ASHESI UNIVERSITY

BUILD OF A LOW-COST PROTOTYPE ROV FOR SEARCH AND RESCUE

CAPSTONE PROJECT

B.Sc. Mechanical Engineering

Jeremiah Paul Konadu Takyi

2020

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CAPSTONE PROJECT

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

Jeremiah Paul Konadu Takyi

2020

DECLARATION

I hereby declare that this capstone project 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:

Jeremiah Paul Konadu Takyi ……………………………………………………………………

Date:

29th May, 2020 ……………………………………………………………………………

I hereby declare that the preparation and presentation of this capstone project 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:

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Date:

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Abstract

Aquatic search and rescue in Ghana and most parts of the world poses lots of disadvantages to the rescuers. Divers being tasked for each search and rescue mission risk their lives trying to locate a body or an object underwater. Sometimes, these divers are attacked by aquatic animals or even hit by submersible objects. This approach is also problematic since divers are not able to stay longer under water due to fixed oxygen tanks. This limits their search periods as they ought to resurface to fill their tanks. Solutions to curb this problem have been brought to light by building a submersible that moves through water to search while the diver stays comfortably above the water with a hand-held controller. The only problem to this solution is that it is highly expensive, and the submersible normally becomes unstable after grabbing unto an object. Other solutions also involve using smart animals to search but still require the diver to go within the water to retrieve whatever thing it is. This project seeks to prevent all these unforeseen dangers that might possibly occur to the diver by building a submersible at a lower cost. This design also sought to solve the issue of instability via a mechanical redesign. To control the submersible, the user uses a friendly hand-held controller with simple knobs and an on-board screen which receives live feed from the vehicle. The submersible was designed to carry a payload of 500g and reach a depth of 1.5m. From test simulations, it should be able to withstand external pressures at that depth. Due to project constraints, only a portion of the mechanical and electronic system could be built. This prototype design will serve as the basis for a full-scale version which promises to be cheaper and be able to lift and resurface heavier payloads depending on the materials used in constructing it.

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1. Introduction

1.1 Project aim

The aim of this project is to build and repurpose a prototype submersible for search and rescue of light masses (representative of an unconscious or missing bodies in water) using readily available components. Users manning this vehicle will be stationed above the water level while controlling the submersible.

1.2 Introduction and Background

In Ghana, the most common form of water rescue is done through deep diving. Both local divers and the marine security team dive into water bodies to rescue drowned victims and/or search for missing bodies or things. This form of search and rescue operation is unsafe as it poses a lot of risks to the rescuer or diver. The process also has lots of disadvantages. In the case of local divers, since most of them lack sophisticated equipment such as oxygen tanks, goggles, and swimsuits, it often limits their search and rescue process. They often must resurface to gasp in air before diving back into the water. Also, since light intensity in water reduces with depth [1], they are unable to see clearly and this causes them to swim blindly at certain levels. On the other hand, in the case of marine securities, specially trained divers even with their swim costume and oxygen tanks still face risks and are disadvantaged. Since oxygen tanks have fixed volumes of storage [2], these divers can only search for a fixed period of time before the oxygen tank runs out. In critical moments, multiple personnel have to wait on board to monitor the rescuer from above. They patiently wait in hope till their fellow diver finds the missing body/bodies or item without any complications. Furthermore, due to increase in pressures as a result of higher depths[3], divers are unable to search at certain levels. This limits the search radius for divers. In both cases, divers are at high risk of dying due to multiple attacks ranging from aquatic animal attacks and collision of obstacles. lastly, divers in general normally have headaches during or after swimming [4]. This can affect their health in the long run and might imped their next missions. This makes the entire method of search and rescue by diving time and resource consuming, and risky at the same time.

Research shows that a drowning person can be rescued for full recovery in no more than a minute and this mainly due to low inspiratory drive to breath [5]. After this point, the person becomes unconscious and immobile due to inrush of water into the lungs [6]. After this stage, the person dies due oxygen deprivation and even at the point, the search for these bodies continues until they are found.

1.3 Problem Definition

Several methods have been schemed to search and rescue persons submerged in water depending on the location. At swimming pool grounds or closed areas, bystanders are present to reach out to a drowning person [7]. In open water such as lakes and the sea, where many drowning incidents occur [8], the use of rescue divers on speedboats are deployed to reach out to these victims – whether alive, unconscious or dead. This same method of human diving into deep waters is also employed when there is a missing body within the water. Local divers or the police force jump into the water in search of body within this relatively large water body such as a lake, pond, or the sea.

The above search and rescue methods always involves a human being trying to rescue the victim or a missing person or item in water, and this poses a lot of risk to the rescuer. Highlighted below are the possible risks rescuers (local divers and/or police forces) face during their rescue missions:

- The diver has limited time to search for a victim due to breath constraints with or without oxygen tanks
- The diver is prone to aquatic dangers as wild animals could attack the diver during search and rescue missions.
- The diver could get tired or gain a muscle pull and this can possibly lead to death.
- Possible headaches leading to health issues.

1.4 Proposed solution

This project seeks to build and repurpose a prototype low class Remotely Operated Vehicle (ROV) for searching missing persons or items and rescuing of unconscious drowning victims in still water bodies such as lakes. This will help eliminate the possible risks rescuers face in their attempt to search and rescue missing or drowning victims in water bodies.

1.5 Proposed project benefit

- Reduced amount of time needed to search for a missing or unconscious drowning person in water.
- Less labor involved: since ROVs are manned from the topside, only one person can be involved in the search and rescue mission.
- Less risk involved: since ROVs are inanimate objects, risks posed by humans will have little to zero effect on this vehicle. Repairs can always be made on machines even at critical levels, whereas some injuries are beyond medication in the case of humans
- Advantage of having Long search periods: As long as an ROV is connected to a power source, it can be used for a long time. This will increase the search duration and increase

the probability of locating a missing person as compared to what divers can accomplish due oxygen constraints.

1.6 Justification /Motivation of Project Topic

Since the world is advancing, there is the need to incorporate advanced technologies in every sector such communication, health, transportation, amongst others. In developed countries, the use of submersibles for search and rescue of missing bodies is advancing [9]. This helps in eliminating the risks divers could possibly face during their search and rescue missions. If developing countries such as Ghana can also implement these technologies, it will help reduce possible unforeseen dangers.

2. Related Works

2.1 ROV for rescue

ROVs are underwater robots that perform subsea functions based on logic from a control station at the topside (above the water surface) [10]. It is usually configured as a camera-based vehicle with propellers attached to motors to help it navigate through water. These machines are controlled by humans via a tether cable called an umbilical. ROVs are used for underwater operations such as intervention and repair works [11], and are normally used for inspection operations during drilling activities. These vehicles come in different classes [Section *2.4*] and sizes. The class 5 type of ROV is normally built to suit specific tasks. This makes them very expensive since they are produced on demand. The more tedious the task, the more expensive it is. They normally range from thousands of dollars up to millions of dollars depending on the task at hand [12]. One such example is the DTG3 ROV specifically built by Deep Trekker, to achieve the purpose of search and rescue.

The DTG3 ROV was designed to achieve this goal of searching and rescuing missing bodies in water. It is able to accomplish this with a gripper attached to it. With the help of a human manning this device from the topside (above the water), the ROV is able to resurface a dummy (body) with it. This vehicle has several modules attached to it to make it achieve the desired task. It has sonar device to detect items during low light conditions, water-linked underwater GPS system to achieve device location, and a rotatable gripper amongst other sophisticated sensors. Even though this submersible performs the desired task, it is very expensive. A DGT3 meant for search and rescue mission costs $12000 [13]. The vehicle also become unstable after holding on to an object. The proposed system to be built will seek to achieve the basic goal at a lower cost and correcting the stability issue with a mechanical redesign. This will be done by eliminating certain components on the said model while using readily available, cheap, but durable components. This redesign will serve as a basis a full-scale design which aims to be cheaper as well.

Figure 2.1: Image of the DGT3 ROV. [14]

Aside the use of ROVs, other works by scientist and local divers that help achieve the same goal are been discussed below:

2.2 DNA test by SureScreen Organization

SureScreen, a health organization that provides diagnostic solutions came up with a unique method of identifying the presence of missing bodies in lakes and ponds using DNA samples [15]. The team conducts a DNA analysis by first collecting DNA samples from the missing person's toothbrush and verifying with the DNA cells in the water body. A buccal swab of a next-of-kin can also be extracted and compared with cells in the water. According to them, this method will save a lot of resources as police forces could use such resources in another domain. The flaw with this method is that it only helps rescuers know whether there's a missing body within the water body or not. It does not specify the exact location of the body just in case both DNA cells match.

2.3 Local divers and Marine agents

This form of search and rescue is common in most parts of the world where local divers and marine forces jump into water bodies to look for missing bodies. This form of search and rescue is commonly observed in Ghana and this poses a lot of risk to the rescuer and the whole process has its disadvantages as well. First, the rescuer has limited oxygen with or without an oxygen tank and will constantly have to resurface to breath in air or refill their tanks, and this delays the search process. Secondly, more labor is normally involved with this process in the case of a search by the police force. There are normally standby personnel who wait above the water surface to ensure that the divers in the water come back at the expected time. Also, divers can be attacked by aquatic animals and this could hinder or halt the search process.

The proposed system will help eliminate the possible risks divers face during their search and rescue missions. Since the proposed system is a mechanical robot, dangerous risks that could harm a human will have little impact on it. Instead of the possible loss of another human life, this robot can only get damaged. Also, this system will involve less labor as only one person above the water surface will be required to control the vehicle within the water. Lastly, with a constant supply of power, the system could be used for longer periods without having to resurface. This could increase and improve the search duration and results.

2.4 Types of ROVs

ROVs as described above are manned underwater vehicles normally used for exploration and used to perform subsea tasks that are out of reach by divers. According to the NORSOK standards, an international standardization body, there are five classes of ROVs [16] which are:

- Class I: These class of ROVs are basically used for exploration activities using video cameras. They relatively smaller compared to other classes of ROVs and are equipped with cameras, lights, and propellers. In order to perform other operations aside video streaming, the ROV would have to be modified.

- Class II: These class of ROVs can carry extra payload in the form of measuring instruments, extra cameras, and sonar components. These vehicles still perform the basic tasks of the Class I ROVs whilst carrying out additional operations.

- Class III: These class of ROVs are larger in size and more powerful as compared to the Class I and Class II vehicles. They have extra sensors and manipulators for performing various tasks underwater such as removal of blockages.
- Class IV: These class of ROVs are large underwater vehicles that have moving parts such as tracks or tyres beneath them. They are propelled by thrusters or jet power. These are used for deep underwater works such as excavation, cable lining and other subsea operational activities.

