DESIGN AND FABRICATION OF A SUBMERSIBLE REMOTELY OPERATED VEHICLE (ROV) FOR LAKEBED EXPLORATION

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DEPARTMENT OF MECHANICAL ENGINEERING

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CERTIFICATION

This is to certify that the project titled: “DESIGN AND FABRICATION OF REMOTELY OPERATED VEHICLE (ROV) FOR LAKEBED EXPLORATION” was carried out under the supervision of Prof. E.A Sadjere.

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DEDICATION

We dedicate this project to our families, whose unwavering support and encouragement have been the foundation of our academic journey. Their belief in our potential has been our driving force through every challenge and success. We are also deeply grateful to our supervisor and lecturers, who have guided us with their knowledge and wisdom, shaping our understanding of engineering and innovation.

Furthermore, this work is dedicated to all aspiring engineers and researchers in underwater robotics. May this project inspire future innovations in submersible Remotely Operated Vehicles (ROVs) and contribute to advancements in marine exploration and technology.

Lastly, We extend this dedication to the scientific and research communities striving to make underwater exploration more accessible, efficient, and impactful. May this work serve as a steppingstone towards new discoveries and technological improvements in the field of marine engineering.

ACKNOWLEDGEMENTS

I would like to extend my sincere gratitude to everyone who contributed to the successful completion of this project. Special thanks go to my project advisor, Prof. E.A Sadjere, for their invaluable guidance and support throughout this process. I also appreciate the assistance provided by my colleagues, the technical staff who supported the prototyping and testing phases, and my family for their unwavering encouragement.

ABSTRACT

This project presents the design and fabrication of a cost-effective submersible Remotely Operated Vehicle (ROV) intended for underwater exploration, specifically for lakebed surveys and crack observations. The study aims to develop an affordable, durable, and highly maneuverable ROV using a syringe-actuated buoyancy system, PVC hull construction, and a combination of propellers and pumps for navigation. Unlike conventional ROVs that rely solely on thrusters, this design integrates a novel buoyancy control mechanism to enhance precision and stability in shallow water operations.

The development process involved conceptualizing the structural framework, selecting appropriate materials, and integrating propulsion, control, and buoyancy systems. The ROV was fabricated using lightweight and corrosion-resistant materials such as PVC pipes and acrylic plates, ensuring durability and cost efficiency. A single brushless motor provided forward propulsion, while four strategically placed syringe-actuated pumps enabled controlled vertical and lateral movement. The prototype underwent rigorous testing to evaluate maneuverability, depth control, and structural integrity.

Results demonstrated that the ROV successfully achieved stable and precise movements, making it an effective tool for underwater inspections. The syringe-actuated buoyancy system provided reliable depth control, although minor delays in response time were noted. While the design proved efficient for shallow-water exploration, enhancements in power efficiency and material optimization are recommended for future iterations. Overall, this project contributes to the advancement of affordable underwater robotics, offering a practical solution for research, environmental monitoring, and industrial applications.

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CHAPTER 1

INTRODUCTION

The marine environment presents a vast, fascinating, yet challenging frontier for exploration, with much of its depths remaining untouched due to its complex and hazardous nature. These complexities limit human access and the scope of underwater research and operations. To address this, specialized equipment such as Remotely Operated Vehicles (ROVs) has become essential, allowing researchers and operators to explore, monitor, and interact with environments otherwise inaccessible. This paper outlines the design and construction of ROV tailored for underwater exploration, emphasizing variations based on application needs. ROVs are classified into categories such as micro, mini, general-purpose, light work-class, and heavy work-class, with each type designed for specific underwater tasks. Selecting the appropriate design and classification is crucial when developing a new ROV to meet the demands of diverse underwater missions.

ROVs, a subset of Unmanned Underwater Vehicles (UUVs), are instrumental in conducting underwater tasks that require real-time data collection and visual monitoring via on-board cameras and sensors. Operated through tethered cables linked to control interfaces like joysticks, touch panels, or keyboards, ROVs allow precise maneuvering in underwater environments. Autonomous Underwater Vehicles (AUVs), a more independent type, operate without direct human input, although tethered ROVs provide advantages in real-time decision-making, especially in unpredictable conditions. In this work, we present a cost-effective, portable, small-class observation ROV designed specifically for lakebed exploration, with a focus on achieving real-time data telemetry and operator control. To enhance operability in dynamic lake environments, the system enables responsive human intervention during missions. Modern ROVs vary widely, distinguished by factors such as size, depth rating, horsepower, and propulsion type (electro-hydraulic or fully electric). The proposed ROV falls within the micro and mini categories, operating under 5 horsepower, and is intended for efficient and effective visual inspection of lakes. This paper details the ROV's design and fabrication process, tailored for comprehensive underwater observation in challenging lake conditions.

1.1 Background to study

1.1.1. Definition of Remotely Operated Vehicles (ROVs)

Remotely Operated Vehicles (ROVs) are submersible robotic systems designed to explore and observe the depths of large bodies of water from a distance. They enable operators to conduct underwater exploration without the need for direct human presence in potentially hazardous environments. This capability is particularly valuable in marine research and exploration, allowing scientists and researchers to investigate aquatic ecosystems, underwater geological formations, and archaeological sites.

1.1.2. Brief history of ROVs in marine exploration

The origins of remotely operated vehicles (ROVs) date back to the mid-19th century. The first precursor was the Programmed Underwater Vehicle (PUV), an early torpedo design developed by the Luppis-Whitehead Automobile Company in Austria in 1864. However, the first true modern ROV didn't appear until 1953 when Dimitri Rebikoff created the "POODLE," a tethered ROV, marking a significant advancement over the PUV's untethered design.

ROV technology began to see rapid development during the 1960s when the U.S. Navy recognized its potential for deep-sea exploration. The Navy's first models were known as "Cable-Controlled Underwater Recovery Vehicles" (CURVs), designed primarily for search and recovery missions in deep, hazardous waters. With these devices, the longstanding belief that sunken objects were irretrievably lost began to shift. Notable expeditions, including explorations of the Titanic and other shipwrecks, became possible, shedding new light on lost maritime history.

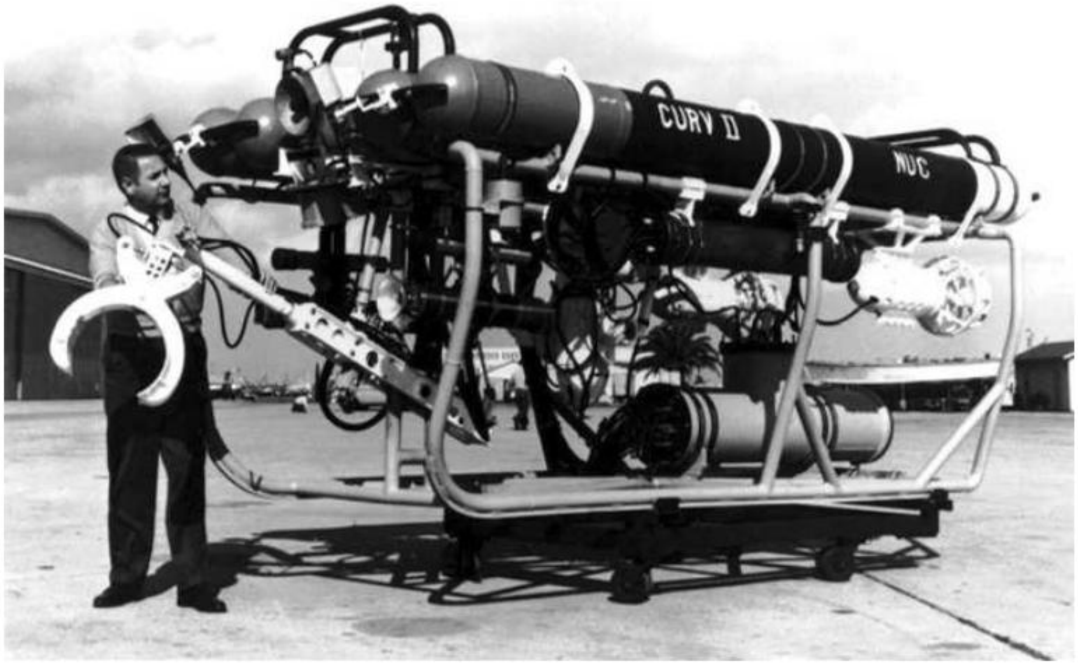


Fig 1: The Navy's CURV II vehicle.

By the 1980s, ROV technology had evolved and found applications in the oil and gas industry. Today, after decades of refinement, ROVs are integral to numerous sectors beyond military and marine industries.

Interest in manned underwater exploration also surged in the late 20th century, especially to study chemical, biological, and geological processes in underwater environments. This trend began with the FAMOUS Project in the 1970s along the Mid-Ocean Ridge. The 1980s saw a growing demand for ROVs, particularly for oil and gas applications. Research and development have continued to expand, leading to the creation of Unmanned Underwater Vehicles (UUVs), which now support a range of uses, from inspecting hull conditions to oceanographic research and pollution analysis.

Among UUVs, a specialized category called Autonomous Underwater Vehicles (AUVs) operates independently, guided by on-board microcomputers. In contrast, ROVs require direct human control, typically through cables or wireless systems. Today, both ROVs and AUVs are vital tools in advancing underwater exploration and understanding our marine environments.

1.1.3 Importance of ROVs in Underwater Applications

I. **Archaeological and Deep-Sea Exploration:** ROVs enable the detection of underwater archaeological objects, essential for preserving cultural heritage. Technologies like the SURF algorithm enhance object recognition capabilities, specifically tailored for ROVs. Deep-water ROVs are modified to take seabed samples, aiding marine geology and environmental research.

II. **Oil and Gas Industry:** ROVs are indispensable in high-pressure deep-water environments, where human divers cannot operate safely. They support the construction and maintenance of offshore oil and gas fields, crucial for the energy sector. Examples include the Mexican Oil ROV, which is tailored for the industry's needs, showcasing their utility in hazardous environments.

III. **Research-Oriented ROVs:** Specialized ROVs, such as "DENA," "H-ROV," and "Eyeball," are developed for scientific research, contributing to marine biology and ecological studies. They provide insights into aquatic ecosystems, supporting knowledge expansion and biodiversity conservation.

IV. **Military and Defense:** ROVs are adapted for military uses, such as mine detection and surveillance, providing a safer alternative to human-operated missions in dangerous zones

V. **Underwater Communication Challenges:** Communication between ROVs and base stations is complex due to underwater conditions.

VI. **Acoustic Communication:** Sound waves allow long-range communication, but suffer from limitations in speed, bandwidth, and signal strength.

VII. **Optical Communication:** Used for short distances but limited by light scattering in water. Preferred Method: Tethered communication (e.g., optical fiber, Ethernet cable) is favored for its reliability and practicality in most operations.

VIII. **Accessibility in Restricted Zones:** ROVs reach depths and confined areas that are otherwise inaccessible to human divers, expanding exploration capabilities. Essential for conducting ecological studies where human presence might disturb wildlife, such as in aquaculture.

