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Low-Cost Submarine Design for Subsurface Underwater Surveillance and Monitoring

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Abstract - *This report introduces an affordable ROV concept engineered for subsurface observation and environmental data collection. The central goal of this effort is to produce an underwater platform that remains accessible while performing tasks typically handled by more advanced—or prohibitively costly—autonomous systems[1]. By significantly lowering material and manufacturing expenses, this design seeks to remove the financial obstacles often faced by smaller academic teams and institutions in need of practical underwater research tools[1]. A low-budget Marine Autonomous Robotic Vehicle Explorer offers an economical pathway for conducting underwater monitoring and surveillance within shallow aquatic regions, built at roughly ₹20,000 using a modular assembly and inexpensive hardware [2].Beyond affordability, such designs support quicker prototype refinement cycles that are especially valuable when addressing evolving marine research needs. These systems also provide the flexibility to integrate customized scientific payloads, enabling the collection of targeted environmental data that would otherwise require costly equipment [3],[4].*

By lowering economic and technical barriers, this approach widens participation in underwater science by enabling diverse research teams—including those with limited funding to perform sustained environmental observations. The report outlines the structural layout, component choices, and essential low-cost engineering strategies used to develop this accessible ROV platform. It further elaborates on the structural design and low-cost equipment crucial for developing such an accessible underwater vehicle. [5]

Key Words: **Remotely Operated Vehicle (ROV), Underwater inspection, Low-cost marine technology, Environmental monitoring, Modular payload architecture**

1. INTRODUCTION

The growing demand for comprehensive underwater research and monitoring has amplified the significance of unmanned underwater vehicles, including both Autonomous Underwater Vehicles and Remotely Operated Vehicle[6]. These robotic systems are indispensable across a wide spectrum of critical applications, including military operations and scientific research. Furthermore, they contribute significantly to sustainable development goals through the sustained monitoring of the physical and chemical parameters that define the state of aquatic environments [7].The broad implementation of sophisticated commercial ROVs is often constrained by significant capital investment requirements. The considerable financial outlay required for purchasing, operating, and maintaining these sophisticated systems often creates significant barriers for smaller research groups, educational institutions, and regions with limited resources. Such financial obstacles have directly resulted in major gaps in our knowledge concerning ocean exploration and characterization, a problem that is particularly acute in marine environments[8].

In response to these challenges, there is a clear need for the development of low-cost ROV. Recent advancements in technology, coupled with the increasing availability of affordable off-the-shelf components and modern manufacturing techniques have made it feasible to design and construct capable ROVs at a fraction of the cost of traditional system [9]. This new way of working makes it easy to quickly test and improve designs. This encourages new ideas and allows for important underwater research and exploration that would be too expensive otherwise[10].

For the past three decades, Remotely Operated Vehicles (ROVs) have been deployed globally by various organizations to access underwater locations otherwise inaccessible to human divers or other conventional methods. Recently, ROVs have expanded their roles, now executing tasks traditionally performed by divers, such as hull cleaning, primarily driven by economic necessity and safety concerns. While the performance and reliability of commercial ROV equipment have continuously improved over this thirty-year span, these technological advancements have unfortunately resulted in substantially increased costs thus making it our primary objective to minimize these operational costs[11].

This report details a systematic approach to designing a low-cost, Remotely Operated Vehicle for subsurface surveillance and environmental monitoring. By emphasizing the integration of readily available components which are inexpensive, this report aims to bridge the gap between expensive commercial systems and cost-effective ROVs [12]. The proposed design here intends to create an affordable platform capable of performance, thereby providing access to essential underwater exploration and data acquisition necessities for a broader community of researchers and educators [3] [8].

The Remotely Operated Vehicle (ROV) shown in Figures 1(a) and 1(b) is specifically designed for exploring lake beds, prioritizing cost-effectiveness, portability, and straightforward control. A crucial element of this design is enabling real-time data transmission between the vehicle and the human operator. The presence of an operator is considered essential for successful expeditions, as human judgment allows for immediate adaptation to the unexpected and often unpredictable changes inherent to the lake environment [13]. In the broader industry, contemporary ROV platforms are systematically classified based on key specifications, including their physical size, operational depth rating, power source, horsepower, and overall functional capability.

Fig -1(a), (b): Our ROV model

2. PROBLEM STATEMENT

The current landscape of underwater surveillance and monitoring is fundamentally constrained by the reliance on complex, and prohibitively expensive Remotely Operated Vehicles (ROVs). These platforms often require specialized equipment, extensive logistical support, and highly trained personnel, making routine checks and ease of access unattainable for many organizations and individuals. This limitation hinders critical activities like rapid environmental assessments, small-scale infrastructure inspections, and academic training programs.

2.1 Our Solution

We are introducing a prototype shift with our Low-Cost Underwater ROV. This solution is purpose-built to be compact, modular, and exceptionally cost-effective without sacrificing essential performance. Our ROV provides an agile, easily deployable, and accessible platform that brings the capability of underwater observation out of the highly specialized domain and into the hands of a much broader user base. This approach directly addresses the financial and logistical barriers that have historically limited underwater exploration and data collection, thereby democratizing access to crucial aquatic insights [14].

2.2 The Goal

The global demand for underwater exploration, data acquisition, and robotics training is accelerating across multiple sectors. Our primary goal is to address this need by providing a cost-effective and readily accessible platform. This system is ideal for:

- Educational Institutions: Allowing students to gain hands-on experience in marine robotics, control systems, and oceanography.
- Small Businesses & NGOs: Enabling affordable data collection for local environmental projects or inspection services.
- Hobbyists & Researchers: Providing a tool for independent discovery and preliminary fieldwork.
- Rapid Deployment Operations: Offering quick and efficient surveillance capabilities for immediate response scenarios, such as disaster assessment or localized pollution tracking [15].

2.3 Impact

The long-term impact of this low-cost solution is the democratization of access to subsurface monitoring for a diverse array of essential applications:

Environmental Monitoring: Facilitating frequent, widespread monitoring of coral reefs, aquatic ecosystems, and pollution levels, enabling prompt conservation efforts and data-intensive research. [15], [16].

Infrastructure Inspection: Providing an affordable means for routine checks of submerged assets such as bridge piers, dam walls, and municipal water pipes, significantly lowering maintenance costs and increasing safety. [15], [17]

3.COST ANALYSIS AND OPTIMIZATION

The total expenditure for manufacturing the prototype ROV was meticulously documented, amounting to a budget under rupees twenty thousand which is notably competitive when benchmarked against commercially available ROVs that are typically more expensive. This cost-effectiveness is primarily attributed to the strategic selection of readily available, off-the-shelf components and the adoption of simplified manufacturing techniques, which significantly reduce both material and labour costs without compromising fundamental operational capabilities [18]. This cost reduction directly addresses the prevalent issue of expensive underwater equipment, making advanced surveillance accessible to a wider range of users including smaller research groups, educational institutions, and even hobbyists [3], [10], [19]. Moreover, the utilization of commercial-off-the-shelf components, as opposed to custom-fabricated parts, drastically lowers manufacturing expenses [20]. This strategy not only reduces the initial investment but also simplifies maintenance and part replacement, as these components are widely available and often interchangeable [20] [21].

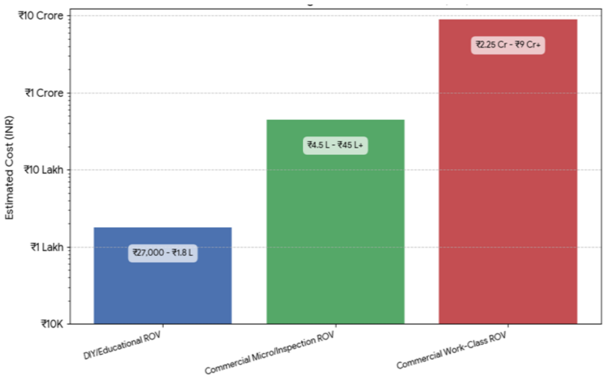


Chart -1: The estimated cost range of underwater ROV's

The bar chart shown above illustrates the estimated cost ranges for different classes of Remotely Operated Vehicles (ROVs), with values in Indian Rupees (INR). The cost categories are:

- DIY/Educational ROV: (Like our project)
- Commercial Micro/Inspection ROV: (Entry-level professional tools)
- Commercial Work-Class ROV: (Heavy-duty industrial machines)

The Y-axis employs a logarithmic scale to clearly illustrate the substantial variations in cost magnitudes.
A key insight is the striking, non-linear correlation between ROV classification and financial outlay, where expenses increase exponentially with greater depth ratings, reliability, and advanced feature requirements.

- DIY/Educational ROVs present an exceptionally low barrier to entry, making this technology accessible to hobbyists and academic institutions with an initial investment under rupees 2 lakh. This price point is transformative for practical learning and small-scale, shallow-water investigations.
- The transition from an educational unit to a Commercial Micro/Inspection ROV signifies an approximate 25-fold increase in cost at the higher end. This jump reflects the inclusion of professional, pressure-rated components and sealed brushless thrusters.
- The most significant financial escalation occurs with the move to a Commercial Work-Class ROV, demanding investments in the tens of crores. This immense capital expenditure is reserved for highly specialized, mission-critical operations in extreme conditions, necessitating robust, certified components such as titanium frames and powerful hydraulic systems [22] [23].

Ultimately, the graph supports the strategic choice to pursue a DIY design: while our ROV compromises on deep-water capabilities, it delivers unparalleled value and accessibility for fundamental inspection and educational purposes, effectively separating functional underwater access from multi-crore budgets. This economical approach encourages wider adoption and experimentation, fostering innovation and broadening the practical applications of underwater robotics beyond traditional high-cost endeavours [20] [3].

Table -1: Component and cost analysis (in INR).