- Class V: this class of ROVs are being developed to suit specific tasks. They are regarded as prototypes and do not fit into the above classes of ROVs.

The vehicle to be built for this project will be placed in a Class 5 types of ROV since it is more tailored to a specific task. It could also be placed into class 2 type because it will carry extra payload in the form of sensors whilst performing the tailored task of locating and resurfacing missing bodies or items.

3. Requirement and Architecture

In this chapter, the design requirements of the proposed system will be discussed. It will detail the system, user, and environmental requirements of the system and surrounding. These requirements will influence the design and selection of materials for the proposed system.

3.1 Design Proposal

The aim of this project is to build a manned submersible for search and rescue of missing bodies or items within water bodies such as lakes, ponds, and lagoons. The proposed device if built at full scale, could be used by rescue teams in Ghana to aid with their search and rescue missions. This will be implemented by building a robust underwater vehicle to achieve the desired task.

3.2 System, User, and Environmental Requirements

All requirements stated in this document will aid in the development of the proposed system. The requirements will be taken from the user's perspective, that of the environment, and the system itself. This will help in creating a system that achieves the desired basic task. The main users for the proposed system will be local guard rescuers and marine security agents. Any of these users can control this underwater vehicle from above the water surface whilst having visuals of what is happening beneath the water. With the help of basic controls, the user will be able to grab onto an object or body with a gripper and activate other sub-components when needed for proper functioning.

For the ROV and the mission to be accomplished appropriately, the following requirements should be met:

3.2.1 System requirement:

The vehicle should:

1. have lights for low light conditions underwater.
2. be able to grab unto an object firmly
3. be able to descend to a maximum depth of 1.5 m
4. be able to lift a maximum payload of about 500g
5. be close to being neutrally buoyant (slightly positively buoyant)
6. house all electronic components in an air-tight container
7. Move at a maximum constant forward rate of 0.3m/s
8. Ascend and descend at a maximum constant rate of 0.3m/s

3.2.2 User Requirement:

The user should be able to:

1. control the vehicle with ease
2. know the depth of the submersible
3. actuate the gripper from the topside (above the water)

3.2.3 Environmental Requirement:

1. The test environment should be conducted in clear water such as a pool.
2. The materials used should have little or no negative impact on the environment

3.2.4 Non-Functional Requirement:

1. The device should be portable

2. The device should be low-cost within $100 range
3. The controller should be user friendly

3.3 System Architecture

The system to be built will be separated into the mechanical phase, electrical phase, and programming phase. The mechanical phase includes all hardware such as frame materials and buoyancy modules needed to build the structure. The electrical phase includes all the necessary circuit designs needed to achieve the specified tasks. Lastly, the programming phase will include the control logic that will be implemented in coding the electronic system.

3.4 Part selection

Table 3.1- PUGH chart for frame material

		Options			
Criteria	Weight	PVC pipes	Aluminium pipes	Steel pipes	Galvanized steel pipes
Durability	2	1	1.5	2	1.7
Cost	5	5	3	2	3
Availability	5	4	3	2	2
Density (light weight)	5	5	3	1	2
Total	22	19	11.5	8	9.7

PVC was selected because it has a relatively lower density ($1450\ kgm^{-3}$) as compared to the other materials. This means that lesser buoyancy modules will be needed to make the overall submersible near neutrally buoyant (slightly positively buoyant). Having a denser material requires the use of more buoyancy modules, which results in a large drag. The use of PVC pipes seeks to eliminate this since it has a lower density. Also, PVC pipe was selected mainly because it is easier to work with, readily available, and relatively cheaper. It does not involve the use of extra sophisticated tools such as the welding machine and drilling machine to join parts together. With the help of PVC connectors, several members can be joined. Also, since the unit will be tested and submersed in water, it follows that the material must be able to withstand relatively high pressures. Schedule 40 ¾ ” PVC pipes are rated to withstand hydrostatic pressure of about 289 psi [17] which converts to 1.99 MPa at a depth of 202.9 meters. This pressure is highly overrated as the testing will be conducted at a maximum depth of about 1.5 meters corresponding to a gauge pressure of 14.72 KPa at that depth. This makes PVC pipes the best suitable material for the frame of the submersible. Calculations to these values are shown below:

From the relation: $P_{max} = \rho g h_{max}$ $\quad$ P_{max} = max pressure of schedule 40 ¾” PVC pipe

$$h_{max} = \frac{P_{max}}{\rho g} = \frac{1.99x10^{6}Pa}{1000kgm^{-3}\ x\ 9.81ms^{-2}} = 202.9m$$

Since, the testing will be conducted within this depth (1.5m), it is therefore safe to use Schedule 40 3/4” PVC pipes.

Table 3.2 – PUGH chart for buoyancy module

		Options		
Criteria	Weight	Buoyancy blocks	Styrofoam	Balloons
mass	5	3	4	2
Durability	4	3.5	3.5	1
Availability	5	1	4	4
Total	14	7.5	11.5	7

Styrofoam was selected mainly because of its mass and availability. The density of Styrofoam is about $0.05 gcm^{-3}$. This density is lower than that of water and hence would provide an uplift force when placed in water. Since Styrofoam is made of synthetic plastic, it can be sized into any shape with ease with the help of a hot wire. On the other hand, even though air-filled balloons are lighter as compared to the other two materials, they are less durable and could easily burst at high pressures in water. Also, sizing the balloon to have a fixed volume can be very difficult as the gas within it would compress, and effect reduce the overall volume causing a reduction in the buoyant force.

Table 3.3 -PUGH chart for Gripper

		Options		
Criteria	Weight	Hydraulic gripper	Motorized gripper	Pneumatic gripper
Manufacturability	5	3	3.5	2
Speed of actuation	4	2	3.5	1
availability	5	4	4.5	1
Cost	2	2	1	1
Total	16	11	12.5	5

The motorized gripper was selected because it will provide several degrees of actuation during operation as compared to the other two modes which either completely open or close. This form of gripper can also be designed to be very compact which will help reduce the overall drag of the submersible. A two-arm gripper will be designed and manufactured to firmly grip unto an object in water using 3D printed parts since it is also readily available. The MG996R servo motor will be used for this operation because it is readily available, and it provides a maximum torque of about 11kg/cm[18]. This available torque is enough to lift the said payload of about 0.5kg. The only flaw to this mode of operation is power consumption since the motor needs power to drive the claw, and hence reduce the power available.

Table 3.4 - PUGH chart for microcontroller

		Options		
Criteria	Weight	Arduino	Raspberry py	Texas microcontroller
Processing speed	4	2	4	3
Usability	5	5	2	1
Cost	5	5	2	2
Availability	5	5	3	1
Total	19	17	11	7

The Arduino microcontroller is selected mainly because of its ease of usability and availability. Even though it has relatively lower processing speed, it supports several electronic modules and libraries that will aid in both the coding and electronic build of the submersible. The Arduino nano specifically will be used for this project because it is smaller and fairly has the same processing speed as the Arduino Uno.

3.4.1 Propulsion

ROVs locomote in water with the help of propellers coupled to motors (thrusters).
The motors can either be Brushless DC motors (BLDC) or brushed DC motors. For the purpose of this project, brushed DC motors will be used since its speed can be varied with the help of a robust H-bridge. BLDCs are powerful but also require Electronic Speed Controllers (ESCs) to control its speed. These ESCs are expensive and normally burn out at loaded conditions and this makes it not suitable for this project.

3.4.1.1 Propulsion calculation

Submersibles moving through water experience forces in the form of drag, gravity, buoyancy, and lift. These forces oppose the movement of the submersible in any given direction. To size the needed thruster to overcome the forward and vertical forces, the following calculations had to be made.

For a levelled steady forward motion:

Table 3.5: Forward motion parameters

Parameter	Value
Frontal surface area of ROV (A)	$0.313m^2$
Drag Coefficient (C_D) [*Appendix A*]	0.23
Speed of ROV (U)	$0.3ms^{-1}$
Density of water (ρ)	$1000kgm^{-3}$

From Newton's second law of motion:

$\sum F_x = ma \quad ; for\ a\ body\ moving\ at\ constant\ speed, a = 0.$

$- F_{drag} + F_{thrust} = 0$

For a forward propulsion system:

$F_{thrust} = F_{drag}$

$F_{thrust} = \frac{1}{2}\rho C_D A U^2$

$F_{thrust} = \frac{1}{2}\ x\ 1000kgm^{-3}\ x\ 0.23\ x\ 0.313m^2\ x\ (0.3ms^{-1})^2$

$F_{thrust} = 3.24N$

Hence, a propulsion system (motor and propeller) producing a minimum thrust of 3.24N must be used. This needed thrust will increase as the submersible pitches upwards or downwards leading to an increase in surface area (and C_D) . This will then increase the drag force. To compensate for such instances, a propulsion system producing thrust above 3.24N must be used.

For steady vertical movement:

Table 3.6: Vertical motion parameters

Parameter	Value
Vertical surface area of ROV (A)	$0.719m^2$
Drag Coefficient (C_D) [Appendix A]	0.41
Mass of payload (m)	$0.5kg$

N

From Newton's second law of motion:

$\sum F_y = ma$ $\quad$ $; for\ a\ body\ moving\ at\ constant\ speed, a = 0.$

$F_{thrust} + F_{buoyancy} - F_{drag} - F_{gravity} = 0$

For a nearly neutrally buoyant body (slightly positively buoyant), $F_{buoyancy} \approx F_{gravity}$

$F_{thrust} = F_{drag}$

With an added maximum payload of 0.5kg, the total the minimum thrust force required is:

$F_{thrust} = F_{drag} + F_{payload}$

$F_{thrust} = \frac{1}{2}\rho C_D A U^2 + mg$

$F_{thrust} = \frac{1}{2}(1000kgm^{-3}\ x\ 0.41\ x\ 0.719m^2\ x\ (0.3ms^{-1})^2) + (0.5kg)(9.81ms^{-2})$

$F_{thrust} = 18.17N$

In order to meet the desired requirement, a thrust of about 19N from a propulsion system must be used.