IX. **Routine Maintenance and Inspection:** ROVs perform essential inspections of underwater hulls, ensuring structural integrity and preventing invasive species contamination. These include inspecting pipelines and inshore infrastructure to detect potential issues that could impact both operational safety and environmental health

1.2. Statement of the Problem

Remotely Operated Vehicles (ROVs) are essential tools for underwater exploration, maintenance, and research. However, most available ROV systems are either too expensive for widespread use, or the affordable ones either lack durability in harsh environments, or do not possess the versatility required for a range of underwater tasks. The high cost of advanced ROVs restricts their use to specific industries or organizations with significant budgets, while cheaper alternatives often fail to meet the operational demands for deep-water exploration, accessing areas vessels or humans can't fit into, everyday use like retrieval of lost items in beaches and ocean, precise control, or multi-task capabilities. This study addresses the pressing need for a cost-effective, durable, and versatile ROV capable of performing a wide variety of underwater tasks across multiple industries, from research to offshore energy, with enhanced maneuverability and control.

The demand for affordable and resilient ROVs is growing rapidly as industries such as oceanography, offshore drilling, and marine biology increasingly rely on these vehicles for tasks ranging from exploration to infrastructure maintenance. Existing solutions often fail to balance the three essential attributes of cost-effectiveness, durability, and versatility. Many commercially available ROVs are prohibitively expensive, limiting their use to high-budget projects. Furthermore, these systems may lack the robustness needed to withstand harsh underwater conditions like high pressure, strong currents, and variable temperatures. The ability to design a versatile ROV capable of adapting to multiple missions—whether it's pipeline inspection, environmental monitoring, or rescue operations—is crucial to filling this need.

This research aims to address several critical gaps in the current market for ROVs:

1. Affordability: Many ROV systems are inaccessible to smaller institutions or industries due to high costs. A key objective is to develop a more cost-effective solution that can still perform complex underwater tasks.

2. Durability: Existing ROVs often struggle with long-term operation in challenging environments. The proposed design will prioritize materials and structural integrity, allowing the ROV to endure high-pressure depths and rough conditions without frequent repairs or replacement.
3. Versatility: Current ROVs are often designed for single-use cases. The ROV in this study will be multipurpose, capable of performing diverse underwater tasks such as monitoring, inspection, exploration, and rescue missions. It will also be adaptable to both shallow and deep-water operations, with precise and easy to use controls.
4. Maneuverability and Control: Many ROVs lack precision in control, especially in strong currents or confined spaces. This design will focus on improving control mechanisms to allow for enhanced navigation and task execution.

1.3 Aim and Objectives of the Study

1.3.1 Aim

The aim of this study is to design and fabricate a cost-effective, durable, and versatile submarine Remotely Operated Vehicle (ROV) capable of performing a wide range of underwater tasks with high efficiency, maneuverability, and control precision.

1.3.2 Objectives

The primary objectives of the study include:

1. Improved Maneuverability: To design an ROV that can be precisely controlled in various underwater environments, including strong currents and confined spaces, ensuring stability and ease of navigation.
2. Depth Capability: The ROV should be capable of operating at significant depths without compromising performance or durability, achieving a higher depth tolerance than most commercially available systems in the same price range.
3. Control Precision: Incorporating advanced sensors and control systems to enhance the ROV’s ability to perform detailed tasks like object retrieval, inspection, and monitoring with minimal operator input.

4. Durability: Using corrosion-resistant materials and robust structural design to ensure long-term operation in harsh underwater environments, including deep-sea conditions.
5. Cost-Effectiveness: Maintaining a focus on affordability by using readily available components and efficient design principles to ensure that the ROV is accessible to industries and institutions with limited budgets.

1.4 Significance of Study.

1.4.1. Coverage of the Design

This study focuses on the design and operational framework of a small-class Remotely Operated Vehicle (ROV) optimized for freshwater lake exploration. The primary design aim is to create an affordable and portable ROV suited for real-time lakebed inspection and other underwater tasks, like environmental monitoring, object retrieval, and structure inspection. Key design coverage areas include:

- Depth Capabilities: The ROV is configured to operate within shallow to moderate depths typical of lake environments, ensuring sufficient pressure resistance and maneuverability for efficient lakebed observation.
- Environmental Adaptability: To address the unique conditions in lakes, such as low visibility, temperature fluctuations, and variable water currents, the ROV integrates appropriate sensors and durable materials.
- Operational Tasks: Equipped with visual and data telemetry tools, the ROV allows for continuous inspection and monitoring, crucial for environmental assessments and maintaining underwater structures. Onboard sensors support data collection on environmental variables, while real-time communication ensures prompt decision-making by the operator.
- System Classification and Power: The ROV falls within the micro/mini class, utilizing an all-electric design with under 5 horsepower, balancing power with portability. This design choice enhances ease of control while maintaining enough propulsion for targeted freshwater tasks.

1.4.2. Limitations of the Design

While the ROV is engineered to meet specific operational needs, certain limitations are acknowledged that impact its broader functionality:

1. *Restricted Operational Depth:* The ROV's size and power configuration constrain it to shallow and moderate depths, limiting its suitability for deep-water exploration or high-pressure environments.
2. *Mobility Constraints Due to Tethering:* As a tethered vehicle, the ROV's range of motion is restricted by the cable length and potential entanglement risks, limiting its exploration area, especially in expansive lake settings.
3. *Environmental Challenges:* External disturbances like unpredictable currents, low visibility, and water temperature shifts may affect the ROV's stability, sensor performance, and image clarity during missions, requiring skilled operator control.
4. *Task Limitations:* The ROV is intended for non-invasive tasks such as observation and monitoring, meaning it lacks the power and structural reinforcement for heavy-duty functions like excavation, lifting, or intense physical interaction with underwater objects.

1.4.3 Contribution to Marine Exploration, Inspection, and Related Fields

This study contributes to the advancement of marine exploration and inspection by developing a small-class observation ROV specifically tailored for freshwater environments. By focusing on cost-effective and portable design solutions, this research expands accessibility to underwater exploration tools, which were traditionally limited to larger, high-budget projects. The ROV's real-time telemetry, onboard sensors, and adaptability to shallow and mid-depth conditions make it a valuable resource for continuous visual inspection and monitoring in otherwise inaccessible underwater areas.

The ROV's design can support a range of marine activities beyond lakebed exploration, such as environmental assessments, biodiversity studies, and infrastructure inspections for assets like dams and pipelines. These contributions bridge a gap in existing technologies by providing an affordable solution for marine research, which can be utilized by educational institutions, environmental agencies, and commercial operators. Furthermore, this ROV's application to real-time data collection and responsive maneuvering offers insight into how small, portable ROVs can enhance ecological monitoring, inform conservation efforts, and facilitate safer underwater asset maintenance.

This study is significant because it addresses a growing need for accessible, efficient, and precise tools in both industrial and academic fields related to marine and freshwater environments. For industry, this ROV's compact design and operational versatility offers a practical solution for inspection tasks in sectors like environmental services, water management, and infrastructure maintenance, especially where cost and maneuverability are priorities. By enabling safer, remote inspections in potentially hazardous areas, this ROV could reduce the need for direct human intervention in confined or difficult underwater environments, thereby enhancing safety and operational efficiency.

In academia, the ROV's design and adaptability serve as an educational model for engineering and marine science programs, offering hands-on learning opportunities in underwater robotics, data collection, and environmental analysis. Universities and research institutions can utilize this ROV in field studies, providing students with practical experience in using advanced technology for ecological monitoring and aquatic research. Moreover, the ROV's affordability makes it an attractive resource for long-term environmental studies, biodiversity assessments, and the development of sustainable practices in water resource management.

In essence, this study not only contributes to technological advancements in marine exploration but also aligns with the broader goals of safety, sustainability, and accessibility, making it a significant asset in both industrial and academic applications.

1.5 Research Gap

Despite the advancements in Remotely operational vehicles (ROVs) for underwater exploration, several critical gaps remain in existing designs, particularly for cost-effective, durable, and versatile small-class ROVs suited for lakebed exploration. The following gaps in current research and technology justify the need for this study:

1. **Cost vs. performance Trade-off** – Existing small-class ROVs are either too expensive for widespread use or lack the necessary durability and versatility for prolonged

underwater operations. While cost-effective models exist, they often compromise on advanced control systems, depth capabilities, and structural resilience.

2. **Limited adaptability for shallow water and Dynamic Environments -** Most commercially available ROVs are either optimized for deep-sea operations or confined to laboratory research, with limited adaptability to dynamic freshwater environments like lakes. Challenges such as varying turbidity strong currents, and temperature fluctuations impact the effectiveness of current models.
3. **Maneuverability and control Limitations** – Many small class ROVs struggle with precise maneuvering, especially in constrained spaces. The absence of advanced thrust-vectoring mechanisms or efficient propulsion layouts often results in limited stability and reduced operational control in real-time applications.
4. **Lack of affordable Real-Time data Telemetry** – While high-end ROVs offer sophisticated real-time data transmission and telemetry systems, lower cost alternatives often lack these capabilities, reducing their effectiveness for continuous monitoring, environmental assessment, and research applications.
5. **Material and durability concerns** – The majority of cost-effective ROVs are constructed using materials that are not optimized for prolonged underwater exposure, leading to reduced lifespan and frequent maintenance issues. Research is lacking in how to innovate material choices, such as PVC and corrosion resistant components, can enhance longevity without significantly increasing production costs.
6. **Energy Efficient and Power Constraints** – Battery life and energy management remains critical concerns for small-class ROVs, especially in missions requiring extended operational time. Current research does not sufficiently address how optimized propulsion systems and lightweight designs can extend operational time. Current research does not sufficiently address how optimized propulsion systems and lightweight designs can extend operational efficiency while maintaining power sustainability.

1.5.1 Addressing the Research Gap

This study aims to bridge a gap by designing and fabricating a **cost-effective, highly maneuverable, and durable small** ROV tailored for lakebed exploration. By integrating an **optimized propulsion system, real-time data telemetry, and innovative material selection**, this project seeks to create a practical solution that balances affordability with high functionality.

The findings will contribute to the growing field of underwater robotics by offering insights into **low-cost, high performance ROV development for research, commercial and industrial applications.**

CHAPTER 2

LITERATURE REVIEW

2.1. Overview of ROV Technology

Remotely Operated Vehicles (ROVs) are submersible robotic systems designed to explore and observe the depths of large bodies of water from a distance. They enable operators to conduct underwater exploration without the need for direct human presence in potentially hazardous environments. This capability is particularly valuable in marine research and exploration, allowing scientists and researchers to investigate aquatic ecosystems, underwater geological formations, and archaeological sites.

2.1.1 Operational Mechanism

ROVs are typically operated by personnel located on a surface vessel, using controls that resemble those found in video gaming. The connection between the ROV and the surface vessel is established through a series of cables, known as tethers, which facilitate the transmission of electrical signals. This tether system allows for real-time control and monitoring of the ROV's activities.

Most ROVs are equipped with essential imaging devices, including still and video cameras, as well as illumination systems that enable them to capture high-quality images and videos in low-light underwater conditions. In addition to these basic components, ROVs can be outfitted with a variety of specialized equipment, such as robotic manipulators, cutting tools, water sampling devices, and sensors that measure various environmental parameters like water clarity, temperature, and pressure. This versatility makes ROVs suitable for a broad range of applications, from scientific research to industrial inspections.

