Submarine or Underwater Robot

TEAM PROBOT

Darshil Sheth
Raj Randive
Anuj Patel
Pushkar Kadam
Darshil Pithva

Document (Technical Details for Proposed Robot)

INTRODUCTION:

Underwater submarines, also known as Remotely Operated Vehicles (ROVs), are unmanned vehicles designed for exploration and operations in aquatic environments. These vehicles rely on principles of buoyancy and propulsion to navigate through water, often tethered to a surface vessel or control station for remote control. Their robust hull structures and waterproofing ensure durability and protection in challenging underwater conditions, allowing them to withstand high pressures and corrosive environments.

Advanced PID controllers play a crucial role in maintaining stability and precision during maneuvering tasks. With their sophisticated technology and capabilities, ROVs play a vital role in underwater exploration, conducting tasks such as inspections, research, and maintenance in marine environments, contributing to scientific discovery and industrial applications.

PROBLEM STATEMENT:

An underwater robot which has the ability to be completely submerged and has the ability to move in 3 degrees of freedom (up, down, front back and left right). Needs to be immersed at least 2 meters deep.

OBJECTIVES:

1. To be submerged completely underwater
2. To move in all 6 directions underwater.
3. To be immersed at least 2 meters deep**.**

TYPE OF ROBOT:

Submarine or underwater robot

SYSTEM MODELLING:

Coordinate System and Dead Reckoning (DR) navigation principle:

Dead Reckoning also known as "**deduced reckoning**", relies on the principle of estimating current position based on the last known position, velocity, and heading. It involves using the direction and speed of movement to calculate where you are now relative to where you were previously.

In the navigation coordinate system, the position and attitude of the Remotely Operated Underwater Vehicles (ROV) is represented as $\mathbf{P = [L, A]^T}$, where the vector $\mathbf{L = [\xi, \eta, \zeta]^T}$ is the displacement of the ROV on the direction of $\boldsymbol{\xi}$, $\boldsymbol{\eta}$, and $\boldsymbol{\zeta}$ respectively, while the vector $\mathbf{A = [\varphi, \theta, \psi]^T}$ represents the angle of roll, pitch, and yaw, respectively. In the body coordinate system, the velocity of the ROV is represented as $\mathbf{V = [U, \Omega]^T}$, where the linear velocity of the ROV is denoted as $\mathbf{U = [u, v, w]^T}$, while the angular velocity of the ROV is denoted as $\mathbf{\Omega = [p, q, r]^T}$.

During the DR navigation, when we obtain the value of linear velocity u in the body coordinate system, we can deduce the velocity in the navigation coordinate system using the transformation matrix C_b^n

$$V^n = \begin{bmatrix} V_\xi \\ V_\eta \end{bmatrix} = C_b^n V^b = C_b^n u$$

$$C_b^n = \begin{bmatrix} \cos\psi \\ \sin\psi \end{bmatrix}$$

where $\boldsymbol{\psi}$ is the yaw angle in the navigation coordinate system.

Dynamic modeling and analysis:

A new DR method for obtaining the linear acceleration and angular acceleration through detecting the rotating speed of the propellers combined with hydrodynamics analysis of ROV rather than using accelerometer, gyroscope, magnetometer, or DVL and the dynamic equation of the ROV in the horizontal plane can be simplified as follows:

$$\begin{cases} F = \sum_{i=1}^{2} T_i + F_r + F_c = m\dot{u} = m\dfrac{du}{dt} \\ M = \sum_{i=1}^{2} M_i + M_r = I\dot{r} = I\dfrac{dr}{dt} \end{cases}$$

where **F** represents the resultant force of forward movement, $\sum_{i=1}^{2} T_i$ denotes the force from the two horizontal propellers, **Fr** is the water resistance, **Fc** represents the force from the umbilical cable, m denotes the weight of the ROV with its value 30.53kg, M is the resultant moment, $\sum_{i=1}^{2} M_i$ is the moment from the two horizontal propellers, **Mr** is the moment from the water resistance, and denotes the moment of inertia of the ROV. To get the value of u and r before DR navigation algorithm, we need to calculate **˙u and ˙r** using above mentioned Equation at first.

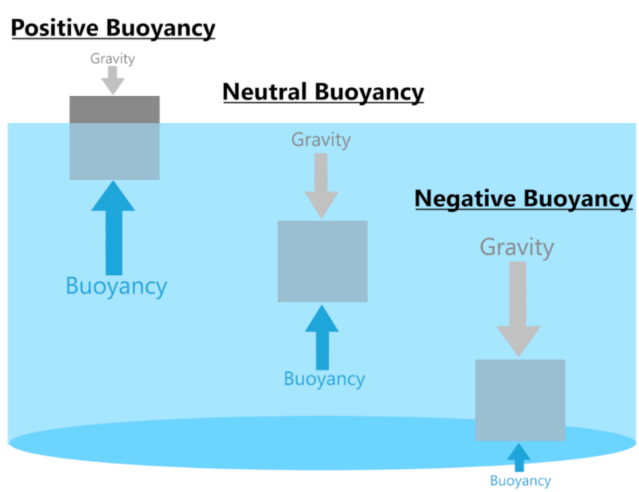


Figure 1: Buoyancy of Underwater Robot

Maintain Depth:

Maintaining depth in submarine navigation hinges on achieving a delicate balance between buoyancy and gravity. Neutral buoyancy, where the submarine's weight matches the buoyant force, ensures stable vertical positioning. Through careful ballasting and design, submarines sustain desired depths reliably. Yet, deviations like leaks or hull compression can disrupt this balance, demanding constant monitoring and corrective measures to ensure navigation accuracy and safety.

Force of Pressure:

The force of pressure experienced by an underwater Remotely Operated Vehicle (ROV) is governed by Pascal's principle, which states that pressure applied to a fluid is transmitted uniformly in all directions. In the context of an ROV underwater, this principle manifests as hydrostatic pressure exerted by the surrounding water column.

The hydrostatic pressure experienced by the ROV increases linearly with depth according to the equation:

$$\mathbf{P = \rho \cdot g \cdot h}$$

Where: P is the hydrostatic pressure, ρ is the density of the fluid (water), g is the acceleration due to gravity, and h is the depth of the ROV underwater.

This equation illustrates that the pressure experienced by the ROV is directly proportional to the density of the water and the depth at which it operates. As the ROV descends deeper into the water column, the hydrostatic pressure increases accordingly.

Depth Control:

Exploring depth control methods for submarines reveals varied approaches and challenges. Initially, propellers were used for responsiveness but required precise weight calibration. Alternatively, employing an air compressor and balloon system, along with a piston ballast mechanism, offers stability. Better solution is considering a syringe ballast system, offering precise control with an servo motor. While propeller-based control remains optimal, hull considerations favor the syringe ballast approach for streamlined designs.

Sealing:

To waterproof the underwater robot's hull, opt for marine-grade materials like plastics or acrylic industrial grade tubes. Employ robust sealing methods such as O-rings, gaskets, or silicone caulking to seal gaps and joints thoroughly. Validate effectiveness through pressure testing simulating underwater conditions. Apply waterproof coatings or sealants to exterior surfaces for added protection against water ingress and corrosion.

Design:

Hull in robot is used as a center for the whole buffer ROV components, that is for placement of electronic circuits, a DC motor casing, foot, cover the hull and ballast. To connect components on a ROV mechanical component, several kinds of materials are used, including pipe glue, epoxy glue, glue silicon rubber and resins. There are some parts of the mechanical components that are connected permanent and non-permanent. Electronic components used in this ROV is not directly placed inside the hull. To minimize the entry of water, the hull front and back cover was given in advance before being closed by the cover hull.