3.5 Design Components

In order to fully meet the requirements of this project, the following components need to be used. These components were sized to meet all three requirements – system, user, and non-functional requirements. The components are listed below:

- Schedule 40 ¾" PVC pipes: schedule 40 pipe of ¾" diameter serve as the structural frame for the entire ROV. This will hold the various parts on the ROV together.
- Wire gauze: This material will serve as a platform at the base of the ROV to hold various electronic components.
- Thrusters: These motor-coupled propellers will serve as propulsion system for the ROV.
- CAT 5 network cable: This wire will serve as the umbilical to transfer data from the controller to the ROV
- Silicon glue: This adhesive will be used to waterproof the PVC pipes and electronic components.

- Servo motor (MG 996R): This high torque motor will be used in the gripper to hold onto an object.
- LCD screen: This will be used to display information from the ROV onto the controller.
- Joysticks: these analog output components will be used to send signals to the microcontroller to control the thrusters.
- Water-tight container: This container will be used to house the electronic components for further protection against water.
- Camera: this module will be used to provide live feed from the ROV to the user.
- 4.3” TFT screen: this screen will be used to display live feed captured by the camera. This will be mounted onto the hand-held controller.

4. Design & Fabrication

4.1 Overview

This section elaborates on the methods involved in designing the model and processes needed to implement the design of the Remotely Operated Vehicle (ROV). It focuses on the mechanical design and overview, circuit design, how the parts could be assembled to make the complete unit, and the control logic. The diagram below [figure 4.1] shows an overview of the whole ROV system.

Figure 4.1 – overview of the whole system

4.2 Mechanical Design and Overview

This section details the techniques involved in sizing and modelling of the structural frame, positioning of the thrusters, sizing of buoyancy modules, and the fabrication processes.

4.2.1 ROV frame

The size of the structural frame of an ROV is designed to contain all electronic components as well as ballast weights and floats. The size of the frame depends on the following factors [19]:

1. Volume of the buoyancy modules
2. Volume of electronic components in the form of thrusters, camera, and lightening
3. Weight of the vehicle in air

Based on the stated parameters, a frame size of dimensions (LBH) 350mm x 300mm x 300mm was used in modelling the unit. These dimensions were enough to contain all the necessary electronics and buoyancy modules required by the system. *Figure 4.2* shows a CAD image of the ROV with the various allocations for the equipment and sensors.

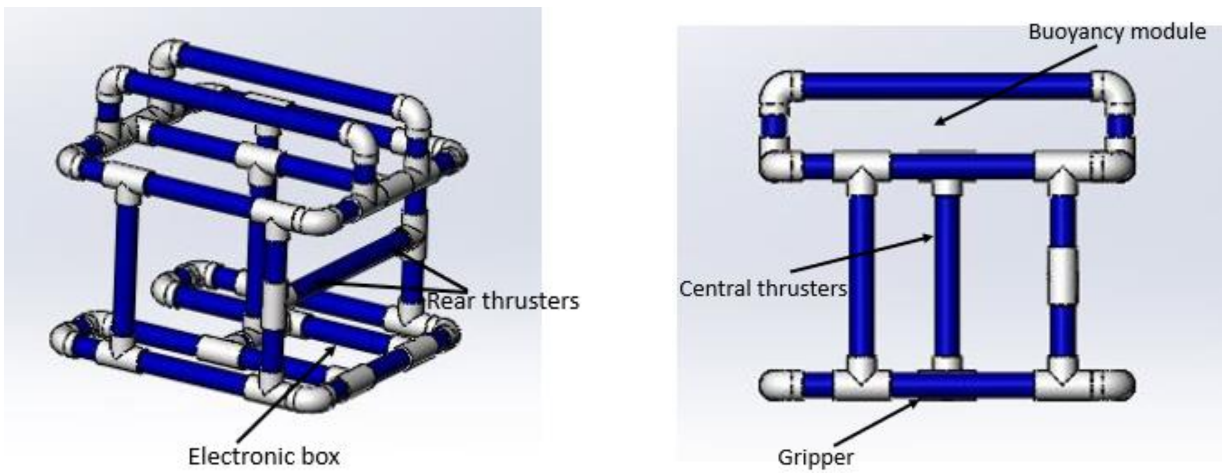


Figure 4.2: Image of ROV frame detailing the locations of the equipment to be placed on it

4.2.2 Thruster configuration

Thrusters (motor-coupled-propellers) are responsible for driving the ROV in the forward and vertical directions. The number and placement of thrusters highly depends on the ease of maneuverability the user is looking for. It also depends on the force needed to overcome added loads and drag experienced by the vehicle. *Figure 4.3* below shows the various thruster configurations used by most ROVs.

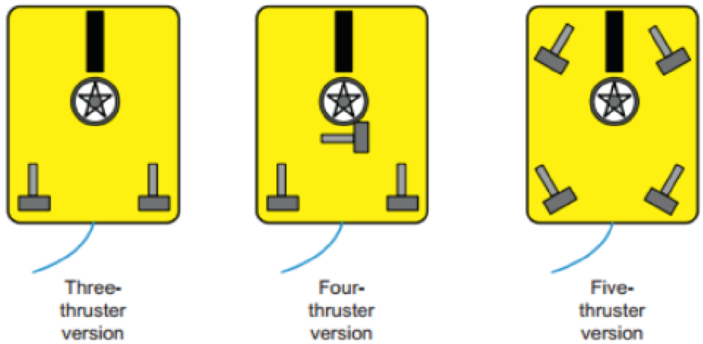


Figure 4.3 – Image showing various thruster locations [20]

The figure above shows the various thruster placements used by most ROVs. The first design allows the ROV to perform fore and yaw motions. The second design provides the functionality of the former in addition to lateral translations. The third design permits movements in any horizontal direction in addition to what the former designs offer. Based on analysis and the kind of ROV to be built (search and rescue), a merge of the first and third designs will be used with the use of 4 thrusters. Two thrusters will be used for vertical motion and the remaining two will be placed at an angle of 45° at the rear section of the ROV. Due to this tilt in angle, the forward thrust available will reduce per the following calculations:

$$forward\ thrust = F_{y1} + F_{y2}$$

$$= F_T \cos(45) + F_T \cos(45)$$

$$= 2F_T \cos(45)$$

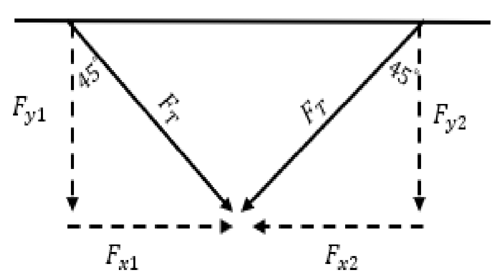


Figure 4.4 – Free body diagram of rear thruster configuration

Where:

$F_T = thrust\ supplied\ by\ each\ thruster$

For this type of slant configuration to work, the calculated forward thrust must be greater than or equal to the minimum required thrust for forward motion of 3.24N. This value could not be fully determined due to the stated reasons in chapter 6.

Also, in order to prevent torque steering and improve stability, the rear thrusters must be placed at separate points with a considerable amount of distance between them and run in anti-clockwise direction [21]. This will help reduce torque steering when the thrusters are positioned and run this way as shown in *Figure 4.4*. Based on this, a 200 mm gap will be created in between the two rear thrusters and run in anticlockwise direction to improve stability and prevent torque steering.

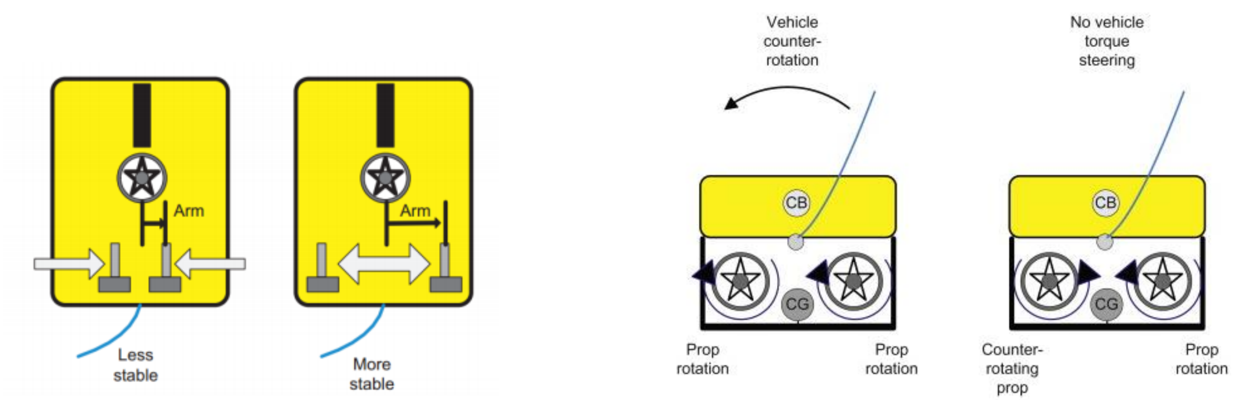


Figure 4.5 – images showing ROV stability based on rear thruster positioning and direction of rotation [22]

4.2.3 Buoyancy modules

Buoyancy modules provide uplift to the ROV and prevent it from sinking. For a near neutrally buoyant (slightly positively buoyant) ROV, the upward force (buoyant force) must be approximately equal to the weight of the ROV [23]. Since this ROV must be nearly neutrally buoyant, the following calculations need to be made to get the right sizing of buoyancy modules (Styrofoam) to be fixed onto the vehicle:

Table 4.1: Table containing parameters for sizing buoyancy module

Parameter	Value
Mass of ROV (M_{ROV})	5.99kg [*Appendix B*]
Volume of ROV (V_{ROV})	$0.0057m^3$ [*From SolidWorks*]
Density of fluid (ρ_{water})	$988.75kgm^{-3}$ [*Appendix C*]

Sizing of Buoyancy module (Styrofoam)

