TECHNICAL REPORT

TEAM NIRA, AUV SOCIETY

IIITDM KACNCHEEPURAM, INDIA

AUV SOCIETY IIITDM KANCHEEPURAM

MATE ROV COMPETITION

IIITD&M Kancheepuram

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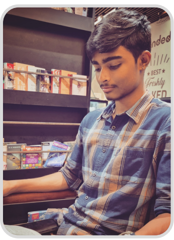
INTRODUCTION

Abstract

- We are a team of 12 interdisciplinary undergrads working to build an autonomous underwater vehicle for participating in various international underwater robotics competitions related to ROVs, AUVs and WAMVs.
- We have participated and qualified in SAUVC 2018, 2019, 2020 and 2022.
- We have also qualified to the Internationals for the MATE-ROV World Championship 2022 (PIONEER).
- We have also made three publications related to Underwater Robotics from our organization.
- We want to bind together our theoretical knowledge and put it into an underwater vehicle that can go and explore the vast seas.

OUR TEAM

Venkata Madhav
Software Team,
CEO



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Software Team,
Pilot

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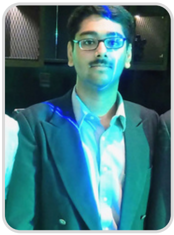
SoftwareTeam
Operations

R Soorya
Software Team
Vision Control

Abhishek M J
Software Team
Vision Control

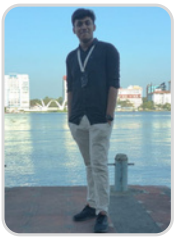


M. Nithin
Electronics Team
Systems

K S Raahul
Electronics Team
CTO

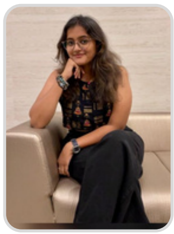
Srikrishnan S
Mechanical Team
CFO

Vishal A S
Mechanical Team
R&D



Raghavendran S
Mechanical Team
R&D

Vijay Krishna R V
Mechanical Team
Publicity Lead



Vaishnavi M
Mechanical Team
Testing

DESIGN RATIONALE

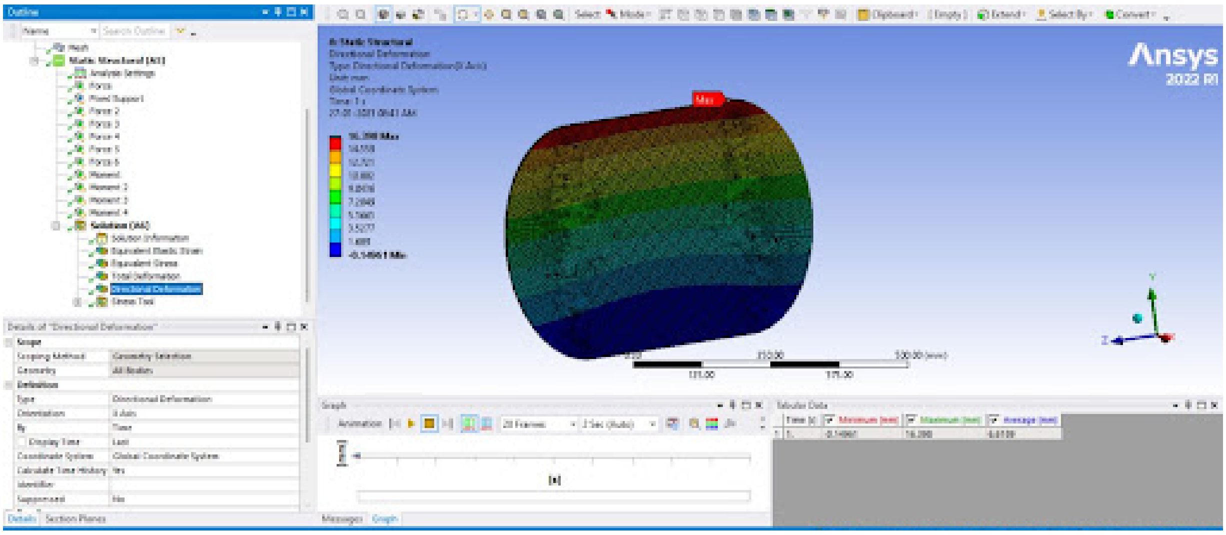
During the design evolution process of our underwater vehicle, we focused on achieving a design that fulfilled the task requirements while also considering factors such as **modularity, stability, buoyancy control, and ease of maintenance**. The design evolved through a collaborative effort of our engineers, encompassing various aspects of the vehicle's structure, propulsion system, and pneumatics. Let's explore the design evolution in more detail.

Frame Structure

The frame structure of our underwater vehicle consists of top and side frames, as well as a bottom frame, each playing a crucial role in maintaining structural integrity, stability, and supporting various components.

The top frames are constructed using 4mm thick aluminum 6061 racks, which have been carefully designed and analyzed through Finite Element Analysis (FEA). The FEA simulations helped determine the optimal thickness to ensure the frames possess sufficient strength and stiffness. These top frames not only hold the side frames together but also house one of the thrusters, contributing to heave, roll, and pitch motions. They also serve as a connection point for the tether, facilitating data and power transmission.

The side frames are constructed from 12mm thick HDPE Sheets . HDPE was chosen for their Lightweight , Buoyancy Properties , Impact and corrosion Resistance and Ease of Fabrication . Their elliptical shape, determined through previous design iterations such as hexagonal shapes, enhances stability, modularity, and the streamlined design of the vehicle.The flexibility provided by HDPE also acts a shock absorbent and at the same time providing necessary rigidity.