Component	Our ROV (DIY/Educational)	Commercial Micro/Inspection ROV	Commercial Work-Class ROV
Price Range (Initial Cost)	₹27,000 – ₹1,80,000	₹4.5 Lakh – ₹45 Lakh+	₹2.25 Crore – ₹9 Crore+
Frame Material	PVC pipe, Acrylic, 3D-Printed Plastic	Aluminum, Reinforced Composites	Titanium, High-Grade Aluminum Alloys
Depth Rating	Shallow water (≈ 10–30m)	Medium depth (≈ 100–300m)	Extreme depth (600m to 3,000m+)
Thrusters	Modified hobby DC motors, small COTS thrusters	High-efficiency, sealed brushless thrusters	Powerful hydraulic or high-voltage electric thrusters
Sensors	Basic camera, depth sensor, simple IMU	4K/HD Camera, Sonar (optional), DVL, advanced IMU	Advanced multi-beam Sonar, Manipulator Arm(s), NDT probes
Tether	Simple CAT5/Ethernet or thinner cable	High-strength, armored, neutrally buoyant cable	Reinforced umbilical with Fiber Optics.

The analysis, visually supported by the accompanying bar graph, clearly demonstrates that the financial outlay for underwater robotics technology escalates significantly with increased depth ratings and industrial certifications. Our project effectively navigates this capital-intensive domain by achieving remarkable cost-effectiveness, thereby making underwater exploration functionally accessible at an educational level [18].

Our ROV, constructed for approximately ₹20,000, represents a transformative platform. In stark contrast to entry-level Commercial Micro/Inspection ROVs, which typically commence at ₹4.5 Lakh, our design fulfills its primary objectives—visual inspection and basic shallow-water maneuverability—at a cost less than 5% of the cheapest professional alternatives.

This favourable cost-to-capability ratio offers three key advantages:

1. Democratization of Technology: It removes the significant financial hurdles typically associated with underwater robotics, making it available to students, researchers operating with limited funding, and small-scale environmental monitoring initiatives, particularly within Indian waterways [3], [10], [19].

2. Learning and Development Platform: The minimal initial investment encourages hands-on experimentation, risk-taking, and rapid design iteration, which are crucial elements for practical engineering education and the development of robotics skills.
3. Local Applicability: The ROV is ideally suited for common regional applications, such as the inspection of ponds, lakes, and tanks, or coastal ecosystem studies. In these contexts, extreme depth capabilities and industrial certifications are less critical than accessibility, ease of repair, and the utilization of readily available, commercial-off-the-shelf components [20], [21].

In essence, the affordability of our ₹20,000 ROV unequivocally demonstrates that sophisticated, mission-relevant underwater robotics can be achieved without requiring multi-lakh expenditures. This positions our solution as a highly efficient and socially responsible option for both educational and localized scientific applications.

3.1 Component Cost Percentage Breakdown

Table -2: Our low-cost ROV cost percentage breakdown

Component	Estimated Cost (₹)	Percentage (%)	Key Inference
Thrusters/Motors (x3)	₹6,000	30%	Cost reduced by dropping motors, lowering the total percentage.
Controller/Electronics	₹8,000	40%	Reflects investment in quality ESCs or advanced sensors.
Camera & Lights	₹3,000	15%	Dedicated budget for a basic visual feedback system.
Tether & Connectors	₹2,000	10%	Essential costs for power and communication lines.
Frame (PVC) & Foam	₹1,000	5%	Negligible cost due to simple PVC material choice.
Total	₹20,000	100%	

1. Our ROV: Money goes mainly into functionality (thrusters/electronics).
2. Commercial ROV: Money is heavily spent on reliability (pressure hull) and advanced data (sensors).

4. METHODOLOGY

This section systematically outlines the engineering approach used to create our low-cost submarine for underwater monitoring. It details the iterative design cycle, covering everything from initial concepts and the careful selection of components to the practical steps of fabrication and comprehensive testing. This rigorous process was undertaken to ensure the vehicle is both fully functional and truly cost-effective.

4.1 Design Approach

The selection of a box-like, open-frame structure for the Remotely Operated Vehicle (ROV) as shown in Figure 2 is a deliberate engineering trade-off that prioritizes ease of fabrication and adaptability. This design choice, characterized by its inherently simple and rectangular geometry, offers several key advantages that make it particularly well-suited for subsurface surveillance [24].

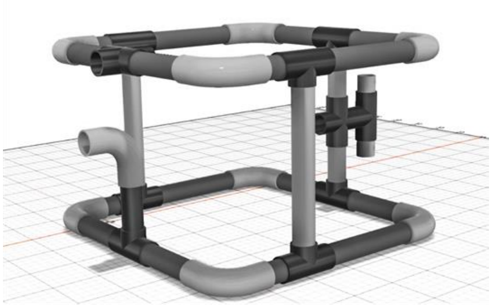


Fig -2: 3D modeling of the ROV's box-like architecture

4.1.1 Technical Advantages of the Box Geometry

Structural and Modular Benefits

- Simplicity and Cost-Effectiveness: This rectangular shape allows for straightforward, low-complexity manufacturing and assembly, minimizing fabrication costs and time.
- Adaptability and Expansion: The open, multi-sided frame provides an extensive surface area with numerous accessible points for component attachment [24].
- This facilitates the modular integration of cameras, motors, lights and additional instrumentation, catering to diverse mission requirements without extensive redesign [25] [16].

Maneuverability and Control

- Zero Steady Turning Radius: The symmetry and rigidity of the box-frame, coupled with strategically placed thrusters, enable decoupled translational and rotational control. This allows the ROV to achieve a zero steady-state turning radius—it can rotate purely about its vertical axis without any forward or lateral motion (yawing in place), which is critical for precise positioning in confined environments or close-quarters inspection. This enhanced maneuverability is crucial for navigating complex underwater topographies and performing detailed inspections of structures [26] . Furthermore, the wide structure of the frame facilitates optimal thruster placement, maximizing torque generation for agile movements such as spinning [27].

- Optimized Stability Profile: The greater the distance between center of gravity and the center of buoyancy, greater is the static and dynamic stability of the ROV, making it resistant to roll and pitch when operating in unpredictable underwater environments. This stability enhances overall operational reliability and minimizes the power required to maintain a desired orientation, particularly during precise inspection tasks [17].

4.1.2 Materials Selection and Justification

The selection of materials for the low-cost ROV prioritizes a balance between structural integrity, corrosion resistance, weight, and manufacturability to ensure both performance and economic viability. Polyvinyl Chloride pipe (PVC) was chosen for the construction due to its optimal balance of characteristics, specifically its contribution to weight reduction, inherent corrosion resistance, neutral chemical behaviour, and acceptable stiffness and shock absorption [13]. The widespread availability of PVC pipes and fittings allows for straightforward, low-complexity manufacturing and assembly, minimizing fabrication costs and time as they can be easily cut, drilled, and joined using readily available tools and epoxy glue. This ease of fabrication is crucial for rapid prototyping and repair [28].

From a structural perspective, PVC's inherent rigidity in pipe form provides sufficient support for the ROV's components and payload under expected operational loads, contributing significantly to its overall structural integrity. Unlike many metals, PVC is entirely inert to water corrosion, eliminating the need for protective coatings and significantly extending the ROV's lifespan in harsh marine environments. This also mitigates the risk of galvanic corrosion when the frame interacts with other metallic components [28].

Furthermore, PVC's relatively low density contributes to the overall weight reduction of the ROV, which simplifies buoyancy control and reduces the power demands on the thrusters, thereby impacting battery life. Its neutral chemical behaviour ensures it does not leach harmful substances into the water and remains stable across varying water chemistries. While rigid, PVC also possesses a degree of flexibility that allows it to absorb minor impacts and vibrations, protecting sensitive internal components from shock damage during operation or handling. The design approach consciously minimized the use of metal in the frame to reduce both cost and weight, simultaneously mitigating the risk of galvanic corrosion in water. The suitability of PVC was further confirmed by its capability to withstand the operational pressure requirements while remaining cost-effective, thereby validating its role as a key structural component for typical shallow to moderate depth ROV operations [28].

The selection of an endoscopic camera for the ROV was driven by its optimal balance of characteristics essential for low-cost, effective underwater surveillance. Its compact size minimizes hydrodynamic impact, contributing to the vehicle's maneuverability and reducing power consumption [29], [30]. The robust and often waterproof construction of endoscopic cameras makes them inherently suitable for challenging aquatic environments, ensuring durability and reliable performance without requiring extensive custom-built pressure housings [31]. Furthermore, the ability of these cameras to deliver clear video feeds facilitates detailed observation and inspection tasks crucial for scientific research and environmental monitoring [32], [33]. Economically, these cameras are a compelling choice due to their affordability and widespread availability, making them accessible to a broader community of researchers and educators and helping to overcome the financial barriers typically associated with advanced underwater imaging systems [8], [34], [35], [36]. This approach allows for the development of capable underwater vehicles at a fraction of the cost of traditional systems, democratizing access to crucial aquatic insights [4], [18]. The integration is simplified through versatile connectivity like Type-C USB cables, which provide both power and data transmission, and their small form factor allows for secure encasement within protective PVC piping and affixation with simple cable ties, thereby safeguarding the sensitive imaging device from physical impacts and water pressure while maintaining a stable viewing platform [28].

5. ROV COMPONENTS

5.1 Thrusters

The ROV's propulsion system is engineered for both precise depth control and versatile horizontal movement. The vertical thruster, crucial for controlling ascent and descent, employs a readily available and cost-effective modified 1100-gallon-per-hour bilge pump [37]. These pumps are favored for their simplicity, durability, and low acquisition cost, making them ideal for budget-conscious designs. This pump is meticulously mounted vertically and structurally integrated using a robust PVC three-way connector, which provides a secure and stable housing, minimizing vibration and ensuring efficient power transfer to the impeller.