2.1.2 Historical Context and Applications

Initially developed for industrial purposes, ROVs were primarily used for internal and external inspections of underwater pipelines and the structural testing of offshore platforms. Over time, their applications have expanded significantly. ROVs have become indispensable tools in ocean exploration, offering significant contributions to marine science by enabling researchers to access and study environments that are otherwise challenging to reach.

In addition to scientific exploration, ROVs are utilized in educational programs at aquariums and marine research institutions, providing live feeds of underwater activities to audiences around the world via the Internet. This capability enhances public engagement and interest in marine sciences and conservation efforts.

2.1.2 Size and Design Variability

ROVs vary greatly in size, ranging from compact units comparable to a small computer to larger systems that can be as big as a small truck. The larger ROVs typically require additional equipment, such as winches, to safely deploy them from the deck of a vessel into the water. The design and construction of ROVs are tailored to meet specific operational requirements, including depth capabilities, maneuverability, and payload capacity.

2.1.3. Safety and Advantages

One of the primary advantages of using ROVs is the elimination of human presence in potentially dangerous underwater environments. This significantly reduces the risks associated with diving operations and manned submersibles. ROVs can conduct operations in depths that are beyond the safe reach of human divers, and they can remain submerged for extended periods, far exceeding the duration of human divers. This capability expands the window for exploration and data collection, facilitating more thorough research and investigation of underwater sites.

Overall, ROV technology represents a significant advancement in marine exploration and research. Their continued development and deployment not only enhance our understanding of the ocean and its ecosystems but also provide critical support for various industrial applications, making them essential tools in both scientific and commercial fields.

2.2. Types of ROVs:

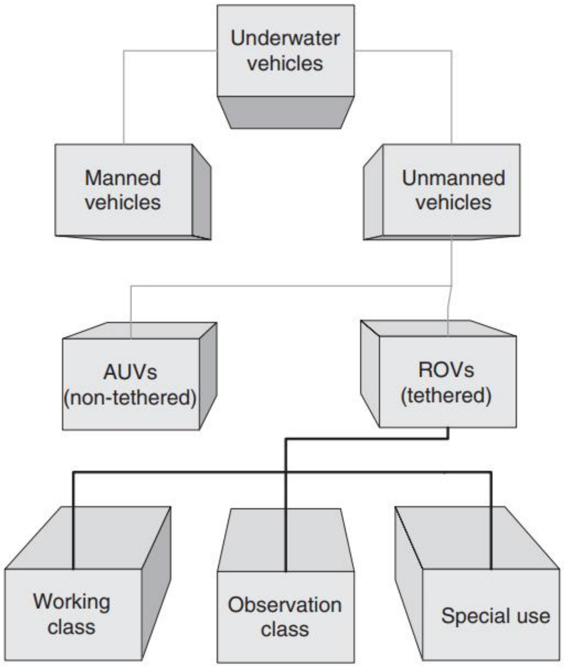


Fig 2: underwater vehicles

a) **Work Class ROV**

A work class ROV is used for ocean floor exploration and inspections at depths that divers are often unable to reach. They act as a safe alternative to divers and are often used in offshore energy projects and deep archaeological investigations. The typical depth rating for a Work Class ROV ranges from 3,000 meters (9,800 feet) to 6,000 meters (19,700 feet). They can carry additional sensors and have multiple capabilities that allow for additional tools due to their FO-equipped umbilical. They are very powerful and useful for many industries, especially the oil and gas industries where they are used to carry out drilling and other operations. Their sensor and sonar arrays can image large areas or provide minute details to specific structures. Most are equipped with a pair of manipulators—one for heavy lifting and grasping and the other with up to 7 individual functions that can be nearly as nimble as the human hand! The thrusters on these ROVs are vectored and very powerful, producing from 50 to over 200hp.

The mechanical side of a work class ROV system consists of these major subsystems:

1. Power source generator and power distribution unit (PDU)
2. The control console (housed in the control shack)

3. Deck cable, umbilical, and tether
4. The launch and recovery system (LARS), with crane and/or winch
5. Tether management system (TMS)

b) Light Work Class ROV

The in-between cousin of observation and work class, light work class ROVs are used for medium to deep depths of water and can carry light payloads. They can have large extensions and special inspection devices to help with their work. Many have more sophisticated manipulators to help them complete tasks that require more dexterity (3 to 4 functions). Light work class ones are being used for offshore wind farm maintenance, survey research, infrastructure repair, dive support, and much more. These ROVs are also generally vectored thrust vehicles that can maintain position and move through the water with more precision and are FO capable.

The ROV is deployed from ships in lieu of divers to explore. It can be used during inspections to make repairs. Large extensions, such as laser scanners or specialized inspection devices and sensors, can be added on. The depth rating for Light Work Class ROVs falls within the range of 1,000 meters (3,280 feet) to 3,000 meters (9,800 feet).

c) Observation Class ROV

An Observation Class ROV is small, it is used to explore lakes, rivers and coastal waters. They are often used to test water safety prior to a diver entering the water during missions and conducting inspections. Able to be equipped with sonar and custom sensors, they are versatile vehicles. The depth rating for Observation Class ROVs depending on the model, typically ranges from 300 meters (984 feet) to 1,000 meters (3,280 feet). These ROVs are equipped with high-end cameras and lightweight sonar systems to avoid missing any small details like cracks. A manipulator (arms and hands) on one of these vehicles tends to be small with limited functionality (1-3 functions typically), and their thrusters can be either vectored or standard. Some of these ROVs are Fiber Optic (FO) capable, allowing them to operate a wider variety and number of sensors/instruments at the same time.

d) Micro or Mini ROV

The micro or mini ROV is the smallest class, often used to inspect hard to reach areas at shallow depths, such as pipe systems and submerged infrastructure. The depth rating for Micro and Mini class ROVs generally ranges from 100 meters (328 feet) to 300 meters (984 feet). They are usually equipped with a light, camera, and maybe a grabber (single function manipulator) to pick objects up with. Recreational ROVs fall under the mini or portable class and are typically not vectored or FO capable of.

2.2.1 Key Components and Subsystems of ROVs

The design of Remotely Operated Vehicles (ROVs) involves several critical components and subsystems that ensure functionality, maneuverability, and efficiency. These include the frame, buoyancy system, propulsion and thrust systems, lighting, cameras, sensors, and manipulators.

1. **Frame**

The ROV frame serves as the structural foundation, providing a platform for mounting mechanical, electrical, and propulsion components. It also supports specialized tooling such as sonar, cameras, lighting, manipulators, and scientific sensors. Materials for ROV frames range from plastic composites to aluminum tubing, chosen for their strength-to-weight ratio. Since weight must be offset by buoyancy, lightweight yet durable materials are critical. Frame size (21 in. × 4 in) depends on factors such as the weight of the ROV, volume of onboard equipment, and load-bearing requirements.

2. **Buoyancy**

Our ROV requires a well-balanced buoyancy system to maintain neutral buoyancy, counteracting the weight of pressure housing and internal components. Following Archimedes' principle, the buoyant force must equal the weight of the displaced water. The syringe acts as an adjustable buoyancy chamber, which can be filled with water and emptied depending on the syringe movement

3. **Propulsion and Thrust**

The thruster configuration is a critical aspect of our ROV’s maneuverability and performance. Our current design incorporates a streamlined cylindrical frame, ideal for reducing drag.

a) ***Propeller-Based Propulsion:***

The propeller at the back of the ROV is responsible for forward propulsion. When powered by an electric motor, the propeller generates thrust, pushing the ROV forward in the water. The design and size of the propeller are crucial for generating adequate thrust while minimizing drag. The motor powering the propeller should be chosen based on the required speed and torque to propel the ROV through the water. In our design, a small, efficient motor of 150W power is used to achieve the desired forward motion.

b) ***Pumps for Maneuverability and Thrust Control:***

The six pumps (four for ballasting and deballasting and two at the front maneuverability) play an essential role in maneuverability and fine control of the ROV's motion. These pumps provide additional thrust for:

i. Vertical Movement: The front pumps push water forward or backward, allowing the ROV to move up or down with more precision.

ii. Lateral Movement and Turning: The rear pumps control side-to-side movement and rotational thrust, enabling the ROV to rotate or change direction without requiring a traditional steering mechanism.

c) **Thrust Vectoring:**

By adjusting the speed of the pumps at the front and sides of the ROV, we can achieve thrust vectoring. This allows the ROV to change direction efficiently without needing to rely on large, cumbersome rudders or mechanical steering mechanisms.

A combination of front and side pump speeds allows for precise maneuvering in tight spaces or while navigating over the lakebed.

d) ***Syringe-Controlled Movement:***

The syringe-actuating principle ties into propulsion indirectly by altering the buoyancy and weight distribution of the ROV. As the syringe chambers fill or empty, the change in buoyancy can affect how the ROV interacts with the surrounding water and its overall stability during propulsion.

In addition, adjusting buoyancy helps maintain balance while the ROV moves forward or backward, making sure the vehicle stays level or tilts as desired during operation.

e) ***Thrust and Power Considerations:***

Power Supply: The motors and pumps are powered by a battery. The choice of battery will depend on the operational depth and duration of the mission, as well as the power demands of the motors and pumps. High-efficiency motors and pumps are essential to optimize battery life.

Types of Thrust:

i. Forward Thrust: Generated by the propeller at the rear of the ROV, pushing the vehicle forward through the water. The direction of the propeller's rotation will determine the forward or reverse movement.
ii. Maneuvering Thrust: Generated by the four pumps. By controlling these pumps, you can steer the ROV up, down, or rotate it. This offers high maneuverability in tight spaces, such as when exploring cracks or uneven lakebed features.
iii. Overall Thrust System: The propeller at the back creates the primary forward propulsion force, while the pumps at the front and back provide the precision and control necessary for depth control (up and down) and directional control (yaw and roll).

The interaction between these propulsion components ensures that the ROV can move efficiently in all directions, even in difficult underwater environments like lakebeds or areas with obstacles.

f) **Thrust Efficiency:** To ensure effective propulsion, you'll need to optimize the design of the propellers and pumps. Propeller pitch and diameter should be carefully chosen to balance speed, thrust, and power consumption. Additionally, the placement of pumps relative to the ROV's center of mass affects how effectively it can be steered.

4. **Lighting and Cameras**

Given that light diminishes rapidly underwater, our ROV will incorporate high-intensity LED lighting, chosen for its low power consumption and long lifespan. LEDs will be strategically placed at the front and sides of the ROV to maximize visibility.

For imaging and operational monitoring:

a) A high-definition (HD) CCD camera will be mounted at the front, providing clear real-time feedback.

b) Additional wide-angle cameras may be positioned to enhance situational awareness, depending on mission requirements.

5. **Sensors and Manipulators**

To improve functionality and navigation, our ROV will include:

a) Depth and pressure sensors for real-time environmental data collection.

b) Temperature and conductivity sensors to support environmental analysis.

For light intervention tasks, our design will feature a compact electric manipulator arm, optimized to perform minor retrieval and interaction functions. Careful attention will be given to motor selection to prevent issues like stalling and oxidation, which could impact performance over time.