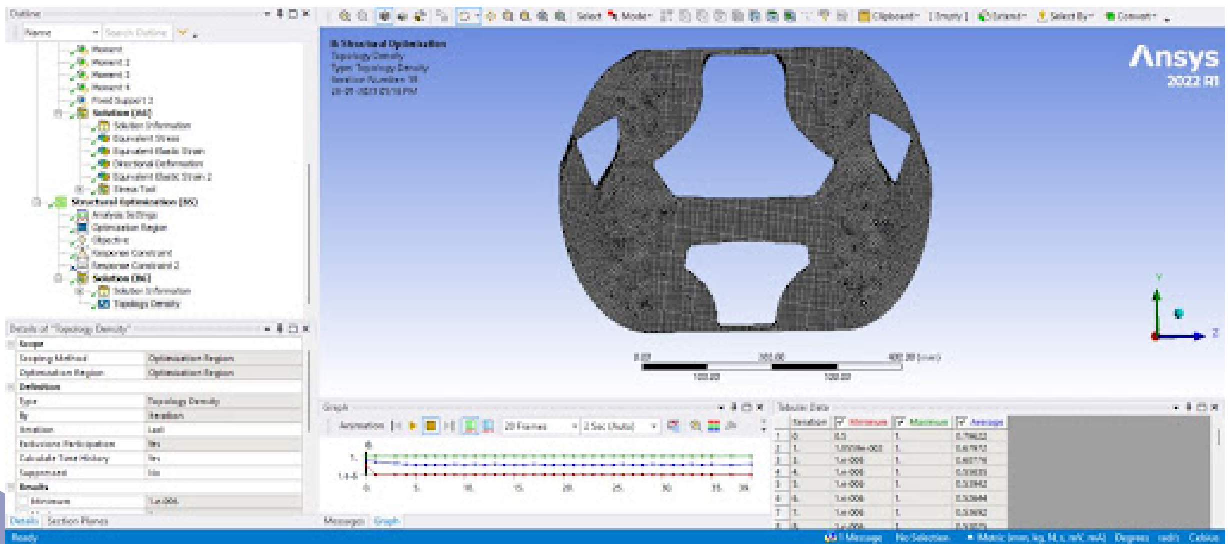


Finite Element Analysis (FEA)

We conducted FEA on the side frame to evaluate its structural integrity and determine areas of potential stress concentration. This analysis allowed us to identify critical regions that required reinforcement or modification.

Topology Optimization

After the FEA, we performed topology optimization to identify areas of the frame where material could be strategically removed without compromising its strength. This optimization process involved finding the ideal distribution of material to achieve the desired mass reduction while maintaining structural stability.



Custom Cutouts

Based on the results of topology optimization, we implemented custom cutouts in the side frame design. These cutouts were strategically placed to remove excess material and achieve the desired weight reduction. We considered factors such as tether management and water flow for the thrusters when determining the placement and shape of the cutouts.

Structural Integrity and Performance

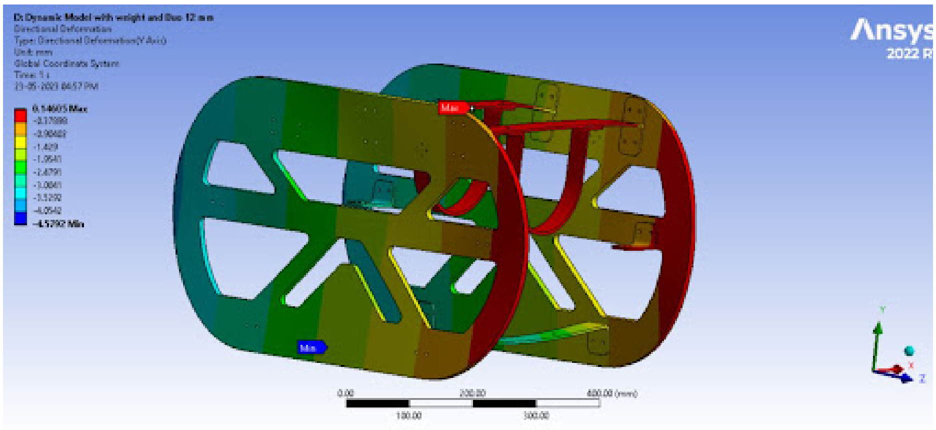
Despite the material removal through topology optimization and cutouts, we ensured that the side frame retained its structural integrity and met the necessary strength requirements. The design modifications were carefully implemented to maintain the overall robustness and reliability of the robot.

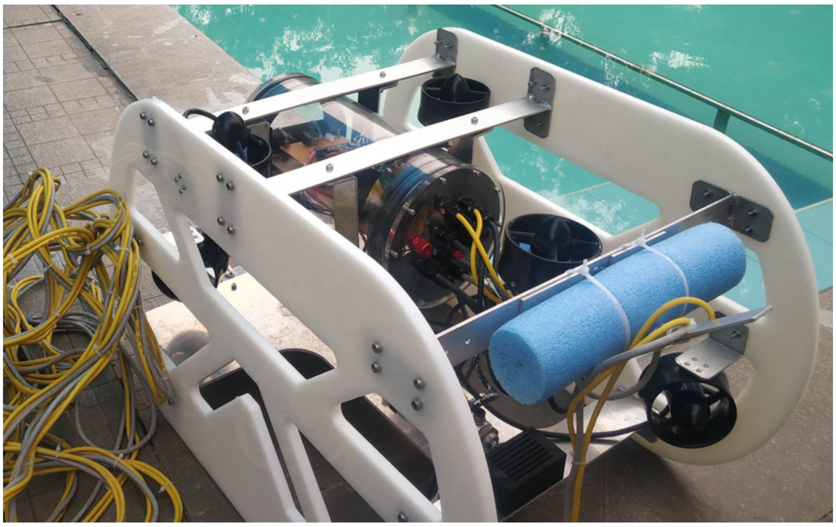
Enhanced Hydrodynamics

The chosen elliptical oval shape, along with the optimized cutouts, helped improve water flow around the side frame. This enhanced hydrodynamics reduced drag and turbulence, enabling smoother movement and better overall performance in underwater environments.

Weight Reduction

The combination of topology optimization and custom cutouts allowed us to achieve the desired mass reduction while still maintaining the necessary structural strength. The reduced weight of the side frame contributed to improved maneuverability and increased payload capacity for our underwater robot.





The bottom frame, equally subjected to FEA analysis, plays a crucial role in maintaining stability and supporting the overall structure. Constructed from aluminum 6061 grade, it serves as a platform to hold payloads, tools, and important mechanisms such as the gripper and its pneumatic actuator. The bottom frame is designed to prevent excessive movement or wobbling, ensuring the vehicle remains steady during operation.

