SINERGI Vol. 30, No. 1, February 2026: 11-22
http://publikasi.mercubuana.ac.id/index.php/sinergi
http://doi.org/10.22441/sinergi.2026.1.002

Performance analysis of a micro underwater Remotely Operated Vehicle (ROV)

Fauzal Naim Zohedi[1]*, Chan Yeow Chuan[1], Mohd Shahrieel Mohd Aras[1], Alias Khamis[1], Zairi Ismael Rizman[2]
[1]Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Malaysia
[2]Faculty of Electrical Engineering, Universiti Teknologi MARA, Malaysia

Abstract
Underwater Remote Operated Vehicle (ROV), a tethered marine robot, is widely employed for scientific and commercial applications. Underwater robots are being developed by a number of industries to improve production, monitoring, and surveillance, particularly in the gas and oil sectors. These operations are often performed by human divers; however, the underwater environment poses hazards and pressure-related limits, making them costly and risky. ROVs have, therefore, been designed to take the place of actual divers. Using a PS2 controller, the operator manually controls this tethered underwater robot. Through the use of suitable frame material and other components such as a waterproof endoscopic camera, MPU6050 IMU sensor, and pressure/depth sensor, the ROV was made to endure underwater pressure. Standard testing procedures were employed to assess the ROV's performance in buoyancy and control efficiency tests for the propulsion system in a real environment, including a laboratory pool. With 90% negative buoyancy, which was considered essential for the ROV to execute successful submerge and raise operations, as well as stable velocity and acceleration in forward, backward, and submerged directions, the constructed ROV prototype demonstrated promising performance. Since the horizontal thrusters were positioned at a 45° angle toward the rear of the ROV, the steering tests demonstrated that the ROV was more maneuverable and turned more quickly. The project's results are expected to significantly benefit sectors related to underwater applications.

This is an open-access article under the CC BY-SA license.

Keywords:
Buoyancy;
Maneuver;
Remotely operated underwater vehicle (ROV);
Stability;
Underwater inspection;

Article History:
Received: July 31, 2024
Revised: Jun 16, 2025
Accepted: July 10, 2025
Published: January 2, 2026

Corresponding Author:
Fauzal Naim Zohedi
Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Malaysia
Email: fauzal@utem.edu.my

INTRODUCTION

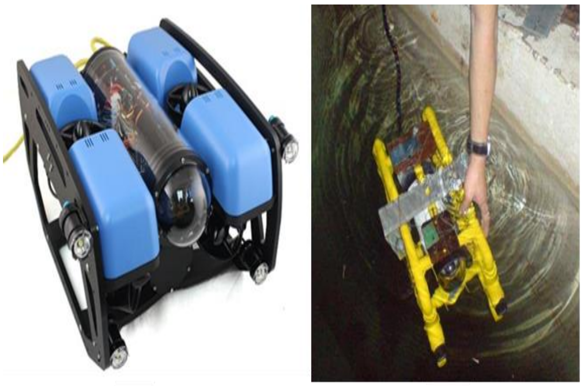
The design and development of underwater remotely operated vehicles (ROVs) has advanced significantly over the last few decades, enabling them to handle a variety of issues associated with underwater exploration, monitoring, and maintenance. ROVs have become essential vehicles for scientific research, commercial applications, and defense operations because of their ability to carry out activities in challenging and inaccessible underwater environments [1][2]. Nevertheless, the task of designing an underwater ROV that can be cost-effective and accessible for monitoring purposes remains a substantial obstacle. Traditional ROVs frequently encounter limitations in maneuverability, cost, and ease of deployment [3].

Multiple studies have highlighted the crucial challenges encountered by existing ROV designs. These systems' drawbacks include elevated manufacturing and operating costs [4], short battery life, integration of sophisticated thruster systems [5], operational distance, and inadequate control systems for accurate maneuvering [6]. In addition, current remotely operated vehicles (ROVs) require significant maintenance and lack flexibility in supporting various mission parameters [7]. The proposed solutions include the integration of advanced thruster systems [5], utilization of more efficient power management systems [8], and implementation of modular design principles to enhance flexibility and optimize maintenance [9]. Researchers also suggest combining these technologies to develop a compact Remotely Operated Vehicle (ROV) that is both cost-efficient and highly versatile for different underwater monitoring operations [10].

The development of highly efficient propulsion systems, complex control algorithms, and robust, lightweight construction components is an example of recent advancements in remotely operated vehicle (ROV) technology [5][11]. This study introduced several innovative contributions, including the incorporation of an advanced thruster configuration for better maneuverability, a small design for convenient deployment, and an enhanced control system to improve the operational capabilities of the ROV. Although there have been significant developments in ROV technology, there is still a need for the development of smaller and more affordable ROVs tailored for specific monitoring purposes [13]. Previous studies have primarily focused on expensive and large-scale remotely operated vehicles (ROVs), resulting in a gap for cost-effective and adaptable alternatives [10].

Research on BlueROV2 and BabyROV, shown in Figure 1, explained the potential and limitations of current ROV technologies [13][14]. BlueROV2, developed by BlueRobotics, is well known for its user-friendliness and modular construction, but its cost keeps it out of reach for smaller research projects [15]. An ROV called BabyROV shows that small-scale ROVs can be used for instructional reasons, but it lacks the resilience needed for heavy applications [16, 17, 18]. Conversely, few researchers have concentrated on developing inexpensive ROVs, but these frequently lack maneuverability and sensor integration [19, 20, 21, 22].

In this project, a micro underwater ROV was designed and developed as it offers a cost-effective and efficient solution for underwater monitoring. This ROV is deemed versatile and can be used for underwater applications, contributing significantly to environmental monitoring and industrial applications due to its modular construction, advanced control systems, and innovative thruster configurations.



(a) (b)

Figure 1. (a) BlueROV 2 (b) BabyROV

METHODOLOGY

Mechanical Design

The mechanical design of the ROV included the structural framework, buoyancy control, and propulsion system. The structural framework design was chosen with the intention of improving the ROV's maneuver capability during underwater operations. The ROV's frame body, which serves as its backbone and holds all of its component elements, is often constructed from sturdy materials like polyvinyl chloride (PVC) or aluminum to withstand the harsh underwater environment [23, 24, 25, 26]. Some of the essential features of buoyancy control include ballast systems or buoyancy tanks that aid in stability and control during maneuvers. The propulsion system involves the utilization of thrusters that are arranged so that they can facilitate movement in forward, backward, sideward, raised, and submerged motions.

