Technical Design Report of Agastya-2.0 Mini, Remote Operated Underwater Vehicle

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1. Abstract

Team Nirma AUV has developed its second-generation Underwater Vehicle, Agastya 2.0 (AUV) and Agastya 2.0 Mini (ROV) ,which is designed to perform various tasks with ease and precision. Agastya 2.0 Mini is the official entry of Team Nirma AUV for the AMUROV 2.0 Competition. The team comprises of 19 members including 2 faculty advisors. Agastya 2.0 is designed to maneuver well underwater and is equipped with various sensors and electronics. It can detect shapes and colors accurately, it has a manipulator for pick & drop and is designed to pass through gates and rings, making it suitable for real-life applications. This report provides an overview of the project, including team structure, system design, and project management, as well as information about the mechanical, electronic, and software components of the AUV, and the techniques and methods used by the team to complete tasks.

2. Introduction

Underwater ROV stands for Remote Operated Vehicle that is designed to work underwater and is controlled remotely by an operator. It is connected to the remote operator through a series of cables for transmission of data. It can be deployed underwater in place of human divers to carry out some specific tasks. It is equipped with a camera, manipulators, etc and may have one or many manipulators to grab things, cut the objects or lift the stuff. It can be used in shipwreck inspection, ship hull inspection, deep-sea study, ocean exploration, oil rigs, and oil spills to reach areas where humans' reach is difficult.

For the development of the ROV which can complete the competition tasks, an interdisciplinary team of students is formed which is mainly structured into three divisions like Mechanical, Software, and Electrical. The mechanical division is responsible for hull design, waterproofing, gripper design, and fabrication of the structure. The software division is responsible for developing software such as GUI interface, ROS programming, establishing communication, and underwater image enhancement. While the electrical division looks after power delivery to each component, PCB designing, and development of the kill switch. All the divisions have their assigned tasks but still they are integrated and united in one team with one goal.

3. Competition Strategy

The vehicle was designed for the AMUROV competition that will take place at Aligarh Muslim University in Uttar Pradesh, India. The competition consists of three main tasks, namely surface maneuvering, vision control, and depth control, each of which is further divided into various subtasks, such as self-stability, key mapping for movement, sensor integration, and microcontroller programming. The vehicle has been integrated in a way that it can perform all the competition tasks seamlessly.

Success in the competition requires a well-thought-out strategy. The aim is to complete all the tasks in the shortest possible time, with the assumption that the difficulty of the tasks will correspond to their order.

The first task, called the Maze Walk, is to test the vehicle's maneuverability. The ROV must navigate through a 100 cm wide maze from the starting point to the exit while following the indicated path. To maximize points, the ROV should avoid touching the maze periphery as 5 points will be deducted each time it does.

The second task, Vision and Control, requires the ROV to locate and grab a target among two colored balloons placed at the bottom of the pool. The objective is to pass the gate and touch the balloon with the prescribed shape to earn additional points.

The final task, Depth Control, involves approaching the target pipe holder and transporting each pipe from its original position to a designated location beneath the water. Time is a critical factor in this task, so the ROV should move as quickly as possible to dislocate the pipes.

4. Vehicle Design

Many trials and analyses on the program for the design of our unmanned underwater vehicle have been made. Before testing, we can perform our calculations on the program in the most accurate way that has been carried out. Features such as the weight and dimensions of the vehicle, the designs of the thrusters modified and optimised for the competition.

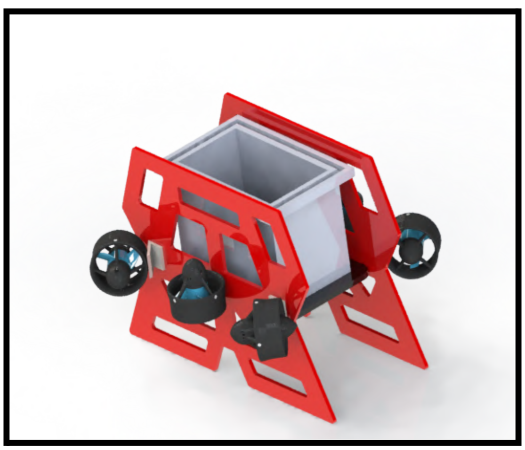


Figure 1 : CAD Model of ROV

Figure 2 : ROV at Testing Site

We used a 6 thruster configuration As a result of research on tasks and mobility for vehicle movement, different pusher position variations were obtained. These variations were scored according to the criteria in the figure below.

