**MCTA4372**

**UNDERWATER AND AERIAL ROBOTS**

**SEMESTER 2 2023/2024**

# Project Report: Comparative Analysis of ROV, AUV, and USV in Fieldwork Applications within Underwater Robotics Technology

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# 1. Introduction

Underwater robots technology has ushered in a new era of marine exploration and industry, providing unparalleled possibilities for precise data collecting, efficient mapping, and exploration of difficult underwater settings. This technological breakthrough is demonstrated by the deployment of unmanned underwater vehicles, such as Remotely Operated Vehicles (ROVs), Autonomous Underwater Vehicles (AUVs), and Unmanned Surface Vehicles (USVs). ROVs, as described by NOAA (2019), are highly manoeuvrable devices linked to surface vessels and designed to explore ocean depths in hazardous or inaccessible environments. Huvenne et al. (2017) describe their primary features as tethered operation, imaging capabilities, sample retrieval methods, customisable sensors, thrusters for mobility, and a control room on the surface vessel.

ROVs, as cited by Christ and Wernli (2007) and Ridao et al. (2007), were originally designed for military uses in the 1960s and have now shifted to the industrial sector, where they are most commonly used in the oil and gas industry, scientific research, and salvage operations. AUVs, on the other hand, are autonomous undersea robots that collect high-resolution data on planned missions (Griffiths, 2003; Hobson et al., 2012; Furlong et al., 2012). Their adaptability is demonstrated by their classification as "cruising" or "hovering" vehicles (Rigaud, 2007; Caress et al., 2008), which excel at travelling preset courses for both commercial and scientific reasons (Yoerger et al., 1998; Wagner et al., 2013).

In the realm of surface waters, USVs, defined by Liu et al. (2016) and Wright (2022), represent autonomous vessels equipped with GPS tracking, robotics, sonars, and various sensors. They operate without a crew, offering a cost-effective alternative to manned vessels and finding applications in oceanographic studies, hydrographic surveys, military operations, and environmental monitoring (CSMI, 2022; Wright, 2022). USVs are recognized for their autonomy, precise navigation, durability, and collision avoidance capabilities.

These advancements collectively underscore the profound impact of underwater robotics technology on safety, operational efficiency, and precision in underwater tasks across diverse industries.

# 2. Underwater ROVs (Remotely Operated Vehicles):

## 2.1. Components in an ROV

| Components | | Purpose |
|---|---|---|
| 1 | Frame Structure | ROVs typically have a sturdy frame designed to withstand the pressures of the underwater environment. The structure is often modular, allowing for easy customization and adaptation to various tasks. |
| 2 | Propulsion System | ROVs use thrusters for movement in multiple directions. These thrusters provide the necessary manoeuvrability to navigate complex underwater terrain. |
| 3 | Power Supply | ROVs receive power through the umbilical cable from the surface vessel. This power is used to operate thrusters, cameras, manipulator arms, and other equipment on board. |
| 4 | Tether or Umbilical | ROVs are connected to a surface vessel by a cable known as an umbilical, which houses communication and power lines. This tether allows operators to control the ROV from the surface. |
| 5 | Control System | Operators control ROVs from a dedicated control console on the surface vessel. The console provides a user interface for steering, operating manipulator arms, and monitoring sensor data. |
| 6 | Cameras and Lights | ROVs are equipped with high-resolution cameras and lights to capture clear images and videos in the underwater environment. These are crucial for navigation and data collection. |
| 7 | Sensors | Various sensors may be integrated into an ROV for tasks such as measuring temperature, pressure, salinity, and other environmental factors. Specialised sensors can be added based on the mission requirements. |
| 8 | Manipulator Arms | Many ROVs are equipped with manipulator arms or tools that can be remotely operated. These arms enable the ROV to interact with its surroundings, performing tasks such as grabbing samples or manipulating objects. |
| 9 | Buoyancy Control System | ROVs may be equipped with a buoyancy control system to adjust their depth in the water. This can include ballast tanks or other mechanisms to control buoyancy. |
| 10 | Navigation System | Navigation systems, including gyroscopes and depth sensors, assist in maintaining the ROV's position and orientation underwater. |

| | | |
|---|---|---|
| 11 | Communication Equipment | The umbilical tether facilitates two-way communication between the ROV and the surface vessel. This enables real-time control and data transmission. |