For horizontal locomotion, the ROV is equipped with two modified 1100-gallon-per-hour bilge pumps. These specific pumps were selected for their inherent power and potential for adaptation, providing sufficient thrust for effective maneuverability [38]. To achieve enhanced thrust and propulsive efficiency, a significant modification was undertaken: the original bottom housing of each bilge pump was carefully removed, and the factory-standard impeller was replaced with a custom-designed propeller. This alteration significantly improves the hydrodynamic characteristics by optimizing blade shape and pitch for underwater propulsion, allowing for greater thrust generation and more agile maneuverability through the water column compared to the less efficient stock impellers [39]. The strategic placement of these thrusters—one vertical and two horizontal—enables effective control over the ROV's translational movements (forward, backward, up, down) and rotational movements (yaw), facilitating precise navigation and positioning in various underwater environments [40].

5.2 Tether

The tether serves as the indispensable lifeline for the ROV, acting as the primary conduit for both critical control signals and electrical power transmission to the propulsion systems. This dual functionality is efficiently managed through a durable Cat 5e Ethernet cable, which offers multiple twisted pairs suitable for reliable data and low-voltage power transfer, benefiting from its widespread availability and robustness in outdoor applications [41]. Crucially, the onboard camera, responsible for capturing real-time underwater video, operates independently, relying on its own dedicated video/power cable. This separation minimizes potential electromagnetic interference with sensitive control signals, ensuring stable ROV operation, and also guarantees optimal video quality without degradation from power fluctuations or data crosstalk [42]. For enhanced operational stability, improved hydrodynamic efficiency by reducing drag, and to prevent entanglement with underwater obstacles or the ROV itself, all power cables, data lines, and the polypropylene rope are meticulously bundled together using industrial-grade cable ties and weather-resistant electrical tape, creating a streamlined and organized umbilical cable [28].

5.3 DPDT Switches

A comprehensive power management system is integrated to ensure efficient distribution and regulation of the 12V supply to various components, including the thrusters, tether, and the camera surveillance system [43]. This system is critical for preventing overcurrent's, protecting sensitive electronics, and optimizing battery life. Directional control for the ROV's three thruster motors is achieved through the use of three momentary Double-Pole, Double-Throw switches located in its control box. Each switch functions as a mechanical H-bridge, a common circuit configuration used to control motor direction, enabling the reversal of the motor's electrical polarity. This polarity reversal is accomplished by a criss-cross wiring pattern on the four outer terminals, where a dedicated positive wire and a negative wire are connected diagonally across the switch contacts. The switch's two centre terminals act as the output poles, directly linking to the thruster motor leads [13], [25]. Power for all three switches is supplied in parallel from the main 12V battery bus, ensuring consistent voltage delivery to each thruster. The momentary nature of these switches is crucial for safety and precise control, as it ensures immediate power cutoff to the thruster upon release, preventing unintended continuous operation [44].

5.4 Power Supply

The ROV's entire electronic system, encompassing all thrusters and the camera, is powered by a robust 12V lithium-ion battery. This specific battery chemistry was selected for its high energy density, providing significant power relative to its volume and weight; and its consistent power output throughout its discharge cycle, ensuring stable performance [45]. With an approximate capacity of 2000mAh, this power source is engineered to provide an operational duration of about 4 to 5 hours, depending on the intensity of thruster usage and other electrical loads, offering ample time for typical inspection or monitoring missions. As a rechargeable unit, this battery is central to the ROV's operational autonomy, serving as the sole and primary power source [28]. For missions requiring extended operational periods, an external power supply can be integrated, delivering continuous power via the tether to circumvent battery life limitations [46]. This approach allows for prolonged subsurface deployment necessary for extensive surveillance and data collection efforts, thereby expanding the ROV's utility beyond the inherent constraints of onboard battery capacity [47]. This design consideration highlights a crucial trade-off between untethered operational flexibility and prolonged mission endurance, a common challenge in autonomous underwater vehicle and remotely operated vehicle designs [48].

5.5 Camera

For comprehensive underwater visualization, an advanced endoscopic camera, equipped with a versatile Type-C USB cable, is precisely integrated into the ROV's framework. To ensure its longevity and reliable performance, the sensitive imaging device is securely encased within a protective PVC pipe. This enclosure not only shields the camera from potential physical impacts and the increasing water pressure at depth but also provides a stable housing that allows for effortless adjustment of its viewing angle and focal position through simple mechanical means, offering flexibility in surveillance tasks [49]. This camera is specifically chosen for its compact size, which allows for minimal hydrodynamic impact; its robust, often waterproof, construction suitable for challenging aquatic environments; and its ability to deliver clear video feeds, facilitating detailed observation and inspection tasks [50]. The entire camera assembly is then firmly affixed to the ROV's base grid using durable cable ties, preventing any unwanted movement or vibration during operation that could degrade video quality. The camera comes pre-equipped with in built lights as well as supporting lights attached to the front face of the ROV to increase visibility. The Type-C USB cable is thoughtfully routed through the internal structure of the ROV frame, connecting directly to the control system to provide both continuous electrical power, leveraging its capacity for higher power delivery, and facilitate the real-time transmission of high-quality video footage to the surface operator [28].

5.6 Foam Tubes

Buoyancy Control: The main purpose of the foam tubes is to counteract the weight of the ROV's components, including the PVC frame, motors, and wiring, to achieve neutral buoyancy [51]. Without these flotation elements, the ROV would be negatively buoyant and would simply sink [51]. By strategically adding foam, an upward buoyant force is introduced that effectively balances the ROV's overall weight in water, allowing it to "hover" at a desired depth with minimal reliance on the vertical thruster for station-keeping [48], [52]. This precise buoyancy management is a fundamental aspect of underwater vehicle design, crucial for operational efficiency and stability [23], [53].

Stability: The strategic placement of foam tubes is critical for maintaining the ROV's stability, helping to keep it upright and preventing it from flipping unexpectedly [54]. This is achieved by positioning the foam tubes high on the frame, which raises the vehicle's center of buoyancy [54]. Ensuring the center of buoyancy is above the center of gravity—where heavier components like motors are typically situated—provides the ROV with inherent stability and a self-righting tendency [48], [51].

Modifiability: Foam tubes offer a practical solution for adapting the ROV's buoyancy due to their ease of addition or removal. This allows for quick adjustments to accommodate different payloads, such as additional cameras or tools, ensuring the ROV remains neutrally buoyant despite changes in its overall weight [55]. Furthermore, this modifiability facilitates adjustments for varying water densities, whether operating in freshwater or saltwater, as the buoyant force required will differ [56], [57]. The use of foam, particularly in low-cost designs, also presents an economical alternative to more complex and expensive buoyancy compensation systems, enabling greater accessibility and flexibility for researchers [4], [10], [58].

6. Calculations

6.1 Determining The Forces

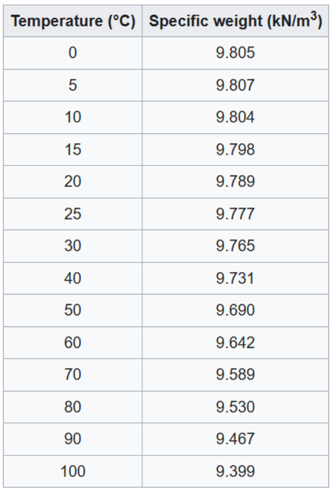
The forces acting on a Remotely Operated Vehicle (ROV) change drastically upon submersion due to the rapid, linear increase in hydrostatic pressure with depth ,i.e, the magnitude of the normal force exerted on the ROV's pressure vessel escalates significantly as the water column's weight above the vehicle increases [55].

$$P = \gamma x \qquad (Eq.1)$$

Where:
P is the pressure [Pa]
γ is the specific weight of the fluid [N/m^3]

h is the depth [m]

Table -3: Specific weight of water at standard atmospheric pressure (metric units).



Temperature (°C)	Specific weight (kN/m³)
0	9.805
5	9.807
10	9.804
15	9.798
20	9.789
25	9.777
30	9.765
40	9.731
50	9.690
60	9.642
70	9.589
80	9.530
90	9.467
100	9.399

Considering an average of the specific weights from 15 – 30 °C.

Average specific weight of fluid = $\frac{48860}{5}$ = 9772

P = 9772 x 10 m = 97720 = 0.0977 MPa
This calculation confirms that at a depth of 10 meters the water itself exerts a pressure of approximately **0.0977 MPa.**

The **critical pressure** of a material is the absolute, maximum amount of force per area it can handle before its structural integrity is permanently compromised. Exceeding this ultimate pressure limit guarantees the material will undergo failure [55].

$$P_{cr} = \frac{2E}{1-\mu^2}\left(\frac{e}{D-e}\right)^3 \qquad (Eq.2)$$

P_{cr} = Critical pressure (failure condition) [Pa]
E = Modulus of elasticity of the material [GPa]
e = Pipe thickness [m]
D = External diameter of the pipe [m]
μ = Poisson's ratio

Substituting the values, elasticity for PVC as 2.89 GPa, the Poisson's ratio as 0.41 the thickness of the pipe by 3.15 x 10^{-3}, and the outside diameter of the pipe as 22.2 x 10^{-3}m, a critical pressure of **0.314 MPa** was obtained [55].
Since the maximum pressure the ROV can withstand is 0.314MPa which is greater than the pressure it will actually experience 0.0977 MPa, the structure has a **factor of safety** and is deemed safe for operation at the depth of 10m indicating that the ROV would be safe under the working conditions [55].

6.2 Design of Immersion System

When an object is immersed in a liquid, the liquid generates a force that tends to push the object towards the surface, known as the buoyant force B, given by the equation,

B = ρgV *(Eq.3)*

where:
ρ is the density of the fluid
g is the acceleration due to gravity
V is the volume of the displaced fluid.