2.3 Previous Designs and Developments

2.3.1 Review of Existing ROV Designs and Innovations

1.Types of ROV Designs

For lakebed exploration, ROVS are generally designed to operate in depths ranging from a few meters to around 200 meters. These vehicles are often smaller, lightweight, and designed for precision rather than heavy-duty tasks.

a) **Observation-Class ROVs**: These are often used for visual inspections, including in shallow waters like rivers, lakes, or harbors. They are small, compact, and come with a set of cameras and simple manipulator arms.
b) **Inspection-Class ROVs:** Slightly more powerful, these ROVs can carry additional sensors for environmental monitoring, such as temperature, pH, or turbidity sensors, making them ideal for shallow water research or infrastructure inspection.
c) **Light-Duty Work-Class ROVs:** Though typically used in deeper waters, there are smaller versions of work-class ROVs adapted for shallow water that feature enhanced sensors or robotic arms for tasks such as marine biology studies or underwater cable inspections.

2. Innovations in ROVs:

a) *Autonomous Capabilities:* While shallow water ROVs may not require the deep autonomy necessary for oceanic exploration, innovations in semi-autonomous capabilities, such as automated mapping and path-following, have been integrated into these vehicles.
b) *Low-Cost, Compact Design:* Shallow water ROVs are often designed to be cost-effective and easy to deploy, with a focus on portability and simple operational control. Innovations in battery life, wireless communication, and miniaturization of sensors have made these ROVs accessible for researchers and enthusiasts alike.
c) *Real-time Data Transmission:* Wireless communication and real-time data streaming are becoming standard in shallow water ROVs, allowing for easier operation and enhanced collaboration during live inspections or research.

2.4. Challenges in Design and Fabrication

Designing ROVs involves balancing weight, buoyancy, and power efficiency. Challenges include:

1. **Power Supply and Energy Management:** Battery Life remains a challenge, even in shallow water applications. While shallow water depths might not demand as much power for pressure resistance, sensor operation and continuous propulsion (especially when working near the surface) require efficient energy management for extended operation.

   The design needs to balance the power demands of motors, sensors, and communication systems without sacrificing mission duration.

2. **Stability and Maneuverability:** Shallow water environments often have high currents, obstacles, or varying terrain, making stability and precise maneuverability crucial. The ROV's ability to adjust buoyancy and respond quickly to changes in water conditions, such as turbulence or waves, becomes a design challenge.

3. **Environmental Sensitivity:** In shallow water, the ROV must handle variable depths and potentially low visibility due to sediment, algae, or other underwater conditions. The visibility and performance of sensors must be optimized to deal with murky waters.

4. **Cost-Effectiveness:** Shallow water ROVs typically need to be more affordable for broader application, especially in research, environmental monitoring, and recreational use. Striking a balance between cost, functionality, and durability is an ongoing challenge.

2.5 Advancements in ROV Control Systems

2.5.1 Control Mechanisms

ROVs are typically controlled via tethered systems, which provide power and data transmission.

Tethers can include copper conductors for power and fiber optics for high-bandwidth data transmission. Wireless control systems are less common due to limitations in underwater communication.

1. **Simplified Control Systems:** In shallow water ROVs, control systems tend to be less complex, with remote control. However, advances in motion-sensing control and one-touch navigation are improving the ease of use, particularly in environments with frequent changes in depth or water current.
2. **Wireless Control:** Shallow water ROVs benefit from wireless control systems, which offer easier deployment without the constraints of cables. The use of Wi-Fi, Bluetooth, and acoustic modems ensures effective communication over short distances while maintaining mobility and reducing the risk of tangling cables.

2.5.1 Software and Hardware Advancements:

1. Enhanced Pathfinding Algorithms: Although shallow water ROVs don't require deep autonomy, advances in pathfinding algorithms are allowing these vehicles to perform missions like underwater mapping or environmental monitoring with minimal human intervention.

2. Real-time Imaging and Feedback: For tasks in shallow waters, ROVs are integrating advanced imaging software for high-quality video feeds that can be instantly analyzed. This feature is crucial for inspection tasks, where high-quality visuals of structures or aquatic environments are needed.

2.6 Materials and Manufacturing Processes

2.6.1 Common Materials Used in ROV Fabrication

1. **Lightweight Materials:** For shallow water ROVs, materials like PVC, aluminum, and fiberglass are common. These materials are lightweight and offer the required durability without excess weight, which is important for ease of transport and handling.
2. **Corrosion-Resistant Materials:** Since shallow water ROVs are exposed to brackish or fresh water, materials like stainless steel for motor shafts and coated aluminum for the frame are frequently used to resist corrosion. Plastics such as ABS are also popular in

smaller ROV designs due to their durability, flexibility, and resistance to underwater pressure at shallow depths.

2.6.2 Techniques for Construction and Waterproofing

Waterproofing is critical for ROV components, particularly electrical connections. Techniques include using fluid-filled housings, magnetic couplings, and synthetic rubber seals. Connectors must be carefully maintained to prevent water ingress and ensure reliable operation.

1. **Pressure Resistance:** For shallow water ROVs, pressure resistance is less of an issue compared to deep-sea ROVs, but it's still crucial to ensure that the hull design can withstand typical fluctuations in shallow water pressure. Molded plastic or composite housings are often used for this.
2. **Injection Molding and 3D Printing:** These techniques allow for the rapid prototyping of ROV components, such as hulls, sensor mounts, or lightweight frames. 3D printing especially helps in customizing parts quickly without the need for expensive molds.

CHAPTER 3

METHODOLOGY

3.1 Design Considerations

Designing a Remotely Operated Vehicle (ROV) requires careful attention to various factors, including its **structural integrity**, **buoyancy**, **propulsion system**, and how different subsystems are integrated. The process involves balancing these elements to ensure the ROV can perform its intended mission. The overall design process is divided into three main phases:

1. **Pre-design phase**: The user outlines the specific tasks the ROV needs to accomplish underwater.
2. **Design phase**: The designer creates a solution based on the user’s needs, ensuring the project is feasible within technical limitations.
3. **Post-design phase**: This phase covers manufacturing, testing, evaluation, and any adjustments based on test results, providing feedback for future designs.

3.1.1 Pre-design Phase

During the pre-design phase, the vehicle's intended user describes the mission the ROV is meant to carry out. The missions can be categorized into types such as:

1. **Industrial**: Tasks related to maintenance, resource extraction, etc.
2. **Scientific**: Activities focused on research, exploration, and environmental monitoring.
3. **Military**: Involving reconnaissance, surveillance, and defense-related tasks.
4. **Recreational**: Used for leisure activities like diving or exploration.

Each mission is further defined by specific tasks like inspection, survey, sampling, and maintenance. The mission requirements also include factors such as:

- i. **Depth**: The operating depth of the vehicle.
- ii. **Work object**: A description of the object or environment with which the ROV will interact.
- iii. **Location**: Whether the ROV will be land-based or ship-based, and the specific site of the mission.
- iv. **Required equipment**: Details on the launch equipment and personnel required for the mission.

3.1.2 Design Phases

The ROV design process consists of four distinct phases:

1) **Conception Phase**

   In the conception phase, the primary goal is to determine how to best meet the user's mission needs. The following factors are addressed:

   - a) **System capabilities**: Ensuring the ROV can perform the required tasks.
   - b) **Key characteristics**: Defining the ROV's main features according to mission goals.
   - c) **Cost estimation**: Calculating the potential costs for building and operating the ROV.
   - d) **Mission identification**: Matching the mission's needs with the vehicle's capabilities.

2) Preliminary Design Phase

A major focus is understanding the specifics of the mission, including details about the task, operating environment, and any objects the ROV will work with.

This phase defines the major specifications and cost estimates of the ROV, considering optimization factors. The designer focuses on refining the design based on the information gathered during the conception phase.

3) Technical Design Phase

In this phase, detailed planning begins, including:

a) **Creating technical documentation**: Generating specifications, material lists, and detailed plans for the ROV.

b) **Testing**: Conducting tests and evaluations to ensure the design meets expectations.

c) **Approval**: Finalizing the design after review and approval by the owner.

4) Manufacturing Design Phase

This final phase involves the physical creation of the ROV, including:

a) **Construction**: Building each subsystem and assembling the ROV.

b) **Manufacturing procedures**: Outlining how parts are made and assembled.

This stage requires significant effort to ensure that the ROV is produced according to the design specifications.

By following these structured phases, the ROV is designed to meet its specific mission requirements, ensuring its effectiveness and operational success underwater.

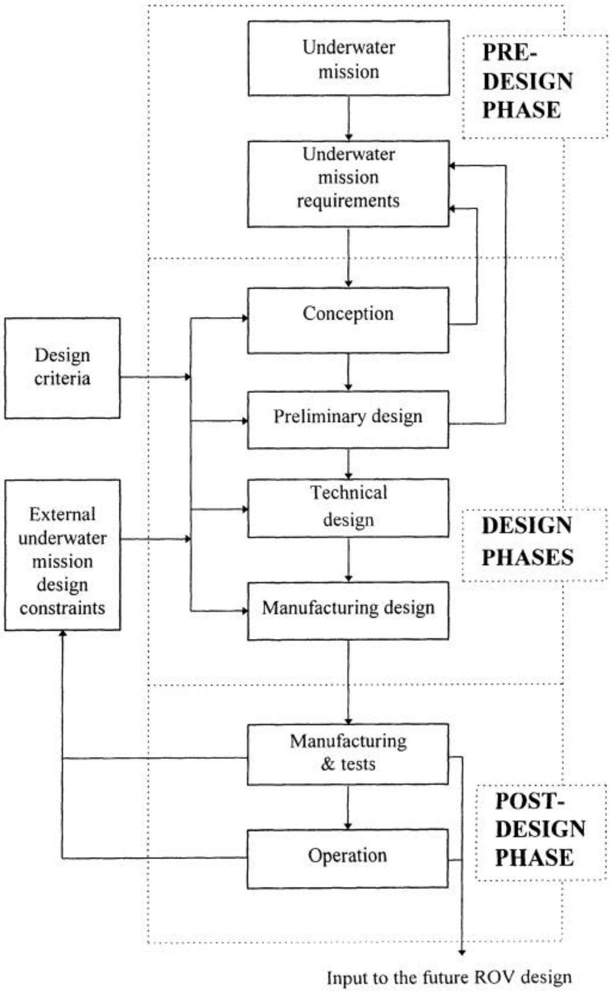


Fig 3.1: Design process chart

5) Conceptual Design: Structural Framework, Buoyancy, and Propulsion

It is essential to identify the design concept and the classification of a new proposed ROV for underwater application. The conceptual design phase is critical in ensuring that the basic functionality and goals of the ROV align with its intended use in shallow water exploration. This phase is primarily focused on generating ideas, brainstorming, and setting the framework for the detailed design.

a) **Initial Brainstorming and Sketching:** The design process begins with brainstorming to outline the primary objectives of the ROV. Key objectives include:

b) **Exploration:** The ROV needs to be compact enough to navigate through tight or shallow spaces while being powerful enough to perform basic tasks like mapping, observation, and monitoring.

c) **Stability and Maneuverability:** Ensuring that the ROV is stable under varying water conditions while being responsive and easy to control.

d) **Cost-Effectiveness**: A focus on affordability without sacrificing the performance of the vehicle.

e) During this phase, initial sketches are made to visualize the ROV's general form and layout. These sketches serve as a starting point for refining the design and ensuring that all components (propulsion, actuators, and hull) are optimally placed.

f) **Selection of Design Principles:** Based on the results of the initial brainstorming, key design principles are selected:

g) **Modularity:** The design should allow easy access to internal components for maintenance, upgrades, and troubleshooting.

h) **Lightweight and Durability:** The materials selected should ensure the ROV is lightweight yet durable to withstand operational conditions in shallow waters.

i) **Compact and Ergonomic:** A small size to ensure maneuverability in confined spaces, along with a shape that minimizes drag in the water.

j) **Simplicity and User-Friendliness:** The design should ensure ease of operation, even for users with minimal experience with ROVs.