After analysing all the above orientations we finalised the third orientation for our machine because In the selected engine sequence, 6 thrusters control the vehicle. 2 of the thrusters will be responsible for the balance of the vehicle and its movements on the z-axis, and the other 4 will be responsible for the rotation of the vehicle around its own axis and its movements on the x and y axes. In this competition we will be using all T100 thrusters. For our body we have used 6 thruster orientation where 4 are at 45° angle. And 2 are for the vertical thrust .The process for installing thrusters was a bit complicated but we had successfully done it. While designing our base plate, at that point only we had also provided holes similar in dimension to holes of thruster. So that at the time of installation we could easily match the holes and get them screwed to their respective positions.

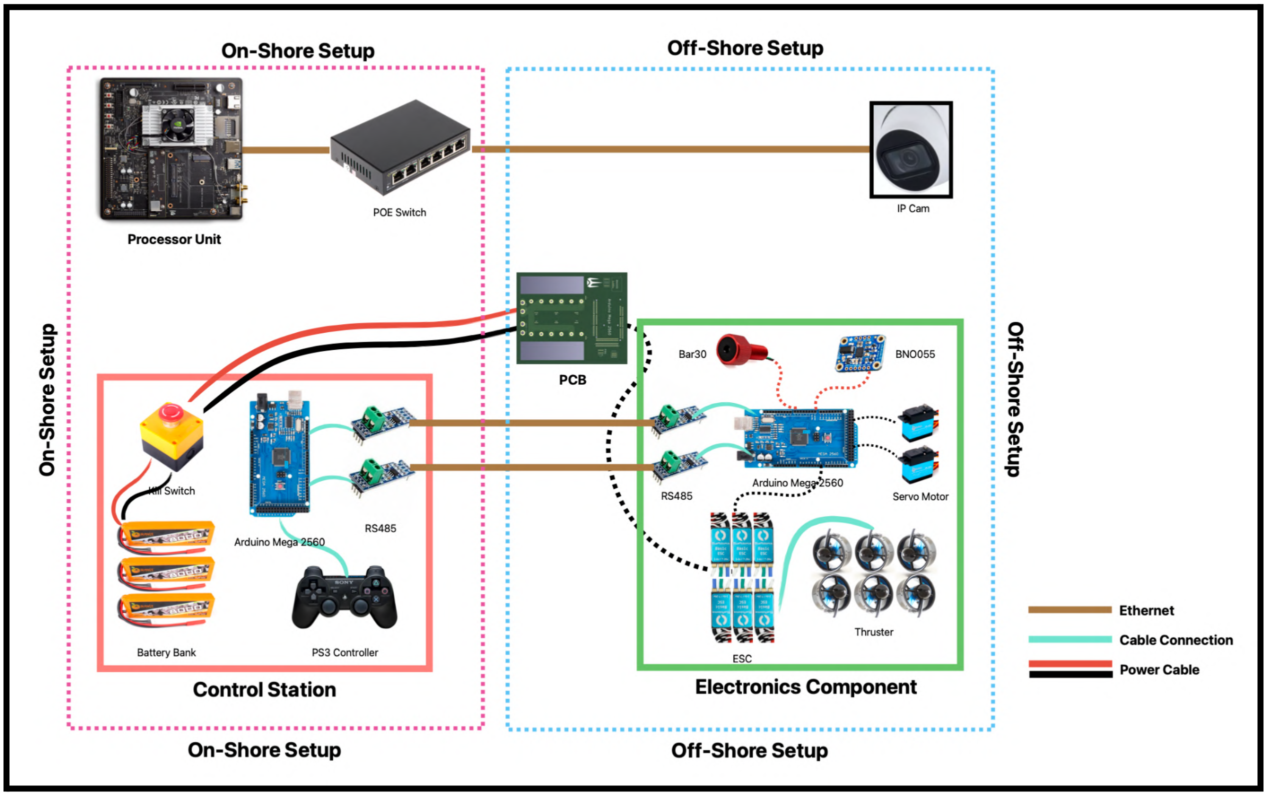


Figure 3 : Overall System Diagram

The control station is a crucial component of the system, responsible for directing and monitoring the operations of the underwater vehicle. It comprises several key components, including a power supply that provides an overall voltage of 16.8V, a kill switch, an Arduino Mega 2560 microcontroller, an RS485 communication module, and a PS3 Controller for input.