From case 1, figure 4.6 $\sum F_Y = 0$

$$W_a + F_{buoyant\ force} - W_{ROV} = 0$$

$$W_a = W_{ROV} - F_{buoyant\ force}$$

Where:

$$W_a = Apparent\ weight\ of\ ROV$$

$$W_{ROV} = Weight\ of\ ROV$$

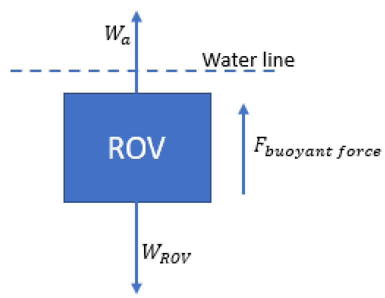


Figure 4.6 – case 1. Free body diagram of ROV in water

Case 2, Figure 4.7: For the ROV to be Neutrally buoyant:

$$F_{new\ buoyant\ force} = W_a$$

$$F_{new\ buoyant\ force} = W_{ROV} - F_{buoyant\ force}$$

$$\rho_{water} V_{nbf}\, g = M_{ROV}\, g - \rho_{water} V_{ROV}\, g$$

$$V_{nbf} = \frac{M_{ROV}}{\rho_{water}} - V_{ROV}$$

$$V_{nbf} = \frac{5.99}{988.75} - 0.0057$$

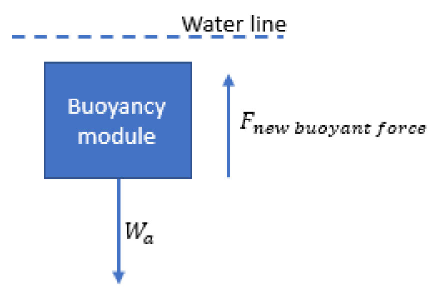


Figure 4.7 – case 2. Free body diagram of buoyancy module

$= 3.58x10^{-4}m^3$

$= 358cm^3$

A Styrofoam of this size must be cut to gain the required volume for the needed uplift. For improved results, the Styrofoam must be cut into smaller places and placed at vantage points to help keep the vehicle stable in water. *Assumption: the mass of the Styrofoam was neglected.*

4.2.4 Mechanical fabrication

After getting all the parameters right, the structural frame will be built using schedule 40 ¾" PVC pipes. These pipes will be cut according to the required dimensions as shown in *Appendix D* while following the design in *Figure 4.2*. End connectors (elbow and T connectors) will be used to join the various pipes together. To make the whole frame water resistant, Teflon tape and PVC adhesive will be applied at the joints before fixing the parts together. A sized piece of wire gauze will be placed at the bottom of the frame to serve as a platform for the main electronic components to sit on. The thrusters on the other hand will be placed at the said locations on the frame as described in *Section 4.2.2*. The buoyancy modules (Styrofoam) will also be locked in the topmost part of the frame to ensure that the center of buoyancy is significantly further away from the center of gravity. The bottom pipes of the unit will also be filled with extra ballast weight (sand) to shift the center of gravity closer to the base. *Figure 4.9* below shows the frame of the ROV. *The frame and buoyancy modules could not be completed due to the reasons stated in chapter 6.*

Figure 4.9- Image of uncompleted ROV frame

4.3 Circuit design

This section highlights the electronics to be incorporated into the whole unit. It will be partitioned into the circuitry for the vehicle itself and the hand-held controller.

4.3.1 Vehicle circuitry

The vehicle will be main device that will receive input from the controller. It will have an onboard Arduino microcontroller to receive input signals from sensors such as the joystick, pressure sensor, and moisture sensor. The moisture sensor is to act as a fail-safe mechanism to detect when there is liquid around the circuit area within the electronic box. This relays the information to the microcontroller and in effect, causes the central thrusters to resurface the vehicle. This is to ensure that none of the components gets destroyed incase water accidentally enters the electronic box. The pressure sensor will aid in determining the depth of the ROV. The job of the microcontroller is also to send signals to servo motor and relay modules to control the thrusters. The servo motor, upon receiving inputs from the microcontroller will open and close at specific angles to move the gripper that will be attached to it. To control the speed of the central thrusters, an IRF450 MOSFET will be coupled to the motors to achieve the desired speed regulation. The vehicle circuitry will also include lights and a camera system to provide vision during low light conditions and send live feed to the hand-held controller, respectively. The entire circuitry will be powered by three 12V 2000mAh batteries. To establish a long-distance communication between the ROV and the hand-held controller with lesser noise interference, an RS-485 module will be used at both ends. A schematic of how the components will be fixed to achieve the desired aim is shown in *Figure 4.10* below.

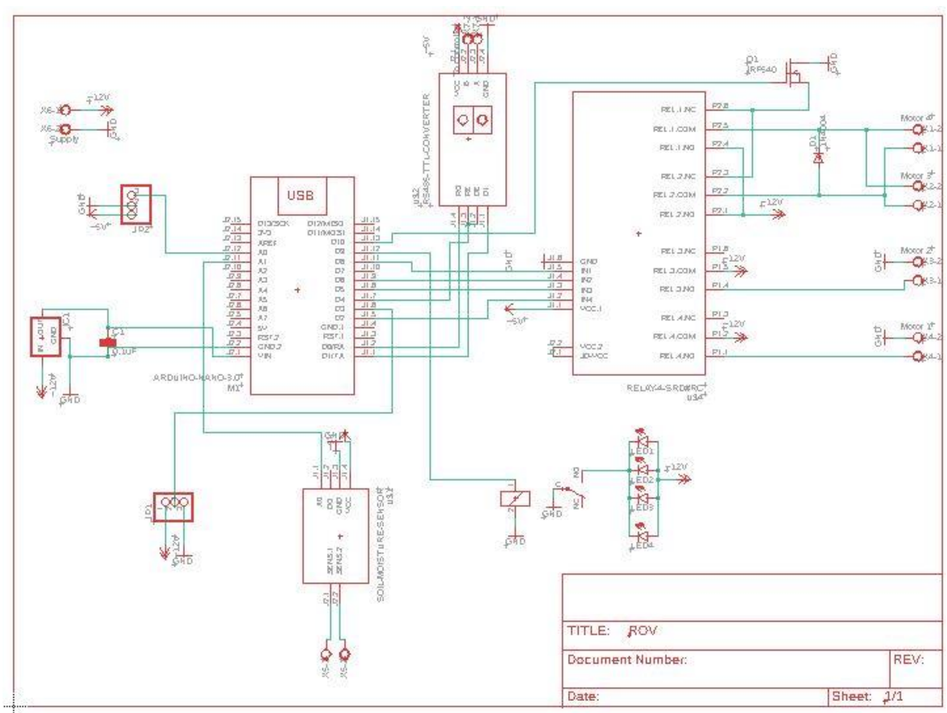


Figure 4.10 – circuit diagram for ROV connections

After creating the circuit diagram, a follow up design was made to show how the electronic components will be arranged on the Printed Circuit Board (PCB). This design was done using the Eagle software. To ensure that the electrical traces do not cross each other as shown in *Figure 11*, a double-sided PCB was designed [*Appendix E*]. The PCB will then be printed at a print house and the components soldered unto it upon return. *Figure 4.11* below shows how the components will be arranged and connected on the printed circuit board.

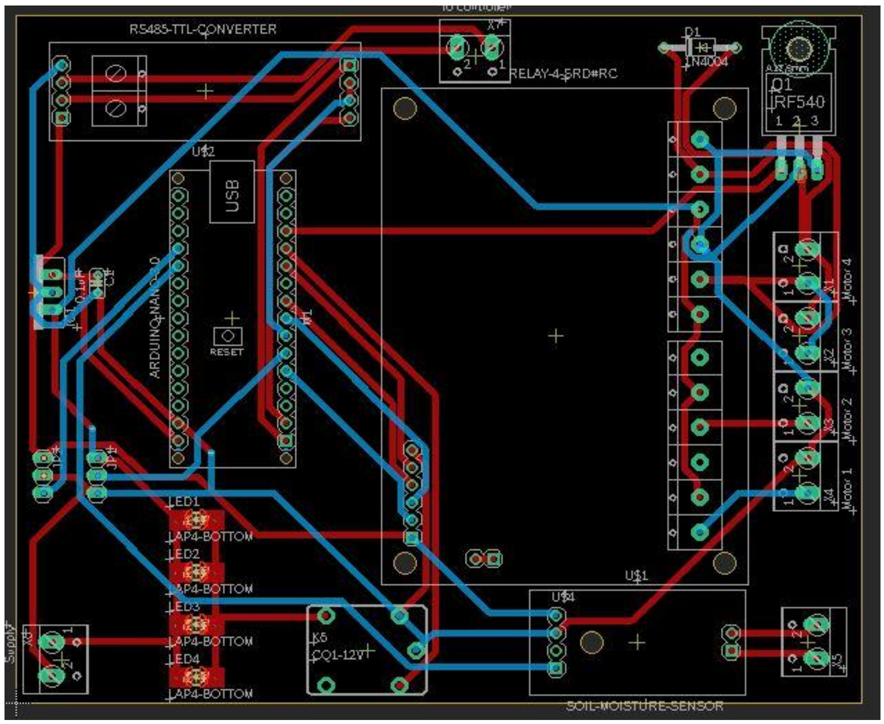


Figure 4.11 – PCB layout of ROV circuitry.

4.3.2 Controller Circuitry

To control the vehicle underwater, a hand-held controller needs to be made. This controller will send signals to the Arduino microcontroller via the RS485 module to actuate the various thrusters and servo motor using two joystick modules and three potentiometer knobs. It will also have an onboard LCD screen to display the depth of the ROV with the help of the pressure sensor stationed in the ROV. The controller will also feature a 4.3inch RCA screen which will receive live feed from the ROV's camera. With the help of potentiometer knobs, key operations such as setting depth, speed of thrusters, and actuating the servo motor can be performed. The whole controller circuitry will be powered with a 9-12V battery. To supply the microcontroller with the required input voltage (5V), an LM7805 MOSFET will be used. The controller will also feature LED indicators to display the power level of the on-board battery. This will be achieved by sizing the resistors to deliver the right output voltage to the microcontroller for processing. The equation below was used in determining the resistor values.

$$V_{out} = V_s\left(\frac{R_2}{R_1+R_2}\right), where\ V_{out} = 5V\ and\ \ V_s = 12V$$

After solving, $R_1\ and\ R_2$ came out to be 1.4k ohm and 1k ohm, respectively. Figure 4.12 shows the schematic for the hand-held controller.