PID Controller:

We have used a PID Controller for better and accurate results. There are primarily three constant parameters in the PID controller. The terms proportional, derivative, and integral. It is also known as a negative feedback system and is a closed loop control system. Error is the difference between the desired state and the measured state, and it serves three purposes when it is provided as a controller input. The proportional, integral, and derivative terms will be executed on the controller using the error term. The output of the controller is given by,

$$V(t) = K_p e(t) + K_i \int e(t) + K_d e(t)$$

Free Body Diagrams:

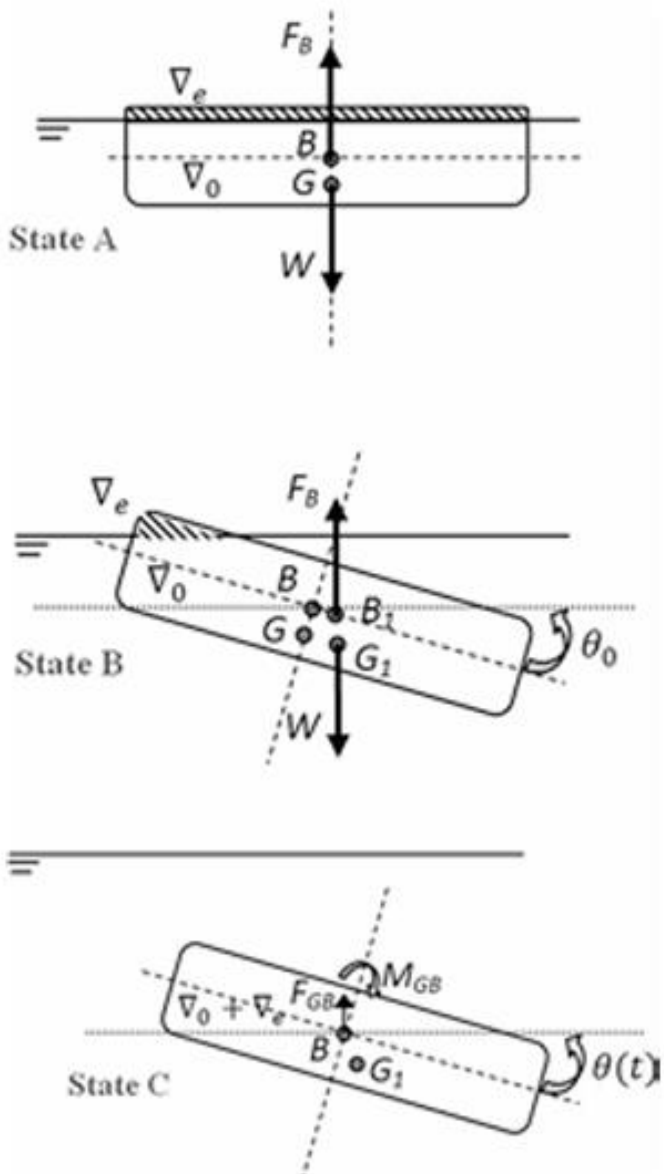


Figure 2: Free Body Diagram of Underwater Robot

State A is floating at zero trim. State B is introducing an initial pitch angle by moving the center of mass forward. State C is fully submerged with instantaneous pitch angle θ(t)

Hardware/Electronics & Structure Description:

1. **Robot Chassis:** The chassis is the supporting frame of the structure. It is the body that houses all other components. The thick acrylic pipe holds all the electronic circuitry and keeps it waterproof and the improves strength of chassis.

   A. POC

      Width of Chassis = 35cm

      Height of Robot = 15cm

      Length of Robot = 25cm

   B. Prototype

      Width of chassis = 40cm

      Height of robot = 20cm

      Length of robot = 36cm

2. **Motion Components:** Mechanical design of underwater robot needs to satisfy strict requirements of hydrodynamics, buoyancy stability in conditions of strong water current and drags, balance of masses with aim to enable reliable hovering and laminar motion (dive and ascent accomplishing), fine maneuver capabilities in restricted task space, etc. Robot has a supporting system (fins) to enable reliable lending to the bottom but also to improve horizontal stability.

   A. POC

      No. of Rotors = 4

      Diameter of Rotors = 10cm

      Width between the Rotors= 20cm

B. Prototype

No. of Rotors = 5

Diameter of Rotors = 10cm

Width between the Rotors = 30cm

3. **Microcontroller:** The microcontroller is a programmable system on a chip used to provide input/output control to the robot.

   A. POC

   The Raspberry-Pi Zero 2W is used in the POC. The Raspberry-Pi Zero 2W has up to 40 programmable pins.

   B. Prototype

   The prototype would use a Raspberry-Pi Model B. The Raspberry-Pi Model B has up to 40 programmable pins.

4. **Battery:** The self-balancing robot is powered by 2 X 3.7V LiPo batteries connected in parallel.

5. **Motor Driver Specifications:** Pololu 2130 DRV8833 is a complete micro-stepping motor driver with built-in translator for easy operation. It is designed to operate bipolar stepper motors in full-, half-, quarter-, eighth-, and sixteenth-step modes, with an output drive capacity of up to 35 V and ±2 A. The DRV8833 Motor Driver includes a fixed off-time current regulator which has the ability to operate in Slow or Mixed decay modes.

6. **Sensors:** Underwater robots utilize a range of sensors for navigation and data collection. An Inertial Measurement Unit (IMU) integrates gyroscopes and accelerometers to precisely track the robot's orientation and motion. An MPU-6050 sensor is used to track the position of the ROV. Temperature and depth sensors monitor water properties, while Laser Distance Sensor (Whadda WPSE337) systems enable mapping and obstacle

detection. Additionally, Pressure Sensors (Honeywell BMP) is used to measure pressure exerted on the ROV by the water.

7. **Controllers:** ROV control system in designing this is using a PS (Playstation) joystick. The PS joystick has 16 buttons and 4 analog lines. In this study a UTP cable is used to connect a PS joystick with a microcontroller. Not all buttons on the joystick PS are being used, DC motor speed setting on the ROV is made with three modes, that is low, medium, and high. This ROV is equipped with LED lights. To turn on and off the LED this controller is used. The design of the robot program consists of readings made from the joystick of PS, the movement of the ROV, and speed setting of a DC motor . When the power supply is ON, the program began clicking joystick initialization.

Figure 3: Controllers for Underwater Robot

8. **Connection:** Using Ethernet Cable (100 feet of Cat 5e Ethernet cable), the underwater robot transmits data to the surface for real-time monitoring. Surface equipment receives signals, aided by optimized protocols for efficient data exchange. Monitoring software allows remote control and visualization. Sensor suite, power management, and fail-safes ensure reliable operation, enabling effective real-time monitoring from the surface.

9. **Other than the above mentioned,** certain parts such as an LCD, LEDs, breadboards, etc. are used for diagnostic and prototyping purposes. Adding LED lights to have a better visual underwater, and attaching a camera to have underwater footage to further process on.

BLOCK DIAGRAM:

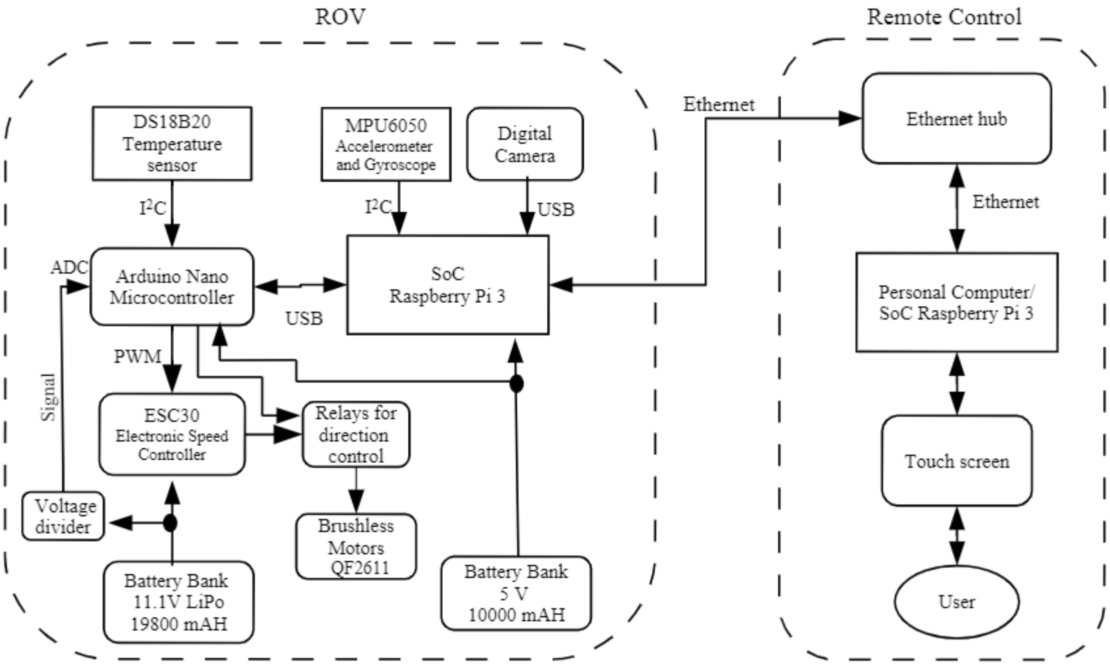


Figure 4: Block Diagram of Underwater Robot

CONTROL SYSTEM DIAGRAM:

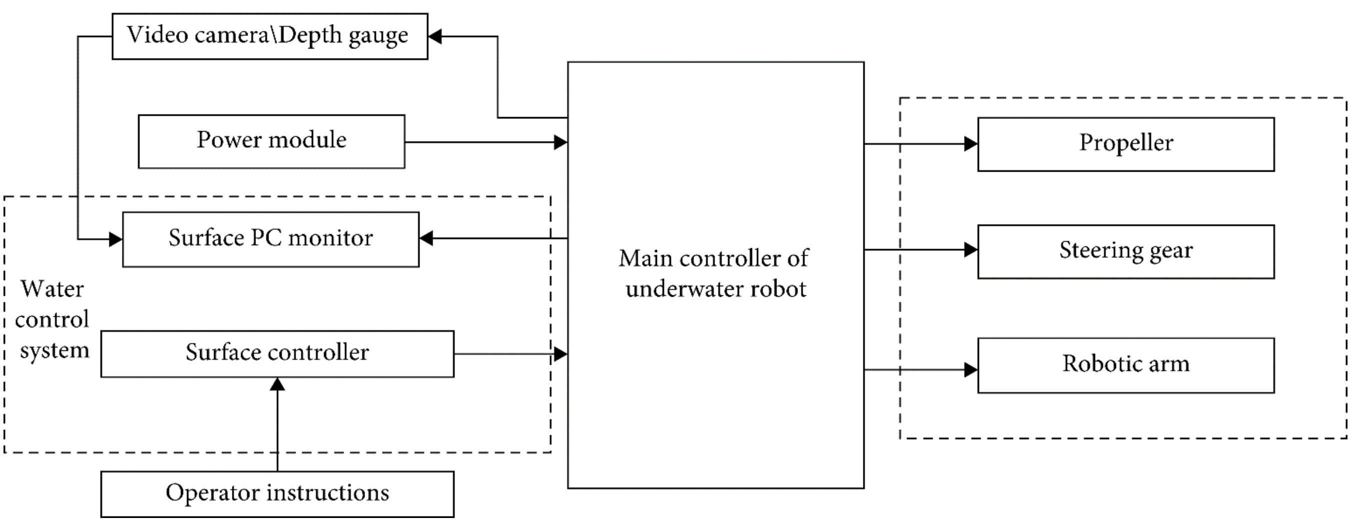


Figure 5: Underwater Control System

END-TO-END SYSTEM CONFIGURATION DIAGRAM:

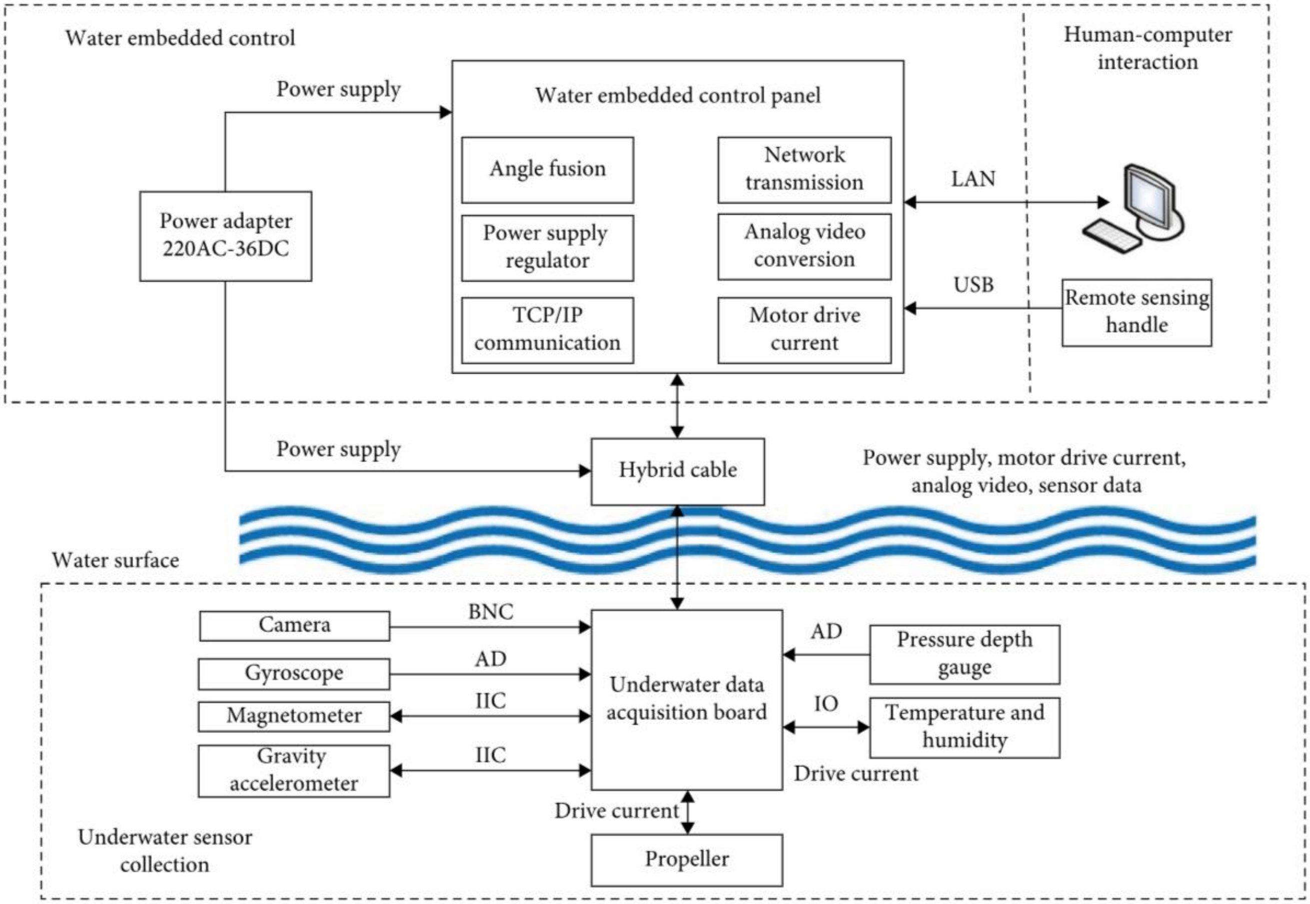


Figure 6: Circuit Diagram of the Underwater Robot

CIRCUIT DIAGRAM:

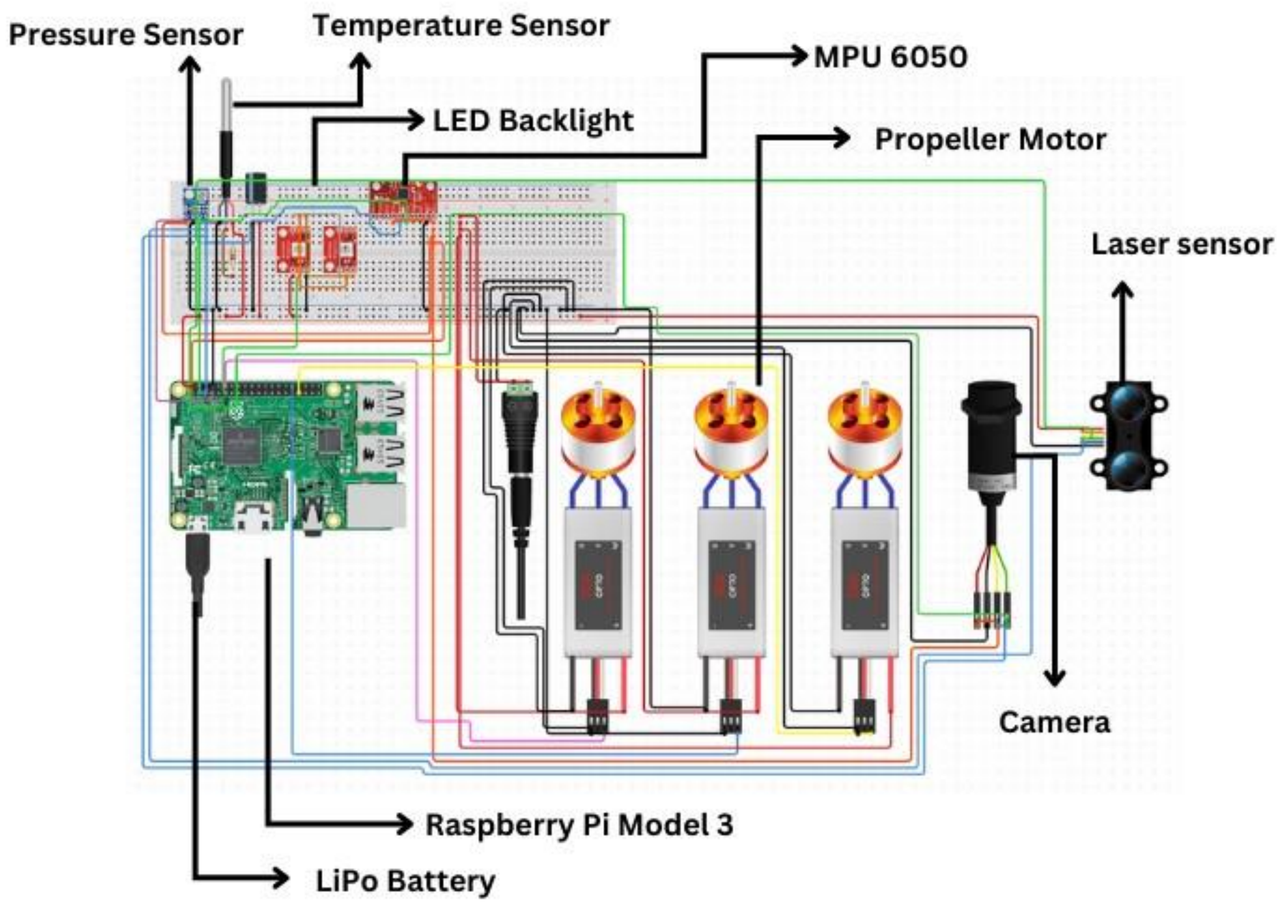
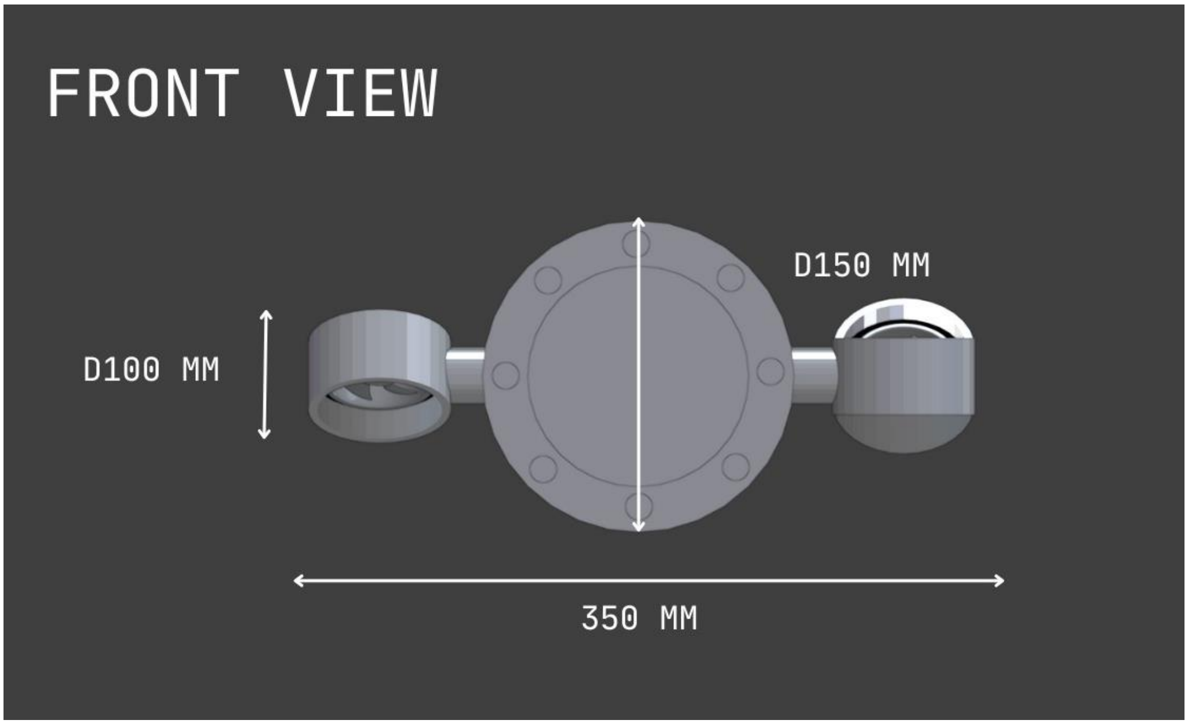
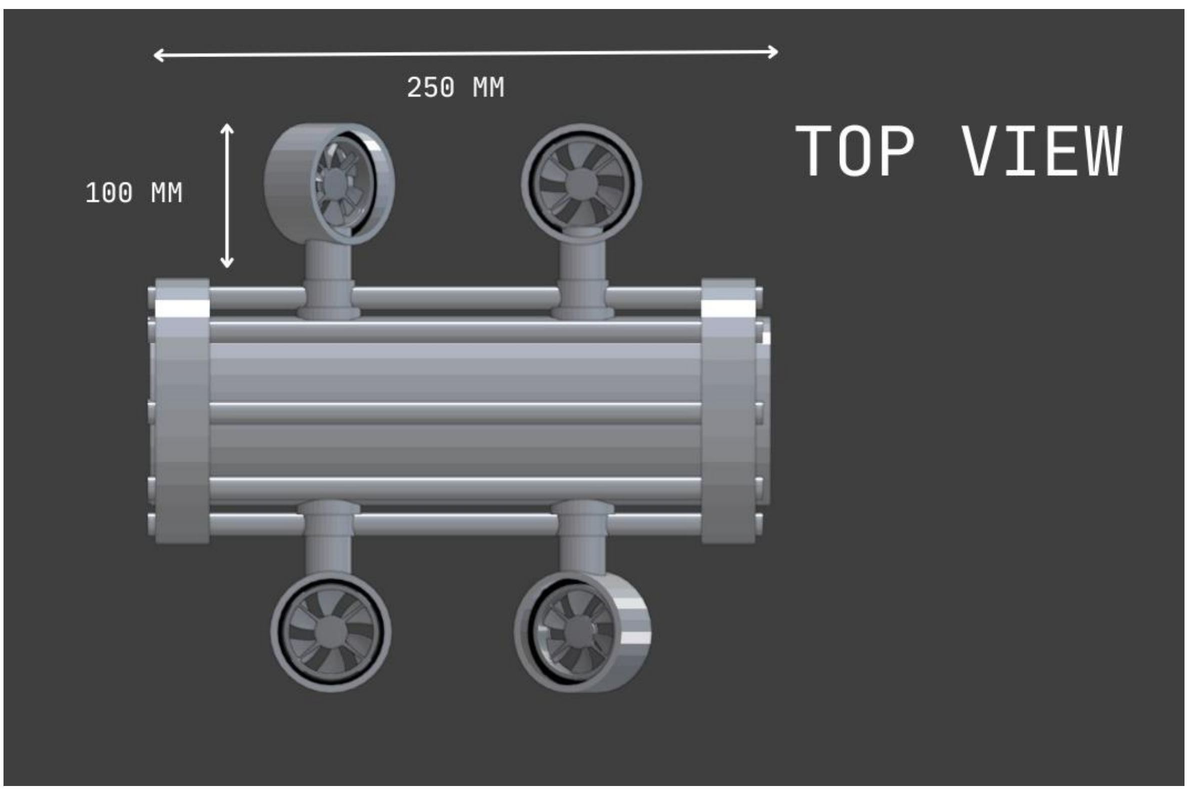