Aluminium 6061 was chosen for its high resistance to corrosion, strength-to-weight ratio and its ease of availability.

Through the careful design and analysis of the frame structure, we have achieved a balance between stability, strength, modularity, and weight reduction. The top frames, side frames, and bottom frames work together to provide a robust and reliable foundation for the underwater vehicle, allowing for efficient integration of components and ensuring optimal performance in various underwater operations.

ELECTRICAL DESIGN

Our electrical design is centered on being modular, simple to build & debug and compact at the same time. We used standard components and connectors wherever necessary for ensuring safety and quality. The design is modular - divided into low power, high power and converter sections. This makes it easy to debug and maintain.

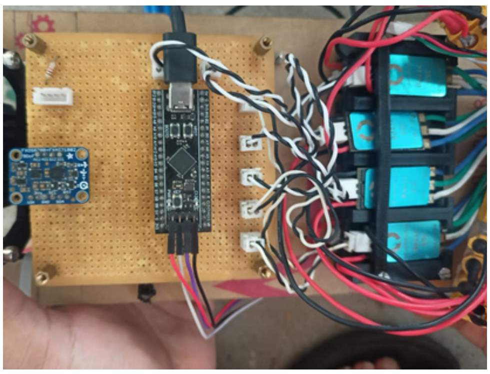
Power Management

The ROV is powered by a 48VDC Power Supply, which goes through the tether into the ROV through an XT90 Connector. It is then passed through two 48V to 12V 20A DC-DC Converters, which power the ESCs, Lumen Lights and give power to the NVIDIA Jetson Nano, OAK-D Camera and the Perfboard Circuit through two 12V-5V 4A DC-DC Converters. There are 7 ESCs which are fixed on ESC Holders and are powered by 2 power hubs consisting of XT60 Connectors for cable management.

Sensors

We have used FXAS21002/FXOS8700Q breakout module , which is a 9 axis sensor with 3 axis accelerometer , gyroscope and magnetometer , to determine the rotational angles We have implemented Madgwicks Algorithm to fuse the sensor data and get the roll , pitch and yaw angles. The Blue Robotics Bar02 digital pressure sensor is used for determining the depth of the ROV from the surface of the water. The Bar02 pressure sensor has a resolution of about 0.16mm and can measure up to 2bar (i.e 10m).

Perf Board Design



The use of perf boards greatly reduced the use of wires for connections and made things look neat. The circuit consists of the MCU communicating with the depth and the IMU Sensor through an I2C Bus. It is also connected to the PWM Inputs of the ESCs through JST Connectors. The MCU also communicates with the NVIDIA Jetson Nano through Serial via USB. It can also be programmed through the Jetson via the JTAG.

ELECTRICAL DESIGN

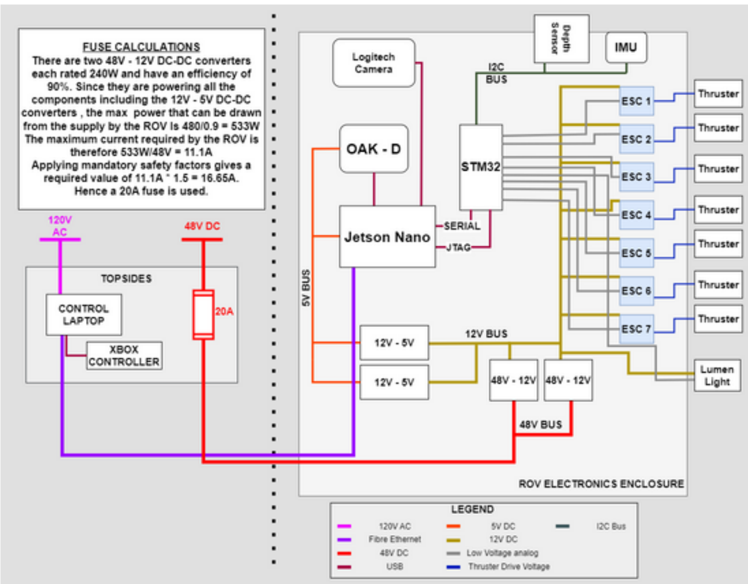
Power Consumption

component	Max current(A)	Voltage(V)	Max power / component	Qty	Max Power(W)
T200	5.1	12	61.2	3	183.6
T100	5.1	12	61.2	4	244.8
Jetson Nano	3.5	5	17.5	1	17.5
Oak D	3.5	5	17.5	1	17.5
Lumen	1.25	12	15	1	15
STM32				1	0
IMU				1	
Depth Sensor				1	
				Total Power (W)	478.4

The above table gives data about the maximum power each electronic component used on the ROV.
The total max power the ROV requires is 478W. The efficiency of the 48V-12V power supply is 90%, so input power is 478/0.9 = 531.11W, so the current is 11.06A.
Multiplying with the safety factor, we get 11.06*1.5 = 16.59A. **Hence the fuse used is 20A.**

Tether

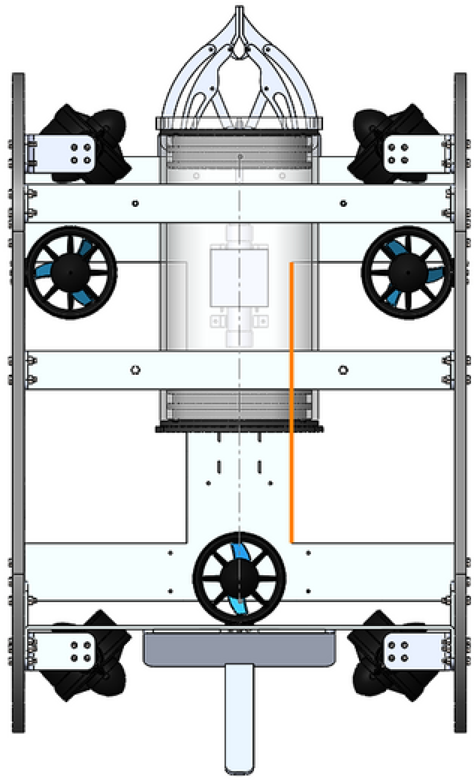
The tether used for the ROV is 25m long, more than enough for travelling through the given area. It consists of two 10AWG Cables for power, one CAT-6 cable for communication with the Jetson Nano and 4 Pneumatic Cables for controlling 2 pistons.
This much wire has to be managed properly for safety and ease of use. The lump of tether which is extra is wound around a cylinder for cable management. Both ends of the tether (on ROV and on control system side) have been strain relieved to ensure safety. Special focus has been given for tether management.