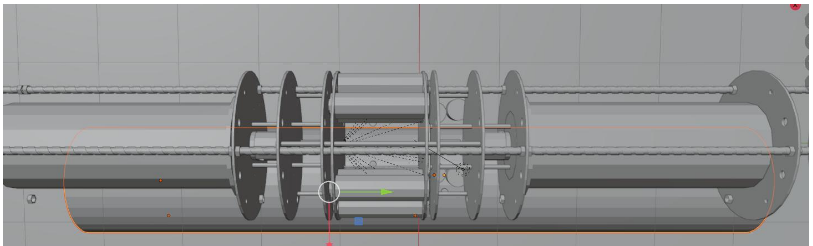
3.2 Detailed Component Design

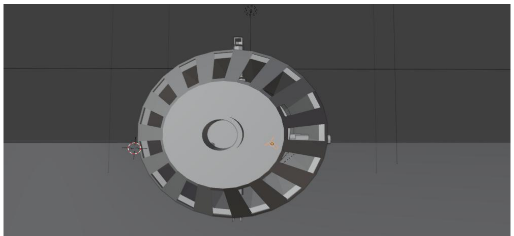
3.2.1 Detailed Design:

In this phase, the conceptual design is turned into a more detailed and technically feasible version. This is where most of the design work happens, involving technical drawings, simulations, and final decisions on components and materials.

1. CAD Models and Simulations:

a) **CAD Models:** Detailed 3D CAD model of the ROV is created using software such as SolidWorks. This allows for precise visualization of all components, including the propellers, pumps, sensors, and actuators.





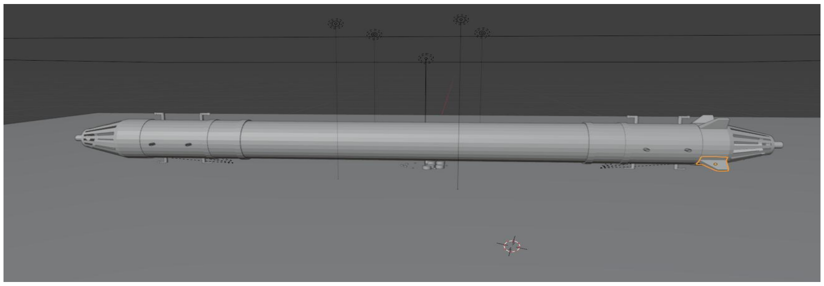


Fig 3.2 CAD model

b) **Simulations:** Once the CAD models are developed, fluid dynamics simulations (CFD) are run to predict the vehicle's behavior in water. This helps evaluate drag, stability, and buoyancy and ensures that the propellers and pumps are optimized for performance. Simulation also helps in testing the ROV's maneuverability and overall handling, confirming whether the design meets the control and stability needs.

3.2.2 Component Specifications:

1. **Propellers:** The ROV is equipped with a single propeller located at the back for forward propulsion, while six pumps (two on opposite sides in front and at the back and the remaining two at the fore of the ROV) provide precise maneuverability. The propellers are chosen based on their ability to provide the necessary thrust while maintaining efficiency at low power consumption.

Fig 3.3 Propeller

2. **Pumps:** The pumps are sized based on the expected weight and volume of the ROV, considering the required thrust for directional control. They are placed to optimize maneuvering, with a focus on hovering and side-to-side movements.

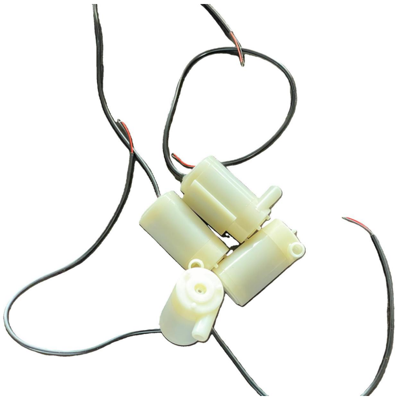


Fig 3.2 pumps

3. **Hull Material:** PVC pipe is selected for the hull material due to its lightweight nature, resistance to corrosion, and ease of fabrication. PVC’s durability in shallow water environments allows for effective operation while minimizing overall weight.

Fig 3.4 PVC hull

3.3 Prototype Development

3.3.1 Materials and Tools Used:

i. PVC for the Hull: The PVC material ensures the ROV remains buoyant, preventing it from sinking and allowing it to float in shallow water. The use of PVC piping for the hull provides a rigid yet flexible structure that absorbs impact and is resistant to abrasions.

ii. Other Components: Additional materials like waterproof seals, O-rings, and connectors are used to protect the internal electronic systems. Stainless steel bolts and nuts are used for securing the thrusters and other components to ensure durability and corrosion resistance.

iii. Tools: Standard tools used in the fabrication process include a circular saw for cutting PVC, pipe cutters for accurate trimming, glue and solvent for sealing joints, drills for making holes in the hull for components, and wrenches for tightening bolts.

3.3.2 Description of Fabrication Methods:

1. **Cutting:** The PVC pipes are carefully measured and cut to the required lengths using a pipe cutter or circular saw.

2. **Joining:** The sections of the hull are joined using a solvent cement designed for PVC, ensuring a strong and water-tight seal. PVC couplings are used to secure the ends of the hull pipe, and O-rings are inserted between the joints to create a watertight seal.

3. **Sealing:** To protect sensitive components from water, silicone-based sealants are applied at key junctions, such as where the propellers are mounted, and around the hull's end caps to ensure no leaks occur.

3.3.3 Actuating Systems:

1) **Syringe-Actuating Principle:** The core actuation system relies on the use of syringes to manage internal buoyancy and pressure regulation. By using a syringe-based actuation system, the internal volume of the ROV can be increased or decreased, providing a mechanism for controlling its buoyancy without relying on foam-based solutions. This system uses an easy-to-operate manual or automated system, where a motor is used to move the syringe's plunger in and out to inject or expel water from the syringes, adjusting the overall displacement of the vehicle and allowing it to maintain neutral buoyancy.

Fig 3.5 Syringe

2) Propulsion and Maneuverability Systems: The single propeller provides forward motion, while the six pumps ensure controlled movement in all directions. The pumps are designed with high efficiency in mind, and their position allows for excellent side-to-side and vertical maneuverability. The propulsion system is designed to be low-maintenance and provides just the right amount of power for shallow water exploration.

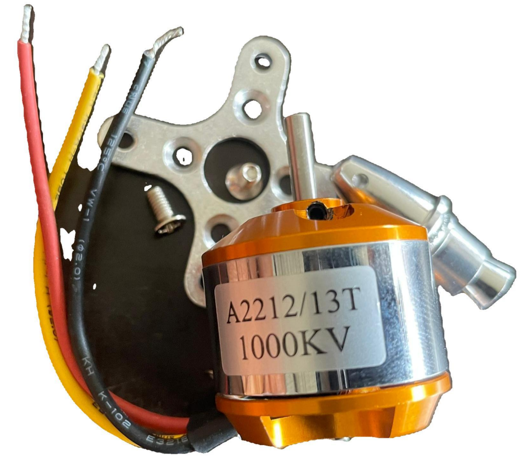


Fig 3.6 Motor

3.4 Selection of Materials

To ensure optimal performance, durability, and cost-effectiveness, the materials used in the fabrication of the ROV have been carefully selected based on their strength, corrosion resistance, weight, and waterproofing properties. Below is a detailed breakdown of the materials used, including their specifications and rationale for selection.

1. Hull and Structural Components

Table 3.1 – Hull and structural components

S/N	Material	Specification	Reason for Selection
1.	PVC Pipe	Diameter: 4 inches, Length: 36 inches	• High durability and strength for shallow water depths. • Lightweight and easy to fabricate. • Corrosion-resistant in freshwater and saltwater.
2.	PVC Sheet (for support of internal components)	Thickness: 0.25mm	• Cost effectiveness • Ease of machinability and fabrication • Chemical and corrosion resistant.
3.	**Marine Epoxy (for Sealing Joints)**	Waterproof, two-part epoxy resin	• Ensure watertight seals at pipe connections. • Strong adhesion to PVC and acrylic. • Resistant to underwater pressure.

2. Buoyancy and Actuation Components

Table 3.2 – Buoyancy and Actuation Components

S/N	Material	Specification	Reason for Selection
1.	Syringe (for Buoyancy Control)	500ml medical grade plastic syringe	• Provides fine control over buoyancy. • Water-resistant and durable.

			- Easy to integrate into the control system.
2.	Tubing for Water Transfer	Flexible PVC tubing (Diameter: 4inches)	- Ensures smooth water flow in the syringe system. - Corrosion-resistant and flexible for routing in confined spaces.

3. Propulsion and Maneuvering System

Table 3.3 Propulsion and Maneuvering System

S/N	Material	Specification	Reason for Selection
1.	Propeller	Diameter: 6inches, 2 blade design, plastic.	- Provides efficient forward thrust. - Corrosion-resistant for long-term underwater use.
2.	DC Motor (for Main Propeller)	Voltage: 1000KV	- Delivers sufficient thrust. - Compatible with 3.7V power supply. - Encased for waterproofing
3.	Bilge Pumps (for Maneuverability)	Flow Rate: 70 liters/hour	- Provides lateral movement and fine control. - Designed for underwater applications. - Low power consumption

4. Electronics and Control System

Table 3.4 Electronics and Control System

S/N	Material	Specification	Reason for Selection
1.	Battery (Power Supply)	3.7V, 3.8Ah Lithium-ion (6 batteries)	- Provides adequate power for motors and pumps.

			- Rechargeable and light weight.
2.	Control Board	HD 16RX/2.4G receiver	- Reliable wireless communication with minimal latency - Multiple channel; allowing multiple actuators and propellers. - Compatible with standard power sources.

5. Waterproofing and Fasteners

Table 3.5 Waterproofing and Fasteners

S/N	Material	Specification	Reason for Selection
1.	Silicone Sealant	100% waterproof, flexible	- Provides additional waterproofing at joints. - Resistant to wear and underwater pressure
2.	Stainless Steel Screws and Bolts	316 stainless-steel, rustproof	- Prevents corrosion in water. - Secures components effectively

This detailed material specification ensures the ROV meets the performance requirements for shallow water exploration while maintaining a balance between cost and efficiency.

3.5 Comparison of Designs

Thruster based vs. Pump based ROV:

In this section, we compare the performance metrics of a thruster-based and a pump-based ROV design. The comparison focuses on factors such as maneuverability, efficiency, complexity, and operational performance to determine which design is more suitable for your lakebed exploration, crack observation, and shallow water exploration project.