Figure 7: Circuit Diagram

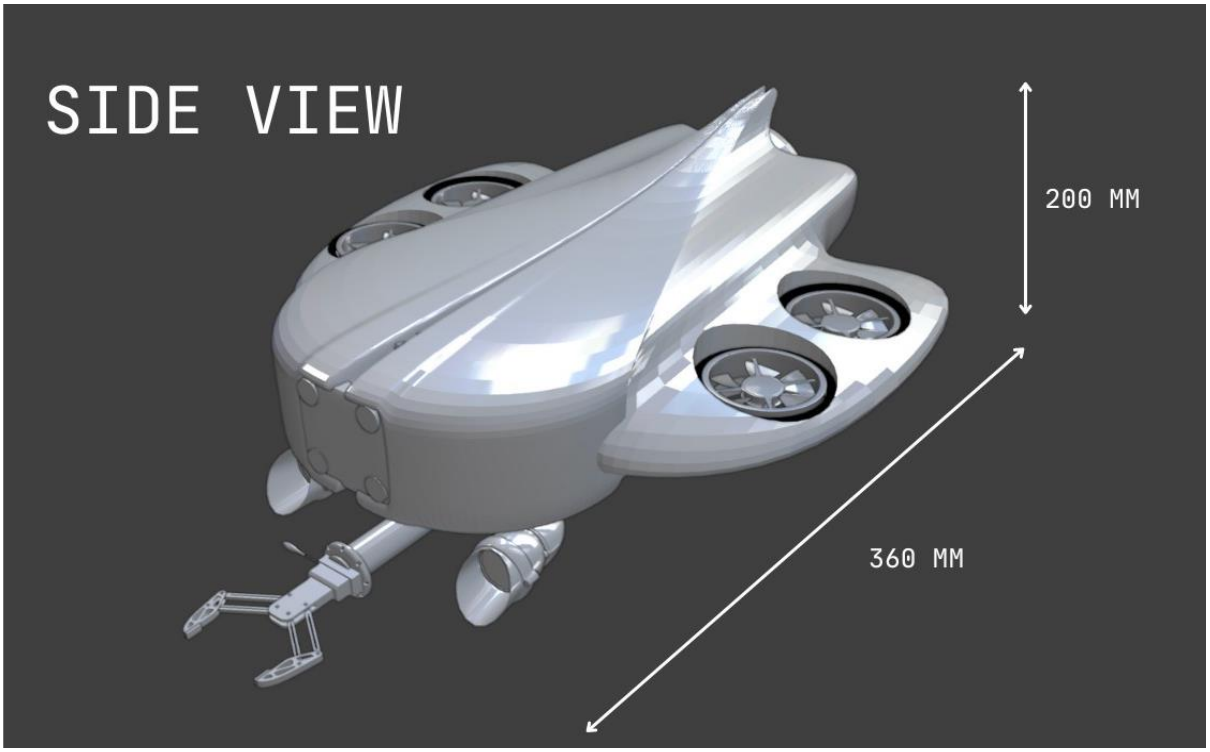
ROBOT ASSEMBLY DESIGN (PROPOSED DIAGRAM):

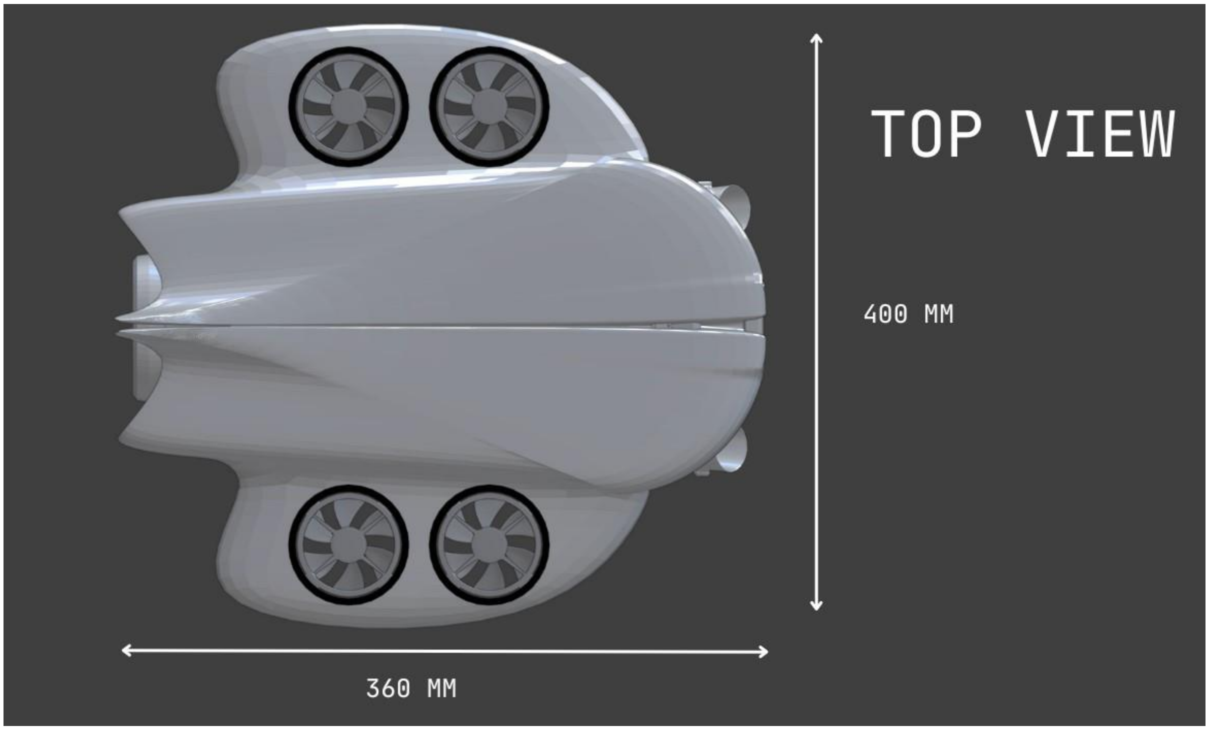
a. POC (Proof of Concept) Design: Snapshots





b. Prototype Design: Snapshots





COMPONENTS TO BE USED:

A. POC (Proof of Concept):

I. List of Structure components:

#	
1	Acrylic Tube (Thickness: 3-5 mm)
2	PCB board (12x19)
3	Wires and Wire Jumpers
4	Switches
5	Flat Head Screws (as required)
6	Nut and Bolt
7	Breadboards
8	O-ring set
9	Magnetic couplings - Neodymium magnet
10	Tungsten Pellets

II. List of Motion Components:

#	
1	Motor Driver - DRV8833
2	LiPo Batteries (3.7V x 2)
3	Rotor and propellers (100 mm diameter)
4	Stepper motors
5	4 x 2212 920KV BLDC

III. List of electronics components:

#	
1	Gyroscope (MPU6050)
2	Resistors and Potentiometers
3	Raspberry Pi Zero 2
4	Backlight LCD
5	Pressure Sensor (Honeywell BMP)
6	Laser Sensor (Whadda WPSE337)
7	PlayStation Controller
8	100 feet of Cat 5e Ethernet cable
9	DS18B20 Digital Temperature Sensor

IV. List of other Accessories:

#	
1	LED Backlights
2	Camera- Faironly Firefly Q6

B. Prototype:

I. List of Structure components:

#	
1	Acrylic Tube (Thickness: 3-5 mm)
2	PCB board (12x19)
3	Wires and Wire Jumpers
4	Switches
5	Flat Head Screws (as required)
6	Nut and Bolt
7	Breadboards
8	Magnetic couplings - Neodymium magnet
9	Tungsten Pallets
10	O-ring set
11	Claw Manipulator