When the kill switch is turned on, the power supply activates and starts flowing through the main printed circuit board (PCB). The commands made using the PS3 Controller are processed by the Arduino Mega and transmitted to the underwater vehicle using the RS485 module, which is capable of transmitting signals over long distances.

The electronics component includes the Bar30, BNO055, Servo Motors, Electronic Speed Controller (ESC), and Thrusters. The power from the PCB and signals from the Arduino are transmitted to the ESC, which in turn controls the movement of the thrusters.

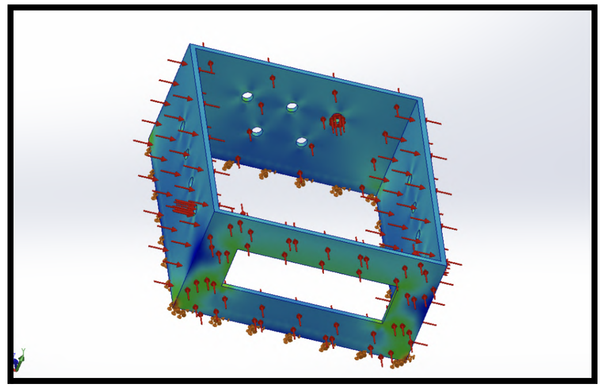
Finally, the processor unit takes the data from the IP camera through a POE switch, and displays the feedback on the screen for the operator to use to make further adjustments to the system.

4.1. Mechanical Design Process

4.1.1. Simulations & Analysis

We have simulated the Stress, Pressure and Flow analysis of our machine.

1. Stress & Strain Analysis: To ensure the structural integrity of our machine, we conducted a thorough stress analysis on our CAD model. This helped us to identify any potential areas of weakness and determine whether the body could withstand the high pressures and forces exerted by the thrusters on the side frame and base plate. After multiple iterations and detailed strain analysis, we arrived at a final design for the side plate that gave us the confidence in its ability to withstand the required conditions. This new design was achieved by using the appropriate material and sheet shape.



2. Pressure Analysis: We conducted a thorough pressure analysis on our AUV's hull to ensure its structural integrity and ability to withstand the external pressures of the aquatic environment. By simulating various scenarios and evaluating the results, we were able to confirm that our design was capable of resisting the pressure without deforming. This gave us the confidence that our hull would perform well in any situation. We used Solidworks to perform this analysis, which also helped us in our overall design process.

3. Flow Analysis: We utilised Solidworks Flow Simulation to analyse the flow of one of our thrusters. This software offers a robust automatic mesher for both fluid and solid regions, with the ability to refine the mesh based on geometric or physical requirements. Through this analysis, we were able to optimise the design of our side plate to ensure minimal obstruction of water flow from the thruster, resulting in maximum thrust output.

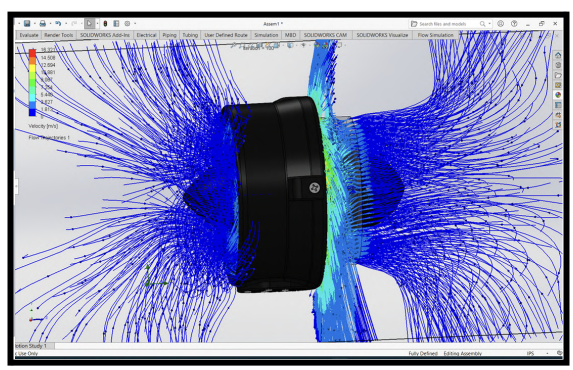


Figure 5 : Flow Analysis

4.1.2. Materials

Our vehicle consists of 6 thrusters, two vertical and four horizontal, acrylic tube, plexiglass side plates and a custom made hull which is made up of acrylic. Plexiglass was used in the construction of the AUV's side frame and hull.

PlexiGlass :
• Its resistance to impacts and damage has led to its use in the machinery industry as well.
• It is light due to its low density, highly resistant to cracking, and suitable for a wide variety of forming methods
• It is resistant to pressure. It ensures that the joints do not come out and break under pressure.