When constructing ROV prototypes, buoyancy control is essential for stability and agility underwater. This is often accomplished by using buoyancy tanks or ballast systems to assist the ROV prototype in obtaining negatively buoyant underwater. PVC pipes used on the ROV's top and bottom sides regulate buoyancy in this particular model [24]. Figure 2 shows the isometric view of the prototype design of the underwater ROV.

Figure 3 illustrates how the air-filled upper PVC pipes served as a buoyancy tank. In order to offset the weight of the ROV and keep it afloat and stable while operating underwater, the air-filled PVC pipe generated an upthrust buoyancy force. The ROV's positive buoyancy balanced its weight and kept it from sinking uncontrollably.

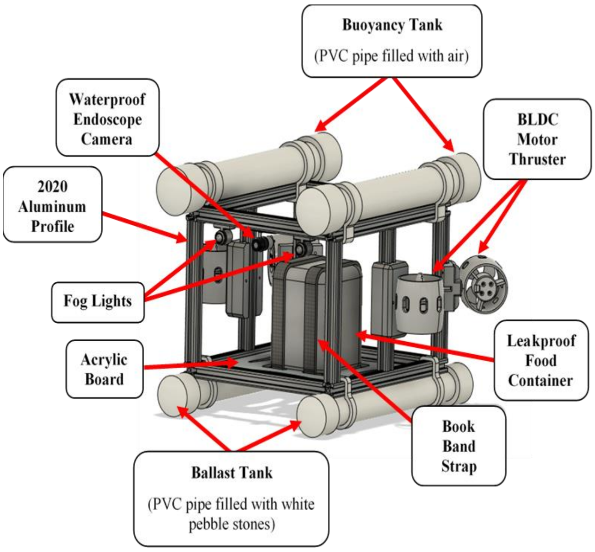


Figure 2. Isometric View of the Prototype Design of the Underwater ROV


Figure 3. Upper PVC Pipe (Buoyancy Tank)

The bottom PVC pipes were drilled with some small holes and filled with white pebble stones, serving as ballast (Figure 4). Air bubbles were able to escape via the tiny pores in the PVC pipes, ensuring that the ROV prototype's buoyancy would not be impacted. These ballast tanks enabled the provision of negative buoyancy, which in this case was a necessity as it helped to offer weight to the ROV to counteract the buoyant forces produced by the air-filled PVC pipe tops. In addition, the overall weight from the pebbles helped in lowering the center of gravity of Additionally, the total weight of the pebbles decreased the ROV prototype's center of gravity and reduced the likelihood that it would tip or roll.

The combination of the air-filled upper PVC pipe and weighted bottom PVC pipe formed a balanced buoyancy system, ensuring that the ROV prototype remained negatively buoyant during underwater operations.


Figure 4. Bottom PVC Pipe (Ballast Tank)

The upward force from the buoyancy tank and the downward force from the ballast provided a stabilizing effect, reducing undesirable tilting or drifting.

To maneuver the ROV, 4 thrusters were used. Two (2) thrusters were positioned at the ROB's side for submerge and rise, and two more thrusters were positioned at the rear of the ROV at a 45-degree angle for surge and turn. For monitoring purposes, the 45-degree angle guarantees the effectiveness of turning (Figure 5). Although it might impact the surge speed, speed was not the primary criterion for monitoring.

Electrical Design

The electrical design of the ROV prototype involved the function of devices and components used in the ROV prototype, circuit connection and flowchart of the ROV prototype control system. The Arduino Uno controlled all the operations of the ROV, including sensors, motor thrusters, and control inputs, while the circuit connection guaranteed that all the components were correctly powered and connected.

Table 1 shows the devices and components used in the design and development of a micro underwater ROV

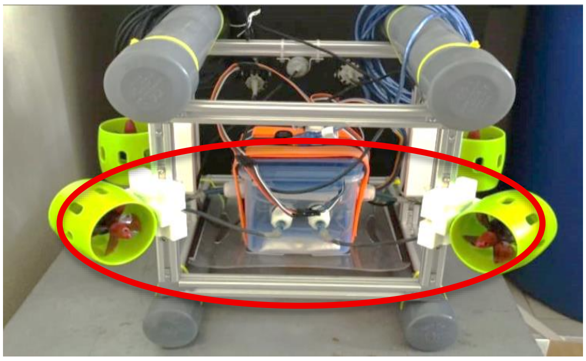


Figure 5. Thruster Placement at 45 Degrees for Efficient Turning

Table 1. List of Devices and Components Used in ROV Prototype

Devices/Components	Function
Arduino Uno	• serves as the main control unit for the ROV • manages the overall operation, executing programmed instructions to control the ROV's movement, depth, orientation, and other functionalities.
Brushless Motor Thrusters	• maneuver the ROV during underwater operation
ZMR 30A Bidirectional ESC	• controls the speed and direction of the thrusters based on the commands received from the microcontroller
Bar02 Pressure/Depth Sensor	• detects real-time depth, pressure, and temperature during underwater operation
MPU6050 Accelerometer and Gyroscope Sensor	• determines the ROV's orientation and motion dynamics, allowing for stable and controlled movements.
Waterproof Endoscope Camera	• captures video footage of the underwater environment • provides a visual feed to the operator, allowing for real-time monitoring and navigation
Fog Lights	• illuminate the area around the ROV in dark underwater environments
PS2 Controller	• controls the ROV's movements, depth, and lights. • sends commands to the Arduino Uno to maneuver the ROV
12V/8AH Sealed Lead Acid Battery	• provides power to all the ROV's components, including lights and motor thrusters.

All electronic devices and components mentioned were connected as shown in Figure 6. As all the thrusters' motors used were brushless DC motors (BLDC), a 3A electronic speed control (ESC) was implemented to control the speed. The ROV control system is presented in Figure 7.

Software Design

The software design of the developed ROV prototype entailed programming of the control algorithms using Arduino Integrated Development Environment (IDE). The Graphical User Interface (GUI) was designed using open-source processing software. This project used processing to communicate data between a microcontroller and an operator. Processing received input data from the PS2 controller and then sent commands to the microcontroller. The microcontroller sent sensor data to the processing, including rotation angle, compass, pressure, depth, temperature, and altitude, and then displayed the data on the monitor.

