECTION RESULTS

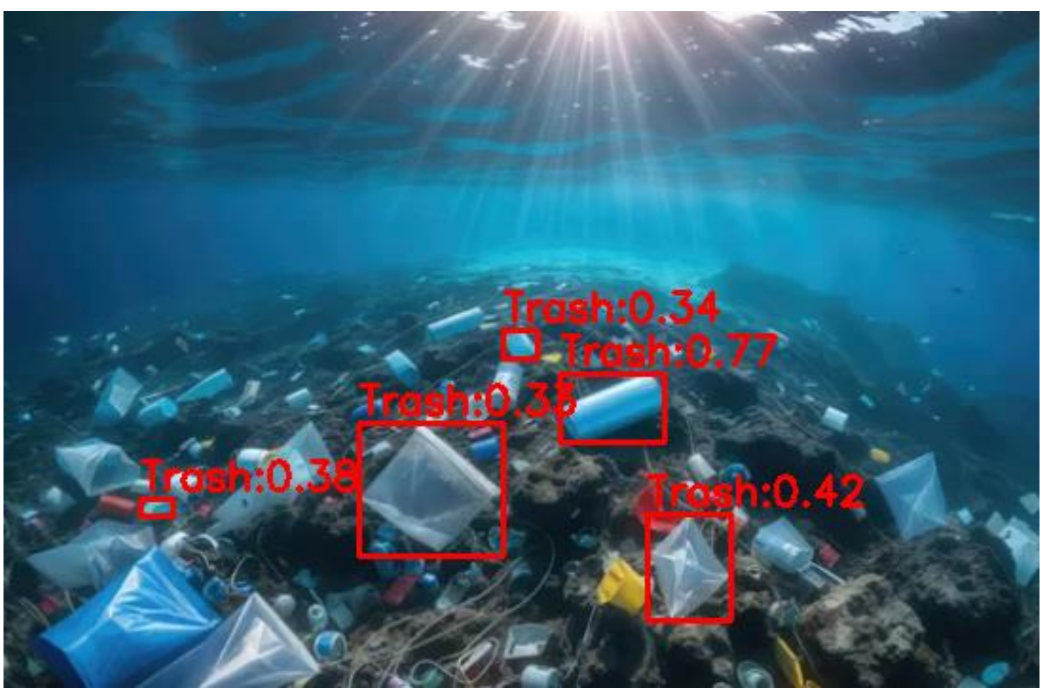

Figure 57. Yolov7 Object Detection Results I

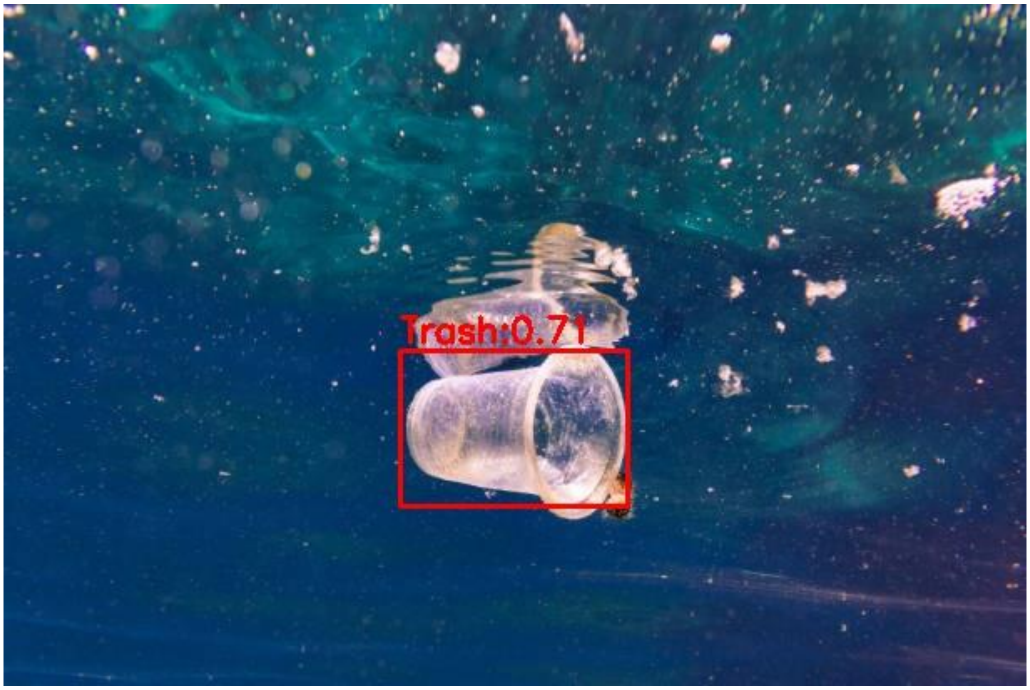

Figure 58. Yolov7 Object Detection Results II

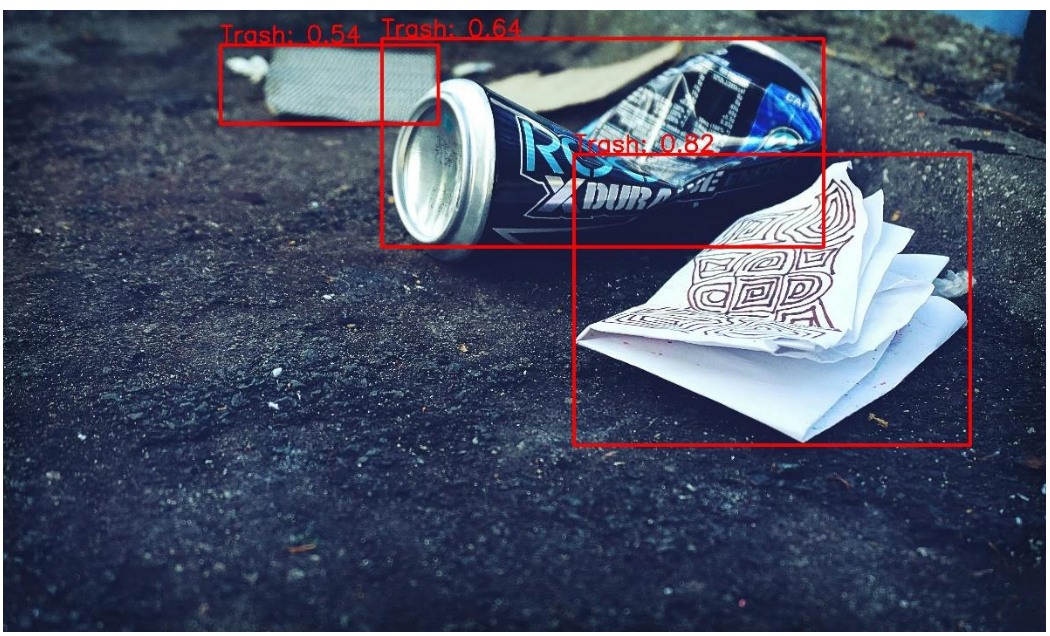

Figure 59. Yolov7 Object Detection Results III

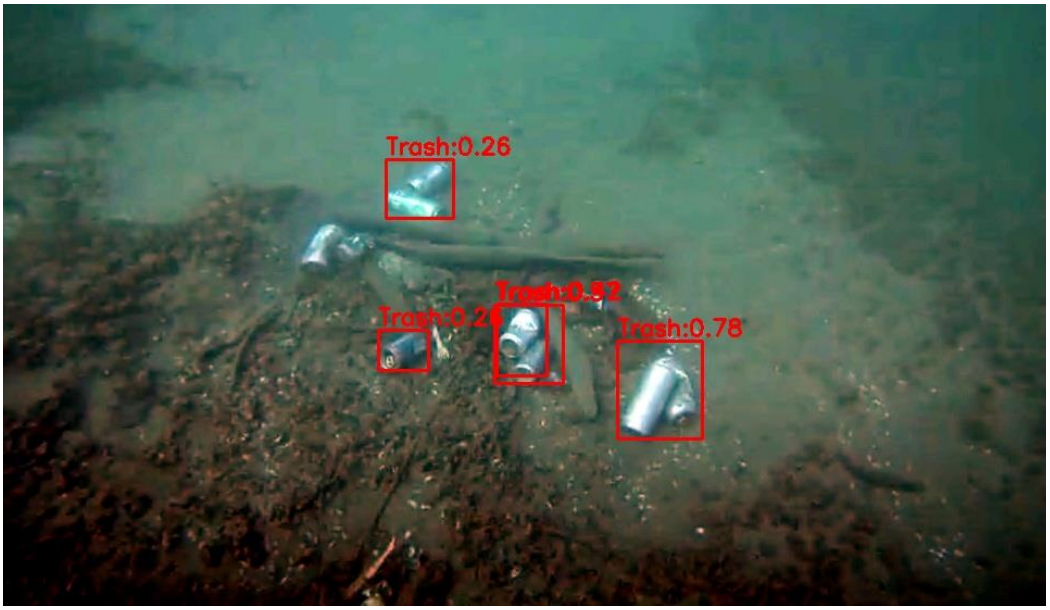

Figure 60. Yolov7 Object Detection Results IV

Figure 61. Yolov7 Object Detection Results V

CHAPTER 05 – CONCLUSION AND FUTURE WORK

5.1 CONCLUSION

The developed water quality evaluation robot signifies a big step in environmental supervision sector. Through the use of robotic advancements, sensors, and machine learning, the AquaBotix team suggested an up-to-date solution to the real-time water quality identification plus underwater trash detection solution. The incorporation of machine learning techniques has played a role in improving the accuracy and also making monitoring more efficient.

Future work on AquaBotix can include focus on improving its independency using autonomous navigational capacities and superior hindrance detection systems. Therefore, the project shows that using new technological advancements can help deal with urgent environmental issues and signals the importance of continued research and development in the field of aquatic robotics.

5.2 FUTURE WORK

Below are specific areas where more work may be required:

1. Autonomous Navigation:

Currently, AquaBotix needs a person to navigate it. Research may be done to build the kind of function within the robot which would enable it move on its own without any external help. This could involve the utilization of complicated programs that will facilitate independent navigation as well as mapping of its surroundings upon the robot.

Furthermore, attachment of sesnsors with improved algorithms for immediate identification of barriers so that AquaBotix can move in difficult habitats without endangering the safety of the robot.

2. Speed and Movement Control:

By integrating the PID controller with the motors and electronic speed controllers, the robot's speed may be dynamically controlled in response to sensor data. The PID controller continually changes the motor output to keep the robot at the appropriate speed and slow it smoothly when necessary. This method improves the robot's agility and safety.

3. Incorporation of Advanced Water Quality Sensors

In future developments, AquaBotix's sensing capabilities can be elevated by integrating advanced sensors such as turbidity sensors, dissolved oxygen sensors, and nitrate sensors which will aid in providing a more comprehensive assessment of water quality.

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APPENDIX A

SUSTAINABLE DEVELOPMENT GOALS FOR FYP

FYP TITLE: AquaBotix - AI Based Water Quality Assessment Robot

FYP SUPERVISOR: Asst. Prof Sobia Hayee

GROUP MEMBERS:

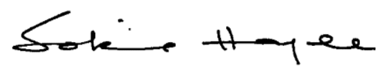
S No.	REGISTRATION NUMBER	NAME
1	336091	Osaid Ahmad
2	346190	Dua Khan
3	348890	Aliya Rubaab

SDGs:

	SDG No.	Justification after consulting
1	03 (Good Health and Well-being)	Our project's role in monitoring water quality, detecting trash, and supporting ecosystem health contributes to creating conditions conducive to good health and well-being for both humans and the environment.
2	06 (Clean Water and Sanitation)	Our project contributes to this target by: **a. Monitoring water quality:** By measuring parameters like pH, TDS, and temperature, we can identify potential pollutants and track changes in water quality over time. **b. Identifying trash:** By detecting trash using the camera, we can help raise awareness about pollution and inform cleanupefforts.
3	09 (Industry, Innovation and Infrastructure)	Our project contributes to this SDG by driving innovation in underwater technology, promoting research and development activities, and supporting sustainable practices in marine industries.

4	13 (Climate Action)	Our project contributes to this target by providing valuabledata for understanding the impacts of climate change on aquatic environments and devise strategies for mitigation and adaptation.
5	14 (Life Below Water)	Our project contributes to this target by identifying and tracking sources of pollution, such as plastic waste, and monitoring its impact on marine ecosystems.