Aluminium Connectors :
Shaped like a through-hole screw with a matching nut to complete the back connection. Cables coming from the outside of the tube pass through this connector and enter the tube. Empty evidence is isolated by filling it with Epoxy.

Thrusters :
We currently have 6 BlueRobotics T100 model thrusters for our machine.

Aluminium L Rods :
Aluminium series 6006 L shape rods were used to hold the base plate and the side plate together. As well as they provide integrity to the structure.It is preferred because it does not crack, does not deteriorate, is light and durable. Below are the properties of the material:

- Corrosion resistant
- Specific gravity 2.7 g/cm3
- Good machining property
- Yield Strength 110 -145 MPa

Nuts & Bolts :
It has been deemed appropriate to use stainless steel M3 and M5 nuts and bolts for the assembly of chassis and other mechanical modules outside the vehicle. The body is easy to assemble and disassemble as well as transport wherever we want.

4.1.3. Production Methods

Laser Cutting :
The production of the mechanical components of the AUV primarily involves using a laser cutting machine on plexiglass. To ensure the success and efficiency of the project, design validation tests are frequently conducted. Our design has been thoroughly verified, eliminating the need for prototyping with alternative materials. The resulting parts are durable and can withstand impacts.

Using plexiglass, a material that is not harmful to both human health and the aquatic environment, in combination with a strong adhesive and silicon for joining components, is the most cost-effective and optimal choice for underwater products. The precision of laser cutting allows for the production of highly accurate, millimetric parts and even the screw gaps on the plexiglass sheet can be created using laser cutting.

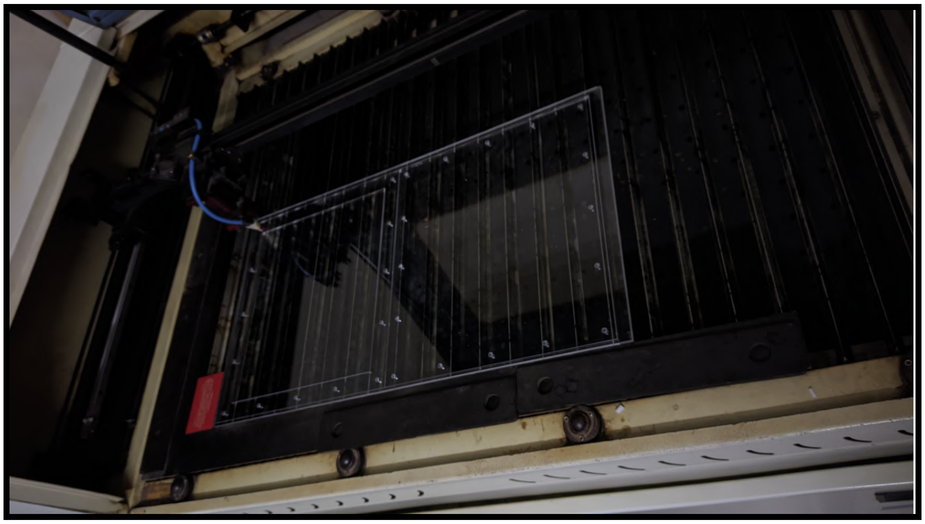


Figure 7 : Laser Cutting

Waterproofing :

The process of waterproofing the main hull of our AUV was achieved through the use of a liquid gasket. This method involves applying the gasket between the hull opening and the hull before screwing and then allowing it to cure for 30 minutes. This ensures that the hull is completely sealed and protected from any water infiltration. This method was found to be effective after multiple attempts and testing.

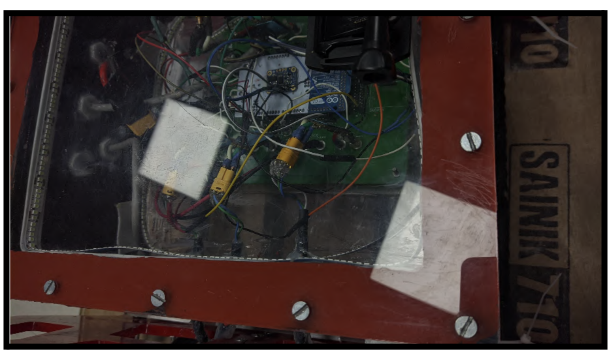


Figure 8 : Waterproof Hull

Figure 9 : Liquid Gasket

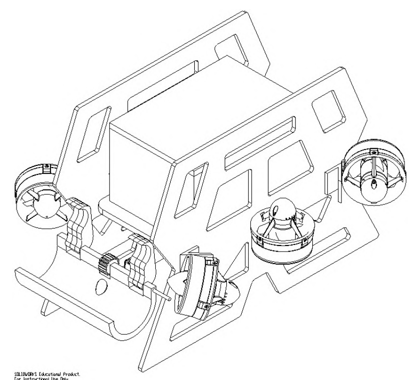
Parts of Machine :