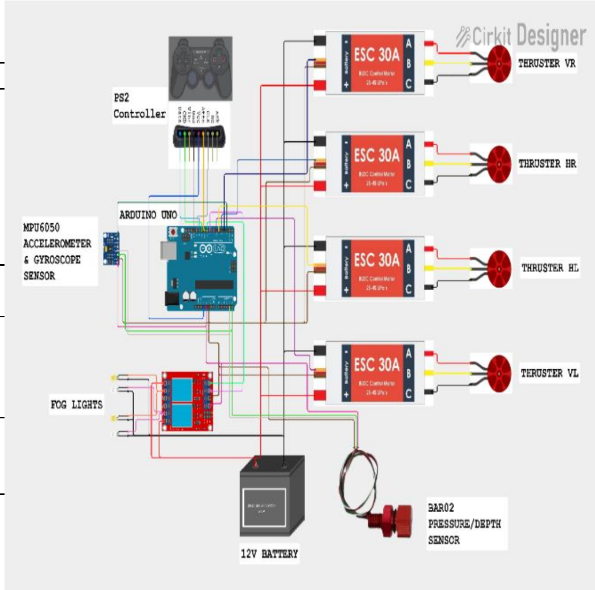


Figure 6. Schematic Circuit Wiring Connection Diagram

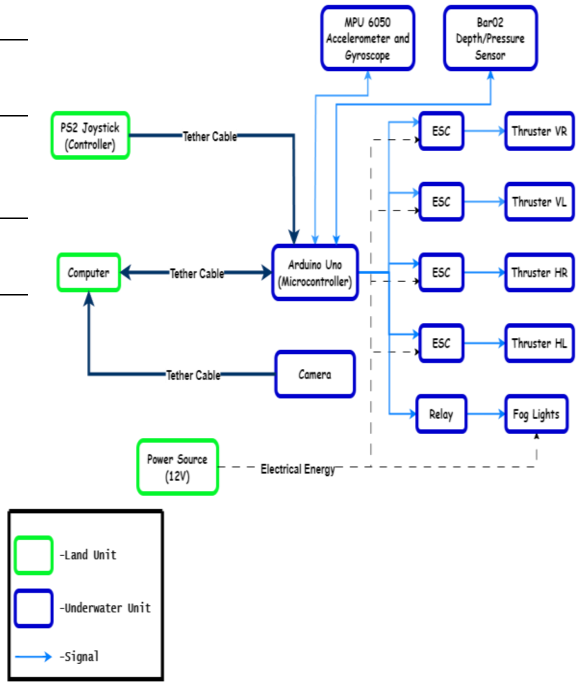


Figure 7. Flow Diagram for ROV Control System

Figure 8 shows the GUI display for the ROV. Users could observe the movement and the surrounding environment of the ROV prototype in real-time.

When operating an ROV, video feed from the camera mounted on the vehicle is a major consideration. A waterproof endoscope camera was fixed on the ROV to provide live video images, which are useful in maneuvering the ROV and doing inspection tasks.

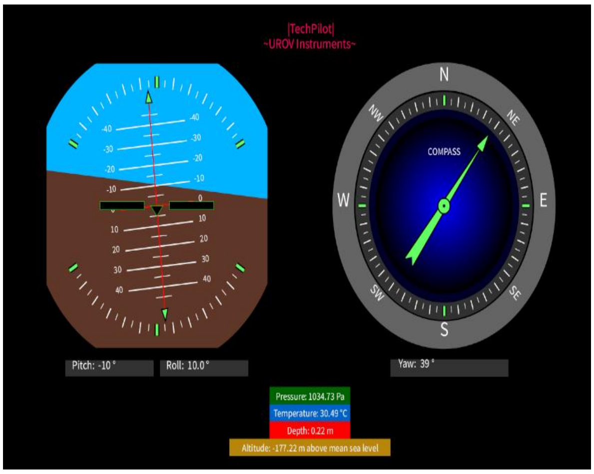


Figure 8. GUI Display for ROV

OBS Studio open-source apps received this video feed from the camera directly. It ensures that the operator can have a good view without blurring or lagging. This configuration helps the operator to maneuver the vehicle and accomplish monitoring tasks. The high flexibility in OBS Studio in managing multiple video inputs guarantees that the camera feed is transmitted frequently, and the quality is optimal for precise operations. The combination of OBS Studio to show the ROV's camera feed and the Processing GUI brings an efficient, reliable, and friendly UX/UI to control the operations underwater. This setup improved the operator's real-time control and manipulation of the ROV since important operational information is displayed at the operator's fingertips in a single intuitive interface. The functions of OBS Studio, like recording and streaming, enhance the facility of using the ROV system in real-time as well as in post operation used. Figure 9 shows the ROV Screen Display in OBS Studio

Finite Element Analysis (FEA)

Finite Element Analysis (FEA) was conducted to ensure the designed ROV operation efficiency. FEA is a computational tool designed to identify the behavior of physical systems or components under certain conditions or loads. It is used to simulate and analyze structural or component behavior due to diverse load input situations as well as boundary conditions.

Water Pressure Estimation

The water pressure exerted on the ROV at a certain depth can be calculated by using Pascal's Law. This principle states that a pressure change at any point in a confined incompressible fluid is transmitted equally in all directions.

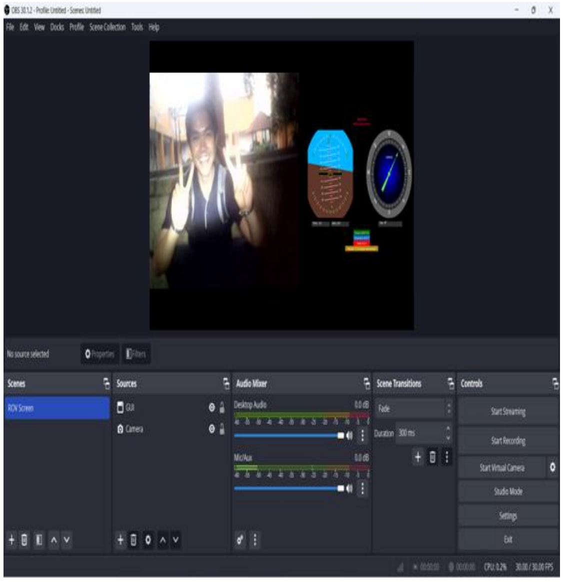


Figure 9. ROV Screen Display in OBS Studio

The equation to calculate pressure exerted at a certain depth is given by:

$$P = \rho g h \qquad (1)$$

where:
P is the pressure at the given depth,
ρ is the density of the fluid (1000kg/m^3 for water)
g is the acceleration due to gravity (9.81m/s^2)
h is the depth below the surface of the water.