MECHANICAL DESIGN

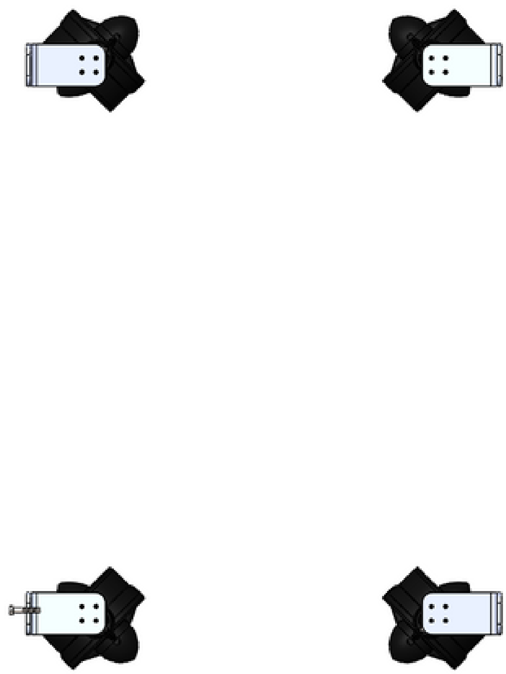
Propulsion

Careful consideration was given to the tradeoffs between stability and control in the propulsion system of our underwater vehicle. The positioning of the thrusters played a crucial role in achieving optimal performance while avoiding excessive strain on the structure. By analyzing system dynamics and conducting simulations, we evaluated the effects of different thruster placements.



To strike a balance between stability and control, the T200 thrusters responsible for heave, roll, and pitch motions were strategically located at the top half of the vehicle. Their placement was optimized to ensure that the net force passed through the center of mass, maximizing stability. For sway, surge, and yaw motions, the four T100 thrusters were positioned at the bottom half of the vehicle in a vectored configuration, rotated at an angle of 45 degrees to the z-axis. This arrangement allowed for precise control over lateral and rotational movements.

Through careful thruster placement, we achieved a balance between thrust, control, and structural integrity. The positions of the center of buoyancy and center of mass were iteratively adjusted to improve stability, minimizing tipping and rotation. CAD models assisted in tracking and analyzing these key points, enabling informed design modifications for enhanced stability underwater.



vectored configuration

Buoyancy

IIn the design of our underwater vehicle, achieving appropriate buoyancy is crucial. The vehicle was engineered to be slightly positively buoyant, meaning the buoyant force exceeds its weight, allowing it to float in the water. This design offers advantages such as enhanced safety and recoverability, as the vehicle naturally rises to the surface in the event of failure or power loss. Adjusting buoyancy is also more manageable, enabling fine-tuning for optimal performance and stability. Slight positive buoyancy improves maneuverability, reduces energy consumption, and extends mission durations. Overall, our vehicle's buoyancy design prioritizes safety, ease of management, and efficient operation.

Pneumatics System:

To enable the operation of certain tools and mechanisms, we incorporated a pneumatics system into the design of our underwater vehicle. The bottom frame, constructed from aluminum 6061 grade, played a crucial role in supporting the vehicle and preventing excessive movement or wobbling. It housed various payloads and tools, including a gripper and its pneumatic actuator. The pneumatics system provided the necessary force to operate the gripper, enabling the vehicle to perform tasks such as the "red bellies fries" task.

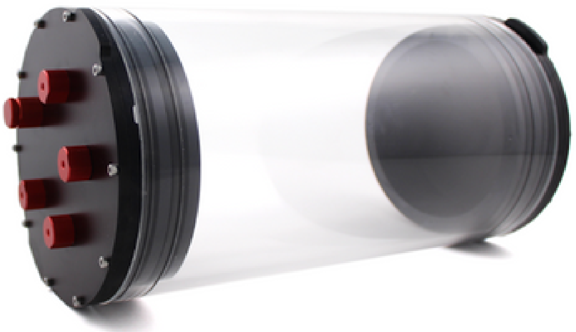
By incorporating these design choices and allowing for collaborative input from our engineering team, we successfully evolved the initial concept into a robust and functional underwater vehicle. The design considered factors such as frame structure, propulsion, and pneumatics to ensure the vehicle's stability, maneuverability, and versatility in various underwater operations.

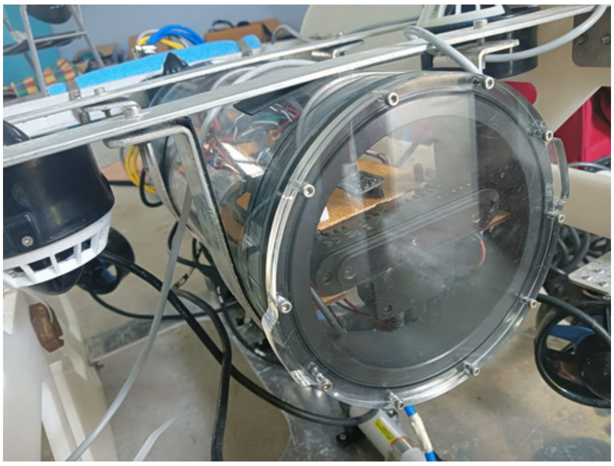
Hull and Penetrators

The hull of our underwater vehicle serves as a waterproof enclosure, protecting electronic components from water seepage and maintaining functionality. After evaluating various geometries, we chose a cylindrical hull due to manufacturing constraints. We selected the Blue Robotics 6" Watertight Enclosure set for its proven reliability and precise waterproofing capabilities. The acrylic material used in the cylindrical hull provides a sturdy and watertight enclosure, accommodating the electronics while addressing overheating concerns. The transparency of the acrylic hull allows for easy detection of water seepage and facilitates maintenance and troubleshooting, although it lacks the thermal conductivity of aluminum hulls. Overall, our choice of a cylindrical acrylic hull with the Blue Robotics enclosure ensures effective waterproofing and component protection in underwater environments.

