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Development of Underwater Vehicle for Survey, Search and Rescue

Suraia Afroz Maria
United International University
Dhaka, Bangladesh
smaria201089@bscse.uiu.ac.bd

Md. Golam Mahmud
United International University
Dhaka, Bangladesh
mmahmud201333@bscse.uiu.ac.bd

Ahmed Junaed Tanim
United International University
Dhaka, Bangladesh
ajunaed192101@bscse.uiu.ac.bd

Md. Yasin
United International University
Dhaka, Bangladesh
myasin191101@bscse.uiu.ac.bd

Md. Abid Hossain
United International University
Dhaka, Bangladesh
abid@cse.uiu.ac.bd

Salekul Islam
North South University
Dhaka, Bangladesh
salekul.islam@northsouth.edu

***Abstract*—This research centers on developing and testing a Remotely Operated Underwater Vehicle (ROUV) with a unique 3D design providing six degrees of freedom. We approach this research using a unique 3D design, hardware implementation, testing, image denoising, and object detection. The ROUV is specifically designed for exploration, search, and rescue missions under the water, maintaining fluid dynamics. The inspiration behind this study comes from the numerous ferry mishaps in Bangladesh, aiming to assist the military in overcoming the challenges divers face during the rescue incidents. The ROUV is constructed from scratch, selecting hardware-compatible components and improving the clarity of the video footage. It can sustain up to 1.09 atmospheres of pressure. This is capable of taking underwater video feeds and storing them.**

***Index Terms*—Underwater Vehicle, ROUV**

I. Introduction

Underwater vehicles are used for a wide range of tasks in the field of ocean exploration, including mapping the seabed, conducting underwater investigations, investigating geological formations, monitoring submarine cable pipelines, documenting shipwrecks, conducting hydrological surveys, recording environmental data, detecting hydrothermal vents, and conducting military reconnaissance [1]. Researchers are focusing to utilize underwater vehicles for surveys, searches, and rescue tasks. Our research is to design an underwater vehicle that will be ROBUST enough to get the best outcome from the hardware. The hardware portion, which includes an electrical circuitry, will be implemented as well. The vehicle will be tested thoroughly to identify the errors, and they will be fixed accordingly. The underwater vehicle we have developed, named Remotely Operated Underwater Vehicle (ROUV), will be able to go to the destined path with the interactions given by the controller and detect objects. While underwater navigation, it will be difficult to see a clear view beneath the water. Therefore, it is crucial to get a clear picture in real-time.

In Bangladesh, ferries are one of the major means of commuting. While this prevalent vehicle helps in commuting, disasters occur as well [2]. These disasters cause harmful effects on the mass population, divers, and ferry authorities. Divers face serious health issues and logistical challenges, even sometimes their lives are in danger during the rescue operations.

Developing an underwater vehicle is a challenging task that needs to address many hardware and software related issues. However, while studying the literature, we have not found any detailed study guiding the beginners into these complex processes. Therefore, we have to develop almost everything from scratch.

Our research aims to explore the underwater area, search, and rescue that will assist the military or similar rescue teams. The prime contributions of this research are listed below:

- A unique 3D design—the ROUV has been made according to the design that we have made.
- We have chosen the hardware components according to the design and our accessibility.
- After constructing the ROUV from scratch, we have built our algorithm for navigation and detecting objects along the way.
- Underwater camera feed is strenuous to capture as it becomes distorted. Our ROUV will be able to denoise images from the distorted image frames.

For the stages, at first we went through works related to advanced underwater robotics, then tried to find the issues they faced and tried to resolve those by analyzing them thoroughly, and lastly did simulation and replication of the simulated idea, and lastly ran evaluations upon that with proper validations.

The rest of the paper is organized as follows: section II summarizes the present studies that have a focus similar to ours. Section III is the main contribution of our work, where we have explained in detail how we have developed our prototype. Next, we verified the prototype through different types of tests. Section IV presents those testing scenarios and the observations we have found. Finally, Section V concludes the paper with a future direction.