RESULTS AND DISCUSSION

The overall construction of the ROV is shown in Figure 10. It contained several parts, such as a battery supply, PS2 controller, laptop, tethered micro ROV prototype, and laboratory pool.

Finite Element Analysis (FEA)

FEA enabled the simulation of water pressure on the ROV's structure by analyzing how the components, buoyancy tank and frame, responded to the static pressure exerted by water at required depths. Static stress study, safety factor and displacement of deformation analysis were conducted on the designed ROV

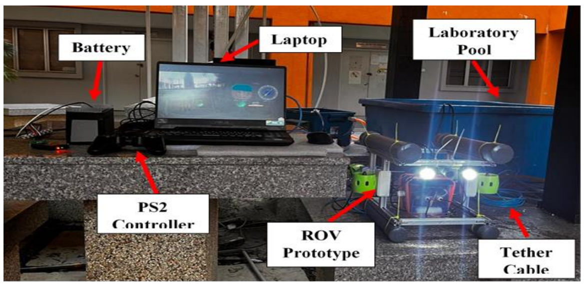
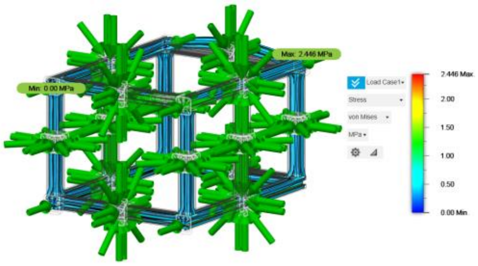
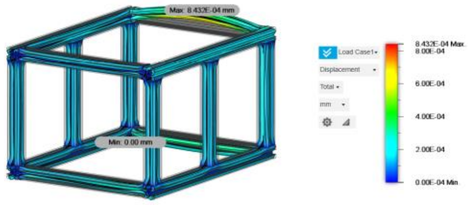
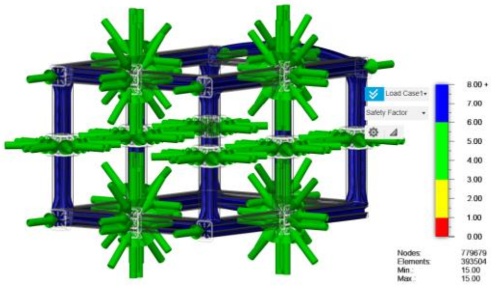
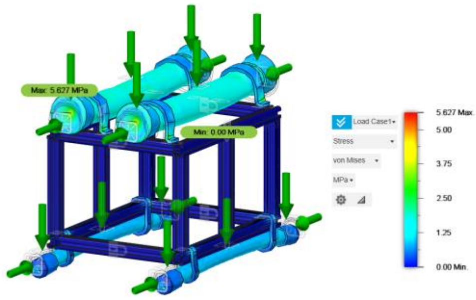
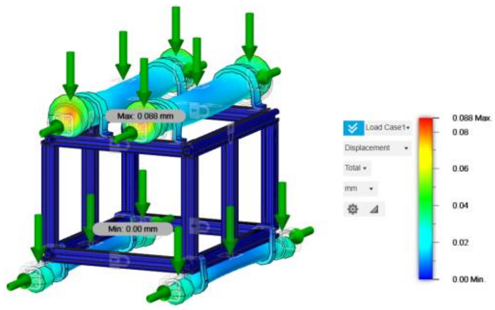
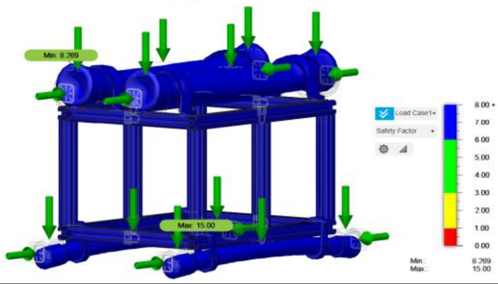


Figure 10. Micro Underwater ROV Prototype

Table 2. Finite Element Analysis of the Component of ROV

Component	Type of Analysis	Result	Figure
	Stress Analysis	Applied pressure = 150 kPa Max. stress value: 2.446 MPa Min. stress value: 0 MPa	
Frame	Displacement of Deformation Analysis	Max. displacement: 8.432×10^{-4} mm Min. displacement: 0 mm	
	Safety Factor Analysis	Max safety factor: 15	
	Stress Analysis	Applied pressure = 150 kPa Max. stress value: 5.627 MPa Min. stress value: 0 MPa	
Frame with Buoyancy Tank and Ballast Tank	Displacement of Deformation Analysis	Max. displacement: 0.088 mm Min. displacement: 0 mm	
	Safety Factor Analysis	Max safety factor: 8.27	

A 2020 aluminum profile, with a yield strength of 240 MPa, was utilized for the underwater ROV's frame. Based on depth estimation, the pressure exerted on the underwater ROV was about 150kPa when submerged into water of 15 meters' depth. Table 2 shows the FEA analysis conducted on the designed ROV. This analysis spectrum resembled a rainbow, with blue being the lowest value and red being the highest

The finite element analysis results showed that the forces applied to the material did not exceed its yield strength, indicating that the material could withstand the forces without deformation or failure. Furthermore, the factor of safety analysis revealed that all the materials utilized in the design possessed safety factors greater than 1, suggesting that they could sustain the applied forces without breaking.

Mechanical Prototype Design

The mechanical aspect plays a vital role in developing an underwater ROV with key considerations including size, stability, material, and buoyancy to ensure efficient underwater performance. The ROV prototype body structure is shown in Figure 11. The dimensions of the frame were 280mm (L) × 300mm (W) × 230mm (H).