1. Required Volume (V) for Neutral Buoyancy:

$$V = \frac{m_{ROV}}{\rho_{water}} = \frac{4\ \text{kg}}{1000\ \text{kg/m}^3} = 0.004\ \text{m}^3$$

. *(Eq. 4)*

(This assumes the water is fresh water at 4 °C with a density (**ρ**) of 1000 kg/m³).

2. Buoyant Force (B) at Neutral Buoyancy:

$$B = \rho g V = 1000\ \text{kg/m}^3 \times 9.81\ \text{m/s}^2 \times 0.004\ \text{m}^3 = 39.24\ \text{N}$$

The immersion system facilitates the vertical motion of the ROV in the water. The existing ways for implementing the immersion system are:

a) Mechanical method by using propellers to achieve the displacement, and
b) Hydraulic method by using ballast tanks which can be filled with water or air in order to submerge or emerge. For the sake of simplicity, we have used the mechanical means of immersion. By simplifying the equation cancelling g, we can find the volume required to displace water equal to the ROV's mass:
From our prototype, we have assumed the weight of the ROV to be 4kgs.
The conclusion that the ROV is neutrally buoyant when fully submerged and displacing 0.004m³. The shape being cuboidal does not affect the calculation for buoyancy.

6.3 Drag force

The core objective is to calculate the drag force, which represents the specific amount of physical resistance the water exerts on the ROV as it moves at maximum speed. Once this is precisely known, we use it to determine the power that the thruster motors must continuously generate, ensuring the ROV can consistently overcome the water's opposition.
The drag force is determined by a modified drag equation that sums up the resistance from both the ROV's main body and its attached umbilical cable.

$$F_d = \left[\frac{1}{2}\rho V^2 C_d A\right]_{\text{Body/ROV}} + \left[\frac{1}{2}\rho V^2 C_d A\right]_{\text{Umbilical}} \qquad \textit{(Eq.5)}$$

Density (ρ) 1000 kg/m^3
Velocity (V) = 0.25722 m/s
The conclusion that the ROV's maximum speed is 0.5 knot is typically not a direct measurement, but a design assumption based on several practical and engineering constraints for a small, observation-class ROV. Limiting the speed to 0.5 knot reduces the required motor power and overall energy consumption. This is crucial as it increases their run time [13].
Drag Coefficient (Cd) of ROV 1.5 - 2 (This value is an estimate based on the bluff shape of the ROV)
Frontal Area (A) 0.09 m^2 (this is the cross-sectional area that faces the water flow. The dimensions are 30cm×30 cm. Converting to meters: 0.30 m×0.30m=0.09 m^2)
Drag Coefficient of the chord – 1.2 since diameter of the chord is 1.5 cm

$$F_d = 0.5 \times 1000 \times (0.25722\,\text{m/s})^2 \times 1.5 \times 0.09 + (0.25722\,\text{m/s})^2 \times 1.2 \times (1.8 \times 0.015)$$

Drag coefficient = 5.54N

The sum of the two drag components is 5.54N. Drag equations often don't account for the fact that a moving object also accelerates the water around it (the added mass effect). To account for this, an extra **10%** is added to the result [13].

Correction = 10% x 5.54 N = 0.554N
Final Drag Force (F_d): 5.54N+ 0.554 N = **6.094N**

The power required is the amount of energy per second needed to push the ROV against the drag force.
Power = Force × Velocity *(Eq.6)*

1. Force (F_d): 6.094N (The final corrected drag force).
2. Velocity (V): 0.25722m/s (The maximum speed of 1 knot).
3. Calculation:

P_d = 6.094N × 0.25722 m/s = **1.57Watts**

This means the ROV thrusters must supply at least 1.57 Watts of mechanical power to overcome the drag and move at its top speed so that the ROV can maintain a speed of 0.5knots under real-world operating conditions [13].
Based on the final drag force calculation, the continuous mechanical power required by the thrusters to move the ROV at its target speed of 0.5 Knots :1.57 Watts This means that 0.5 Knots thrusters only need to convert 1.57 Watts of energy into thrust.

6.4 Available Power and Thrust

We have 3 motors of 8.5 W capacity each = 3 x 8.5 W = **25.5** *(Eq.7)*
Maximum available thrust**:** Using the total available power and the highest theoretical propeller speed from our anemometer measurement 5m/s –

Thrust = $\frac{25.5\text{ W}}{5\text{ m/s}} = 5.1$ *(Eq.8)*
The motor system provides a maximum of 25.5W, which is sufficient to meet the 1.57W requirement for 0.5 knots with a massive safety margin. This confirms the motors are appropriately sized for the 0.5 knot target speed but cannot reach the higher speeds

6.5 Electrical Connections of the ROV

1. **Total power and current**

Power output = Number of motors x power per motor
= 3x 8.5= **25.5** *(Eq.9)*
Maximum current drawn = power / voltage
= 25.5/12 **= 2.13 A**
(Eq.10)

2. **Battery run time (estimate) =** Q/I
= 2000mAh/1000 **= 2Ah**

(Eq.11)
Max run time – Q/I =2/2.13 = 0.94 hrs
= **56 minutes** *(Eq.12)*
This is the theoretical run time at full throttle. Since the ROV is typically moving slowly, the actual current draw is much lower and the actual run time will be significantly longer.

Table -4: Component safety check

Component	System Requirement	Component Rating	Safety Status
Current	2.13A	15A	**Safe** (The switch can easily handle the current load.)
Voltage	12V	250V	**Safe** (The switch is rated for much higher voltage than 12V

Table -5: Summary of the ROV Electrical

Parameter	Calculation	Result	Interpretation
Total Mechanical Power	3 x8.5	25.5 Watts	Max physical power available for thrust.

Max Current Draw	$\frac{25.5\ \mathrm{W}}{12\ \mathrm{V}}$	2.13A	Max current pulled from the battery.
Theoretical Run Time	$\frac{2\ \mathrm{Ah}}{2.13\ \mathrm{A}}$	56 Minutes	Run time at full, continuous throttle.
Switch Safety	15 A rating vs 2.13 A draw	12.87A margin	Components are safely rated for the system's demands.

7. PERFORMANCE EVALUATION

This section comprehensively assesses the ROV's operational capabilities, focusing on its maneuverability, propulsion efficiency for subsurface surveillance and monitoring [60].

7.1 Simulations and Modeling

Computational fluid dynamics simulations are essential for accurately predicting the hydrodynamic performance of the submarine, particularly to analyse drag coefficients and propulsion efficiency under various operational conditions [55]. These simulations allow for the optimization of hull forms and propeller designs, minimizing energy consumption and maximizing speed and maneuverability [61]. Furthermore, numerical models can precisely quantify complex fluid phenomena, such as turbulent flow and cavitation, which are critical for robust design decisions [62].

We have run an Ansys Fluid Flow analysis to calculate the approximate drag that our model would produce for the box-like structure. This analysis helps in determining the viscous drag the model experiences in water and subsequently aids in deciding the power requirements for the ROV, assisting in its overall design [63].
The theoretical value calculated for the drag was 5.54N (excluding tether), which aligns with the experimental drag force of 5.54N obtained from the simulation, thus validating the analytical predictions as shown in Figure 3 [64].

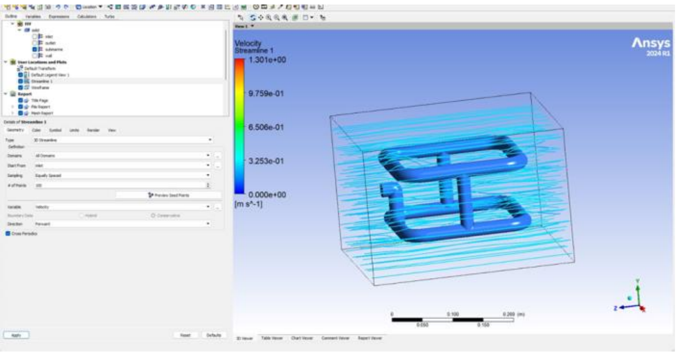


Fig -3: Ansys fluid flow simulation results

7.2 Testing

Phase I: Controlled Hydrostatic Verification
The primary validation of the Remotely Operated Vehicle was executed within a stabilized laboratory environment - specifically, a swimming pool. This controlled setting was imperative for isolating mechanical variables and ensuring the fundamental integrity of the platform's architecture. Key engineering benchmarks achieved during this phase included:

- Structural and Buoyancy Assessment: Confirming the frame's resilience against hydrostatic pressure and verifying that the desired neutral buoyancy was maintained.
- Propulsion System Calibration: Rigorous testing of the thruster array to quantify thrust-to-weight ratios and ensure the vehicle could achieve the designated velocity.
- Dynamic Stability Analysis: Evaluating the ROV's centre of gravity and centre of buoyancy to prevent uncontrolled pitching or rolling during high-torque maneuvers.

Phase II: Field Deployment
Transitioning from laboratory conditions to a lake environment provided a critical "real-world" stress test for the system. Operating in a natural body of water introduced unpredictable variables that cannot be replicated in a pool, allowing for a comprehensive evaluation of:

1. Environmental Resilience: Determining the system's ability to maintain station-keeping while subjected to natural currents and varying thermal layers.
2. Telemetry and Signal Fidelity: Validating the reliability of the communication tether and real-time data transmission through water.
3. Visual Navigational Clarity: Analysing how the onboard camera systems performed when navigating complex, unmapped lake-bed topography compared to the clear, geometric confines of a pool.

Future Work and Scalable Applications
With the successful transition from prototype to field-tested system, the project's roadmap focuses on expanding the ROV's utility for broader scientific and industrial sectors. Future iterations will prioritize:

1. Essential Data Collection: To move beyond basic functional checks and commence the collection of mission-critical environmental data under authentic operational stresses.
2. Performance Optimization: To conduct a comprehensive series of test runs aimed at refining the operational smoothness and minimizing potential failure points. This iterative testing and refinement process is necessary to ensure the ROV operates robustly and reliably in its intended

application setting. This structured approach ensures that the vehicle moves logically from a verified prototype stage to a fully reliable system ready for diverse field deployment.