II. Related Works

While looking for the underwater vehicle from different parts of the world and the appropriate documentation, we have seen that most of them have advanced documentation of their underwater vehicle. A beginner-level documentation source is limited. The Bangladeshi team BRACU Duburi, for RoboSub 2022 competition, focused on improving agility and weight reduction, implementing depth sensors, visual homing, machine learning and sensor fusion for accurate navigation [3]. For Robosub 2024, they use machine learning, search algorithms, visual homing, and obstacle avoidance based on IR, integrated via ROS [4]. Improvements include optimized design, lighter batteries, and upgraded communication. Future plans focus on deep-sea exploration, testing, and system upgrades. The Singapore Bumblebee team BBAUV 4.1 [5], designed for RoboSub 2023, integrates sensor fusion, advanced control, and deep-learning perception pipelines while addressing alignment and localization gaps with IMU upgrades and URDF modeling. Future work focuses on the refinement, testing, and adoption of new technologies. The Ohio State University UWRT [6], focusing on system validation and new capabilities for RoboSub 2024. It employs a hybrid SMC-PID controller for position control and YOLOv8 for object detection. However, it lacks discussion of integration challenges and scalability across environments. Future work aims to improve reliability, task mechanisms, and autonomy for better performance. The University of Alberta ARVP [7], aimed to improve the reliability and performance for RoboSub 2024. Key advancements include a long-horizon motion planner, an external pod-based power system for safety, and a sonar system for hydrophone signal processing. However, the study lacks discussion on integration challenges and scalability across environments. Future work focuses on system reliability, autonomy, task mechanisms and the establishment of this year's processes as a foundation for future AUV designs. Desert WAVE [8], for the RoboSub 2024 competition, by improving its pneumatic system and waypoint-based navigation. Dragon employs Dead Reckoning, integrating Leica GS18 GPS to improve waypoint accuracy and visual markers from Google Earth for task execution. Although machine learning is deprioritized due to time constraints, the team highlights the need for greater precision in waypoint collection. Future work includes refining Dragon's vision system, enhancing navigation reliability, and exploring advanced technologies like machine learning for future iterations. Taluy [9], an AUV for RoboSub 2024, focusing on autonomous underwater operation with advanced mechanical, electrical and software systems. Key features include Dead Reckoning for navigation, AI-based computer vision with YOLOv10, and EKF for sensor fusion and state estimation.

All these works represent some good features, but like every beginner, we felt the need for proper documentation to build an underwater vehicle from scratch that can compete and carry out necessary missions and have an appropriate feature set. So, we attempted to feature our journey stepwise to help researchers in this field.

III. Developing the Prototype

To implement the objectives, we used Fusion 360 for design, Solidworks for flow simulation, the DnCNN algorithm for image denoising, and the YOLO NAS algorithm for object detection.

Performing a comprehensive analysis, we realized that documentation of the building of an underwater vehicle from scratch is limited. In addition, communication and imaging under the water surface do not provide satisfactory results. The camera feedback becomes very poor. We have conducted a 3D simulation of our system to test the mechanical robustness and got the expected outcome.

- Initially, we have made a conceptual diagram to understand the modules that we will need.

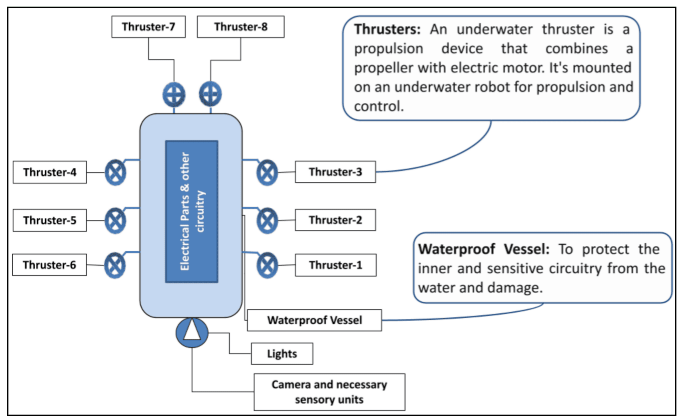


Fig. 1: Systematic Overview Using a Conceptual Diagram

The systematic overview shown in Figure 1 implies the basic components and properties needed for an underwater vehicle. The Components and Properties

- Thruster: A propulsion device used to maneuver and accelerate the mass, ejecting it from the vehicle.
- Waterproof vessel: Protect the inner and sensitive circuitry from water and damage.

A. Components

The following components shown in Figure 2 have been used to build the underwater vehicle.