Figure 11(e) shows that the leak-proof container was chosen as the pressure hull of the ROV prototype due to its waterproof, accessible, modifiable, and uncompressible design structure. All electronic components and wires were stored inside the pressure hull. Few holes had been drilled in the pressure hull for the thruster wires and tethered cable wires.

The nylon plastic IP 68 waterproof cable glands were installed in the holes in the container, allowing the wire cables to pass through while protecting the electronics components from water invasion. The most challenging aspect of this part was to always keep water out of this container. Thus, highly absorbent pads and several packs of silica gel were placed inside the container.

These materials assisted in absorbing water that might enter and offered an extra layer of protection to the electronic components. This technique seeks to keep the pressure hull dry, which improves the reliability and long-term performance of the ROV's internal systems.

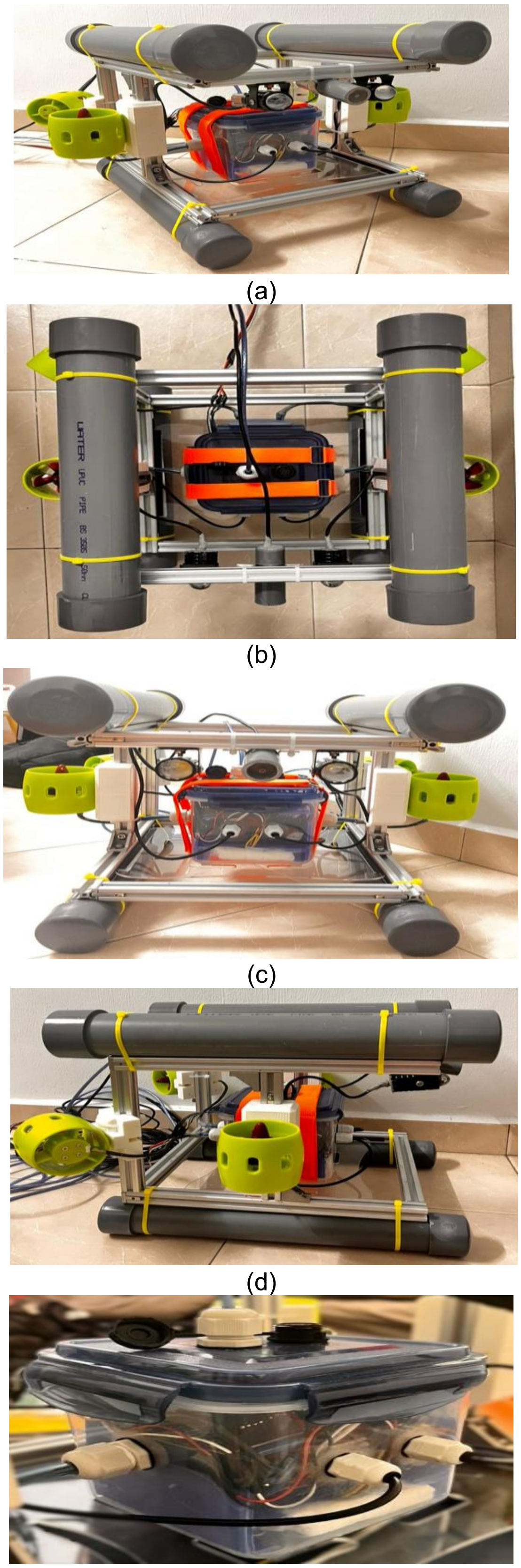

(a) (b) (c) (d) (e)

Figure 11. Overall View of ROV Prototype

Experiment Results

Buoyancy of ROV

Achieving above 90% negative buoyancy was crucial for the ROV to perform effective submerge and raise operations. To accomplish this, an additional external load using white pebble stones was required. 800g of white pebble stones were filled into the PVC pipe bottom to achieve above 90% negative buoyancy. Table 3 shows the external load filled into the ROV from 200g to 800g. 200g of white pebble stones resulted in the ROV achieving 84.78% negative buoyancy. More white pebble stones were added until the percentage of negative buoyancy reached beyond 90%. The optimal ROV performance was 94% buoyancy as shown in Figure 12, enabling an efficient submerge and raise operation.

Underwater operation

The ROV movement was propelled by 4 thrusters. To move forward, 2 propellers at the back were triggered clockwise, whereas to move backward, both propellers turned anticlockwise. Table 4 and Table 5 show the ROV performance.

Figure 12. ROV Prototype Achieve Above 94% Negative Buoyancy

Table 3. Buoyancy Test Data

Mass of White Pebble Stones (g)	First Trial (Negative Buoyancy)		Second Trial (Negative Buoyancy)	
	Height of ROV Prototype Immersed (mm)	Percentage of ROV Body Immersed (%)	Height of Body Immersed (mm)	Percentage of Body Immersed (%)
0	278	82.99	278	82.99
200	284	84.78	288	85.97
400	293	87.46	297	88.66
600	301	89.85	306	91.34
800	310	92.54	315	94.03

Table 4. Forward Performance of ROV

Distance (m)	Average Time Taken (s)	Velocity (m/s)	Acceleration (m/s^2)
0	0	0	0
0.2	0.7633	0.2620	0.3432
0.4	1.5567	0.2570	0.1651
0.6	2.3800	0.2521	0.1059
0.8	3.2133	0.2490	0.0775
1	3.9533	0.2530	0.0640
1.2	4.5533	0.2635	0.0579
1.4	4.9800	0.2811	0.0565
1.6	5.4833	0.2918	0.0532
1.8	6.0067	0.2997	0.0499
2	6.4933	0.3080	0.0474
2.2	6.8133	0.3229	0.0474
2.4	7.0700	0.3395	0.0480

Table 5. Backward Performance of ROV

Distance (m)	Average Time Taken (s)	Velocity (m/s)	Acceleration (m/s^2)
0	0	0	0
0.2	0.7767	0.2575	0.3316
0.4	1.6233	0.2464	0.1518
0.6	2.5633	0.2341	0.0913
0.8	3.4700	0.2305	0.0664
1	4.1567	0.2406	0.0579
1.2	4.7367	0.2533	0.0535
1.4	5.2700	0.2657	0.0504
1.6	5.7467	0.2784	0.0484
1.8	6.1133	0.2944	0.0482
2	6.5733	0.3043	0.0463
2.2	6.8000	0.3235	0.0476
2.4	7.0167	0.3420	0.0487

Figure 13 and Figure 14 show graphs of the forward and reverse performance of the ROV.