8. ADVANTAGES, LIMITATIONS and APPLICATIONS

Despite these limitations, the successful fabrication and operational validation of the prototype underscore the considerable potential for deploying such low-cost ROVs in diverse applications, particularly for educational purposes and preliminary environmental monitoring [26].

8.1 Technical Advantages

- **Affordability and Accessibility:** The utilization of readily available and economical components, such as PVC piping for the structural frame, bilge pump motors for propulsion, and standard Double-Pole, Double-Throw switches, significantly reduces the financial and technical barriers to constructing a Remotely Operated Vehicle.
- **Modular Design and Ease of Repair:** The ROV's PVC frame is assembled using fittings and adhesive, which facilitates straightforward modification, disassembly, and replacement of damaged sections. This design choice simplifies troubleshooting and repair processes, this modularity also allows for easy upgrades and customization, enabling users to adapt the ROV for specific mission requirements without the need for extensive redesign [54].
- **Streamlined Control System:** The reliance on DPDT switches provides a mechanically uncomplicated, robust, and dependable method for reversing motor polarity. This eliminates the need for complex electronic speed controllers or microcontrollers. Furthermore, the momentary nature of these switches acts as a crucial safety feature, instantly cutting power upon release. This design choice enhances operational safety by mitigating uncontrolled movements and simplifying user interaction, making it suitable for novice operators [65].
- **Optimized Power-to-Weight Ratio:** The incorporation of 12V bilge pump motors offers a high thrust-to-volume ratio. This provides ample power for fundamental maneuvering, especially considering the lightweight nature of the PVC frame structure. This careful selection of components ensures efficient power utilization, a critical factor for extending operational endurance in battery-powered underwater vehicles [66].

8.2 Technical Limitations

- **Limited Depth and Durability:** Low-cost ROVs often face significant limitations in their operational depth and overall durability due to the use of more economical materials and components, such as PVC hulls and less robust motors [1]. While some low-cost designs can reach shallow depths, this is far more limited than the capabilities of commercial, higher-cost systems, which are designed for much greater depths [4], [18], [67]. General limitations in structure and durability, such as withstanding immense crush force or functioning in aggressive high-pressure environments, are inherent in such cost-conscious designs [5], [32], [67].
- **Reduced Power and Propulsion Efficiency:** Economical motors commonly used in low-cost ROVs typically lack the power and durability of more expensive thrusters, which directly impacts the vehicle's thrust capabilities and overall propulsive efficiency [1], [68]. There is often a trade-off in efficiency or higher power consumption, leading to lower energy efficiency compared to more advanced systems [69], [70]. For instance, while a system might provide sufficient power for a target speed (e.g., 0.5 knots), it may not be able to achieve higher speeds due to insufficient thrust generated by the motors, often making them inherently power-inefficient [71].
- **Restricted Sensor and Processing Capabilities:** Low Low-cost ROVs often come with limitations in the sophistication and quality of their integrated sensors and the available onboard processing power, which can significantly affect mission effectiveness [4], [32], [72]. This can restrict their ability to execute advanced data processing algorithms or complex navigation tasks, and may introduce challenges related to thermal management for electronic components [4], [73].
- **Constrained Operational Range and Potential for Communication Issues:** The operational range of low-cost ROVs is typically limited by the length of their tether, with common ranges up to a few hundred meters [31]. Furthermore, achieving reliable underwater positioning and navigation, along with stable communication for control signals and video feedback, presents inherent challenges for underwater robots, as communication dependencies introduce exploitable weaknesses and glitches [74], [75], [76], [77].
- **Challenges in Handling and Overall Reliability:** The structural design and component choices in low-cost ROVs can sometimes lead to limitations in their ease of handling and overall reliability, making them more prone to accidents [32], [74]. The inherent trade-offs made to achieve affordability may mean these vehicles are more susceptible to wear and tear or require more careful operation compared to their more robust, high-end counterparts.

8.3 Applications

Despite certain technical limitations, the low-cost design philosophy allows for widespread adoption in areas like educational outreach, where students can assemble and experiment with ROVs without significant financial investment [78], [79], [80]. Furthermore, this approach provides an environmental monitoring where it is cost effective despite the reduced durability and power compared to more expensive alternatives [1]. Remotely Operated Vehicles operating at depths of 10-15 meters are indispensable tools across a range of applications, primarily leveraging their ability to conduct non-intrusive observation and data collection. These low-cost ROVs broaden access to underwater inspection and survey technologies, making them viable for both educational initiatives and preliminary environmental monitoring [1], [18], [26]. They can be used for detailed habitat mapping and aquatic life surveys, capturing high-definition video for monitoring purposes, aiding in ecological studies, and supporting educational outreach programs by allowing students to engage directly with marine environments [1].

For infrastructure management, these ROVs are critical for the safe and efficient inspection of submerged assets. This includes thorough examinations of the footings of bridges and piers, the upstream faces and gates of dams, and the integrity of pipelines and cables that lie on the lakebed, identifying issues such as scour, corrosion, and blockages without needing divers[81]. Their maneuverability allows access to confined spaces, making routine maintenance checks more accessible and reducing the costs and risks associated with human divers [82], [83].

Finally, in search, recovery, and security operations, their maneuverability and potential for integrated sonar capabilities make them ideal for locating and documenting sunken objects, evidence, or potentially hazardous materials. This offers a safe and rapid alternative to manual searching, particularly in hazardous or difficult-to-access underwater environments. However, for precise positioning in complex scenarios or open waters, the absence of an advanced integrated positioning system can be a limitation [84], [85]. The modular design of many low-cost ROVs also facilitates straightforward maintenance and customization, enhancing their utility in diverse operational contexts [54].

9. CONCLUSION

This This research presents an innovative and highly effective design strategy aimed at developing cost-minimized Remotely Operated Vehicles, fundamentally demonstrating the viability of constructing capable underwater systems by leveraging readily available, economical components. The methodological cornerstone of this approach centers the replacement of traditionally expensive ROV components with more accessible and cost-effective alternatives. Specifically, structural integrity is achieved through the use of PVC pipes, propulsion is managed by economical motors, and imaging capabilities are realized via basic endoscopic cameras. This strategic selection significantly mitigates manufacturing costs, consequently broadening access to essential underwater inspection and survey technologies, previously hindered by expensive equipment. This approach provides access to underwater technology, enabling researchers, educators, and hobbyists with limited budgets to engage in marine exploration, environmental monitoring, and educational initiatives that were previously inaccessible. The achieved cost-effectiveness, particularly in comparison to the significantly higher expense of commercial alternatives, positions this ROV as a highly valuable asset for a wide range of users [18].

The operational stability and functionality of the developed ROV were validated through experimental testing. A key aspect of this validation involved the strategic incorporation of foam floats, as detailed in the design phase, which successfully ensured precise buoyancy control and enhanced maneuverability, affirming the vehicle's reliable performance in underwater environments. The rigorous validation through experimental testing confirmed the ROV's operational stability, precise buoyancy control through integrated foam floats, and enhanced maneuverability, underscoring its readiness for practical deployment [86]. Ultimately, this work formally establishes that robust and effective tools for exploring and analyzing both natural and artificial aquatic environments can be reliably engineered through the application of resourceful and economically viable design and construction practices. This research not only proves the feasibility of constructing effective ROVs using economical methods but also paves the way for wider adoption of underwater robotics in various scientific, educational, and conservation efforts, offering a sustainable model for technological innovation in resource-constrained environments.

10. REFERENCES

[1] K. Mason and D. F. Kelly, “Lo-MARVE: A Low Cost Autonomous Underwater Vehicle for Marine Exploration,” arXiv (Cornell University) , Nov. 2024, doi: 10.48550/arxiv.2411.08605. (http://arxiv.org/abs/2411.08605)

[2] K. Mason and D. F. Kelly, “Lo-MARVE: A Low Cost Autonomous Underwater Vehicle for Marine Exploration,” p. 421, Nov. 2024, doi: 10.1109/iccma63715.2024.10843932. (https://doi.org/10.1109/iccma63715.2024.10843932)

[3] C. Edge et al. , “Design and Experiments with LoCO AUV: A Low Cost Open-Source Autonomous Underwater Vehicle,” in 2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) , Oct. 2020, p. 1761. doi: 10.1109/iros45743.2020.9341007. (https://doi.org/10.1109/iros45743.2020.9341007)

[4] E. A. I. Ruland, “Low-Cost Vision Based Autonomous Underwater Vehicle for Abyssal Ocean Ecosystem Research,” Deep Blue (University of Michigan) , Jan. 2020, Accessed:

Aug. 2025. [Online]. Available: https://hdl.handle.net/2027.42/155225

[5] P. Salunkhe, S. Jaybhay, and A. Barbadekar, "Structural Design of Underwater Drone using Brushless DC Motor," International Journal for Research in Applied Science and Engineering Technology , vol. 11, no. 5, p. 2376, May 2023, doi: 10.22214/ijraset.2023.51822. (https://doi.org/10.22214/ijraset.2023.51822)

[6] J. Xu, X. Irigoien, and M. Alouini, "State-of-the-Art Underwater Vehicles and Technologies Enabling Smart Ocean: Survey and Classifications," arXiv (Cornell University) , Dec. 2024, doi: 10.48550/arxiv.2412.18667. (https://doi.org/10.14713/arestyrurj.v1i3.167)

[7] M. J. Er, J. Chen, and Y. Zhang, "Marine Robotics 4.0: Present and Future of Real-Time Detection Techniques for Underwater Objects," in Artificial intelligence , IntechOpen, 2022.
doi: 10.5772/intechopen.107409.
(https://arxiv.org/abs/2303.13063)