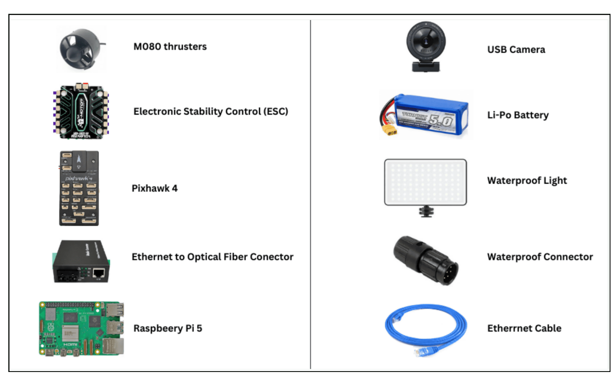


Fig. 2: Components used for making the ROUV

B. Circuit Diagram

The underwater vehicle needed cables to be operated remotely. So, the communication protocol has been maintained to improve the system. The circuit diagram has been followed throughout the assembling process of the underwater vehicle shown in Figure 3. In addition, when compound systems were available, with an approach, the electronics were incorporated into the main body for better architectural independence, which ensured easy access to the important parts [10].

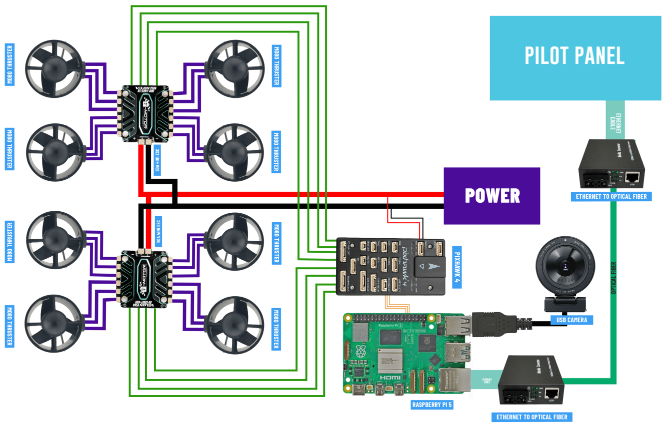
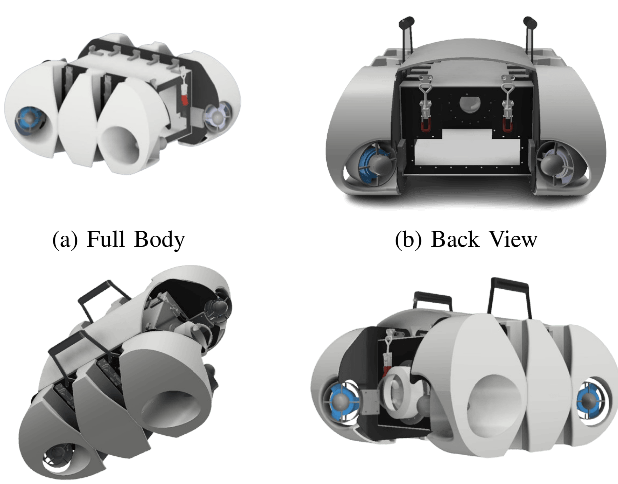


Fig. 3: Circuit Diagram

C. Design

We have made our unique design to build the underwater vehicle. We made the design shown in Figure 4 portraying the full body, the back view, the side view, and the front view. This design is made to maintain hydrodynamic properties such as pressure distribution, stability, maneuverability [11].



(a) Full Body (b) Back View

(c) Side View (d) Front View

Fig. 4: Different views of the object

D. Simulation

After the designing, we went through the flow simulation by setting 57 custom planes with a velocity of 1.8 ms^{-2} in order to test the robustness of the body by putting this in unwelcoming situations shown in Figure 5.

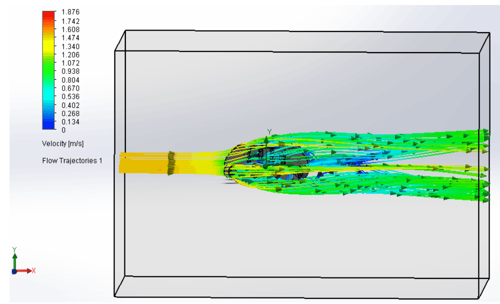


Fig. 5: Flow Simulation on Custom Plates

E. Material Analysis

We selected 3 mm aluminum plates for the inner body shown in Figure 6, because it has a high strength-to-weight ratio compared to traditional materials like steel and is corrosion resistant [12]. and along with that, our own 3D-printed parts of Thermoplastic Polyurethane (TPU) filament have been attached with the other components, like thrusters, outer shells, and other necessary equipment due to its flexibility and elasticity [13].