It is worth noting that we chose acrylic hulls for our underwater vehicle due to their transparency, which allows for easy detection of any potential water seepage. This transparency enables visual inspection of the interior components, facilitating maintenance and troubleshooting processes. However, it is important to acknowledge that by opting for acrylic hulls, we had to sacrifice the thermally conducting properties offered by aluminum hulls.

To ensure waterproofing and efficient cable management, we use Blue Robotics penetrators in our underwater vehicle. These penetrators create sealed passages through the hull, allowing cables to pass through while maintaining a watertight enclosure. They provide a reliable and reusable solution for preventing water seepage and protecting internal components. By utilizing penetrators, we achieve effective waterproofing, durability, and flexibility in cable routing and future upgrades..



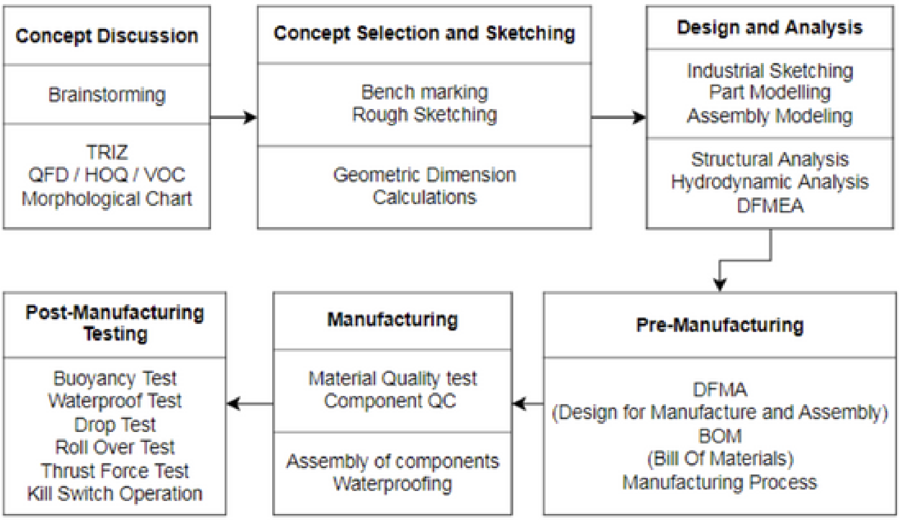


DESIGN APPROACH

As Design Engineers, we have used a holistic approach to balance out different aspects of the vehicle and to achieve an optimal solution.

Different methods like benchmarking, morphological charts, etc... have been used traditionally in the process of designing.

Vital Decisions like open/closed frame, material selection, Cylindrical/Cuboidal hull, gripper/manipulator and end effector design etc.. were made through the critical analysis we follow.

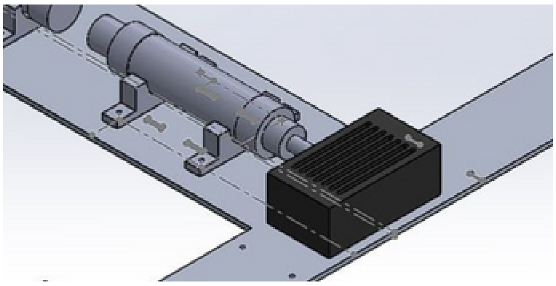


Special Features

- High payload, High speed
- High adaptability to various scenarios
- Custom designed HDPE frame
- Lumen Lights
- Frame designed to act as lifting handle
- Easily interchangeable thruster configuration
- High Quality Camera vision - OAKD Series 3
- Secondary camera to manage gripper usage
- Modular ROS based Control System
- Symmetrical body, 6 degrees of Freedom
- Additional Hull Space for future technical expansion and improvement
- Hybrid - Can be modified to work as both ROV & AUV.

Payload Tools:

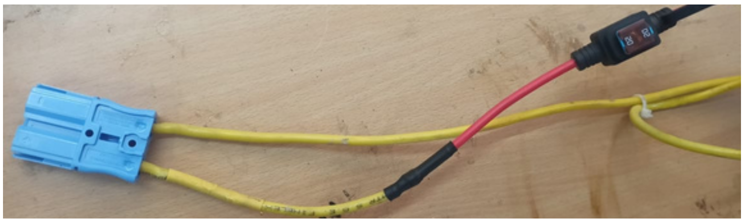
The design of the 3D printed box for holding the "redbelly fries" was carefully engineered to reduce complexities in other systems. By incorporating a unique mechanism similar to an inverted matchbox, we achieved controlled and efficient dispensing of the fries during the task execution. Additionally, the box's robust construction and secure enclosure eliminated the need for complex holding mechanisms. This streamlined approach simplified the overall design and operation of the payload system, resulting in enhanced reliability and performance.



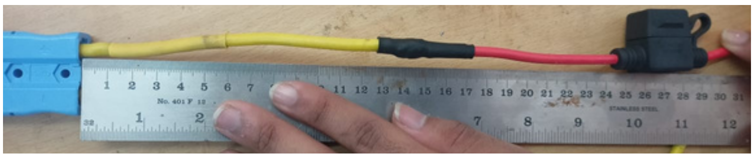
SAFETY

Electrical Safety Features

1. Use of Anderson SBS50 Powerpole Connectors.
2. A Standard Littelfuse of appropriate rating is fitted within 30cm of the Anderson Connector
3. Standard XT and MT connectors are used to prevent any wrong wiring and allow easy debugging.
4. The Float has an appropriate fuse fitted within 5cm of power source.



Use of Anderson SBS50 Powerpole Connectors



20A LittelFuse is within 30cm of the Anderson Connector

SAFETY & TROUBLESHOOTING

Electrical Safety Instructions during work

1. Take utmost precaution while handling electronics near water, always operate with dry hands.
2. Soldering iron should be used with proper stand and to be cleaned with flux after use.
3. When handling sensitive electronics, always remove footwear to prevent ESD.
4. When handling high power electronics, always wear rubber slippers.