1. **Side Frames** : Side Frame is to protect our entire internal body from the external environment. We used the technique of laser cutting to obtain our desired design.
2. **Base Plate** : It plays two roles in our body. They are important and connecting roles in our body. Important role in the sense that our whole hull will be placed on it. And the importance of the second role is that it acts like a bridge or connection to connect both the side frames. The connection between them will be through L- shaped aluminium rods that would also connect them and provide them rigidity. In our current AUV the base plate that we have designed also contains a rectangular cut-out. We have provided this space to obtain the bottom view of our AUV at the time of its manoeuvring.

3. **Main Hull** : The hull of our AUV serves as a protective enclosure for the various components such as PCBs, ESCs, Arduino, penetrators, and other electronic components. In addition to protecting these components from the harsh underwater environment, the hull also features a rectangular cut-out specifically designed for the camera vision system. To create the desired design for the hull, we utilised the laser cutting technique to cut four separate plates, which were then connected using adhesive. To secure the hull to the base plate, we utilised a transparent plate, aligning the holes of the base plate and transparent plate to facilitate easy screwing. To complete the hull design, we created a lid and an additional plate to connect the lid to the hull.
   For hassle free movement of our ROV we are using an external battery bank which would be placed on the shore.

4.1.4. Physical Properties

Volume : 12,645 cm^3/ 12.645 litre
Length : 53 cm
Height : 35 cm
Breadth : 62 cm
Weight (in air) : 12kg



The balance and stability of our underwater vehicle, Agastya 2.0, was carefully considered in the design process. Through the use of Solidworks, we determined the centre of gravity and buoyancy of the vehicle. To maintain stability, we added extra dead weight to the vehicle and incorporated buoyant foam to increase volume. We also aimed to minimise the distance between the centres of gravity and buoyancy. In addition, we ensured that the mechanical design of the vehicle is modular and can be easily disassembled and reassembled with nut-bolt connections. O-ring systems were also implemented for waterproofing. All aspects of the design, including manufacturability, functionality, and cost, were taken into consideration to ensure the success of Agastya 2.0.

4.2. Software Sub-System:

In this Remote Operated Vehicle (ROV), we have customized a Playstation 3 (PS3) controller to control all five degrees of freedom. We have utilized 15 buttons of the PS3 controller for various custom movements and adjusting the thrusters' pulse width modulation (PWM). The "Up ↑" and "Down ↓" buttons are used for forward and backward motion, respectively. The "Left ←" and "Right →" buttons are used for lateral movement in the left and right direction. The "L1" and "R1" buttons are used for depth control, where "L1" decreases the depth and "R1" increases it. The "L2" and "R2" buttons adjust the PWM of the thrusters, with "L2" decreasing the PWM and "R2" increasing it.

Underwater images can be degraded as only higher wavelengths of light can penetrate deeper into the water, causing everything to appear blue and green. This makes it challenging to distinguish between objects, so an underwater image enhancement algorithm has been integrated. We have created this algorithm last year and are continuously enhancing it through ongoing improvements and modifications. This algorithm normalizes and equalizes the image histogram while reducing the intensity of blue and green components based on their average value. A comparison of raw and enhanced images can be seen in *Figure 10 & 11*.

Figure 10 : Enhanced Image

We have utilized the Remote Operating System (ROS) to create a node that publishes the IMU, pressure sensor data, and final PWM given to the thrusters from the Arduino. This could also be achieved through serial communication, but ROS was used to speed up the process and prevent delayed outputs. To maintain stability underwater and ensure the ROV moves according to the input, we have implemented PID control.

Figure 11 : Enhanced Image comparison

PID Control: BNO055 IMU is used to get the orientation (yaw, pitch, and roll) of ROV and BAR30 pressure sensor to calculate its depth. Initially when the ROV is powered on it is kept aligned to the pool and the yaw, pitch, and roll angles are stored in a variable as a set point.