[8] K. L. C. Bell et al. , "Low-Cost, Deep-Sea Imaging and Analysis Tools for Deep-Sea Exploration: A Collaborative Design Study," Frontiers in Marine Science , vol. 9, Aug. 2022,
doi: 10.3389/fmars.2022.873700.
(https://local.forskningsportal.dk/local/dki-cgi/ws/cris-link?src=sdu&id=sdu-20f28a85-21cd-4b9b-9db3-23b82915406e&ti=Military%20Drones%20in%20Europe%20%3A%20The%20European%20Defense%20Market%20and%20the%20Spread%20of%20Military%20UAV%20Technology)

[9] D. Novy et al. , "Maka Niu: A low-cost, modular imaging and sensor platform to increase observation capabilities of the deep ocean," Frontiers in Marine Science , vol. 9, Nov. 2022,
doi: 10.3389/fmars.2022.986237.
(https://doi.org/10.1155/2021/5542920)

[10] A. Tanveer and S. M. Ahmad, "Design of a Low-Cost Prototype Underwater Vehicle",
arXiv (Cornell University) , Jan. 2023, doi: 10.48550/arxiv.2303.13063.
(https://doi.org/10.3390/su152014691)

[11] M. Fabricius, D. Ø. Tarp, R. W. Kristensen, J. M. Andersen, J. Liniger, and S. Pedersen, "Modelling and Validation of a Remotely Operated Towed Vehicle and computational cost analysis of Umbilical Cable," IFAC-PapersOnLine , vol. 56, no. 3, p. 415, Jan. 2023,
doi: 10.1016/j.ifacol.2023.12.059.
(https://doi.org/10.3390/app14219671)

[12] D. Widhalm et al. , "Design and Development of the MeCO Open-Source Autonomous Underwater Vehicle," 2025, doi: 10.48550/ARXIV.2503.10928.
(https://doi.org/10.1016/j.oceaneng.2024.118777)

[13] Y. M. Ahmed, O. Yaakob, and B. K. Sun, "Design of a New Low Cost ROV Vehicle,"
Jurnal Teknologi , vol. 69, no. 7, Jul. 2014, doi: 10.11113/jt.v69.3262.
(http://nopr.niscair.res.in/bitstream/123456789/6204/1/IJMS%2038%283%29%20282-295.pdf)

[14] A. S. P. Pamula, M. J. Krzmarzick, M. Jdiobe, J. Jacob, and D. J. Lampert, "Development of Low-Cost, Open-Source Unmanned Surface Vehicle for Water System Monitoring," EarthArXiv (California Digital Library) , Aug. 2025, doi: 10.31223/x5s74g.
(https://doi.org/10.31223/x5s74g)

[15] T. Panati, S. D. Indraganti, and S. M. Santhanam, "Modeling and performance analysis of open-loop remotely operated vehicles ORCA," IAES International Journal of Robotics and Automation (IJRA) , vol. 12, no. 1, p. 108, Jan. 2023, doi: 10.11591/ijra.v12i1.pp108-124.
(https://doi.org/10.11591/ijra.v12i1.pp108-124)

[16] V. Anitha, N. Raalah, J. Vaishnavi, M. Sharanya, and G. Sneha, "Remote Underwater Robot," International Journal for Research in Applied Science and Engineering Technology , vol. 11, no. 7,
p. 786, Jul. 2023, doi: 10.22214/ijraset.2023.54657.

(https://doi.org/10.22214/ijraset.2023.54657)

[17] C. Maï, M. von Benzon, F. F. Sørensen, S. Klemmensen, S. Pedersen, and J. Liniger, "Design of an Autonomous ROV for Marine Growth Inspection and Cleaning," p. 1, Sep. 2022,
doi: 10.1109/auv53081.2022.9965928.
(https://doi.org/10.1109/auv53081.2022.9965928)

[18] Z. Smolder and J. Yi, "Cost-Effective Remote Operated Vehicle," Aresty Rutgers Undergraduate Research Journal , vol. 1, no. 3, Oct. 2021, doi: 10.14713/arestyrurj.v1i3.167.
(https://doi.org/10.14713/arestyrurj.v1i3.167)

[19] G. L. Foresti and I. Scagnetto, "An integrated low-cost system for object detection in underwater environments," Integrated Computer-Aided Engineering , vol. 29, no. 2, p. 123, Feb. 2022, doi: 10.3233/ica-220675.(https://doi.org/10.3233/ica-220675)

[20] J. S. Willners et al. , "From market-ready ROVs to low-cost AUVs," in OCEANS 2021: San Diego – Porto , Sep. 2021, p. 1. doi: 10.23919/oceans44145.2021.9705798.

(https://doi.org/10.23919/oceans44145.2021.9705798)

[21] M. S. Sujan, J. Howlader, J. Alam, and Md. A. I. Tapu, "Structure Design of Underwater Micro Robot," Modern Mechanical Engineering , vol. 14, no. 1, p. 12, Dec. 2023, doi: 10.4236/mme.2024.141002.(https://doi.org/10.4236/mme.2024.141002)

[22] R. Capocci, G. Dooly, E. Omerdić, J. Coleman, T. Newe, and D. Toal, "Inspection-Class Remotely Operated Vehicles—A Review," Journal of Marine Science and Engineering , vol. 5, no. 1, p. 13, Mar. 2017, doi: 10.3390/jmse5010013. (https://doi.org/10.3390/jmse5010013)

[23] O. Hassanein, G. A. Sreenatha, S. Aboobacker, and S. A. Salman, "Development of Low Cost Autonomous Underwater Vehicle Platform," International Journal on Smart Sensing and Intelligent Systems , vol. 14, no. 1, p. 1, Jan. 2021, doi: 10.21307/ijssis-2021-005.(https://doi.org/10.21307/ijssis-2021-005)

[24] N. M. Puzai, A. F. M. Ayob, and M. Arshad, "A Review on Recent Advancements in Unmanned Underwater Vehicle Design," Journal of Ocean Mechanical and Aerospace -science and engineering- (JOMAse) , vol. 31, no. 1. p. 1, May

30, 2016. doi: 10.36842/jomase.v31i1.411. (https://doi.org/10.36842/jomase.v31i1.411)

[25] S. Mohanty, A. Garg, S. S. Shukla, S. K. Dwivedy, S. Dutta, and R. Bharti, “River and Lake Monitoring Through Underwater Remotely Operated Vehicle,” in Lecture notes in civil engineering , Springer Nature, 2024, p. 265. doi: 10.1007/978-981-97-1227-4_19.
(https://doi.org/10.1007/978-981-97-1227-4_19)

[26] A. Temilolorun and Y. Singh, “Towards Design and Development of a Low-Cost Unmanned Surface Vehicle for Aquaculture Water Quality Monitoring in Shallow Water Environments,”arXiv (Cornell University) , Oct. 2024, doi: 10.48550/arxiv.2410.09513.
(https://doi.org/10.1007/978-981-97-1227-4_19)

[27] W. Denton et al. , “Oogway: Designing, Implementing, and Testing an AUV for RoboSub 2023,” arXiv (Cornell University) , Oct. 2024, doi: 10.48550/arxiv.2410.10900.
(http://arxiv.org/abs/2410.10900)

[28] Mark A. Teece, “An inexpensive remotely operated vehicle for underwater studies,”
Limnology and Oceanography: Methods , vol. 7, no. 3, p. 1, Mar. 2009, doi:10.4319/lom.2009.7.206.(https://aslopubs.onlinelibrary.wiley.com/doi/epdf/10.4319/lom.2009.7.206?domain=p2p_domain&token=JWDQAM5AMK55C3FFVDGR)

[29] B. Phillips et al. , “DEEPi: A miniaturized, robust, and economical camera and computer system for deep-sea exploration,” Deep Sea Research Part I Oceanographic Research Papers , vol. 153,p. 103136, Oct. 2019, doi: 10.1016/j.dsr.2019.103136.
(https://doi.org/10.1016/j.dsr.2019.103136)

[30] N. Madsen, M. Pedersen, K. T. Jensen, P. R. Møller, R. Ern, and T. B. Moeslund, “Fishing with C-TUCs (Cheap Tiny Underwater Cameras) in a Sea of Possibilities,” Research Portal Denmark ,vol. 16, no. 2, p. 19, Jan. 2021, Accessed: Jul. 2025. [Online].
Available: (https://local.forskningsportal.dk/local/dki-cgi/ws/cris-link?src=aau&id=aau-8f32e587-ff98-47c4-b68f-f7fca7707ae7&ti=Fishing%20with%20C-TUCs%20(Cheap%20Tiny%20Underwater%20Cameras)%20in%20a%20Sea%20of%20Possibilities)

[31] A. F. Irlind et al. , “ADVANTAGES AND LIMITATIONS OF USING CAMERAS ON SMALL, LOW-COST ROVS FOR SEABED MONITORING,” Research Portal Denmark , vol. 19, no. 4, p. 36, Jan. 2024, Accessed: Jul. 2025. [Online].
Available: (https://local.forskningsportal.dk/local/dki-cgi/ws/cris-link?src=aau&id=aau-aeeb2b00-bf0a-412d-ba17-7e52f44566e3&ti=ADVANTAGES%20AND%20LIMITATIONS%20OF%20USING%20CAMERAS%20ON%20SMALL%2C%20LOW-COST%20ROVS%20FOR%20SEABED%20MONITORING)

[32] R. Singh, P. Sarkar, V. Goswami, and R. Yadav, “Review of low cost micro remotely operated underwater vehicle,” Ocean Engineering , vol. 266, p. 112796, Oct. 2022, doi: 10.1016/j.oceaneng.2022.112796. (https://doi.org/10.1016/j.oceaneng.2022.112796)