II. List of Motion Components:

#	
1	Motor Driver- DRV8833
2	LiPo Batteries (3.7V x 2)
3	Rotor (100 mm diameter)
4	Stepper motors
5	4 x 2212 920KV BLDC
6	Marine bilge pumps - Rule 1100 GPH

III. List of electronics components:

#	
1	Gyroscope (MPU6050)
2	Resistors and Potentiometers
3	Raspberry Zero 2
4	Backlight LCD
5	Pressure Sensor (Honeywell BMP)
6	Laser Sensor (Whadda WPSE337)
7	PlayStation Controller
8	100 feet of Cat 5e Ethernet cable

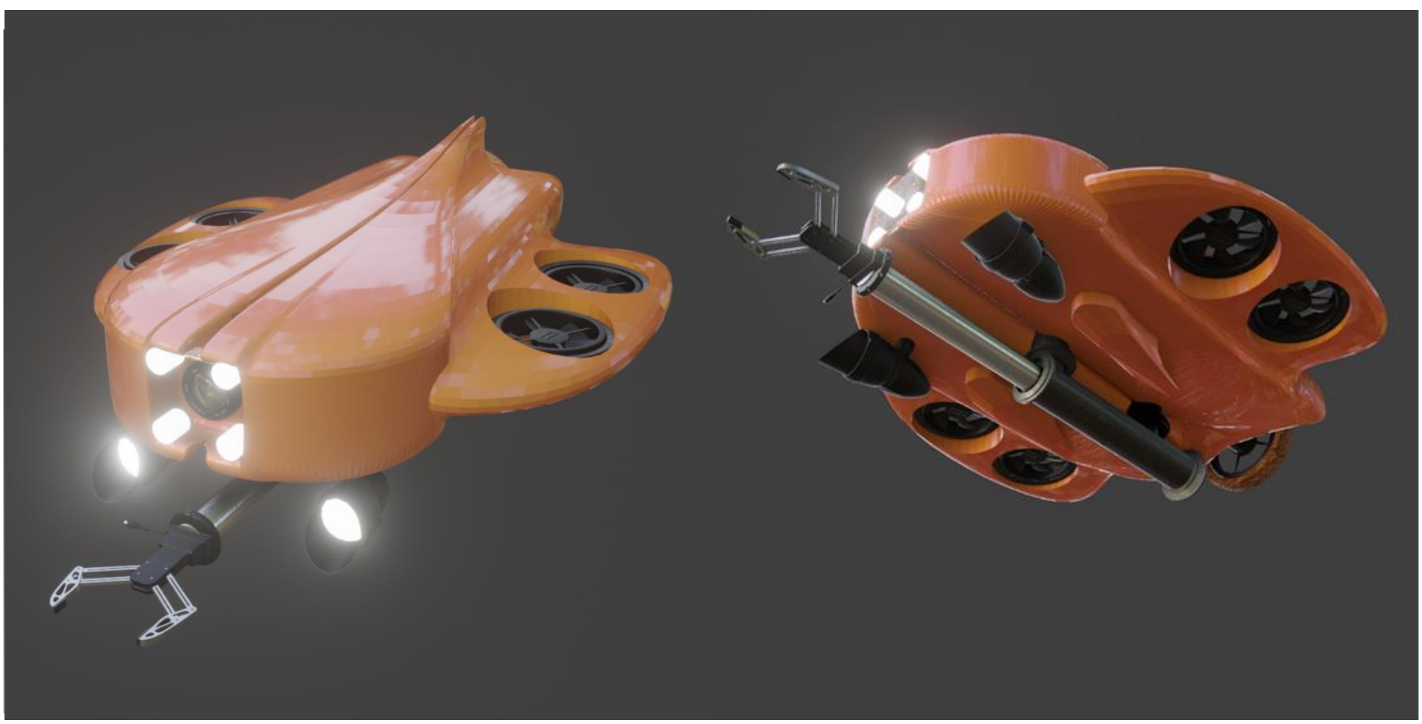
9	DS18B20 Digital Temperature Sensor

IV. List of other Accessories:

#	
1	LEDs
2	Camera- Faironly Firefly Q6

UNIQUE FEATURES:

- **Lights for Deep Exploration:** Our ROV is equipped with powerful LED lights, enhancing visibility for deep-sea exploration. These lights provide clear visibility even in low-light conditions, aiding detailed observation of underwater terrain and marine life.
- **Customizable Claw End Effector (Manipulator):** Featuring versatile hands claw system such as grapplers, drillers our ROV offers customizable functionality for underwater tasks
- **Integrated Camera:** Our ROV features an integrated camera system, offering live video feed for real-time monitoring and recording of underwater activities. This enhances research and documentation capabilities by capturing high-quality footage of underwater environments.



APPLICATIONS OF PROPOSED ROBOT IN A SOCIETAL CONTEXT:

The envisioned underwater robot presents a paradigm shift in societal applications.

1. **Subsea Infrastructure Maintenance:** The underwater robot ensures safety and reliability for critical offshore structures like oil rigs and pipelines by autonomously inspecting and maintaining them in real time. This boosts efficiency and sustainability in the energy sector.
2. **Underwater Resource Extraction:** The robot's expertise in underwater environments proves invaluable for extracting valuable minerals and rare earth elements from ocean depths. This fuels industrial progress while demanding strict environmental protection.
3. **Oceanographic Research and Exploration:** By mapping seabed topography, studying currents, and sampling biodiversity, the robot unlocks oceanographic mysteries, offering vital insights into climate dynamics and ecosystem health for conservation efforts.
4. **Maritime Security and Surveillance:** Equipped with advanced sensors and data analysis, the robot swiftly detects illicit activities and environmental hazards, bolstering maritime security frameworks and safeguarding coastal waters**.**
5. **Underwater Cultural Heritage Preservation:** Acting as a custodian of submerged heritage, the robot documents archaeological sites, salvages artifacts, and mitigates human impacts, enriching global heritage appreciation while ensuring sustainable stewardship for future generations.

SIZE OF ROBOT PROPOSED FOR PROOF OF CONCEPT:

a) Length in cm………25…........

b) Width in cm…..……35……….

c) Height in cm……..…15……….

SIZE OF ROBOT PROPOSED AS PROTOTYPE:

a) Length in cm………36...........