Table 3.6 Comparison of designs

S/N	Factors	Thruster Based	Pump Based
1.	Maneuverability:	**Pros:** • Provides high-speed movement and responsive directional control. • Good for rapid deployment and high-thrust operations. **Cons:** • Limited control in low-speed or precise movements due to lack of fine propulsion control. • Thrusters typically require more power to achieve stable maneuvering, which can lead to increased energy consumption.	**Pros:** • Provides better fine-tuned control and stability, especially in delicate operations such as crack observation. • Better at holding position in strong currents or challenging conditions. **Cons:** • Slower response compared to thrusters due to reliance on water flow. • Less efficient for high-speed travel over long distances.

2.	Efficiency:	**Pros:** • Effective in high-speed movements over long distances. • Typically offers a better thrust-to-weight ratio for greater speeds in open water conditions. **Cons:** • Higher power consumption due to reliance on motor-driven propellers. • Can be inefficient in low-speed operations, which may reduce overall mission duration and energy efficiency.	**Pros:** • More energy-efficient at lower speeds, especially in controlled, slower maneuvers. **Cons:** • Less mechanical wear and tear, leading to longer service life. • Lower maximum speeds and thrust efficiency in open water, reducing the ability to cover larger areas quickly.
3.	Complexity and Maintenance:	**Pros:** Simpler mechanical design, fewer components for propulsion, which reduces overall system complexity. Easier to source and maintain thrusters. **Cons:** • Requires regular maintenance on motor-driven parts, such as bearings and propellers. • Thrusters may suffer from cavitation or	**Pros:** Fewer moving parts involved in propulsion, which can lead to reduced wear and tear and potentially fewer maintenance requirements. **Cons:** • More complex hydraulic or fluid-based systems, which could require more specialized maintenance.

		damage due to debris in the water.	- Pumps may clog or degrade due to sediment or debris in shallow water environments.
4.	Operational Performance:	**Pros:** - Higher power consumption due to reliance on motor-driven propellers. - Can be inefficient in low-speed operations, which may reduce overall mission duration and energy efficiency.	**Pros:** - Better suited for tasks requiring precise positioning, such as lakebed exploration and crack observation. - More suitable for shallow water operations where stability and control are paramount. Cons: Slower movement and less suited for high-speed coverage.
5.	Suitability for Lakebed Exploration:	**Pros:** - Less Ideal for lakebed exploration, as it may have difficulty maintaining a steady position over a specific location, especially in shallow or sediment-laden waters.	**Pros:** More Ideal for lakebed exploration due to better control and stability. The ability to hover in place or move slowly with greater precision makes it better for crack observation and detailed mapping.

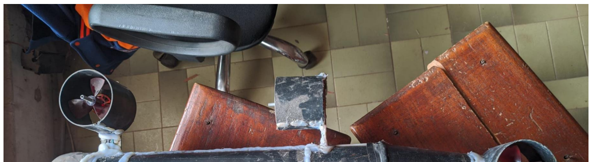


Fig 3.7 Comparison of designs (thruster-based and pump-based

3.5.1 Performance Metrics and Calculations

A key part of the design evaluation is quantifying the ROVs performance. This involves analyzing maneuverability, depth capability, power consumption, stability, buoyancy, and pressure resistance.

1. **Maneuverability Analysis**

Maneuverability is determined by thrust-to-weight ratio, control response time, and turning ability.

Thrust-to-Weight Ratio Calculation

The total thrust required to propel the ROV is calculated using:

$$T = m \times a$$

where:

T = required thrust (N)

m = mass of the ROV (kg)

a = desired acceleration (m/s^2)

Given an estimated mass of **5 kg**, and assuming an acceleration of **0.5 m/s^2**, the required thrust is:

$$\mathbf{T = 5 \times 0.5 = 2.5\ N}$$

The chosen propeller and pump system must generate at least **2.5 N** of thrust for effective movement.

2. Turning Ability and Side Maneuverability

The four pumps located at the front and rear enable lateral movement and turning. The ROV's turning radius depends on the asymmetry of thrust between the pumps, allowing it to pivot efficiently in shallow waters.

3. Depth Capability and Pressure Resistance

The maximum operational depth of the ROV depends on the structural strength of the PVC hull and the external water pressure at depth.

a) Hydrostatic Pressure Calculation

The pressure exerted by water at a given depth is:

$$P=\rho g\ h$$

where:

P = pressure (Pa)

ρ = density of water (1000 kg/m^3)

g = acceleration due to gravity (9.81 m/s^2)

h = depth (m)

For a maximum depth of 10 meters, the pressure is:

$$\mathbf{P=1000\times9.81\times10=98{,}100\ Pa=98.1\ kPa}$$

b) *PVC Strength Check*:

PVC has a maximum pressure rating of ~0.6894 MPa – 2.171 MPa (0.6894 Kpa -2171 kPa), significantly higher than the expected 98.1 kPa at 10 meters.

This ensures safe operation without structural deformation.

3.5.2 Calculations for Stability, Buoyancy, and Pressure Resistance:

1. Buoyancy and Stability Calculations

Stability: Stability is ensured through the strategic placement of propellers and pumps, with the syringe-actuating principle providing flexibility in buoyancy control. Calculations show that the ROV remains stable in shallow water, with minimal tipping when adjusting its position.

Buoyancy: The buoyancy calculations consider the weight of the components, hull material, and internal water displacement in the syringes. The ROV achieves neutral buoyancy under typical operating conditions.

The ROV must achieve neutral buoyancy, meaning the upward buoyant force equals the downward gravitational force.

Buoyancy Force Calculation

The buoyant force (Fb) is given by:

$$F_b = \rho g V$$

where:

V = displaced water volume (m^3)

ρ = water density (1000 kg/m^3)

g = gravity (9.81 m/s^2)

Assuming the ROV has a displacement volume of 0.005 m^3:

$$Fb=1000\times9.81\times0.005=49.05N$$

Weight of the ROV

$$W = mg = 5\times9.81 = 49.05\ N$$

Conclusion: Since Fb=W, the ROV is in neutral buoyancy, meaning it neither sinks nor floats uncontrollably.

2. **Pressure Resistance**: Shallow water pressure resistance is factored into the design, with PVC providing sufficient protection at depths of up to 10 meters.

3.5.3 Effect of Syringe Actuation on Buoyancy

1. By injecting water into internal chambers using syringes, the ROV increases its density, making it sink.
2. By expelling water, it reduces its density, allowing it to rise.

This provides fine control over depth without needing foam blocks for buoyancy.

3.5.4 Power Consumption Analysis

The power required for the propulsion system is calculated based on the current drawing of the motors and pumps.

Power Consumption of Propeller Motor

$$P=V\times I$$

where:

P = power (W)

V = voltage (V)

I = current (A)

Assuming the propeller motor operates at V with a current draw of 3A:

$$P=12\times 3=36\text{ W}$$

Power Consumption of Pumps

Each pump operates at 3.33W, and six pumps are used:

pumps

$$P = 6 \times 3.33 = 20 \text{ W}$$

Total Power Consumption

$$P\ \mathit{total} = 36 + 20 = 56 \text{ W}$$

If powered by a 14.8V, 11.4Ah battery, the estimated runtime is:

$$\text{Runtime} = \text{Battery Capacity (Wh)}$$

Total Power(W)

Runtime= Total Power(W)=Battery Capacity (Wh)

3.5.4 Summary of Performance Metrics

Table 3.6 Summary of performance metrics

Parameter	**Calculated Value**	**Conclusion**
Thrust-to-Weight Ratio	2.5 N thrust required	Achievable with selected propellers and pumps
Maximum Depth	10 meters	PVC hull withstands pressure (98.1 kPa < 1.03 MPa)
Buoyancy	49.05 N (matches weight)	Neutral buoyancy achieved

Maneuverability	12×11.4/56 =2.44 hours	Efficient turning with 1 motor

This confirms that the ROV can operate for approximately 2 hours on a single charge.

Smooth control and navigation

Total Power Consumption- 56 W

Battery lasts ~2 hours per charge

3.6 Step-by-Step Procedure for Assembling the ROV

1. **Hull Construction:** Cut the PVC pipe into the required sections and join them using PVC solvent cement. Seal each joint with O-rings and apply silicone sealant for added protection.
2. **Component Placement:** Mount the actuators, propeller, and pumps to their designated places inside the hull. Ensure secure mounting with stainless steel bolts and nuts.
3. **Syringe Actuation System:** Install the syringes, connecting them to the buoyancy control system. Ensure that the syringes are easily accessible for adjustment.
4. **Electrical Setup:** Install the electronic components (battery, control board) in a waterproof casing inside the ROV.
5. **Final Sealing and Testing:** Apply additional waterproofing, test for leaks, and make final adjustments before deployment.

3.6.1 Testing and Troubleshooting:

After the fabrication and assembly of the ROV, a comprehensive testing and troubleshooting phase is necessary to ensure that all components function as intended. The testing process includes dry tests, buoyancy checks, maneuverability assessments, and field trials in shallow water. Troubleshooting focuses on identifying and resolving issues related to leaks, propulsion inefficiencies, and control system failures.

i. Conduct initial dry testing to ensure all actuators function properly.
ii. Perform buoyancy tests in controlled water environments to ensure stability.
iii. Conduct real-world lakebed exploration tests, adjusting the syringe system and checking maneuverability.

1. Testing Procedures

a) Dry Testing (Pre-Water Testing)

Before submerging the ROV in water, several dry tests are conducted to verify the functionality of the mechanical, electrical, and software systems:

i. Structural Integrity Check:
  a) Visually inspect the PVC hull for any cracks, gaps, or improperly sealed joints.
  b) Ensure that all fasteners, connectors, and seals are tightly secured.

ii. Syringe Actuation System Test:
  a) Check that the syringe-based buoyancy system effectively injects and expels water.
  b) Simulate different buoyancy levels by operating the syringes manually or via control mechanisms to confirm smooth operation.
iii. Propulsion and Pump System Test:
  a) Verify that the main propeller spins correctly and generates thrust.
  b) Check that the four pumps function properly in different directions (forward, backward, left, and right).
iv. Electronics and Control System Check:
  a) Ensure the power system, wiring, and control circuits are properly connected.
  b) Test the motor controller, battery, and actuators to ensure they respond to commands.

b) Buoyancy and Stability Tests

The ROV's neutral buoyancy is crucial for stable operation in shallow water. The following tests are performed:

I. Static Buoyancy Test:
   a) Place the ROV in a shallow water tank to check if it floats, sinks, or maintains neutral buoyancy.
   b) If the ROV sinks too quickly, adjust the internal displacement (by modifying the syringe actuation system).
   c) If it is too buoyant, add small ballast weights for proper balancing.

II. Dynamic Buoyancy Test:
   a) Adjust the syringe system to verify that the ROV can achieve slight positive and negative buoyancy when needed.
   b) Test the actuation system under different water conditions to ensure a smooth transition between floating and sinking states.

III. Tilt and Roll Test:
   a) Check for unintended tilting or rolling when the ROV is stationary.
   b) Adjust the internal weight distribution if necessary to maintain balance.

c) Propulsion and Maneuverability Tests

These tests evaluate the ROVs ability to move efficiently in water using its propeller and pump-based maneuvering system.