Troubleshooting Electronics

1. First check if connections are made correctly.
2. Next, check if power is going to the device.
3. If it doesn't work, we need to check the code/component which is responsible for giving the device the signal.
4. If this is also correct, we need to check whether the executed commands are sending the appropriate signals.
5. After this point, we need to check if something is wrong with the device.

General Safety

AUV Society IIITDM is committed to employee safety. The company meets or surpasses all safety guidelines set forth by MATE (Marine Advanced Technology Education) and has a proven track record of fulfilling MATE's safety requirements. Employees strictly adhere to the company's safety policies and undergo comprehensive training procedures to prevent accidents and injuries.

To ensure a safe working environment, all employees are required to complete safety training. This training covers the proper usage of standard machining tools and soldering stations. Employees are also required to wear safety glasses and safety gloves when working in conditions that could potentially result in eye or hand injuries.

In addition to general safety training, specific safety training is provided to deck crew employees. This specialized training ensures that they adhere to the operations and safety checklist, maintaining the highest level of safety standards throughout all operational activities.

AUV Society IIITDM regularly reviews its safety procedures, seeks employee feedback, and identifies opportunities for improvement. By fostering a culture of safety consciousness, the company strives to create a workplace environment where every employee actively contributes to accident prevention and upholds the highest safety standards.

SAFETY

Safety Rationale

Ensuring the safety of personnel, equipment, and operations is paramount in our underwater robotics project. Our safety measures include:

Personnel Safety:

- Comprehensive training and certification on safety protocols.
- Provision of personal protective equipment (PPE) such as safety glasses, gloves, and appropriate footwear.
- Availability of first aid kits and established communication and emergency procedures.

Equipment Safety:

- Regular inspections to detect wear, damage, or malfunction.
- Prompt maintenance and calibration for optimal performance.
- Electrical safety measures, including insulation were used
- Proper equipment handling techniques to prevent strain or injuries.

Regular Safety Reviews:

- Periodic safety reviews to evaluate effectiveness and identify areas for improvement.
- Encouragement of feedback and reporting of safety concerns or incidents.
- By implementing these safety measures, we create a secure working environment, promote accident prevention, and ensure the well-being of our team members and equipment.

Operational Safety:

- Conducting comprehensive risk assessments before each operational activity.
- Implementation of safety barriers and warning signs.
- Emergency stop mechanisms for immediate halting of operations
- Development and adherence to operational protocols.

CRITICAL ANALYSIS

Testing Methodology , Troubleshooting , Prototyping

Objective:

The mechanical testing phase aimed to assess the structural integrity, durability, and functionality of our underwater vehicle. Through comprehensive testing, we ensured that all mechanical components, including the pneumatically actuated gripper, performed optimally in the underwater environment. Additionally, special attention was given to addressing waterproofing issues to maintain the vehicle's functionality and protect its internal components.

Test Setup and Procedures:

Testing Environment: Mechanical testing was conducted in a controlled swimming pool environment, simulating realistic underwater conditions.

- Frame and Structure: The structural integrity and stability of the vehicle's frame were evaluated to withstand water pressure and maintain the desired configuration during operation.
- Pneumatically Actuated Gripper: The performance and reliability of the gripper, operated using a pneumatic system with a compressor, were evaluated for its gripping strength, control, and responsiveness.

Test Results and Analysis:

- Frame and Structure: The vehicle's frame exhibited excellent structural integrity and stability during testing, withstanding water pressure and maintaining its shape without any deformations or failures.
- Pneumatically Actuated Gripper: The pneumatically actuated gripper performed effectively, providing a strong grip on objects and reliable control. The gripper responded promptly to commands, facilitating object manipulation tasks with ease.

Waterproofing Measures:

To address waterproofing issues and ensure the vehicle's functionality and longevity, the following measures were implemented:

- Sealing Mechanisms: Standard O-Ring seals from Blue Robotics were used to create watertight compartments for electronic components, preventing water ingress.
- Cable Penetrations: Wetlink Penetrators securely sealed cable penetrations, eliminating gaps and ensuring reliable connections without compromising internal component integrity.
- Pressure Testing: The vehicle underwent successful pressure testing to simulate deep-water conditions, revealing no water seepage issues.

Challenges and Lessons Learned:

Waterproofing Optimization: Through rigorous testing and iteration, we successfully addressed waterproofing issues, ensuring the vehicle's robustness in underwater environments.
Design Iterations: Regular evaluation and modification improved waterproofing measures and mechanical component functionality in demanding underwater conditions.
Manufacturing Challenges: Achieving precise dimensions for the Hull holder/clamp was challenging due to the unavailability of a standard-sized die. Fabricating a wooden die and TIG welding end effectors of Small Dimensions presented additional difficulties.

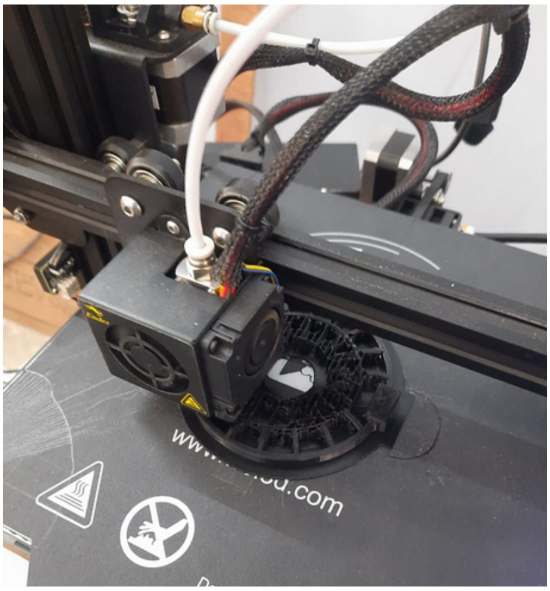
Prototyping and Testing to Evaluate Design Options:

Importance of Prototyping and Testing:

Prototyping and testing played a crucial role in our design process, allowing us to explore different design options and assess their feasibility, functionality, and performance. By employing prototyping and testing, we were able to identify potential issues early on and make informed design decisions.