b) Width in cm……..…40………

c) Height in cm……..…20………

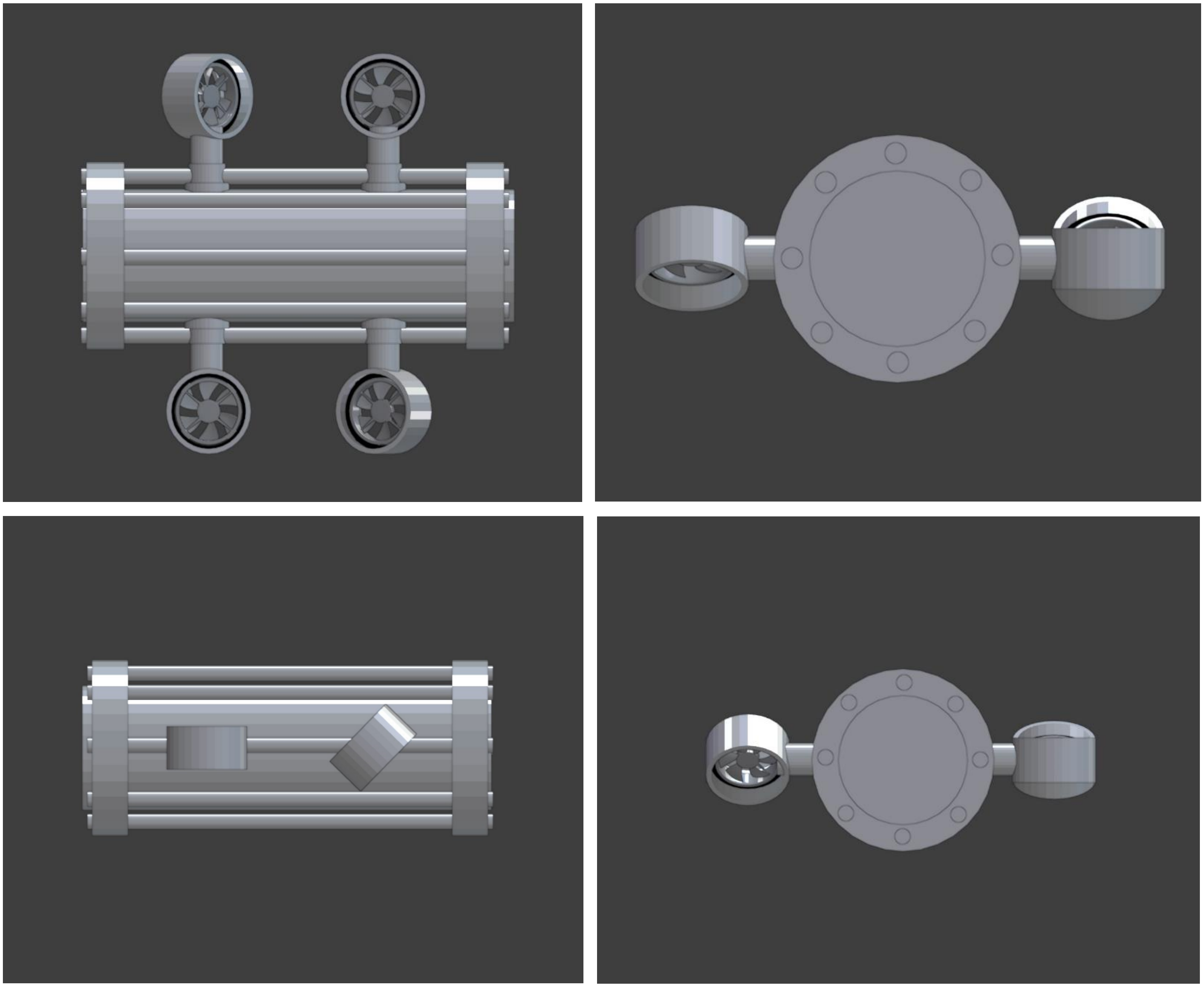
TIMELINE FOR ROBOT MAKING WITH MILESTONES:

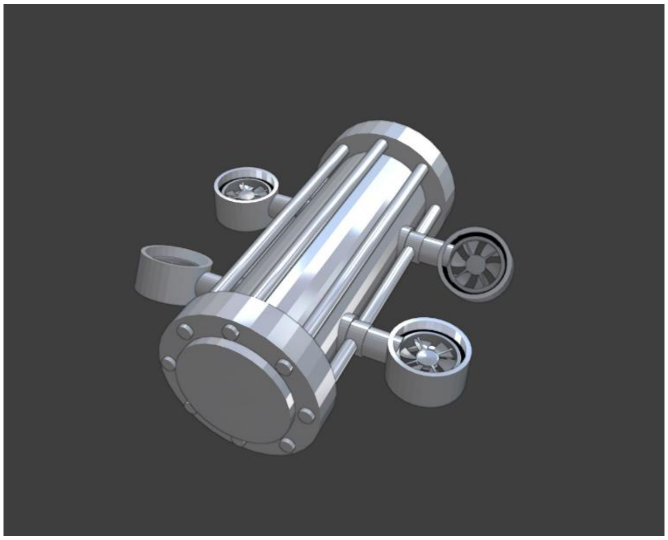
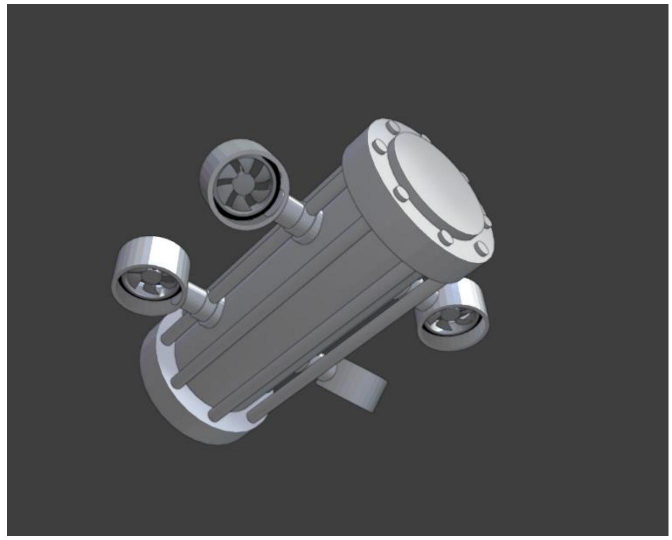
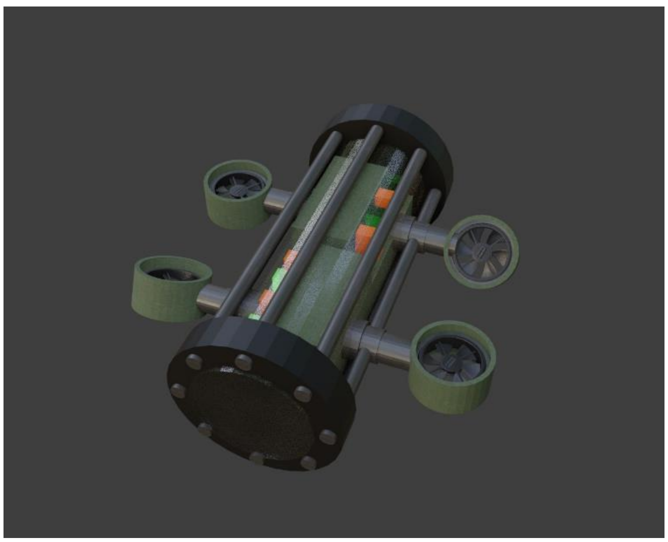
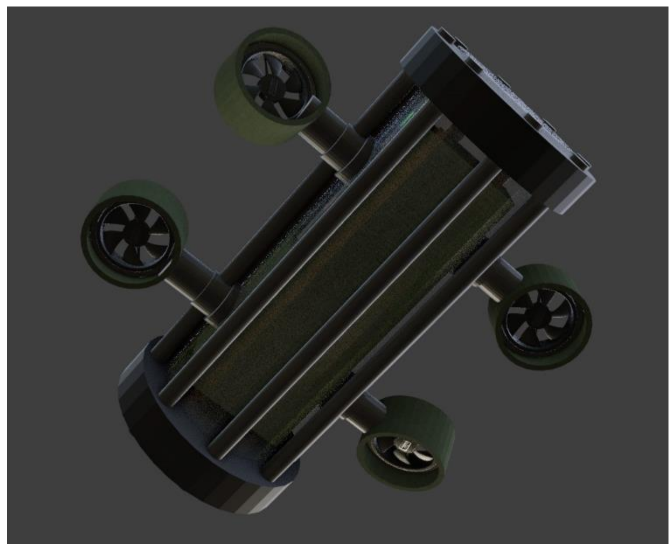
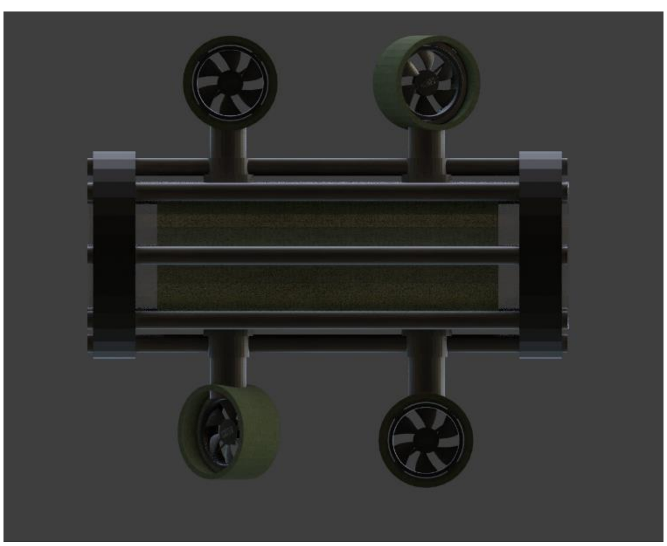
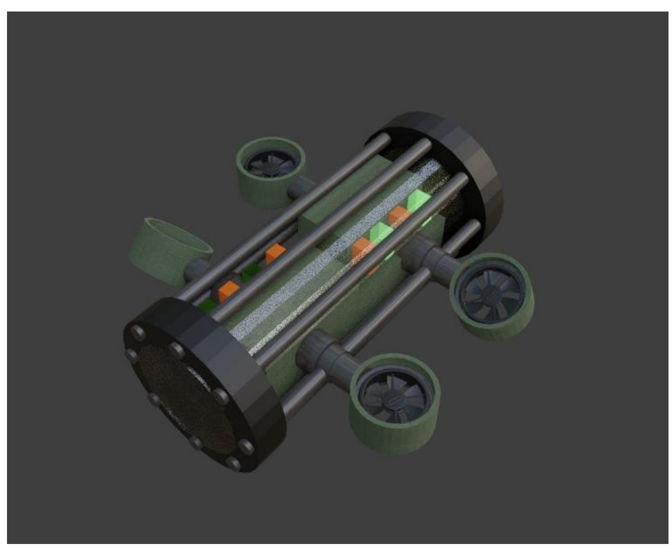
1. **Proof of concept timeline (Total 40 days)**
   - 7 days for Virtual Simulation of ROV in ROS (Robot Operating System)
   - 7 days for designing the ROV
   - 4 days for Electronic Circuits
   - 8 days to Code
   - 6 days for making the ROV
   - 3 days to test waterproofing
   - 5 days to test the ROV