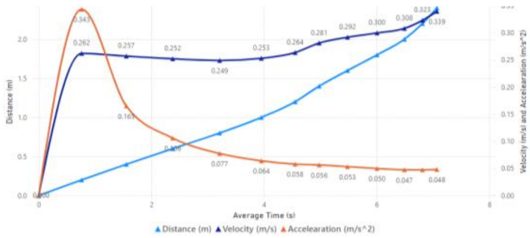


Figure 13. Graph of Forward Performance of ROV

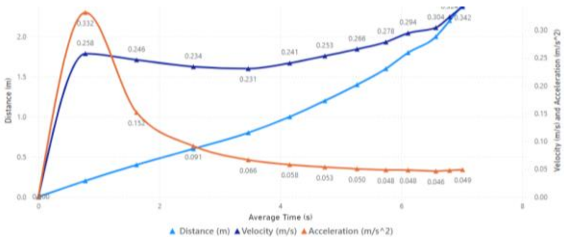


Figure 14. Graph of Backward Performance of ROV

It was observed that the average time taken when moving forward and backward was directly proportional to the distance. In the forward test, velocity started at 0.2620 m/s at 0.2m and slightly decreased to 0.3395 m/s at 2.4m, whereas acceleration began at 0.3432 m/s^2 and dropped to 0.0480 m/s^2, showing the ROV's propulsion system stabilized speed over longer distances.

In the backward test, velocity ranged from 0.2575 m/s to 0.3420 m/s, and acceleration declined from 0.3316 m/s² to 0.0487 m/s². Both forward and backward performance trends indicated that the ROV maintained a consistent speed initially, but slight variations in velocity might occur due to underwater resistance or changes in buoyancy. Furthermore, the ROV performed slightly better in the forward direction than in the backward direction.

Enabling the ROV's right and left turns, similar propellers were used. Table 6 and Table 7 show the right and left turn performance.

Table 6. Right Turn Performance of ROV

Degree (°)	Average Time Taken (s)	Angular Velocity (rad/s)	Angular Acceleration (rad/s²)
0	0	0	0
45	1.3367	0.5876	0.4396
90	1.7933	0.8759	0.4884
135	2.1500	1.0959	0.5097
180	2.6533	1.1840	0.4462

Table 7. Left Turn Performance of ROV

Degree (°)	Average Time Taken (s)	Angular Velocity (rad/s)	Angular Acceleration (rad/s²)
0	0	0	0
45	1.0667	0.7363	0.6903
90	1.4600	1.0759	0.7369
135	1.9500	1.2083	0.6196
180	2.3933	1.3126	0.5485

Figure 15 and Figure 16 show graphs of the right and left turning performance of the ROV.

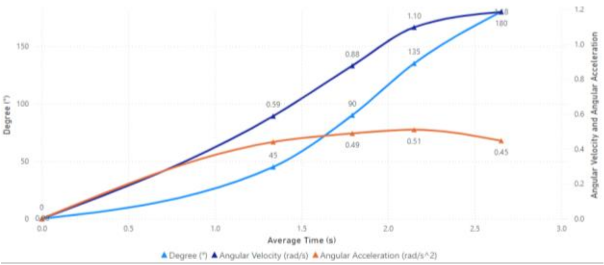


Figure 15. Graph of Turn Right Performance of ROV

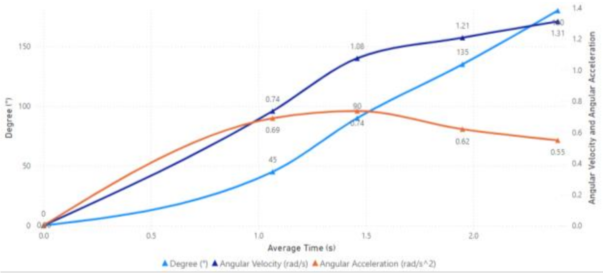


Figure 16. Graph of Turn Left Performance of ROV

The ROV's steering performance showed that completing turns took longer as the angle increased. For example, a 45-degree right turn took an average of 1.34 seconds with an angular velocity of 0.59 rad/s, whereas the same turn to the left took only 1.07 seconds with an angular velocity of 0.74 rad/s. This trend continued with the increasing angles, where the ROV showed higher angular velocities and accelerations for right and left turns compared to forward and backward, indicating better maneuverability due to asymmetries in the thruster configuration.

For heave movement or vertical trajectory, two propellers at the side of the ROV were used. The performance is illustrated in Table 8 and Table 9. Figure 17 and Figure 18 show graphs of submerged and raised performance of the ROV.

Table 8. Raise the Performance of ROV

Distance (m)	Average Time Taken (s)	Velocity (m/s)	Acceleration (m/s²)
0	0	0	0
0.05	0.3633	0.1376	0.3788
0.1	0.8867	0.1128	0.1272
0.15	1.2200	0.1230	0.1008
0.2	1.3967	0.1432	0.1025
0.25	1.6567	0.1509	0.0911
0.3	1.8633	0.1610	0.0864
0.35	2.0500	0.1707	0.0833
0.4	2.2700	0.1762	0.0776
0.45	2.5067	0.1795	0.0716

Table 9. Submerge Performance of ROV

Distance (m)	Average Time Taken (s)	Velocity (m/s)	Acceleration (m/s²)
0	0	0	0
0.05	0.1800	0.2778	1.5432
0.1	0.7733	0.1293	0.1672
0.15	1.3533	0.1108	0.0819
0.2	1.6467	0.1215	0.0738
0.25	1.9100	0.1309	0.0685
0.3	2.1700	0.1382	0.0637
0.35	2.4000	0.1458	0.0608
0.4	2.7167	0.1472	0.0542
0.45	2.8933	0.1555	0.0538