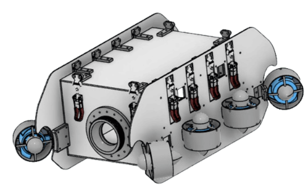


Fig. 6: Inner Body of Aluminum

F. Mathematical Analysis

We know,

Pressure, $P =$ Height $\times$ Density $\times$ Gravitational Constant.

Our target Height, $h = 30\,\text{metres}$.

Water Density (at worst case), $\rho = 1030\,\text{kg/m}^3$.

Gravitational Constant, $g = 9.8\,\text{m/s}^2$.

Therefore, $P = h \times \rho \times g$

$P = 30 \times 1030 \times 9.8$

$P = 302820\,\text{N/m}^2$ or $2.9886\,\text{atmospheres}$

This pressure is close to 3 atmospheres. Simulating our ROUV in Solidworks Software, we have found that it can sustain pressure ranging from $92316.45\,\text{N/m}^2$ to $110478.82\,\text{N/m}^2$ which is approximately between 0.911 and 1.090 atm.

G. Image Denoising

The underwater video feed is distorted and noisy. To denoise them, we have utilized a Denoising Convolutional Neural Network (DnCNN) algorithm. To decrease the distortion, we have explored multiple ways. The most prominent was the

DnCNN algorithm. The architecture can de-noise or estimate a clean signal from a noisy input. The process starts with a noisy input that passes through several layers of convolutional operations, batch normalization (BN), and activation functions such as ReLU. The network refines the input by progressively removing noise through these layers. The clean output is generated by subtracting the noise component from the noisy input. This estimated clean signal is then used for further processing or analysis in the system [14].

H. Object Detection

To enable the underwater vehicle to perform certain tasks, we incorporated the camera feed and implemented an object identification model alongside the denoised stream to ensure safe navigation, complete tasks, and gather valuable data in diverse underwater environments. And, for the base model, we applied a YOLO-based solution, YOLO-NAS, made under the hood of advanced Neural Architecture Search technology and developed by Deci AI. In Figures 7 and 8, it is seen that this advanced neural architecture search technology has shown competence in recognizing small objects compared to other models and is now in a state-of-the-art form for this task [15].

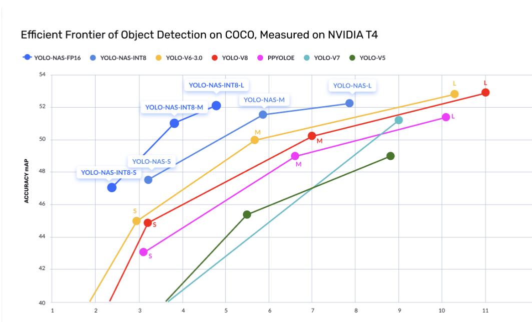


Fig. 7: Efficiency Frontier graph presents a comparison between the YOLO-NAS and other YOLO architectures

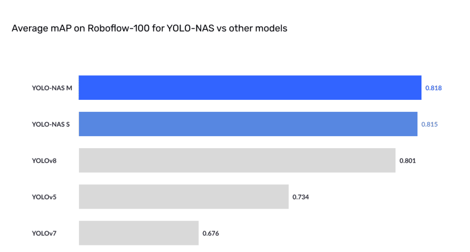


Fig. 8: Average mAP on Roboflow-100 for YOLO-NAS and other YOLO variants

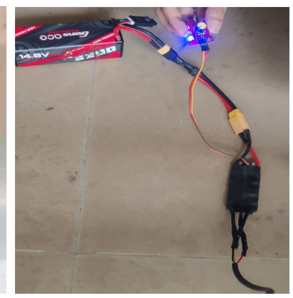
IV. Prototype Testing and Observation

To build an all-round robust system, we have properly tested all ROUV units so that it does not fail during operations. It involves both software and hardware, along with a mechanical structure.