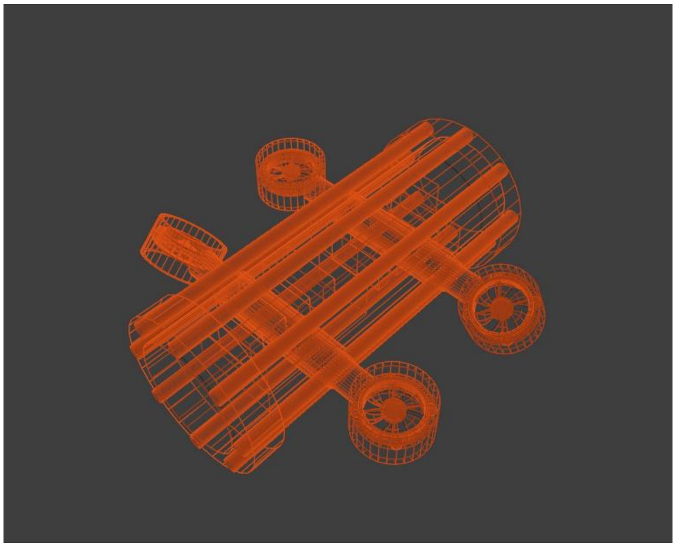
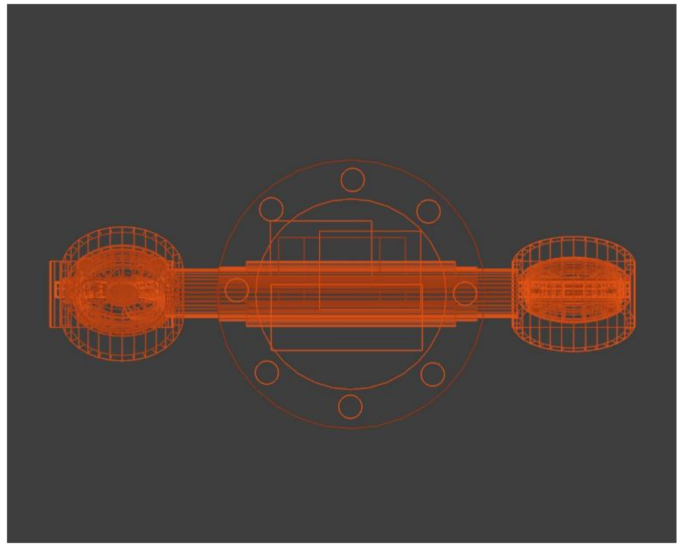
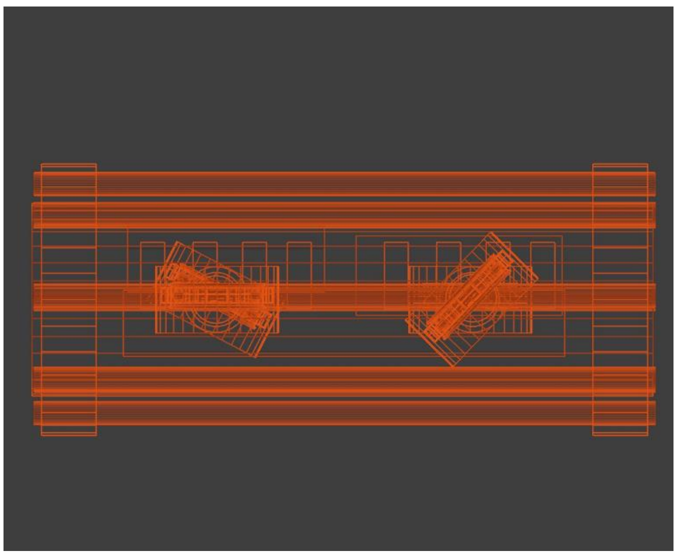
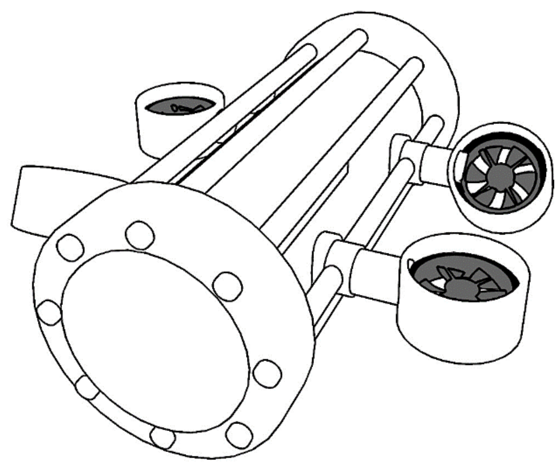
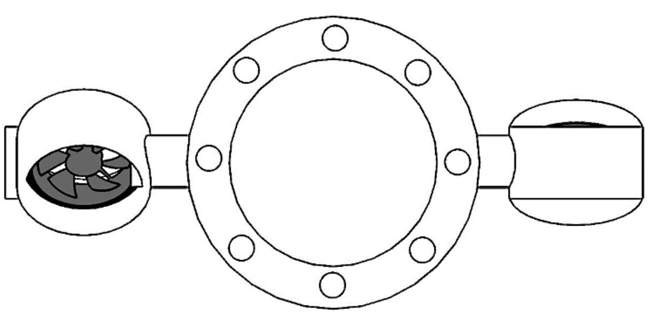
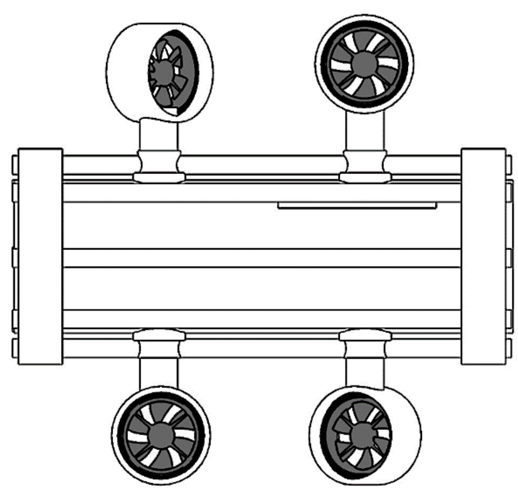
2. **Prototype timeline (Total 60 days)**
   - 10 days for Virtual Simulation of ROV in ROS
   - 12 days for making the ROV
   - 2 days to test waterproofing
   - 7 days for Electronic Circuit
   - 15 days for Code
   - 2 days for assembly of final ROV
   - 5 days to test the movements in 9DOF
   - 5 days test the depth limit
   - 2 days for final testing of ROV

MODEL DESIGNS AND SNAPSHOTS:

a. **POC (Proof of Concept) Design:** Snapshots



b. **Prototype Design:** Snapshots