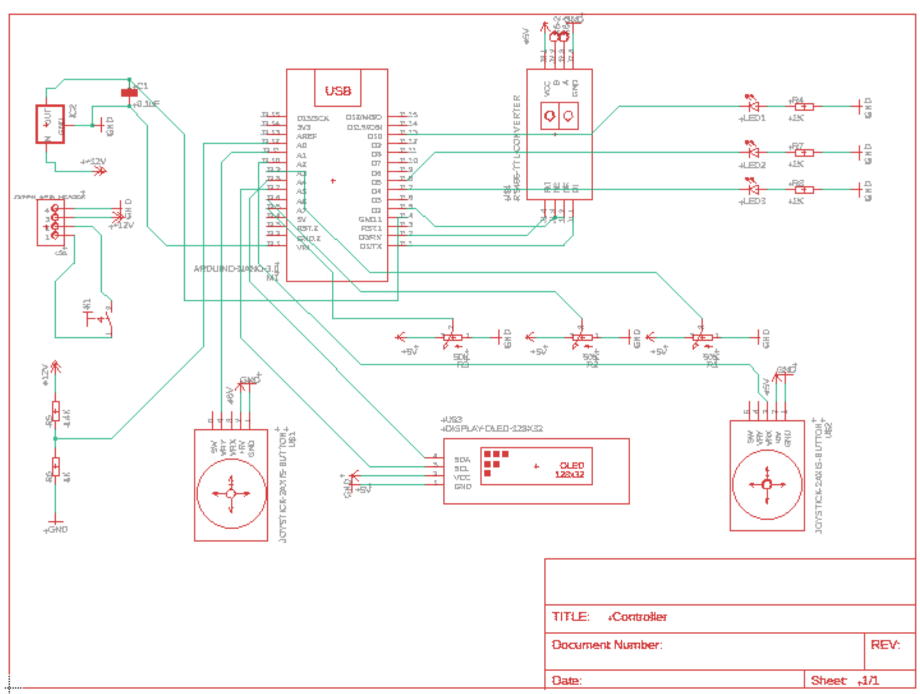


Figure 4.12 – Schematic diagram for controller

After creating the schematic, the PCB design was also made to show the various connections of the electronic components. Terminal ports were created for other peripherals such the RS485 long distance communication module to be connected to the controller. Since the traces (blue and red lines) appear to cross each other, a second design was created as shown in *Appendix F*. *Figure 4.13* shows the circuit design of the PCB.

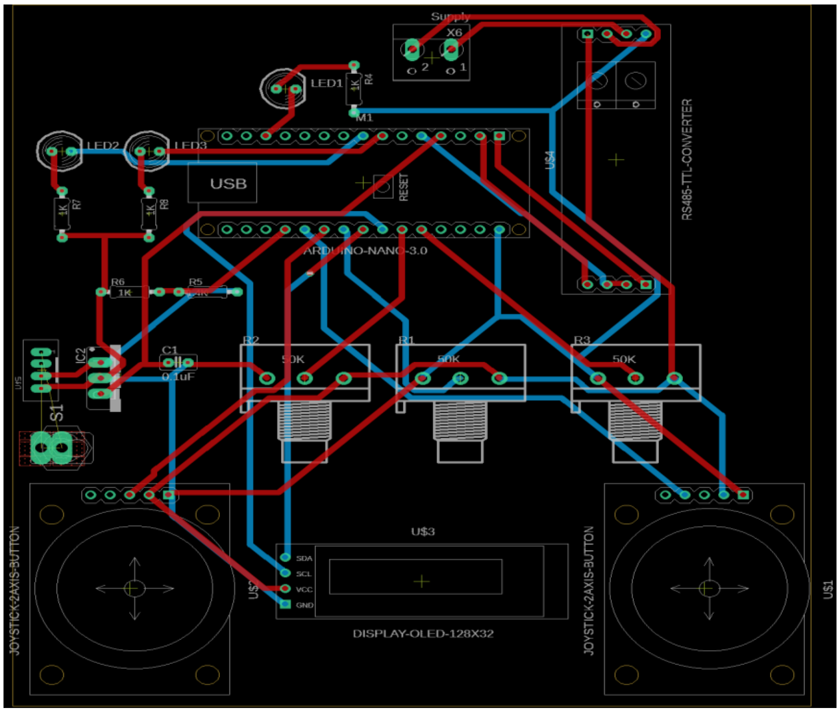


Figure 4.13 – PCB layout of controller

4.4 Prototype assembly

To fully get a functional prototype, the various parts will have to be brought together. Starting with the ROV, its electronic circuit will be placed in a small sized rectangular box and sealed with PVC adhesive. This setup will then be fastened onto the base of the mechanical frame. Components like the camera and pressure sensor will not be placed in this box but rather, fastened onto the central member of the mechanical frame. The gripper will also be stationed close to the ROV's center of gravity. The controller on the other hand will be fully assembled by placing its soldered circuit in a 3D printed casing *[APPENDIX G*]. A CAT 5 network cable (umbilical) will then be connected to the end ports of the controller and vehicle for transfer of signals. The images below are 3D models of the final assembly of the ROV and the hand-held controller.

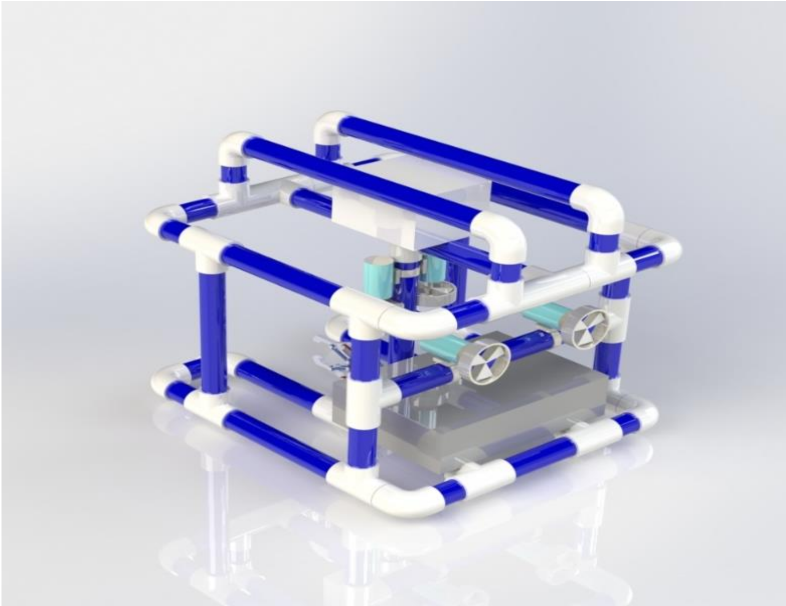


Figure 4.14- Rendered 3D image ROV

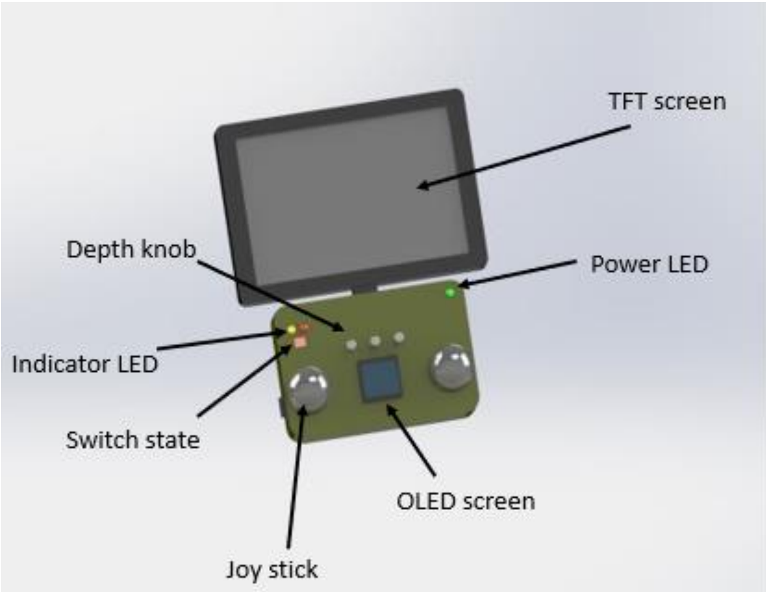


Figure 4.15 – rendered 3D image of hand-held controller

4.5 Control Logic

To control the vehicle with ease, some intelligence was incorporated into the system. The user could man the ROV in either manual or automated mode. In the manual mode, the user was responsible for manually tuning the ROV to a specific depth. This mode comes with an additional benefit of setting the speed of the central thrusters to a desired rpm. In the case of the automatic mode, the user sets the desired depth, and the ROV descends or ascends to that set point. Since the components (thrusters and pressure sensors) were not available as discussed in chapter 6, an effective control system could not be used to achieve this. A simple P controller was used via code to serve a similar goal. To prevent the ROV from missing the set point during an ascend or descend in this mode, the speeds of the thrusters are decreased automatically to a lower rpm. To also ensure that the thrusters do not spontaneously turn on and off when the desired position was almost attained, a dead band (about the setpoint) was created to prevent this behavior from happening. The whole control logic was coded using Arduino. The equation below was used in setting up the P controller.

$$Error = set_{depth} - current_{depth}$$

$$RPM_{needed} = Error * K \quad ; where\ K\ is\ the\ proportional\ (P)\ gain$$

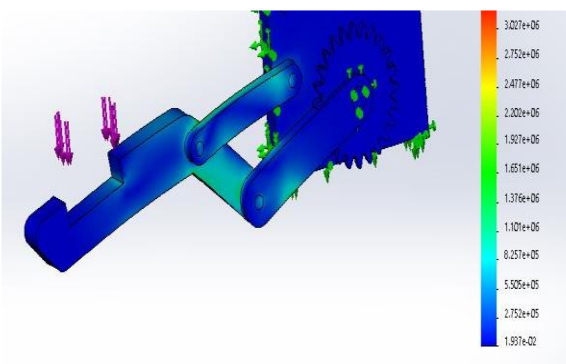
This value was run using a PWM digital pin on the Arduino. This allowed the duty cycle of the PWM signal to be varied and thereby controlling the speed of the central thrusters.

5. Testing and Results

This section details the testing phase of the project to ensure the results met the stated functional and non-functional requirements. Since the project could not be completed due to certain constraints as discussed in chapter 6, the only tests that were conducted were simulations of the ROV under dry and wet conditions, as well as a display of the built circuitry. Other tests that could have been conducted were buoyancy state test, speed test, and visibility test.

5.1 Dry Test

This test was conducted to make sure the ROV's hardware worked properly before placing it into its test environment. Due to the discussed constraints in chapter 6, this test only entailed the simulation of the ROV under its specified payload of 500g. To exhibit the worst-case scenario, the gripper was directly attached to the central pipe and the load was applied to it.