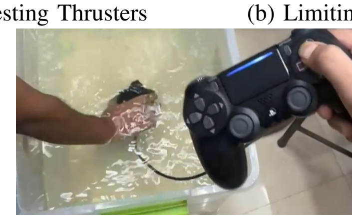
A. Submersibility and Maneuverability Test

Each of the 8 thrusters has been thoroughly tested before plunging in, which can be seen in Figure 9a, as these will play the most important role for this ROUV, and will control the major operations such as submersibility and maneuverability. We also have tried to test each of the electronic speed controllers (ESC) with each thruster applying 1/3 power to the thrusters through the ESC to ensure proper propulsion of the vehicle and proper distribution of the power, as shown in Figures 9b and 9c. After cross-checking on the submersibility tests, we step towards the maneuverability tests. e.g. moving forward, backward, left, and right, along with the YAW and ROLL movements.

(a) Testing Thrusters



(b) Limiting Voltage



(c) Testing Control Unit

Fig. 9: Testing Components.

B. Water-resistance Test

Primitively we wanted to use acrylic because it is lightweight and affordable, but during the simulation we encountered some serious issues regarding the use of acrylic as our primary material. According to our simulation result, each acrylic plate needs to be much thicker. Later, we chose aluminum as the main element of the body, as thin aluminum plates are more usable than acrylic and have plenty of space inside the ROUV, shown in Figure 10a, for its robustness. We have applied thermoplastic polyurethane (TPU) and high-efficiency rubber gaskets with the help of gasket epoxy to check and resolve leak issues10b.

For a pressure of 3 atm and a height of 30 meters, our analyzed results are given below in the table I of the material simulation:

TABLE I: Differences between 2 materials

Material Name	Thickness (Millimetre)
Acrylic	6 to 12
Aluminium	2 to 5

(a) Checking tiny leaks (b) Floating Water tests

Fig. 10: Different testing conditions

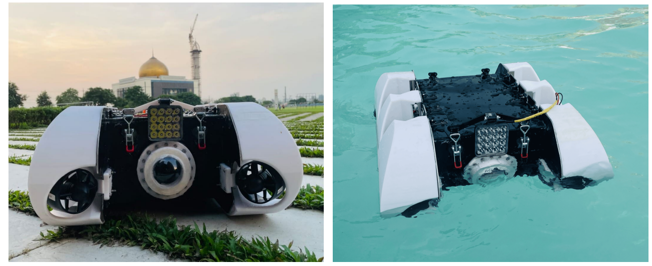
C. Underwater Visibility Test

For the visibility, as per Figure 11, we have set up the camera together with waterproof lighting, which will help the camera to perform better and get better feed considering the underwater environment.

Fig. 11: After Installing Camera and Lights

D. Integration Testing

During the integration test, multiple sub-phases were run in parallel within a limited time, so we could get the utmost output, and also a robust system could be built without any bugs. The major challenge was to assemble the mechanical and electrical components and get the best outcome out of them. However, the software phase only required a discrete hardware setup and support to run the necessary simulations with specific constraints so that it could later be directly connected to the ROUV shown in Figure 12a. We simultaneously performed multiple experiments while integrating everything shown in Figure 12b. During these tests, we often faced issues such as water leakage within the circuitry, which worsened the condition.



(a) Front View (b) Integration of Parts

Fig. 12: Views after integration.

E. Image Denoising

Using the DnCNN network architecture, we have trained Roboflow's underwater training dataset [16]. And we found significant outcomes shown in Figure 13.

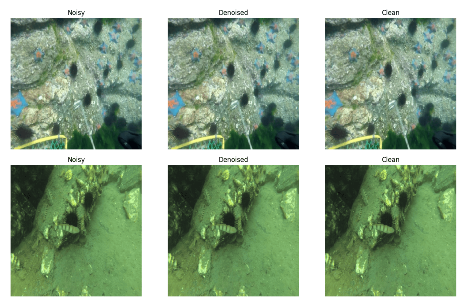


Fig. 13: Noisy vs Clean images

During image denoising, there was also a significant reduction in loss reduction, as shown in Figure 14.