This setpoint is then compared to readings taken rapidly and then the error is calculated in orientation as the difference between current angles and the set point. This error is multiplied by the proportional constant ‘kp’ that is tuned during testing. For the differential part previous error is compared with the current error and divided by the time difference between two readings to get change in error with time. This is then multiplied with the differential constant ‘kd’. A condition is kept such that the integral part comes into action only when the error is less than plus or minus three degrees for fine-tuning. Such PID is also applied for depth control.

4.3. Electrical Sub-System:

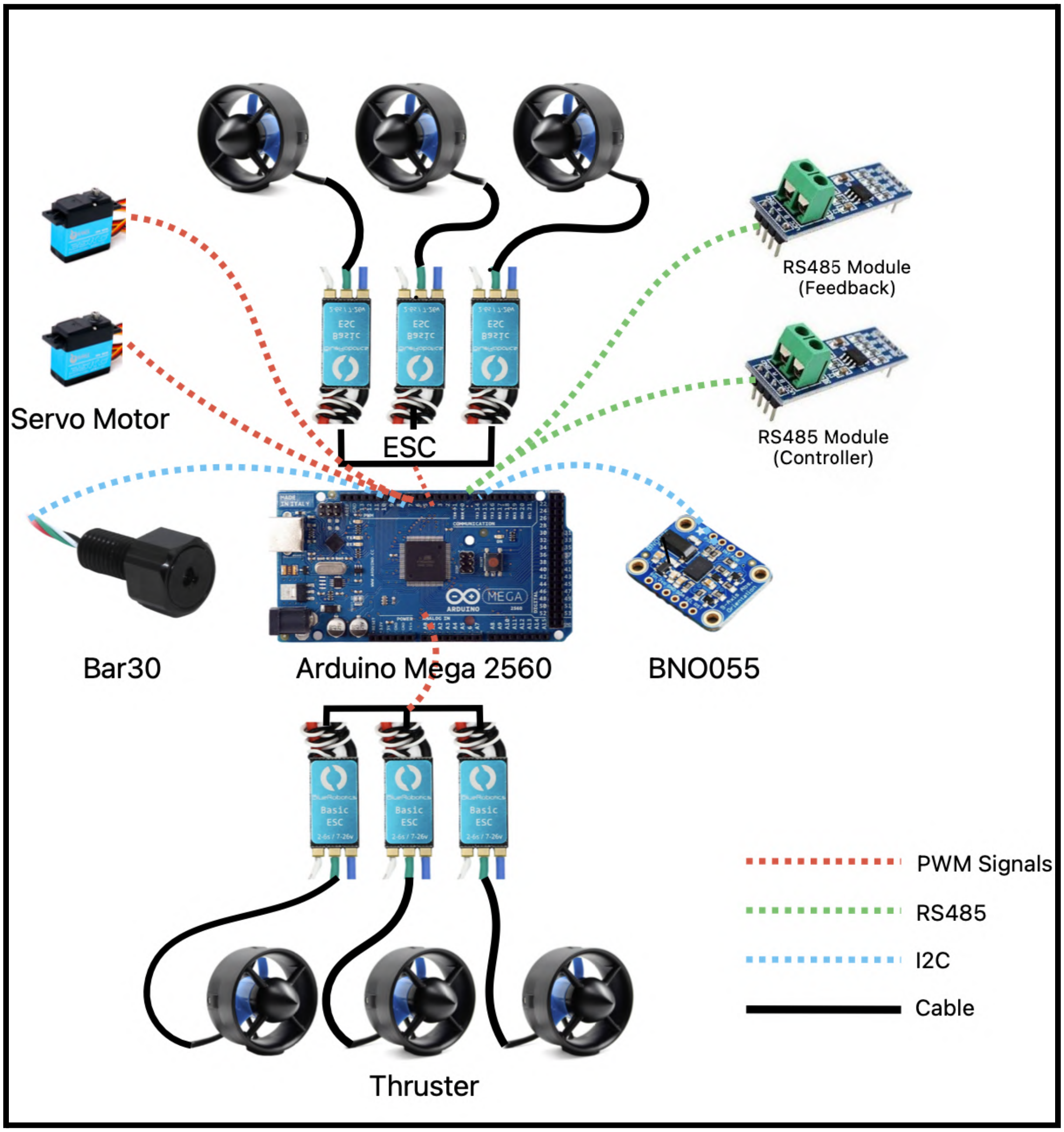


Figure 12 : Arduino Connections Diagram

To control and power the thrusters, a PCB is designed on which all the six ESCs are mounted along with an Arduino Mega Microcontroller as shown in figure 7. These ESCs are used to control the thrusters. Two four-celled, 10000 mAh 14.8V Li-Po batteries are connected to PCB, where each battery provides electric power to four thrusters. Another similar battery provides power to the Nvidia Processor TX2 through a buck-boost converter at 10V and 1.5A.