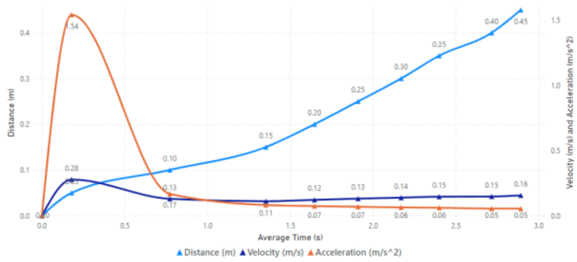


Figure 17. Graph of Submerge Performance of ROV

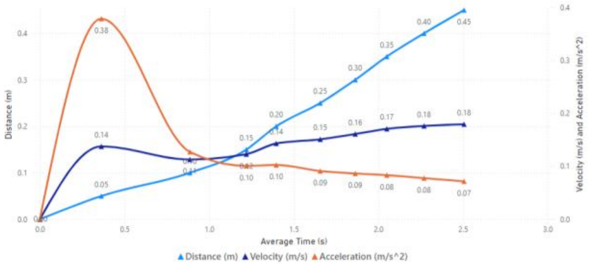


Figure 18. Graph of Raise Performance of ROV

The ROV's submerge and raise performance exhibits the anticipated trends of increasing average time and varying velocities over distance, as shown in Figures 17 and 18.In the submerge test, acceleration dropped from 1.5432 m/s2 to 0.0538 m/s2, and velocity began higher at 0.2778 m/s at 0.05 meters before decreasing to 0.1555 m/s at 0.45 meters, reflecting strong initial propulsion and later stabilization.

During the raise test, velocity started at 0.1376 m/s at 0.05 meters and increased to 0.1795 m/s at 0.45 meters, whereas acceleration decreased from 0.3788 m/s² to 0.0716 m/s², indicating initial acceleration and subsequent stabilization. In contrast, acceleration and velocity at the initial submerging were higher at the ROV due to buoyancy and gravity forces. In short, the use of the ROV was characterized by well-coordinated and stable vertical movements.

Table 10 shows that, in comparison to vertical movements, which submerge and raise at roughly 0.1357 m/s and 0.1355 m/s, the forward and backward movements had much greater average velocities, measuring 0.2600 m/s and 0.2516 m/s, respectively.

This implies that the ROV is designed for horizontal movement rather than vertical. The average accelerations adhered to this, with the maximum acceleration measured during sinking at 0.2167 m/s², implying a higher initial propulsion force against buoyancy.

Table 10. Overall Performance of ROV

Direction	Average Velocity (m/s)	Average Acceleration (m/s²)
Forward	0.2600	0.0858
Backward	0.2516	0.0801
Submerge	0.1357	0.2167
Raise	0.1355	0.1112

Table 11. Overall turning Performance of ROV

Direction	Average Angular Velocity (rad/s)	Average Angular Acceleration (rad/s²)
Left	0.8666	0.7487
Right	0.5191	0.3768

The forward and backward accelerations were almost similar, at 0.0858 m/s² and 0.0801 m/s², demonstrating consistent propulsion power in horizontal movements. The raise operation had a moderate acceleration of 0.1112 m/s², ensuring a calm ascent.

Table 11 shows that the ROV's left and right turn performance for average acceleration and velocity deviates from Table 10. Given that the horizontal thrusters were oriented at a 45° angle in the rear of the ROV, this could suggest that the ROV was more maneuverable and had a faster turning performance.

CONCLUSION

The design and development of a micro ROV is remarkable. The ROV's performance is thoroughly examined in terms of acceleration, velocity, and stability. The outcomes demonstrate how well the ROV can maneuver with a PS2 controller in all directions. The ROV is completely steady both when rising and submerging. The 45° angle greatly facilitates turning to the left and right.

The MPU6050 IMUs and the Bar02 pressure/depth sensors provide precise measurements of the ROV's stability, altitude, depth, and pressure while it is in operation. Additionally, integration with OBS Studio allows the ROV prototype's video feed to be streamed from a waterproof endoscope camera and a graphical user interface (GUI) from Processing, which helps to improve instantaneous control for the optimal user interface experience and operation control.

The cost-effective ROV has been constructed with an aluminum frame, an Arduino Uno controller, four BLDC motors for thrusters, a Bar02 pressure sensor, and an MPU6050 IMU for stabilization. All of these parts work together to create an ROV from the ground up, and they all cost less than RM1000. This value is significantly lower when purchasing an assembled ROV or parts from a reputable company. As a result, a low-cost micro ROV has been developed successfully.

From all the results, it is confirmed that the developed micro ROV performs tremendously well and is able to be used in the real underwater monitoring task.

Regardless, there is a little issue that occurs during underwater operation due to a water leak inside the pressure hull that affects the electronic components, thus an appropriate technique is required by inserting highly absorbent pads and several packs of silica gel to keep the pressure hull dry, which improves the reliability and long-term of the ROV's internal systems.

ACKNOWLEDGMENT

We wish to express our gratitude to the Universiti Teknikal Malaysia Melaka (UTeM) for the financial support via the grant PJP/2022/FKE/S01858. Special appreciation and gratitude, especially for the Faculty of Electrical Technology and Engineering (FTKE) and Underwater Technology Research Group (UTeRG), Center for Robotics and Industrial Automation (CERIA), for supporting this research.

REFERENCES

[1] F. N. Zohedi, M. S. M. Aras, and H. A. Kasdirin, “Comprehensive study of current trend of the remotely operated vehicle for underwater systems,” *Telkomnika (Telecommunication Comput. Electron. Control.)*, vol. 20, no. 2, pp. 437–446, 2022, doi: 10.12928/TELKOMNIKA.v20i2.22835

[2] A A Priyanka et al., “Contriving of ROV,” *International Journal of Engineering Research & Technology*, vol. 8, no. 11, pp. 186-191, Aug. 2020, doi: 10.17577/IJERTCONV8IS11040

[3] S. I. Ali Shah, M. Khan and S. M. Ahmad, "Design, Development, and Fabrication of a Low Cost Remotely Operated Unmanned Underwater Vehicle," *2021 International Conference on Robotics and Automation in Industry (ICRAI)*, Rawalpindi, Pakistan, 2021, pp. 1-5, doi: 10.1109/ICRAI54018.2021.9651355.