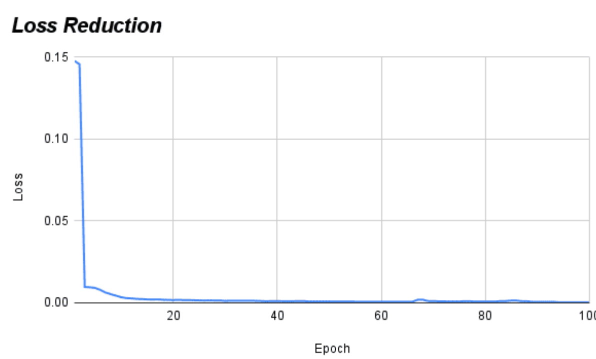
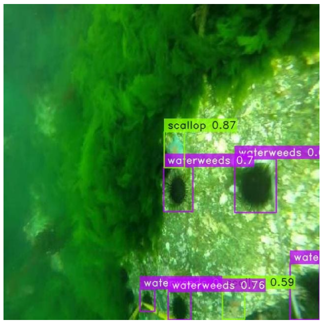


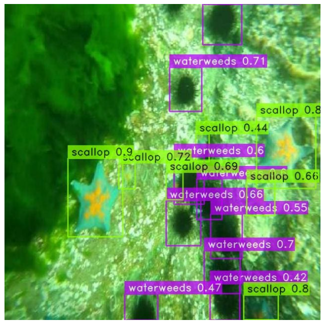
Fig. 14: Loss vs Epoch - Significant reduction in the Loss

F. Object Identification Under Water

To get the best outcomes from the object detection, we have tried 2 stages. At first, we tried to identify the object from Roboflow's dataset, which was very noisy. Although we got an appreciable outcome, after denoising the dataset, we obtained comparable differences in positive aspects applying previous object detection factors, which we can see in Figures 15a and 15b.



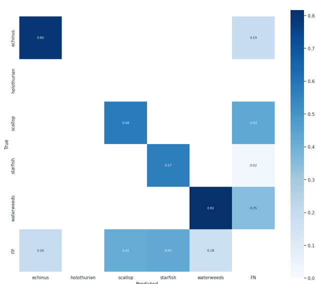
(a) Detection on noisy feed



(b) Detection on denoised feed

Fig. 15: Comparison of detection on different feeds

We have generated confusion matrix before denoising the feed in Figure 16a and after denoising the feed in Figure 16b, and from these we can get an idea of how much elevation the result is having before and after denoising.


(a) Detecting Noisy Feed

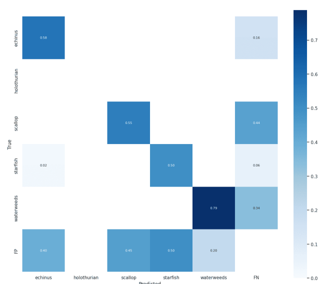
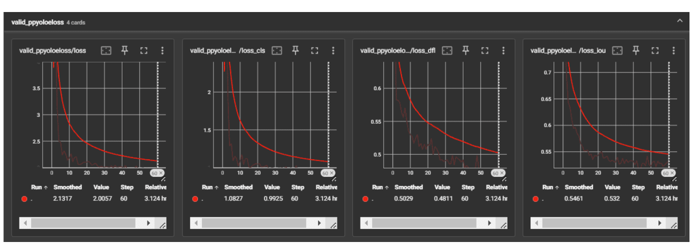

(b) Detecting Denoised Feed

Fig. 16: Comparison of confusion matrices

From Figures 17a and 17b, we can take a look at the validation loss data and get a leaner idea about how the object identification model was detecting better with the denoised feed.


(a) Noisy Feed

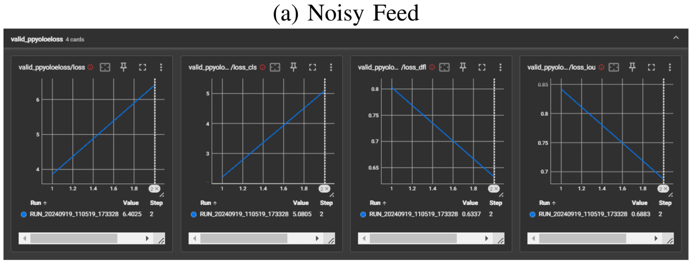

(b) Denoised Feed

Fig. 17: Comparison of validation loss on different feeds

V. Conclusion

The research outlines the design of an underwater vehicle for efficient and safer marine exploration, overcoming challenges such as limited resources in Bangladesh. A functional prototype has been developed that presents the details of each step. Our experience will benefit researchers who want to work on various underwater vehicles. Following this, we aim to focus on improving energy efficiency by validating each scope, and a power management model can be proposed to strengthen this side. In addition, we want to automate the navigation system to enhance the effectiveness of the mission. Furthermore, the ROUV body can be designed prudently to gain immunity against water leakage. However, advanced communication systems can also be improvised.

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