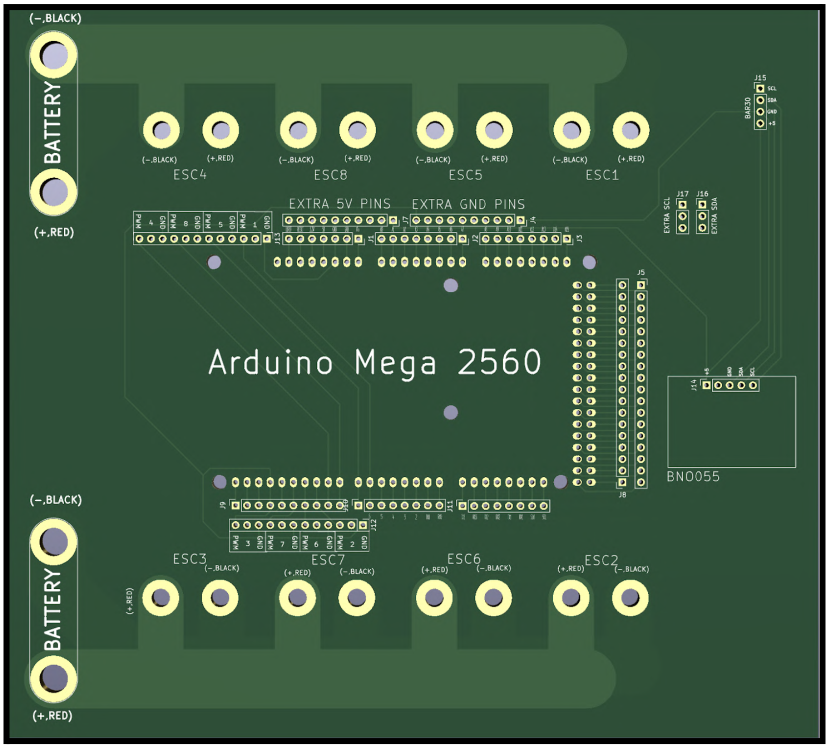


Figure 13 : PCB Design

RS485 : The innovation which we have done this time is bringing in a new communication protocol which is RS485, which basically works on the differential signalling method which saves a lot of time in transmission of the signals due to which we were able to reduce the delay experienced while controlling the ROV from the control station. We have used a half duplex transmission system here due to which we would be able to transmit or receive signals one at a time. And due to the use of this protocol long distance transmission of signals can be done easily.

Sensors:

BNO055 Inertial Measurement Unit (IMU): BNO055 IMU is used that have a 3 axis magnetometer, 3 axis gyroscope, and a 3 axis accelerometer, and also a temperature sensor. It gives the following data outputs:

- Absolute orientation in the Euler vector at 100Hz.
- Absolute orientation in quaternion at 100Hz.
- Angular velocity vector: Three axes angular velocity in rad/s.
- Acceleration vector: three-axis acceleration in m/s^2, gravitational acceleration + linear acceleration.
- Magnetic field strength vector in microtesla at 20Hz
- Temperature (1Hz)
- Gravity vector at 100Hz

- For controlling ROV, Absolute orientation in Euler angles and the temperature data is used.

BAR30 (Pressure Sensor): BAR30 High Resolution 300m Depth/Pressure Sensor is used which is a high-measure pressure sensor with a 0.2mbar resolution that can measure up to 300m depth. It has Measurement Specialties MS5837-30BA and communicates over I2C on a 3.3V I2C.

Camera: The ROV is equipped with a basic IP camera, which is capable of transmitting data over a distance of 50 meters. To power the camera, a Power over Ethernet (POE) switch is utilized, providing a convenient and streamlined solution via a single Ethernet cable.