I. Forward and Reverse Thrust Test:
   a) Submerge the ROV in water and activate the rear propeller to check forward movement.
   b) Reverse the direction and check if the ROV moves backward without excessive drifting.

II. Turning and Lateral Movement Test:
   a) Test the pumps to ensure that the ROV can move side-to-side efficiently.
   b) Perform a 360-degree rotation test.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Prototype Evaluation

The prototype ROV was tested in a controlled water environment to evaluate its performance based on speed, depth capability, manoeuvrability and material durability.

4.1.1 Performance in Water

1. **Speed:**

The ROV's propulsion system, consisting of a single rear propeller and four syringe-actuated pumps, was assessed for speed. Initial tests showed that the propeller provided sufficient forward thrust, but speed was moderate due to resistance from the water. The syringe-actuated pumps allowed for lateral movement, but their reaction time slightly lagged compared to traditional electric thrusters.

2. **Depth Capability:**

The ROV successfully submerged to a moderate depth of approximately [insert depth] meters. However, maintaining neutral buoyancy required precise control of the syringe-actuated pumps. The use of PVC as the hull material contributed to overall buoyancy, but additional weight adjustments were necessary for stability.

3. **Manoeuvrability:**

Manoeuvrability was a strong point of the design. The four pumps, positioned at the front and rear, allowed for fine adjustments in movement. The ROV could turn efficiently and maintain stability, making it suitable for lakebed exploration and crack observation. However, control precision depended on the responsiveness of the pump mechanism, which had slight delays compared to traditional thrusters.

4. **Strength and Durability of Materials:**

The structural integrity of the ROV was ensured by the use of PVC pipes, acrylic plates, and other robust materials. PVC pipes provided a lightweight yet sturdy frame, while acrylic plates added durability and protection for the internal components. Waterproofing techniques, such as sealed compartments for batteries and electronics, helped prevent water ingress. The materials effectively withstood underwater pressure, making the ROV suitable for extended operations.

The PVC hull proved to be lightweight and resistant to corrosion, making it a cost-effective choice. However, testing indicated that under prolonged submersion, some joints required additional sealing to prevent minor leaks. The propeller and pumps functioned well, but the syringe mechanism showed wear after repeated use, suggesting the need for more durable components.

The ROV demonstrated efficient manoeuvrability, achieving stable movement in all directions. The two ballast systems effectively controlled the ascent and descent, allowing smooth depth adjustments.

After analysing, the ballast tank of the ROV, which will be used to dive or go back up to the water surface, needs to have a pump that can supply water with the rate of **250ml/sec.** The reasoning of choosing the pump speed is by considering this class observation ROV needs to be able to maintain its stability during underwater.

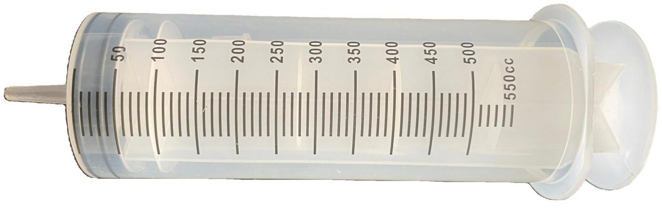


Fig 4.1: Ballast system

The brushless motor provided steady forward propulsion, while the two front pumps enabled reliable backward movement. The side pumps facilitated lateral motion and tilting, ensuring precise positioning and orientation. Speed tests indicated that the forward movement was more efficient compared to reverse due to the difference in propulsion mechanism.

4.2 Comparison with Existing ROVs

Advantages of the Design Compared to conventional ROV, this design offers several improvements:

1. Enhanced Manoeuvrability: The combination of ballast systems, a brushless motor, and multiple pumps provides superior control in six degrees of freedom.
2. Compact and Lightweight Structure: The use of PVC and acrylic reduces weight while maintaining durability.
3. Versatility: The ability to interchange the side pumps for tilting adds an extra dimension of control.
4. Improved Visibility: The integration of a camera, sensors, and lighting enhances navigation in low-light underwater environments.
5. Areas for Improvement
6. Power Efficiency: The multiple pumps and ballast system require a significant power supply, necessitating optimization of battery usage.
7. Material Selection: While PVC and acrylic are effective, exploring alternatives like reinforced composites could improve durability.
8. Autonomy: Implementing AI-based control algorithms could enhance semi-autonomous operation and reduce manual input.

4.3 Challenges Faced During Fabrication

1. **Material Sourcing**

2. Procuring waterproof components, high-quality pumps, and efficient sensors proved challenging. Some materials had to be substituted with locally available alternatives without compromising performance.
3. **Assembly and Integration**
4. Ensuring a watertight seal for electronic compartments required extensive testing and redesigns. The alignment of the syringe-actuated pumps and motors also demanded precise calibration to achieve balanced movement and optimal manoeuvrability, required multiple adjustments.

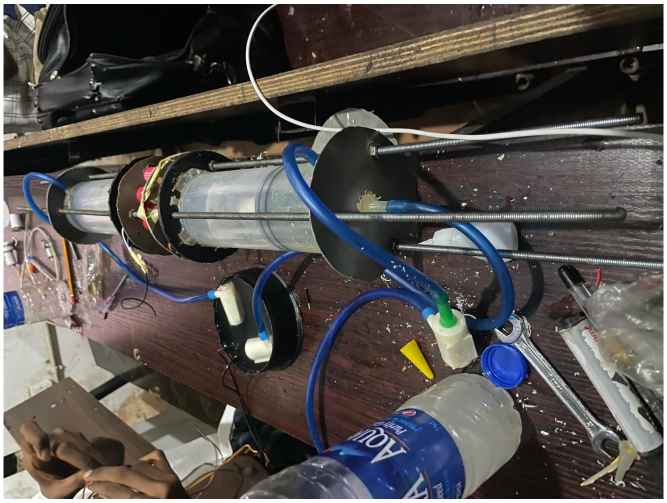


Fig 4.2: Assembly and integration

- **System Control Challenges**

The manual control of the syringe system initially had inconsistencies in responsiveness. Adjustments in tubing and actuation timing were necessary to achieve smoother operation.

4.4 Solutions Implemented

- Reinforcement of Joints and Seals: Waterproof adhesives and additional reinforcement materials were used to improve durability.
- Fine-Tuning Pump Positioning: The placement of the pumps was adjusted multiple times to optimize manoeuvrability.
- Testing and Iteration: Multiple test runs were conducted to refine control mechanisms and overall system performance.

4.5 System Control and Testing

The initial control system experienced signal interference, affecting real-time manoeuvrability. This was addressed by optimizing the wiring and improving the insulation of electronic components.

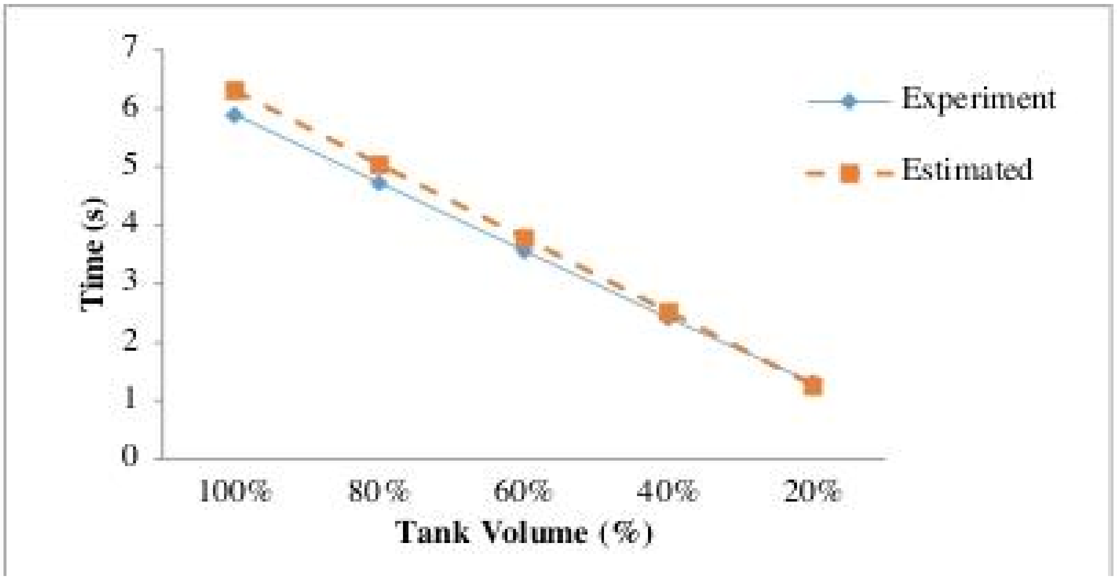


Fig 4.3: System control and testing chart

The ROV motor movement capability results show that torque is dominant at the maximum time of 0.5 second. DC Motor Power also dominant at the maximum time of 0.5 second and the distance is 0.05m. ROV speed testing was done by measuring the time when the ROV moves to achieve a certain distance. The farther the distance travelled the more thrust and strength is needed.

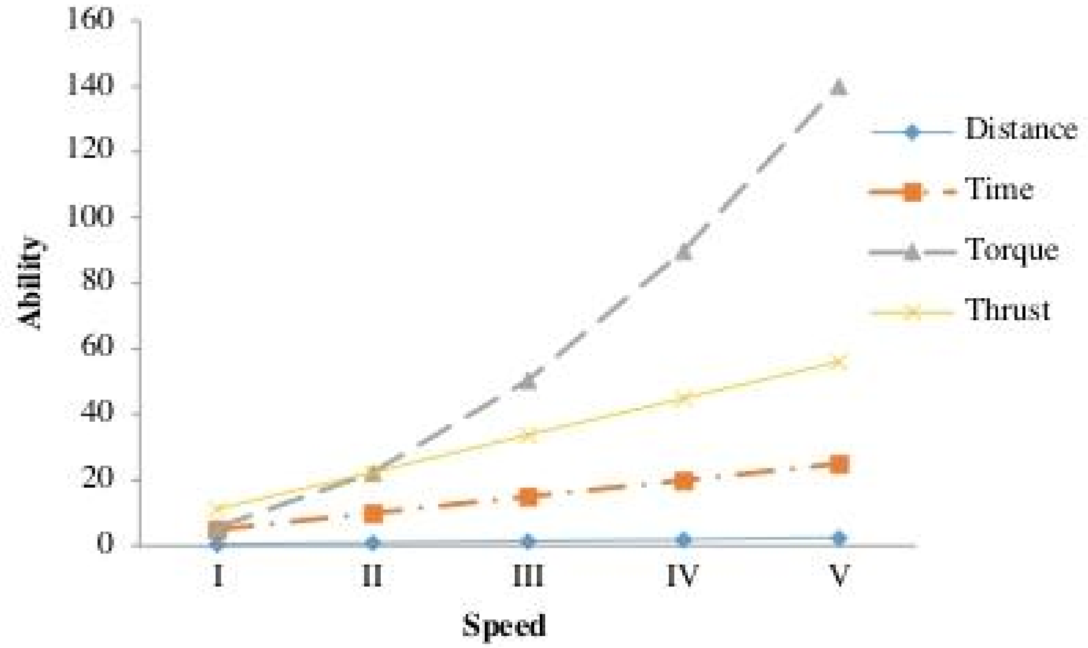


Fig 4.3: System control and testing chart

4.6 ROV Test

The ROV experiment was in a pool. This experiment uses the Archimedes' principle which states "the upward buoyant force that is exerted on a body immersed in a fluid, whether fully or partially submerged, is equal to the weight of the fluid that the body displaces and acts in the upward direction at the centre of mass of the displaced fluid.