FYP Advisor Signature:



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UN Website: https://focus2030.org/Understanding-the-Sustainable-Development-Goals#:~:text=The%20Sustainable%20Development%20Goals%20(SDGs,life%20for%20all%2C%20by%20 2030

APPENDIX B

FYP AS COMPLEX ENGINEERING PROBLEM

Abstract

The degradation of underwater ecosystems due to pollution and littering poses significant challenges to environmental sustainability. This project introduces an innovative solution in the form of an underwater robot designed for multifaceted tasks including water quality assessment, underwater trash detection, and exploration. Traditional methods for monitoring water quality and detecting underwater debris are often labor-intensive and time-consuming. Our approach leverages robotics and sensor technology to streamline these processes, providing efficient and accurate data collection in aquatic environments.

The underwater robot is equipped with a suite of sensors capable of measuring various parameters such as pH, total dissolved solids (TDS), and temperature, enabling real-time assessment of water quality. Additionally, the robot is equipped with advanced imaging systems and machine learning algorithms to detect and classify underwater trash, facilitating targeted cleanup efforts. Furthermore, the robot's maneuverability and exploration capabilities enable thorough inspections of underwater habitats, aiding in environmental monitoring and research.

Key components of the project include the design and fabrication of the underwater robot, integration of sensor and imaging systems for trash detection, and validation of performance through field testing in swimming pool environment. The project aims to contribute to the conservation and management of underwater ecosystems by providing an efficient tool for environmental assessment and cleanup efforts.

By combining robotics, sensor technology, and artificial intelligence, this project addresses pressing environmental challenges while showcasing the potential of interdisciplinary approaches in tackling complex issues facing our planet's oceans and waterways

This project represents a complex engineering problem with characteristics from WP1 to WP7:

1. **WP1 - Depth of Knowledge Required:** (WK3, WK4, WK5, WK8) In-depth engineering knowledge at the level of WK3 (engineering fundamentals), WK4 (engineering specialist knowledge), WK5 (engineering design), WK6 (engineering practice), and possibly WK8 (research literature engagement) is required. This knowledge is necessary to design and fabricate the underwater robot, integrate sensor and imaging systems, and validate performance through field testing.
2. **WP2 - Range of Conflicting Requirements:** The project involves addressing conflicting technical and environmental requirements, such as designing a robot that is both robust and maneuverable, capable of efficiently detecting water quality parameters and underwater trash, while also being cost-effective and environmentally friendly.
3. **WP3 - Depth of Analysis Required:** There is no obvious solution to the problem, requiring abstract thinking and originality in analysis to formulate suitable models for the design, integration, and testing of the underwater robot and its sensor systems.

4. **WP4 - Familiarity of Issues:** Many of the issues encountered in the project, such as designing underwater robotics for environmental monitoring and cleanup, may be infrequently encountered in traditional engineering practice.
5. **WP5 - Extent of Applicable Codes:** The project may involve developing solutions outside the scope of existing standards and codes of practice, particularly in integrating advanced sensor technology and robotics for underwater applications.
6. **WP6 - Extent of Stakeholder Involvement and Level of Conflicting Requirements:** The project involves addressing the needs of diverse stakeholders, including environmental conservation organizations, regulatory agencies, and the general public, each with different needs and expectations regarding underwater ecosystem management.
7. **WP7 - Interdependence:** The project is a high-level problem that includes many component parts or sub-problems, such as designing the robot, integrating sensor and imaging systems, and validating performance through field testing, all of which are interdependent on each other for the successful implementation of the solution.

	WP1						WP2	WP3	WP4	WP5	WP6	WP7
	WK3	WK4	WK5	WK6	WK7	WK8						
PLO1 (WA1)	X											
PLO2 (WA2)		X						X				
PLO3 (WA3)			X									
PLO4 (WA4)						X			X			
PLO5 (WA5)				X					X			
PLO6 (WA6)												
PLO7 (WA7)											X	
PLO8 (WA8)												

Aquabotics, AI BASED WATER QUALITY ASSESSMENT ROBOT

by Sobia Hayee

Submission date: 20-May-2024 11:00AM (UTC-0700)
Submission ID: 2384235501
File name: AquaBotix_Report_Check.pdf (3.19M)
Word count: 12117
Character count: 69047

Aquabotics, AI BASED WATER QUALITY ASSESSMENT ROBOT

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