Prototyping Methods:

To explore different gripper designs, we utilized 3D printing as our initial prototyping method. This allowed us to quickly iterate through various iterations and test different geometries, sizes, and mechanisms. We evaluated the 3D printed gripper prototypes for their gripping strength, control, and compatibility with the underwater environment.

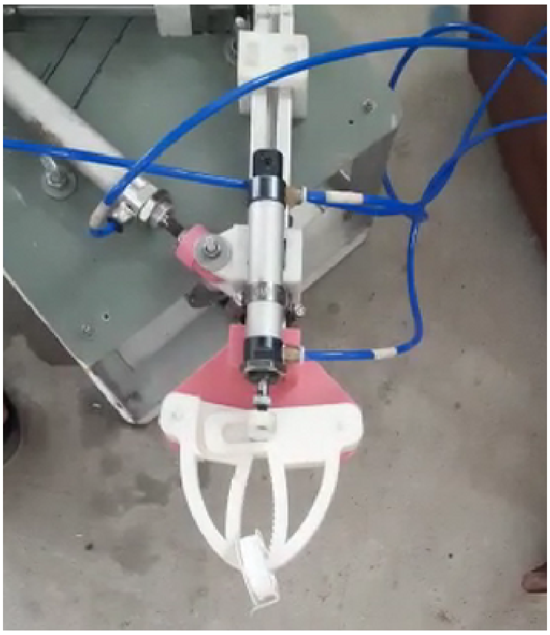


Evaluation Criteria:

Our evaluation criteria for the gripper design included gripping force, reliability, maneuverability, and ease of use. We also considered factors such as material availability, manufacturing feasibility, and cost-effectiveness to ensure a practical and efficient solution.

Prototyping and Testing Process:

Before proceeding to test our concepts with bulky compressors, we initially conducted experiments on the 3D printed gripper using servo motor actuation. This allowed us to evaluate the functionality and effectiveness of the gripper in a controlled manner, providing valuable insights before scaling up to larger-scale compressors for comprehensive proof testing.



3D Printed Gripper:

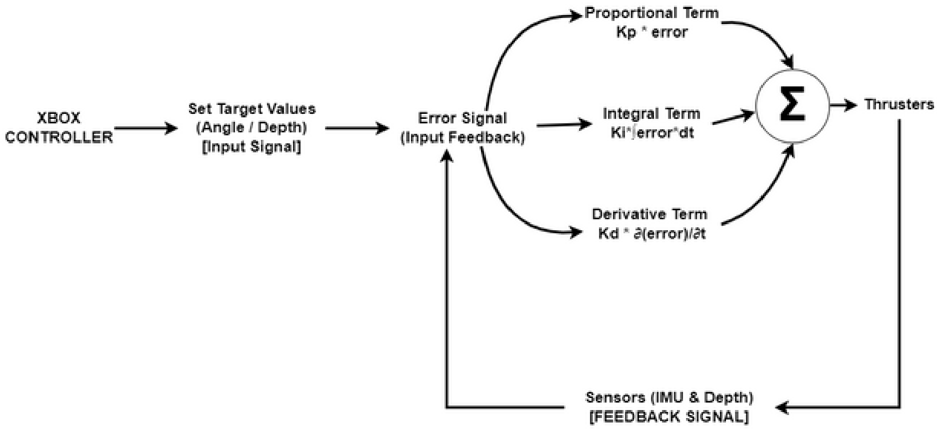
We initially prototyped the gripper using 3D printing. This allowed us to quickly validate our design concept and test its functionality. We performed tests to assess the gripping force, gripping range, and the gripper's ability to securely hold objects underwater. The 3D printed gripper prototypes exhibited promising gripping capabilities and adequate functionality. However, we identified limitations in terms of long-term durability and gripping force

Aluminum Manufactured Gripper:

Based on the insights gained from the 3D printed prototypes, we transitioned to manufacturing the final gripper using aluminum. This allowed us to achieve higher strength and durability compared to the 3D printed version. The aluminum gripper provided significant improvements in terms of gripping force, robustness, and reliability. It demonstrated superior performance and addressed the limitations observed in the 3D printed prototypes.

In summary, the 3D printed gripper was a valuable tool for prototyping and testing the design concept. However, the aluminum gripper was the better choice for the final product due to its superior strength, durability, and reliability.

CONTROL SYSTEM DESIGN



Closed Loop PID Control

Open Loop Control

Vision & Navigation:

The video feed from the **Oak-D Series-3** camera is transferred using RTSP protocol, which stands for **Real Time Streaming Protocol**, the data from the camera is taken, encoded into H.265 packets using the onboard H.265 encoder on the Oak-D, those packets are broadcasted using an RTSP server on the Jetson Nano, and the received on the Control Device (Laptop) using an RTSP Client. With the help of this camera data, we can perform navigation and also various autonomous tasks required for the Product Demonstration.

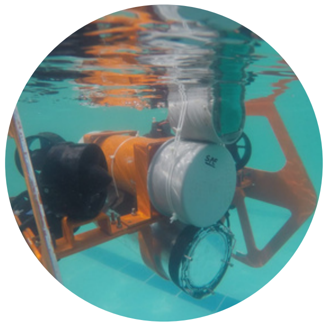
Object Detection and Obstacle Avoidance is one of the key element focused with the help of this camera.

EVOLUTION IN DESIGN

AUV 1.0 (2018)

AUV 2.0 (2019)

ROV Cholan (2022)



AUV 3.0 (2022)

To streamline the project, we repurposed electronic wires and pneumatic equipment from our inventory and previous vehicle, including cylinders, valves, connectors, and tubing. We also utilized available thrusters, including 4 Blue Robotics T100 and 3 T200 thrusters. Pneumatic power was chosen for the gripper to overcome waterproofing challenges of electronic actuators. We employed our existing pneumatic kit, ensuring both gripper functionality and waterproofing.