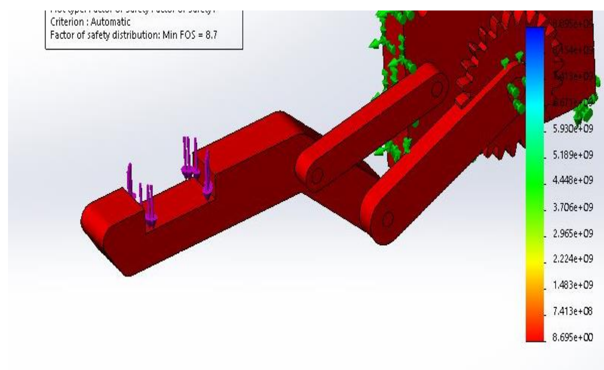


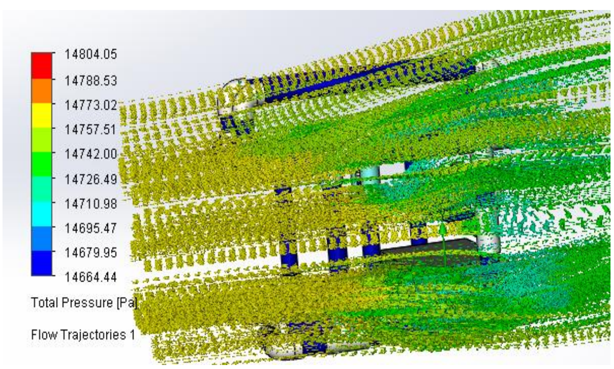
Figure 5.1 (left) and Figure 5.2 (right)- Image of stress simulation by the payload (left) and factor of safety plot (right)

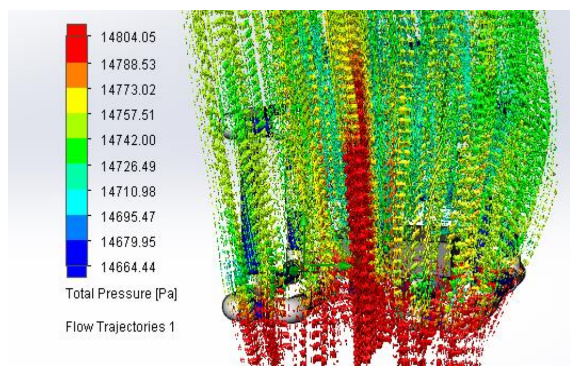
These images show a zoomed part of the vehicle's frame where the payload will be attached. After the load test with a payload of 500g, the stress obtained was 3MPa. This stress will not be sufficient to destroy the gripper and the 3mm screw joints as evident in the Factor of Safety plot (*Figure 5.2*) which gave an overall number of 8.7.

5.2 Wet test

This simulation test was conducted to ensure that the ROV will still maintain its rigid shape under the stated gauge pressure (14.72KPa). The specified materials were applied to each respective component in SolidWorks before running the simulation. The image below shows the results after running the simulation.

5.2.1 Pressure Simulation at 0.3m/s





Summary

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
GG Max Total Pressure 1	[Pa]	14816.40	14818.19	14815.76	14820.16

Summary

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
GG Max Total Pressure 1	[Pa]	15168.73	15151.73	15101.70	15184.43

Figure 5.3(left) and Figure 5.4 (right)– Total pressure simulation of the ROV moving horizontally (left) and vertically (right) at a speed of 0.3m/s through water and pressure of 14.72KPa.

Both simulations results show the distribution of the pressure vectors around the ROV at the speed of 0.3m/s and a depth (1.5m) pressure of 14.72KPa. In the horizontal motion simulation, a maximum total pressure of 14.8Kpa was recorded, whereas 15.1KPa was recorded in the vertical motion simulation at the stated conditions. Since both pressure values are less than the yield strength (24MPa) of the PVC pipes, it would not cause the material to bend or deform. Also, since PVC schedule 40 pipes are rated to have a collapse pressure of 1.2MPa [24], it will be able to withstand these lower pressures without cracking or bursting.

5.2.2 Velocity simulation at 0.3m/s

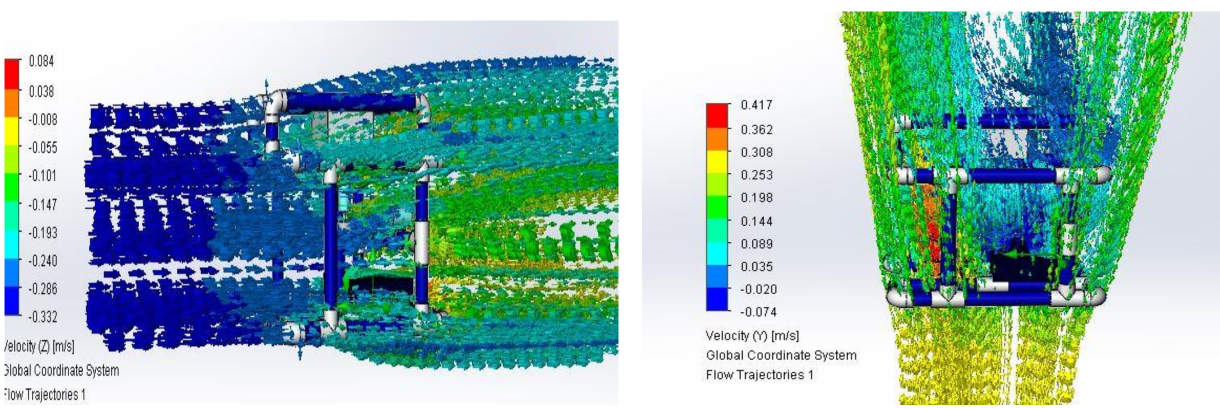


Figure 5.5(left) and Figure 5.6 (right)– Image of velocity plot when ROV is moving horizontally (left) and vertically (right).

This simulation was conducted to see how the velocity vectors change as the vehicle passes through it. As it can be observed, the velocity vectors change rapidly when the ROV is descending (Figure 5.6). This might cause vortices which may end up making the system unstable.

5.3 Circuit Test

This section displays the ROV and hand-held controller circuitry that was built. Both circuits could not be tested together and built onto PCBs/perforated boards due to reasons stated in chapter 6.

5.3.1 ROV circuit

The image below shows some electronic components of the ROV circuit on a breadboard. Dummy motors were used to represent the actual thrusters. Also, A variable resistor was used in place of an actual pressure sensor to achieve the desired effect of obtaining varied pressure levels. Even though this circuit lacked vital components, the main task of controlling the dummy motors could be achieved.

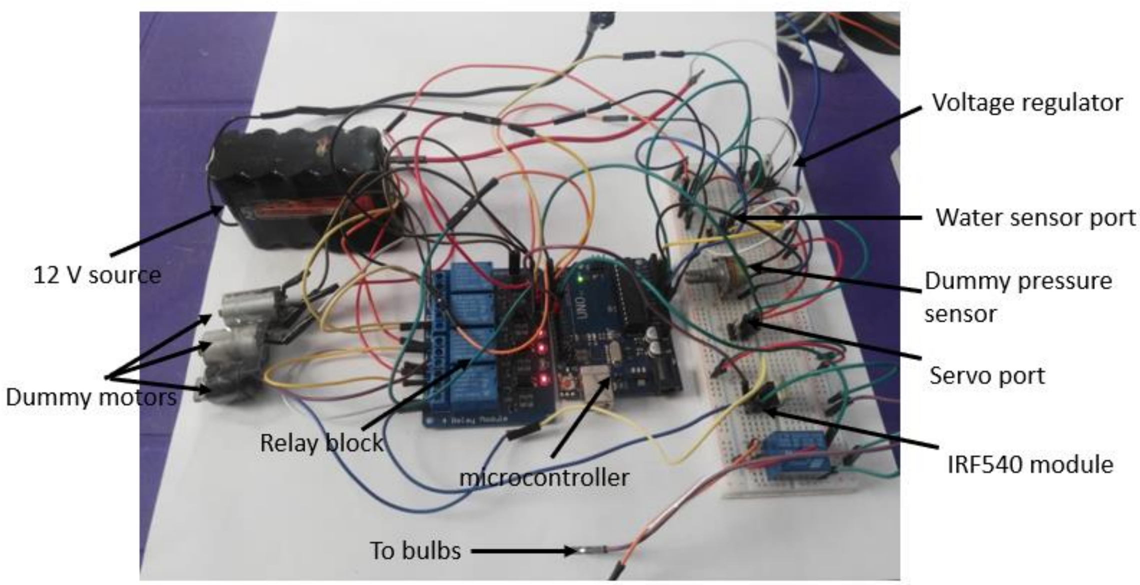


Figure 5.7- Image of ROV circuit on breadboard

5.3.2 Hand-held Controller

The image below (Figure 5.8) shows the circuitry of the hand-held controller on a breadboard. It shows a working battery level indicator based on the sized resistor values calculated. This circuit also lacked vital components too but was able to display content on the screen and switch states between manual and automatic modes.

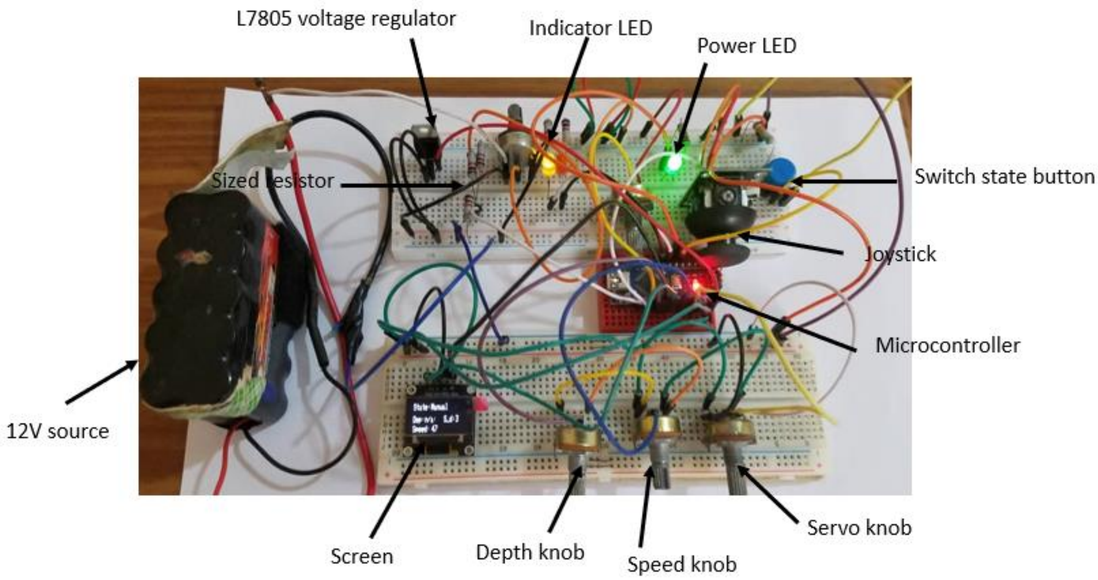


Figure 5.8- Image of hand-held controller on breadboard

6. Conclusion

With the use of this conceptual design, a full-scale version can be built to accomplish the major goal of searching and rescuing of missing beings within still water bodies such as lakes, ponds, and lagoons. It can further be equipped with an improved control system to work properly in very dynamic environments such as rivers. This system can work perfectly for the marine security service in Ghana if built at full scale. As of now, this design will be able to perform the basic task of searching and retrieving objects up to a maximum load of 0.5kg. The tests conducted in chapter 5 also shows that this system could have met some of the specified functional and non-functional requirements.