[4] J. Neira et al., “Review on unmanned underwater robotics, structure designs, materials, sensors, actuators, and navigation control,” *Journal of Robotics,* vol. 2021, no. 1, pp. 5542920, Jul. 2021, doi: 10.1155/2021/5542920

[5] M. Tadros et al., “A nonlinear optimization tool to simulate a marine propulsion system for ship conceptual design,” *Ocean Engineering*, vol. 210, pp. 107417, Aug. 2020, doi: 10.1016/j.oceaneng.2020. 107417

[6] R. Singh et al., “Review of low cost micro remotely operated underwater vehicle,” *Ocean Engineering*, vol. 266, pp. 112796, Dec. 2022, doi: 10.1016/j.oceaneng.2022.112796

[7] T. Gülgün et al., “Low-cost unmanned underwater vehicle design,” *European Journal of Science and Technology*, Special Issue, Sep. 2020, pp. 363-367, doi: 10.31590/ejosat.804610

[8] G. N. A. H. Yar, A. Ahmad and K. Khurshid, "Low Cost Assembly Design of Unmanned Underwater Vehicle (UUV)," *2021 International Bhurban Conference on Applied Sciences and Technologies (IBCAST)*, Islamabad, Pakistan, 2021, pp. 829-834, doi: 10.1109/IBCAST51254.2021.9393178.

[9] M. Vasileiou, N. Manos and E. Kavallieratou, "A low-cost 3D printed mini underwater vehicle: Design and Fabrication," *2021 20th International Conference on Advanced Robotics (ICAR)*, Ljubljana, Slovenia, 2021, pp. 390-395, doi: 10.1109/ICAR53236.2021.9659412.

[10] H. Muzammal, S. A. Mehdi, M. Ahmed Hanif and F. Maurelli, "Design and Fabrication of a Low-Cost 6 DoF Underwater Vehicle," *2021 European Conference on Mobile Robots (ECMR)*, Bonn, Germany, 2021, pp. 1-5, doi: 10.1109/ECMR50962.2021.9568805.

[11] M. Alfattah, I G. A. Arwati, and E. H. Majlan, “A review analysis of corrosion rate on stainless steel pipe in sea water media,” *Sinergi*, vol. 28, no. 3, pp. 567-584, Oct. 2024, doi: 10.22441/sinergi.2024.3.013

[12] Z. Smolder and J. Yi, “Cost-effective remote operated vehicle,” *Aresty Rutgers Undergraduate Research Journal*, vol. 1, no. 3, pp. 1-14, Dec. 2021, doi: 10.14713/arestyrurj.v1i3.167

[13] A. Wilby and E. Lo, "Low-Cost, Open-Source Hovering Autonomous Underwater Vehicle (HAUV) for Marine Robotics Research based on the BlueROV2," *2020 IEEE/OES Autonomous Underwater Vehicles Symposium (AUV),* St. Johns, NL, Canada, 2020, pp. 1-5, doi: 10.1109/AUV50043.2020.9267913.

[14] J. S. Willners *et al.*, "From market-ready ROVs to low-cost AUVs," *OCEANS 2021: San Diego – Porto*, Sep. 2021, pp. 1-7, doi: 10.23919/OCEANS44145.2021.9705798

[15] L. Zhao et al., "Modifying an affordable ROV for under-ice sensing," *OCEANS 2021: San Diego – Porto*, Sep. 2021, pp. 1-5, doi: 10.23919/OCEANS44145.2021.9705886

[16] A. A. Yusof et al., “Open-source platform comparison for research and development in underwater drones,” *12th National Technical Seminar on Unmanned System Technology*, Sep. 2020, pp. 139-151, doi: 10.1007/978-981-16-2406-3_12

[17] P. Tarwadi et al., “Design and development of a robotic vehicle for shallow-water marine inspections,” *Australasian Conference on Robotics and Automation*, Jan. 2020, pp. 1-8, doi: 10.48550/arXiv.2007.04563

[18] R. Singh, P. Sarkar, V. Goswami, and R. Yadav, “Review of low cost micro remotely operated underwater vehicle,” *Ocean*

Engineering, vol. 266, no. P2, p. 112796, 2022, doi: 10.1016/j.oceaneng.2022.112796.
[19] K. M. Salem, M. Rady, H. Aly, and H. Elshimy, “Design and Implementation of a Six-Degrees-of-Freedom Underwater Remotely Operated Vehicle,” *Applied Sciences*, vol. 13, no. 12, pp. 6870, 2023, doi: 10.3390/app13126870.
[20] Y. Liao, C. Shih, J. Wu, Y. Wu, C. Yang, and C. Chang, “ROVs Utilized in Communication and Remote Control Integration Technologies for Smart Ocean Aquaculture Monitoring Systems,” *Journal of Marine Science and Engineering*, vol. 13, no. 7, 1225, pp. 1–20, 2025, doi: 10.3390/jmse13071225
[21] S. Wang, L. Wang, J. Wang, and Y. Chen, “Design and Structural Analysis of the ROV Framework Based on ANSYS,” *Academic Journal of Engineering and Technology Science*, vol. 7, no. 3, pp. 129–136, 2024, doi: 10.25236/AJETS.2024.070318.
[22] M. Chen, Y. Liu, and D. Zhu, “Parameter identification of an open-frame underwater vehicle based on numerical simulation and quantum particle swarm optimization,” *Intell Robot*, vol. 4, no. 2, pp. 216–229, 2024, doi: 10.20517/ir.2024.14.
[23] M. Rohmah, P. A. Paristiawan, and T. B. Romijarso, “Effect of forging load and heat treatment process on the corrosion behavior of A588-1 % NI for weathering steel application in a marine environment”, *Sinergi*, vol. 26, no. 2, pp. 237–248, 2022, doi: 10.22441/sinergi.2022.2.013
[24] F. Ren, X. Guo, X. Deng, B. Wang, and Z. Wang, “The Design of a New Type of Remotely Operated Vehicle System and the Realization of a Thrust Distribution Method,” Applied Sciences, vol. 15, no. 8, 2025, doi: 10.3390/app15084199
[25] B. Bartlett, P. Trslic, M. Santos, M. Penica, J. Riordan and G. Dooly, "Dynamic Positioning System for low-cost ROV," *OCEANS 2023 - Limerick*, Ireland, 2023, pp. 1-5, doi: 10.1109/OCEANSLimerick52467.2023.10244643.
[26] F. Campagnaro et al., “Wireless remote control for underwater vehicles,” *Journal of Marine Science and Engineering*, vol. 8, no. 10, pp. 736, Sep. 2020, doi: 10.3390/jmse8100736