[33] T. Ederer and I. Ivkić, “Implementing Video Monitoring Capabilities by using hardware-based Encoders of the Raspberry Pi Zero 2 W,” arXiv (Cornell University) , Jul. 2025,
doi: 10.48550/arxiv.2507.12487.
(http://arxiv.org/abs/2507.12487)

[34] G. Trobbiani and A. J. Irigoyen, “‘Pepe’: a novel low cost drifting video system for underwater survey,” p. 1, Jun. 2016, doi: 10.1109/saisoe.2016.7922472.
(https://doi.org/10.1109/saisoe.2016.7922472)

[35] E. Nocerino et al. , “MULTI-CAMERA SYSTEM CALIBRATION OF A LOW-COST REMOTELY OPERATED VEHICLE FOR UNDERWATER CAVE EXPLORATION,”
˜The œinternational archives of the photogrammetry, remote sensing and spatial information sciences/International archives of the photogrammetry, remote sensing and spatial information sciences , p. 329, Sep. 2018, doi: 10.5194/isprs-archives-xlii-1-329-2018.
(https://doi.org/10.5194/isprs-archives-xlii-1-329-2018)

[36] S. N. G. Hamal and A. Ulvi, “Investigation of Underwater Photogrammetry Method with Cost-Effective Action Cameras and Comparative Analysis between Reconstructed 3D Point Clouds,” Photogrammetric Engineering & Remote Sensing , vol. 90, no. 4, p. 251, Apr. 2024, doi: 10.14358/pers.23-00042r2. (https://doi.org/10.14358/pers.23-00042r2)

[37] H. R. Bohm, V. Jensen, and N. Johnston, Build your own underwater robot : and other wet projects by Harry Bohm and Vickie Jensen . Japan Society of Medical Entomology and Zoology, 1997. Accessed: Nov. 2025. [Online].
Available: http://ci.nii.ac.jp/ncid/BA82563574

[38] H. M. B. Munir, S. H. Qamar, S. Khan, A. D. Cheok, H. Ali, and M. Shoaib, “Design and Fabrication of a Low-Cost Multi-Purpose Underwater Remotely Operated Vehicle,” Qeios , Aug. 2023, doi: 10.32388/pwfy91. (https://doi.org/10.32388/pwfy91)

[39] W. H. Wang, X. Chen, A. Marburg, J. G. Chase, and C. E. Hann, “Design of low-cost unmanned underwater vehicle for shallow waters,” International Journal of Advanced Mechatronic Systems , vol.1, no. 3, p. 194, Jan. 2009, doi: 10.1504/ijamechs.2009.023202.
(https://doi.org/10.1504/ijamechs.2009.023202)

[40] K. D. Le, H. D. Nguyen, and D. Ranmuthugala, “Development and Control of a Low-Cost, Three-Thruster, Remotely Operated Underwater Vehicle,” International Journal of Automation Technology, vol. 9, no. 1, p. 67, Jan. 2015, doi: 10.20965/ijat.2015.p0067.
(https://doi.org/10.20965/ijat.2015.p0067)

[41] O. Tortorici, C. Péraud, C. Anthierens, and V. Hugel, “Automated Deployment of an Underwater Tether Equipped with a Compliant Buoy–Ballast System for Remotely Operated Vehicle Intervention,” Journal of Marine Science and Engineering , vol. 12, no. 2, p. 279, Feb. 2024, doi: 10.3390/jmse12020279.
(https://doi.org/10.3390/jmse12020279)

[42] A.-T. Nedelcu, C. Faităr, N. Buzbuchi, and L. C. Stan, “Study Simulation of Umbilical Cable for Underwater Vehicle,” Buletinul Institutului Politehnic din Iaşi. Secţia Construcţii de maşini/Buletinul Institutului Politehnic din

Iaşi, Secţia Construcţii de maşini , vol. 67, no. 3, p. 19, Sep. 2021, doi: 10.2478/bipcm-2021-0014.(https://doi.org/10.2478/bipcm-2021-0014)

[43] K. Shahani, C. Wu, R. Persaud, and H. Song, "Design and control of underwater hybrid vehicle capable of performing numerous tasks," Journal of Naval Architecture and Marine Engineering , vol. 15, no. 2, p. 127, Dec. 2018, doi: 10.3329/jname.v15i2.36890. (https://doi.org/10.3329/jname.v15i2.3689)

[44] C. de Q. Cáceres, A. Navarro-Ruíz, A. L. G. Navarro, T. G. Martínez, G. Otero, and J. A. Hernández, "Developing Cost-Effective Drones for 5G Non-Terrestrial Network Research and Experimentation," arXiv (Cornell University) , Sep. 2024, doi: 10.48550/arxiv.2409.19337. (http://arxiv.org/abs/2409.19337)

[45] Ø. Hasvold, N. Størkersen, S. Forseth, and T. Lian, "Power sources for autonomous underwater vehicles," Journal of Power Sources , vol. 162, no. 2, p. 935, Sep. 2005, doi: 10.1016/j.jpowsour.2005.07.021. (https://doi.org/10.1016/j.jpowsour.2005.07.021)

[46] W. Akram, M. U. Din, M. Heshmat, A. Casavola, L. Seneviratne, and I. Hussain, "Active vision-based real-time aquaculture net pens inspection using ROV," Scientific Reports , vol. 15, no. 1, Sep. 2025, doi: 10.1038/s41598-025-21083-6. (https://doi.org/10.1038/s41598-025-21083-6)

[47] A. Gupta, A. Abdullah, X. Li, V. Ramesh, I. Rekleitis, and M. J. Islam, "Demonstrating CavePI: Autonomous Exploration of Underwater Caves by Semantic Guidance," arXiv (Cornell University), Feb. 2025, doi: 10.48550/arxiv.2502.05384. (http://arxiv.org/abs/2502.05384)

[48] A. Abdullah, A. Gupta, V. Ramesh, S. G. Patel, and M. J. Islam, "NemeSys: An Online Underwater Explorer with Goal-Driven Adaptive Autonomy," arXiv (Cornell University) , Jul. 2025, doi: 10.48550/arxiv.2507.11889. (http://arxiv.org/abs/2507.11889)

[49] J. A. Bergshoeff, N. Zargarpour, G. Legge, and B. Favaro, "How to build a low-cost underwater camera housing for aquatic research," FACETS , vol. 2, p. 150, Jan. 2017, doi: 10.1139/facets-2016-0048. (https://doi.org/10.1139/facets-2016-0048)

[50] A. Rasheed, R. M. Hagem, and A. S. M. Khidhir, "Design and Implementation of an Interactive Embedded System as a Low-Cost Remotely Operated Vehicle for Underwater Applications,"Diyala Journal of Engineering Sciences , p. 173, Sep. 2024, doi: 10.24237/djes.2024.17312. (https://doi.org/10.24237/djes.2024.17312)

[51] R. Wiryadinata, A. S. Nurliany, I. Muttakin, and T. Firmansyah, "Design of a Low Cost Remotly Operated Vehicle with 3 Dof Navigation," Bulletin of Electrical Engineering and Informatics, vol. 6, no. 1, p. 13, Mar. 2017, doi: 10.11591/eei.v6i1.596. (https://doi.org/10.11591/eei.v6i1.596)

[52] R. A. S. Fernández, E. A. P. Ricaurte, Z. Milošević, S. Domínguez, and C. Rossi, "Design, Modeling and Control of a Spherical Autonomous Underwater Vehicle for Mine Exploration," in 2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) , Oct. 2018, p. 1513. doi: 10.1109/iros.2018.8594016. (https://doi.org/10.1109/iros.2018.8594016)

[53] C. Zavislak, A. Keow, Z. Chen, and F. H. Ghorbel, "AUV Buoyancy Control With Hard and Soft Actuators," IEEE Control Systems Letters , vol. 5, no. 6, p. 1874, Dec. 2020, doi: 10.1109/lcsys.2020.3044985. (https://doi.org/10.1109/lcsys.2020.3044985)

[54] M. Vukšić, S. Josipović, A. Ćorić, and A. Kraljević, "Underwater ROV as Inspection and Development Platform," Transactions on Maritime Science , vol. 6, no. 1, p. 48, Apr. 2017, doi: 10.7225/toms.v06.n01.005. (https://doi.org/10.7225/toms.v06.n01.005)

[55] B. Allotta et al. , "Preliminary design and fast prototyping of an Autonomous Underwater Vehicle propulsion system," Proceedings of the Institution of Mechanical Engineers Part M Journal of Engineering for the Maritime Environment , vol. 229, no. 3, p. 248, Jan. 2014,doi: 10.1177/1475090213514040.