6.1 Limitations

The list below details the setbacks that prevented the perfect completion of the project:

1. Due to the lockdown and spread of pandemic:
    a. Vital parts such as the ROV and controller frame could not be completed because there was no access to workshop and lab tools.
    b. Ordered parts did not arrive on time.
2. Some sensors that were obtained malfunctioned leading to inaccurate values.
3. Some tools that could have been used to create the PCB were broken.
4. Both electronic circuits could not be fully tested via an alternate form of short distance communication (I^2C) as one microcontroller malfunctioned.

6.2 Future works

This project serves as a steppingstone to help improve the search and rescue system here in Ghana. Below are some recommendations that could be made to further improve the system:

1. Addition of extra cameras so that user can have a wider view of the environment.
2. Sonar technology can be integrated into the system to allow users to have a fair idea of the location of an object before approaching that vicinity.
3. An improved PID control system can be integrated to improve the stability of the system in dynamic environments.
4. A separate movable buoy can be developed to hold vital components such as the battery. This will prevent the ROV circuitry from destroying when there is a leakage.

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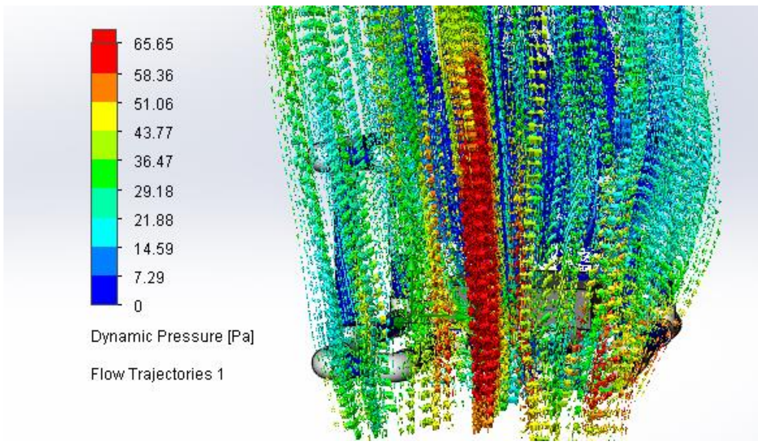
APPENDICES

APPENDIX A – FLOW SIMULATION

Flow simulation of ROV model while moving vertically in SolidWorks



Summary

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
GG Max Dynamic Pressure 2	[Pa]	61.81	62.07	61.05	63.12

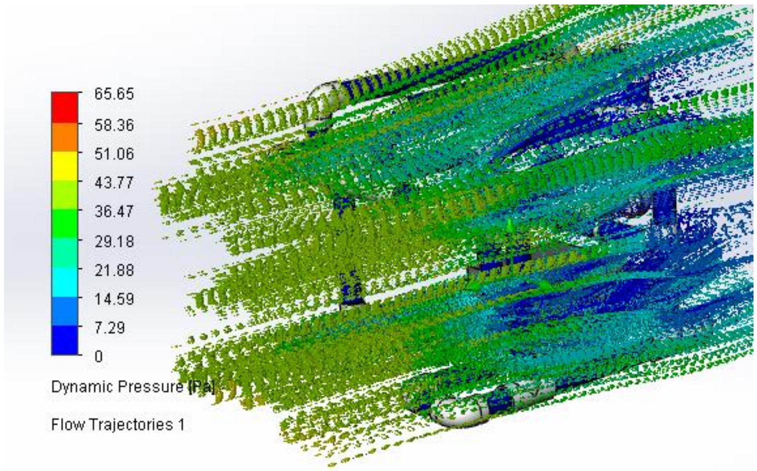
Figure 1: image above shows pressure build up around the submersible when in vertical motion at a speed of 0.3m/s

Summary

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
C_d	[N]	0.397	0.402	0.397	0.409

Drag coefficient of 0.41 after simulating

Flow simulation of ROV model while moving horizontally



Summary

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
GG Max Dynamic Pressure 1	[Pa]	159.98	161.75	133.69	226.64

Figure 2: image above shows pressure build up around the submersible when in horizontal motion at a speed of 0.3m/s.

Summary

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
C_d	[ ]	-0.2295631	-0.2310590	-0.2335989	-0.2295631

Drag coefficient of 0.23 after simulating

APPENDIX B: EXPERIMENTALLY DETERMINING THE MASS OF THE ROV

The mass of the ROV as needed in chapter 4 could be not be accurately inserted due to the challenges stated in chapter 6. Because of this, the individual masses of the supposed components were summed up in order to have a rough estimate of the actual mass of the vehicle. All data on the electronics were obtained from *https://best.aliexpress.com/?lan=en*

Below is a table showing the list of components and their related masses:

Component	Dimension/cm	Quantity	Mass/kg
PVC pipe	Schedule 40 ¾ inch, $L = 35cm$	16	16x114 = 1.8
PVC end connector	-	36	36x0.02 =0.72
Servo motor	-	1	0.055
Battery	-	3	3 x 0.255 =0.765
Relay module	-	1	0.009
Wire	-	-	0.005
Light	-	4	4x0.02 =0.08
Camera	-	1	0.36
Thruster	-	4	4x0.05 =0.2
Ballast weight	-	-	2

TOTAL			5.99

Based on this analysis, the estimated mass of the ROV is 5.99kg. This will feed into sizing of the buoyancy module in chapter 4.

APPENDIX C: DENSITY OF TEST ENVIRONMENT WATER EXPERIMENT

This experiment was conducted to determine the density of the liquid (water) in which the ROV was going to be tested in. Since one requirement of the system was a fairly neutrally buoyant state, knowing the right density of the test environment will aid in the proper sizing of the buoyancy module (Styrofoam).

Aim: to determine the density of the test environment

Apparatus: Measuring cylinder, water sample, electronic balance

Methodology:

1. A sample of the test liquid was fetched into a measuring cylinder.
2. The volume was measured and recorded.
3. The mass of the filled cylinder was measured by placing it on the electronic balance and recorded.

Results

Parameter	Test 1	Test 2	Average
Measured mass (g)	396	395	395.5
Measured volume (mL)	400	400	400

$$Density\ (\rho) = \frac{mass\ (m)}{volume\ (V)}$$

$$= \frac{0.3955kg}{0.0004m^3}$$

$$= 988.75kgm^{-3}$$

Conclusion

The test liquid in which the prototype ROV will be tested in has a density of $988.75kgm^{-3}$. This will feed into the calculation for sizing the right buoyancy module to make the unit fairly neutrally buoyant.