5. Experimental Results

Software: To ensure optimal performance and stability of the Remote Operated Vehicle (ROV), a thorough and precise calibration process was undertaken. This included writing Arduino code to control the PWM values for the thrusters, as well as fine-tuning the PID algorithm according. Integrating the data from the BNO055 and Bar30 sensors further optimized the PID control by assigning a setpoint to the system. In the event of any disturbances, the ROV will automatically return to its original orientation (set-point) thanks to the PID control. To monitor the effectiveness of the PWM values being applied to the thrusters and to provide a visual representation, additional monitoring measures were implemented.

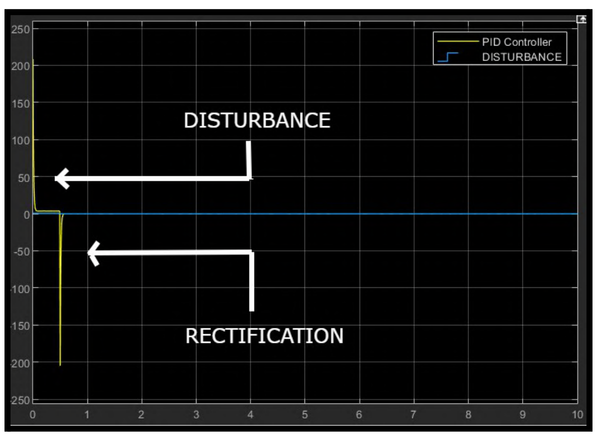


Figure 14 : PID Controller and Disturbance

Waterproofing and durability: To ensure the integrity of the Remote Operated Vehicle (ROV), ensuring its hull was completely waterproof was the top priority. A significant amount of time was dedicated to perfecting the waterproofing process, which was finally achieved through the use of a liquid gasket. This gasket acted as a mechanical seal, providing a complete seal when the lid was closed. To confirm the success of the waterproofing, the ROV was subjected to a comprehensive test. The ROV was placed underwater at a depth of 2 meters for 24 hours to assess its ability to withstand pressure.

6. Procurement Report

Component	Vendor	Model	Specs	Cost (in Rs)
Frame	Designed In-House	Acrylic(8mm)	Dimensions: 70cm X 64cm X 45cm	3000
Main Hull	Designed In-House	Acrylic(8mm)	Dimensions: 32cm X 25cm X 25cm	1500
Waterproof Connectors	Imported	Plastic	GP7 standard size of waterproof connector	600
Motor Control	Blue Robotics	ESC basic R3	-	14000*
Actuators	Blue robotics	T100	BLDC	120000*
	Robokits	Servo 20kg cm	Waterproof for 20N	7200
Battery	Orange	LiPo 4S	16.8V, 10000 mAh	24000
CPU & GPU	Nvidia	Jetson TX2	Memory: 4 GB 128-bit LPDDR4 51.2 GB/s Storage: 16 GB eMMC 5.1	60000*
Programming Languages	–	C++, Python,ROS	–	–
Inertial Measurement Unit (IMU)	Adafruit	BNO055	It is acceleration Sensor from Adafruit having 9-DOF Absolute Orientation IMU Fusion Breakout	4400*
Pressure Sensor	Ocean Robotix	Bar30	High-Resolution 300m Pressure/Depth sensor with 2mm resolution	7000
Kill Switch	ABB	High pressure waterproof Switch	Can handle upto 5A and 120V AC and 26V DC. Can be used till 1000m depth	400

Component	Vendor	Model	Specs	Cost (in Rs)
Camera	DAHUA	IP Camera	2MP	6480
Manipulator	3D printed and designed In-House	Gripper	3D printed and Acrylic	2000
Communication Module	FlyRobo	RS485 Module	MAX485 chip	49

**These items were reused from our previous vehicle.*

7. Acknowledgements

We would like to thank the Institute of Technology, Nirma University for providing all the necessary resources and also the faculty mentors, Dr. Mihir Chauhan and Dr. Akash Mecwan for their valuable insights and guidance in making of this ROV. Furthermore, we would like to express our sincere gratitude to our sponsors SolidWorks and Altium for their invaluable software support that has made this project possible. We would also like to acknowledge the competition organisers who have put in a tremendous amount of effort to make this competition a reality. Their dedication and hard work have created a platform for students to showcase their skills and develop new technologies.