4.6.1 Floating Text

1330 kg/m^3 1000 kg/m^2 Comply with Archimedes' Principle

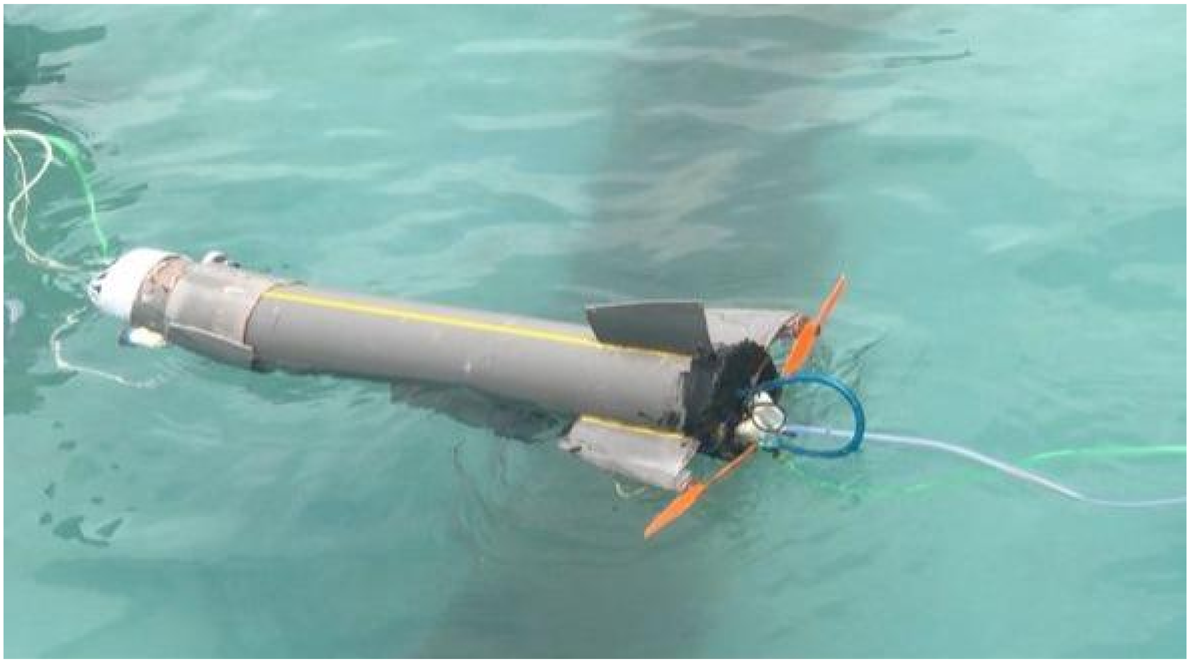


Fig 4.4: ROV during Floating test

4.6.2 Suspended in Depth Test

On this experiment, it was assumed the density of the ROV 1330 kg/m³, thus it complies with W Fa equation, therefore the ballast pump adds 149.071 kg/m³ with the addition of 0.244 kg from the ballast, then the ROV condition complies with the W Fa equation. These conditions require ROV ballast to achieve a neutral position. Some testings are done by adding ballast load to get a neutral position with a total weight of ROV to 1000 kg/m³. Mini ROV body balance greatly affects the ability to dive and movement when manoeuvring.

4.6.3 ROV

On this experiment, it was assumed the density of the ROV with the number of 850.929 kg/m³, thus it doesn't comply with W Fa equation, therefore the ballast pump adds 300 kg/m³ with the addition of 0.522 kg from the ballast, then the ROV condition complies with the $W > Fa$ equation. Nevertheless, the additional mass from the ballast to comply with the W Fa equation could start from 150 kg/m³ or more than that, depends on what the ROV needs.

P total = P ROV + P water ballast

850.929+300 = 1150,929 kg/m²

Fig 4.5: ROV during siniking test

4.7 Manoeuvre test:

Table 4: Manoeuvre test

NO	Command	Distance (m)	Time taken (s)	Remarks
1	Forward	2.0	1.2	Propelled by rear propellers
2	Backward	1.8	1.4	Slightly slower due to water drag
3	Left	90º	1.1	Actuated by right side pumps
4	Right	90º	1.1	Actuated by left side pumps
5	Rotate	360º	1.5	Rotation using opposite side pumps
6	Pump in (down)	-	2.0	Water intake for depth adjustments
7	Pump out (up)	-	2.0	Water expulsion for ascent

CHAPTER 5

RESULTS, DISCUSSION AND CONCLUSION

5.1 Results

The design and development of the syringe-actuated PVC ROV was completed with the aim of providing a cost-effective solution for lakebed exploration. The key performance indicators considered in this project included maneuverability, buoyancy, and hydrodynamic efficiency. After completing the design, simulations and initial calculations indicated that the ROV performed adequately for the intended tasks.

The design and fabrication of submersible Remotely Operated Vehicles (ROVs) have advanced considerably to support underwater exploration, scientific research, environmental monitoring, and industrial applications. ROVs are essential tools for operations ranging from underwater inspections to complex data collection, thanks to their adaptability, cost-efficiency, and operational versatility.

The design process focuses on achieving optimal buoyancy, stability, and maneuverability. Materials such as PVC and aluminum are commonly used due to their corrosion resistance and structural strength. Lightweight acrylic domes protect sensitive equipment, while LED lighting systems enhance visibility in low-light environments. The integration of the control board; HD RX/2.4G receiver, offers reliable wireless communication and manual control.

Propulsion systems, driven by pumps, working on a syringe actuating principle provide the necessary thrust, six strategically placed pumps (four at the sides, 2 at the fore) generate the necessary hydrodynamic force for maneuverability. This innovative approach allows for precise control of the ROVs movement while maintaining a favorable thrust-to-weight ratio, essential for its operation in shallow waters.

Fabrication methods focus on PVC pipes, selected for **lightweight, corrosion resistant, and cost-effective properties.** The PVC hull and syringe-actuating pump system are central to the design, ensuring durability while offering ease of fabrication and affordability. This approach not only meets the functional requirements of the ROV but also provides a balance between performance and cost, making it suitable for lakebed exploration and shallow water observations.

Summary of Key Findings and Achievements

- The ROV successfully demonstrated controlled maneuverability in water, with effective lateral and rotational movements.
- The syringe-actuating principle worked efficiently for fine control, though with minor response delays.
- The PVC hull proved to be durable and cost-effective material but required additional sealing for extended use.
- The ROV's propulsion system allowed it to reach moderate depths, but improvements could enhance speed and efficiency.
- Compared to conventional thruster-based ROVs, this design offered better precision at a lower cost, making it suitable for shallow-water exploration tasks.
- Final Assessment of Performance: While the prototype performed well in terms of maneuverability and cost-effectiveness, further refinements are needed to enhance speed, response time, and waterproofing.

Overall, the ROV is a viable solution for lakebed exploration and crack observation, with potential improvements for broader applications.

5.2 Discussion

The results of the syringe-actuated PVC ROV indicate that it is a viable option for specific underwater applications, such as lakebed exploration and crack observation. However, several challenges were encountered during the development process.

Strengths of the design include is cost-effectiveness and the fine control provided by the syringe-actuated pumps. This allows the ROV to maneuver in tight spaces, where traditional thruster-based systems may struggle. The use of PVC for the hull material also contributed to the lightweight nature of the ROV, which is essential for shallow water exploration. Furthermore, the design’s simplicity reduces chances of mechanical failure.

However, the ROV’s limitations are clear in its lack of speed and the reduced power of propulsion system when compared to traditional ROVs. In addition, the syringe-actuated system, while effective for small-scale movement, may not be suitable for high-speed applications or long-duration missions.

The comparison to other ROV designs, such as traditional propeller-driven models, highlights the distinct advantages of the syringe-actuated system in precise control, but also underscores the need for a more robust propulsion system if speed or large-scale missions are required.

5.3 Conclusion

The syringe-actuated PVC ROV design has proven to be a promising solution for targeted underwater exploration in shallow, confined environments. Its unique propulsion mechanism provides precise control, and its lightweight design allows for easy deployment in range of settings. The design has shown itself to be cost-effective while maintaining functionality for its intended application of lakebed exploration and crack observation.

While the design proves valuable in specific use cases, further improvements are recommended. Future work should focus on enhancing the propulsion system to allow for greater speed and versatility, as well as increasing the overall power efficiency for longer operational durations. Additionally, more advanced sensors and imaging systems could be integrated to broaden the range of tasks the ROV can handle.

In conclusion, this project has demonstrated the feasibility of the syringe-actuated PVC ROV as cost-effective solution for shallow water exploration, with the potential for further innovation and development in the field.

RECOMMENDATIONS

1. Advanced Material Utilization: Incorporating composite materials and syntactic foams can enhance buoyancy while reducing structural weight, especially for deep-sea applications.

2. Improved Propulsion Systems: Hybrid propulsion combining electric and hydraulic systems can improve thrust efficiency. Ducted propellers may reduce debris interference, enhancing durability.

3. Enhanced Automation and Control: Utilizing AI-driven navigation systems and advanced microcontrollers can improve autonomous capabilities. Closed-loop feedback systems can optimize depth and positional accuracy.

4. Energy Efficiency Optimization: Transitioning to lithium-ion or solid-state batteries can extend operational time. Energy recovery systems, such as regenerative braking in thrusters, may further improve efficiency.

5. Modular Design for Scalability: Modular platforms allow easy upgrades, making ROVs adaptable to various missions, including environmental surveys and industrial inspections.

6. Enhanced Communication Systems: While tethered communication remains reliable, exploring acoustic modems with advanced signal processing could expand operational ranges

7. Environmental Impact Consideration: Using quieter thrusters and eco-friendly materials minimizes ecological disturbances, aligning with sustainable marine exploration practices.

8. Real-Time Data Integration: Multi-sensor arrays for real-time monitoring of environmental parameters (e.g., pH, turbidity) can enhance data collection during missions.

9. Safety And Redundancy Features: Redundant systems, such as dual power supplies and fail-safe mechanisms, improve reliability. Automated surface-return protocols can prevent equipment loss.

10. Continuous Skill Development: Training programs focusing on simulation-based ROV piloting can enhance operator proficiency and reduce equipment risks during real missions.

Potential Future Projects

1. Deep-Sea Exploration Variant: A more pressure-resistant version of the ROV could be developed for deeper water exploration.
2. Autonomous ROV Development: Adding AI-based navigation and real-time data processing could enable autonomous underwater exploration.
3. Integration with Sensor Systems: Incorporating cameras, sonar, or environmental sensors could expand the ROV's applications in hydrographic surveying and marine research.

By implementing these recommendations, the next iteration of the ROV can achieve higher efficiency, better durability, and expanded use cases for both research and commercial applications.

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