(https://doi.org/10.1177/1475090213514040)

[56] Z. Wang, Z. Wei, C. Yu, J. Cao, B. Yao, and L. Lian, "DYNAMIC MODELING AND OPTIMAL CONTROL OF A POSITIVE BUOYANCY DIVING AUTONOMOUS VEHICLE," Brodogradnja, vol. 74, no. 1, p. 19, Dec. 2022, doi: 10.21278/brod74102. (https://doi.org/10.21278/brod74102)

[57] M. Li, R. Zheng, F. Ren, and B. Yang, "Design and testing of AUV variable buoyancy device," DOAJ (DOAJ: Directory of Open Access Journals) , Dec. 2021, doi: 10.19693/j.issn.1673-3185.02500. (https://doaj.org/article/17bdcc9d75704c5db38eb5003ab034a7)

[58] R. Dell'Erba, "STUDIO DI FATTIBILITÀ Una schiuma economica per la spinta idrostatica dei ROV," HAL (Le Centre pour la Communication Scientifique Directe) , Jan. 2010, Accessed: Jan. 2025. [Online]. Available: https://hal.science/hal-01977300

[59] "Design and Fabrication of A Low Cost Submersible ROV for Survey of Lakes," International Research Journal of Engineering and Technology (IRJET) , vol. 4, no. 9, p. 1, Sep. 2017.(https://www.irjet.net/archives/V4/i9/IRJET-V4I9125.pdf)

[60] E. V. Palconit and M. L. S. Abundo, "Electric Ferry Ecosystem for Sustainable Inter-Island Transport in Philippines: A Pilot Study," Engineering Technology & Applied Science Research , vol. 8, no. 6, p. 3570, Dec. 2018, doi: 10.48084/etasr.2382. (https://doi.org/10.48084/etasr.2382)

[61] A. K. Lidtke, N. P. Linton, H. L. Wright, S. R. Turnock, and J. A. Downes, "End-to-end efficiency quantification of an autonomous underwater vehicle propulsion system," Ocean Engineering , vol. 234, p. 109223, Jun. 2021, doi: 10.1016/j.oceaneng.2021.109223. (https://doi.org/10.1016/j.oceaneng.2021.109223)

[62] D. Popescu, C. Popescu, and A. Dragomirescu, "Flow control in Banki turbines,"

Energy Procedia , vol. 136, p. 424, Oct. 2017, doi: 10.1016/j.egypro.2017.10.272.
(https://linkinghub.elsevier.com/retrieve/pii/S1876610217352220)

[63] A. Kulkarni, "Unmanned Marine Vehicle for Disaster Management,"
International Journal of Engineering Research and , no. 9, Sep. 2020, doi: 10.17577/ijertv9is090047
(https://doi.org/10.17577/ijertv9is090047)

[64] J. Wang et al. , "Design and architecture of a slender and flexible underwater robot,"
Intelligent Service Robotics , vol. 17, no. 3, p. 445, May 2024, doi: 10.1007/s11370-024-00539-0.
(https://doi.org/10.1007/s11370-024-00539-0)

[65] R. I. Chowdhury, N. Bala, R. N. Roy, and T. Mahmud, "BactoBot: A Low-Cost, Bacteria-Inspired Soft Underwater Robot for Marine Exploration," arXiv (Cornell University) , Sep. 2025,doi: 10.48550/arxiv.2509.20964.
(http://arxiv.org/abs/2509.20964)

[66] H. C. Nguyen and N. H. Hiep, "Design and Simulation of a Fuel Cell-based Hybrid Underwater Vehicle Propulsion System in Matlab/Simulink," Engineering Technology & Applied Science Research , vol. 14, no. 4, p. 14910, Aug. 2024, doi: 10.48084/etasr.7550.
(https://doi.org/10.48084/etasr.7550)

[67] J. Teague, M. J. Allen, and T. B. Scott, "The potential of low-cost ROV for use in deep-sea mineral, ore prospecting and monitoring," Ocean Engineering , vol. 147, p. 333, Nov. 2017, doi: 10.1016/j.oceaneng.2017.10.046.
(https://www.ijraset.com/best-journal/structural-design-of-underwater-drone-using-brushless-dc-motor)

[68] A. Laidani, M. Bouhamida, and Z. Bellahcene, "A marine thruster's model identification based on experimental-simulation approach," Indonesian Journal of Electrical Engineering and Computer Science , vol. 28, no. 3, p. 1414, Oct. 2022, doi: 10.11591/ijeecs.v28.i3.pp1414-1424.(https://arxiv.org/abs/2411.08605)

[69] E. Kelasidi, K. Y. Pettersen, and J. T. Gravdahl, "Energy efficiency of underwater robots," IFAC-PapersOnLine , vol. 48, no. 16, p. 152, Jan. 2015, doi: 10.1016/j.ifacol.2015.10.273.
(https://linkinghub.elsevier.com/retrieve/pii/S2405896315021643)

[70] F. M. Rockenbauer et al. , "Dipper: A Dynamically Transitioning Aerial-Aquatic Unmanned Vehicle," Jun. 2021, doi: 10.15607/rss.2021.xvii.048.
(https://doi.org/10.15607/rss.2021.xvii.048)

[71] K. Macauley, L. Cai, P. G. Adamczyk, and Y. Girdhar, "ReefGlider: A Highly Maneuverable Vectored Buoyancy Engine Based Underwater Robot," p. 6082, May 2024,
doi: 10.1109/icra57147.2024.10610140.
(https://ieeexplore.ieee.org/document/10610140/)

[72] J. D. Hernández, E. Vidal, M. Moll, N. Palomeras, M. Carreras, and L. E. Kavraki, "Online motion planning for unexplored underwater environments using autonomous underwater vehicles," Journal of Field Robotics , vol. 36, no. 2, p. 370, Nov. 2018, doi: 10.1002/rob.21827.
(https://deepblue.lib.umich.edu/items/747fc569-0382-4df7-81a5-0afffd4cc6ef)

[73] A. M. Muñoz, M. J. Morón, D. Cascado-Caballero, F. Díaz-del-Río, and P. Real, "Autonomous Underwater Vehicles: Identifying Critical Issues and Future Perspectives in Image Acquisition," Sensors , vol. 23, no. 10, p. 4986, May 2023, doi: 10.3390/s23104986.
(https://deepblue.lib.umich.edu/items/747fc569-0382-4df7-81a5-0afffd4cc6ef)

[74] G. J. Schaub, K. S. Kristensen, and F. Pradhan-Blach, "Long Time Coming : Developing and Integrating UAVs into the American, British, French, and Danish Armed Forces," Technical University of Denmark, Jan. 2014. Accessed: Jul. 2025. [Online].
Available: (https://local.forskningsportal.dk/local/dki-cgi/ws/cris-link?src=ku&id=ku-031f8250-2bcd-4e49-ae51-cd563780007b&ti=Long%20Time%20Coming%20%3A%20Developing%20and%20Integrating%20UAVs%20into%20the%20American%2C%20British%2C%20French%2C%20and%20Danish%20Armed%20Forces)

[75] "Bayraktar Akinci vs IAI Heron TP (Eitan): Comparative Analysis."
(https://doi.org/10.1038/s41522-018-0073-2)

[76] D. Kunertova, "Military Drones in Europe : The European Defense Market and the Spread of Military UAV Technology," Technical University of Denmark, Jan. 2019. Accessed: Aug. 2025. [Online].Available: (https://local.forskningsportal.dk/local/dki-cgi/ws/cris-link?src=sdu&id=sdu-20f28a85-21cd-4b9b-9db3-23b82915406e&ti=Military%20Drones%20in%20Europe%20%3A%20The%20European%20Defense%20Market%20and%20the%20Spread%20of%20Military%20UAV%20Technology)

[77] L. Sun, Y. Wang, X. Hui, X. Ma, X. Bai, and M. Tan, "Underwater Robots and Key Technologies for Operation Control," Cyborg and Bionic Systems , vol. 5, p. 89, Jan. 2024, doi: 10.34133/cbsystems.0089.(https://doi.org/10.34133/cbsystems.0089)

[78] A. El-Fakdi and X. Cufí, "An Innovative Low Cost Educational Underwater Robotics Platform for Promoting Engineering Interest among Secondary School Students," Electronics , vol. 11, no. 3, p. 373, Jan. 2022, doi: 10.3390/electronics11030373.
(https://www.mdpi.com/2079-9292/11/3/373)

[79] X. Cufí et al. , "EDUROVs: A Low Cost and Sustainable Remotely Operated Vehicles Educational Program," Sustainability , vol. 13, no. 15, p. 8657, Aug. 2021, doi: 10.3390/su13158657.(https://www.mdpi.com/2071-1050/13/15/8657)

[80] C. Song and Z. Zhao, "'ROVer'-Low-Cost ROV for Innovative Ocean Education and Discovery," p. 267, Oct. 2020, doi: 10.1109/cipae51077.2020.00075.
(https://ieeexplore.ieee.org/document/9373660/)

[81] A. Laidani et al. , "Design and Modeling of a Low-Cost Observation Class ROV for Dam Inspection," in 2022 2nd International Conference on Advanced Electrical Engineering (ICAEE),Oct. 2022, p. 1. doi: 10.1109/icaee53772.2022.9962007.

(https://ieeexplore.ieee.org/document/9962007/)

[82] D. T. Nguyen, C. L. Elseth, J. R. Øvstaas, N. Arntzen, G. Hamre, and D.-B. Lillestøl, "Enabling scalable inspection of offshore mooring systems using cost-effective autonomous underwater drones," Frontiers in Robotics and AI , vol. 12, p. 1655242, Oct. 2025, doi: 10.3389/frobt.2025.1655242. (https://www.frontiersin.org/journals/robotics-and-ai/articles/10.3389/frobt.2025.1655242/full)

[83] Underwater Work . IntechOpen, 2020. doi: 10.5772/intechopen.83282. (https://doi.org/10.5772/intechopen.83282)

[84] J. P. Martinez-Esteso, F. J. Castellanos, J. Calvo-Zaragoza, and A. Gallego, "Maritime search and rescue missions with aerial images: A survey," Computer Science Review , vol. 57, p. 100736, Feb. 2025, doi: 10.1016/j.cosrev.2025.100736. (https://www.sciencedirect.com/science/article/pii/S1574013725000139?via%3Dihub)

[85] E. Costa, F. Guerra, and P. Vernier, "SELF-ASSEMBLED ROV AND PHOTOGRAMMETRIC SURVEYS WITH LOW COST TECHNIQUES," ˜The œinternational archives of the photogrammetry, remote sensing and spatial information sciences/International archives of the photogrammetry, remote sensing and spatial information sciences , p. 275, May 2018, doi: 10.5194/isprs-archives-xlii-2-275-2018. (https://isprs-archives.copernicus.org/articles/XLII-2/275/2018/)

[86] Tristan Cowan, "Design Requirements for an ROV for Marine Science Education," University of New Haven: West Haven, CT, USA . 2016. [Online]. Available: (https://www.newhaven.edu/_resources/documents/academics/surf/past-projects/2013/tristan-cowan-paper.pdf)