APPENDIX D: ENGINEERING DRAWING OF ROV

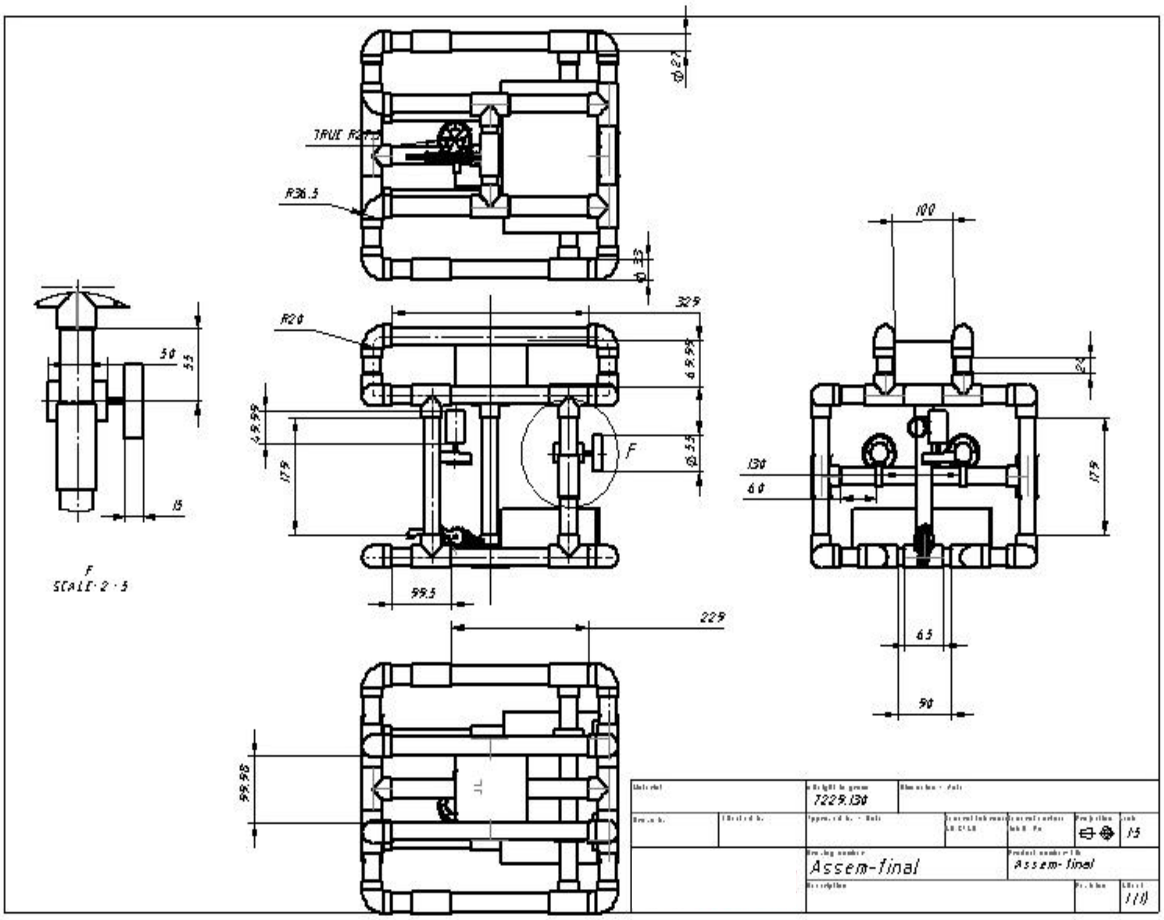


Figure 3: Image showing engineering drawing of submersible

APPENDIX E: ROV CIRCUIT PCB PLATE DESIGN

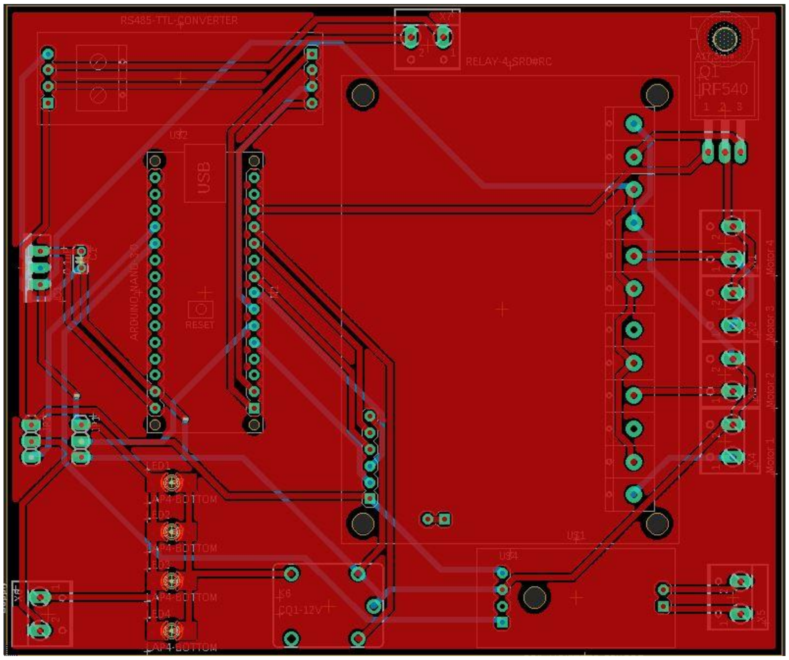


Figure 5 – Top plate of PCB

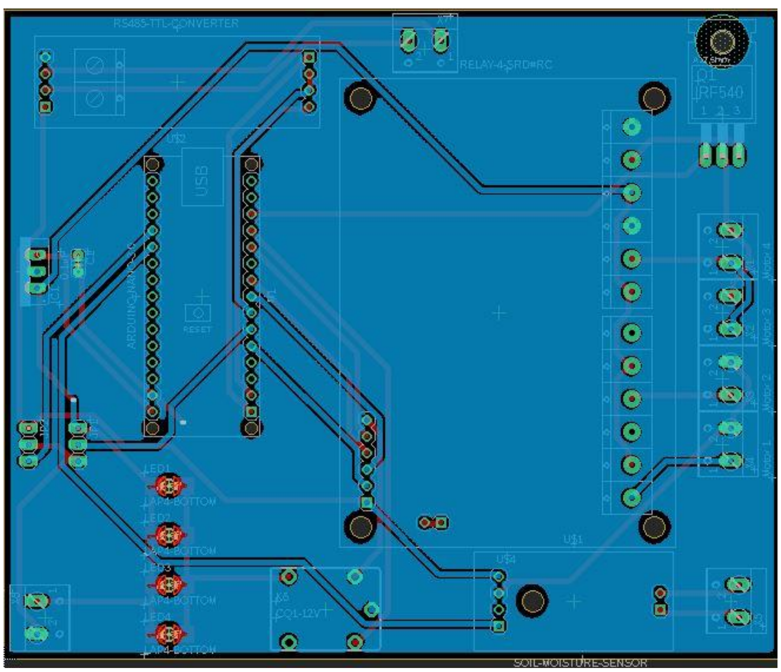


Figure 6 – Bottom plate of PCB

APPENDIX F: CONTROLLER CIRCUIT PCB PLATE DESIGN

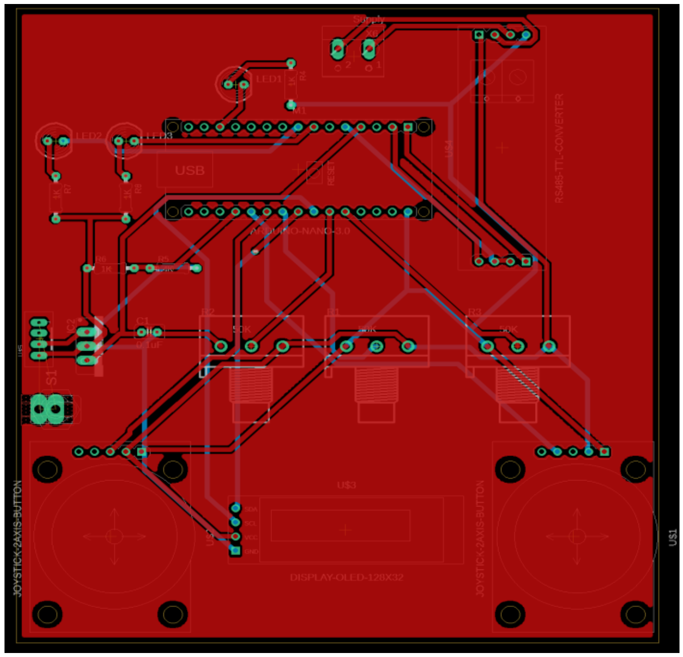


Figure 7 – Top plate of PCB for controller

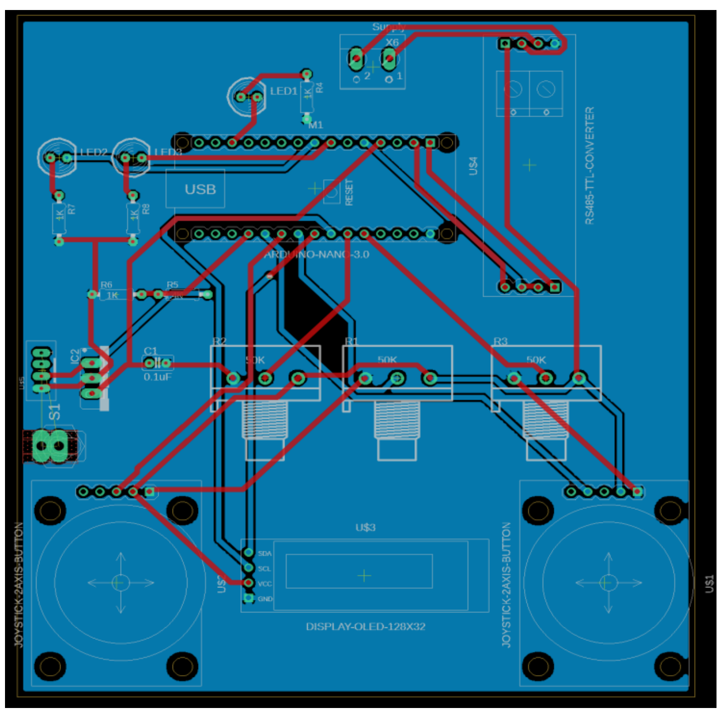


Figure 8 – Bottom plate of PCB for controller

APPENDIX G: ENGINEERING DRAWING OF HAND-HELD CONTROLLER

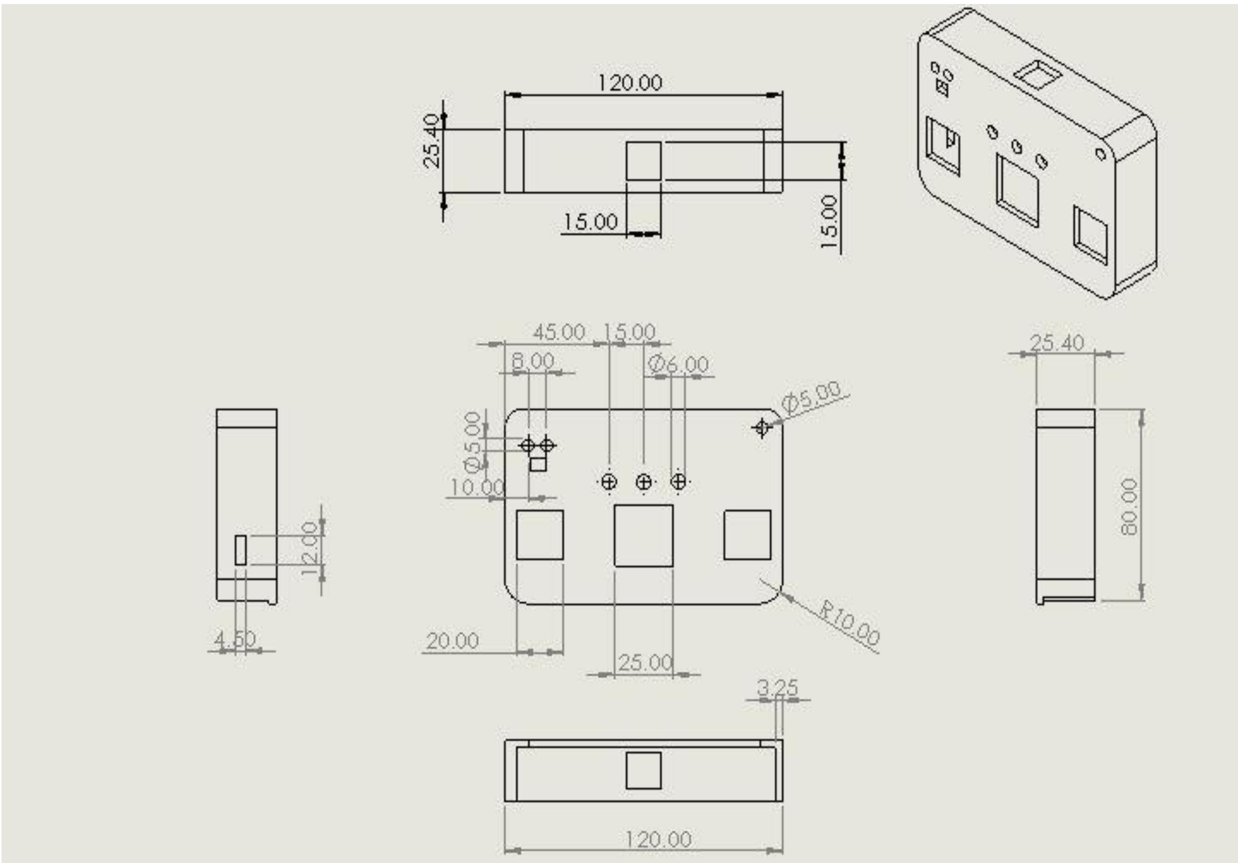


Figure 9 - Image showing engineering drawing of the hand-held controller