Compared to the previous ROV, our new vehicle features a strain relief provision for improved stability and a 6" hull to accommodate electronic components efficiently. We increased the degrees of freedom from 4 to 6 to enhance maneuverability, while simplifying the design for easier assembly and disassembly, which is not the case with our previous vehicle. The gripper design was enhanced by incorporating additional joints to maintain parallel end effectors at all times. Aluminum material was chosen over PLA for reduced size, improved durability, and longevity. Waterproofing issues were addressed by implementing Blue Robotics Wetlink penetrators, previously we had issues with potting type penetrators..

To ensure cost-effectiveness and precision, we purchased off-the-shelf components like a 6-inch hull, end flanges, acrylic end caps, penetrators, O-rings, and standard fasteners. Custom manufacturing these components to the required precision would have been expensive. We outsourced the manufacturing of the mechanical frame for high accuracy, while in-house manufacturing of the gripper allowed us to maintain control over its design and functionality.

COMPONENTS USED

Component Name & Qty	Product Name	Price(INR)	Type	Purpose
IMU Sensor (x1)	Adafruit Precision NXP 9-DOF Breakout Board - FXOS8700 + FXAS21002	1300	Reused	To calculate the Euler angles X,Y,Z for Control System
Depth Sensor (x1)	BlueRobotics Bar02 Ultra High-Resolution 10 m Depth/Pressure Sensor	6300	Purchased	To calculate depth for Control System
ESCs (x7)	BlueRobotics Basic ESC	21,000 (3000 Per piece)	Reused (Purchased 3 for spares)	For controlling speed and direction of thrusters
Thrusters (x7)	BlueRobotics T200 Thruster (x3) and T100 Thruster (x4)	17,000	Reused	For moving the vehicle underwater
Microcontroller (x1)	STM32F411CEU6 (Black Pill)	700	Reused	For getting sensor data, implementing the control system, communicating with the onboard computer
Onboard Computer (x1)	NVIDIA Jetson Nano Developer Kit - B01	21,000	Reused	For getting camera feed, image processing, communicating with the MCU and the control station
DC-DC Converters(48V-12V x2 12V-5V x2)	SNA DC-DC Converter 24V-72V to 12V 20A & LM2596	1000	Purchased	To step down DC Voltage
Power Supply (x1)	Tridev 48V 480W SMPS	3000	Purchased	For powering the ROV
Electrical Safety Components	Anderson SBS50 Powerpole Connectors (x2)	1100	Purchased	For Mandatory Safety Compliance
Electrical Safety Components	Littelfuse Fuse Holder (x1)	1200	Purchased	For Mandatory Safety Compliance
Electrical Safety Components	Littelfuse LP JCase Fuse 20A (x2)	500	Purchased	For Mandatory Safety Compliance
Lights (x1)	Lumen Subsea Light	15,000	Reused	For Lighting / Headlights
Connectors and Cables	XT60, XT90, JST Connectors and Cables	2000	Purchased	For Secure Connections

ACCOUNTING & BUDGET

S.No.	Component	Description	Price (INR)	Type
1	Frame	HDPE frame	30000	Manufactured
2	Hull (enclosure)	BlueRobotics 6" Acrylic Hull	20400	Purchased
3	Gripper	Aluminium gripper	4000	Manufactured
4	Thrusters	BlueRobotics T200 Thrusters x 3 and BlueRobotics T200 Thrusters x 4	119000	Reused
5	Penetrators	BlueRobotics WetLink Penetrators - M10 6.5 mm LC x7, M10 5.5mm HC x2, M10 5.5mm LC x1, M10 4.5 mm LC x1, M06 4.5mm LC x1	12,400	Purchased
6	Pneumatics	Valves, tubings and fittings	16,040	Reused
7	ESCs	BlueRobotics Basic ESC x 7	21,000	Reused
8	IMU Sensor (x1)	Adafruit Precision NXP 9-DOF Breakout Board - FXOS8700 + FXAS21002	1300	Reused
9	Camera	OAK-D Series 3	24000	Reused
10	Depth Sensor (x1)	BlueRobotics Bar02 Ultra High-Resolution 10 m Depth/Pressure Sensor	7500	Purchased
11	Microcontroller (x1)	STM32F411CEU6 (Black Pill)	700	Reused
12	Onboard Computer (x1)	NVIDIA Jetson Nano Developer Kit - B01	21,000	Reused
13	DC-DC Converters (48V-12V x2 12V-5V x2)	SNA DC-DC Converter 24V-72V to 12V 20A & LM2596	1000	Purchased
14	Power Supply (x1)	Tridev 48V 480W SMPS	3000	Purchased
15	Electrical Safety Components	Anderson SBS50 Powerpole Connectors (x2)	1100	Purchased
16	Electrical Safety Components	Littelfuse Fuse Holder (x1)	1200	Purchased
17	Electrical Safety Components	Littelfuse LP JCase Fuse 20A (x2)	500	Purchased
18	Lights (x1)	Lumen Subsea Light	15,000	Reused
19	Connectors and Cables	XT60, XT90, JST Connectors and Cables	2000	Purchased
		Grand Total (INR)	**301140**	

SAFETY CHECKLIST

PRE POWER TEST

- Area clear/safe (no tripping hazards, items in the way).
- Electronics housing sealed.
- Visual inspection of electronics for damaged wires, loose connection
- Nuts tight on electronics housing.
- Thrusters free from obstructions.
- Set compressor output to 3 bar. Power-Up
- Power source connected to TCU.
- TCU receiving 48 Volts nominal.
- Control computers up and running.
- Ensure deck crew members are attentive.
- Power on TCU.
- Perform thruster test/verify thrusters are working properly (joystick movements correspond with thruster activity)
- Verify video feeds.

IN WATER TEST

- Check for bubbles, if large, pull to surface immediately.
- Visually inspect for water leaks.
- Engage thrusters and begin operations.

PIT MAINTENANCE

- Verify thrusters are free of foreign objects and spin freely.
- Visual inspection for any damage.
- All cables are neatly secured.
- Verify tether is free of kinks.
- Visual inspection for leaks.
- Test onboard tools.
- Verify camera positions.
- Washdown thrusters with deionized water.