### 2.2. A visualisation of the components in an ROV:

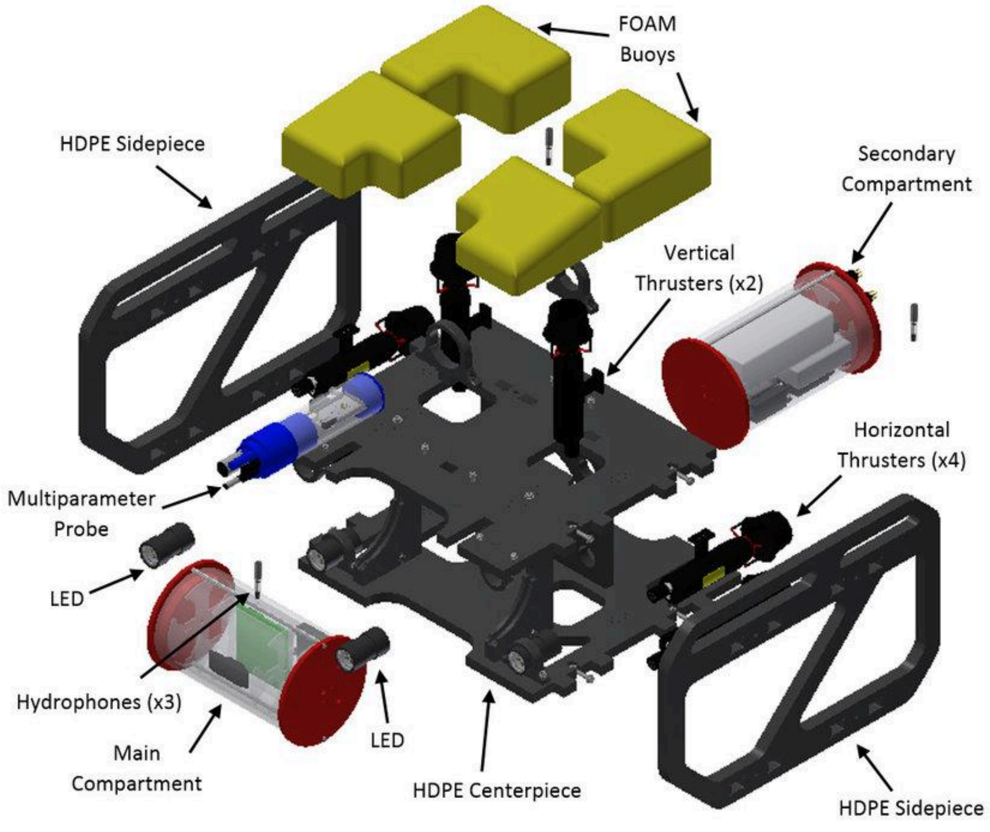


Figure 1: Hidalgo et al. (2015)

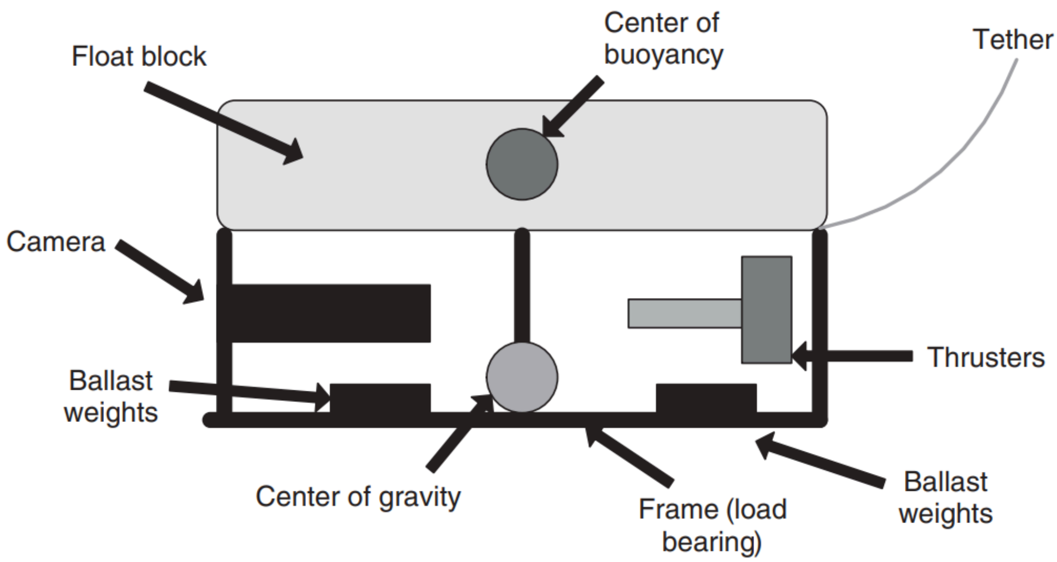

Figure 2: Christ and Wernli (2011)

### 2.3. The Advantages and Limitations of ROVs in underwater tasks:

ROVs, or Remotely Operated Vehicles, stand out as indispensable tools in various industries, offering a multitude of advantages for underwater tasks. The key benefits of utilising ROVs encompass:

1) Versatility:
   i) ROVs demonstrate remarkable adaptability, capable of functioning in diverse water depths, ranging from shallow to deep-sea environments. This versatility allows them to tackle a wide array of tasks across different underwater scenarios.

2) Enhanced Capabilities:
   i) Possessing advanced mechanical, inspection, and recording abilities, ROVs outperform human divers in terms of precision and efficiency, significantly elevating their capabilities in underwater operations.

3) Safety:
   i) Operating in hazardous or hard-to-reach underwater conditions, ROVs effectively mitigate risks to human divers by undertaking tasks that would otherwise pose safety concerns (Diver versus Deep Trekker: A Cost/Benefit Analysis, n.d.).

4) Cost-Effectiveness:
   i) The utilisation of ROVs eliminates the need for extensive diver training, specialised equipment, and associated logistical expenses.

This results in substantial cost savings over the long term (Diver versus Deep Trekker: A Cost/Benefit Analysis, n.d.).

5) Time-Efficiency:
    i) ROVs offer quick deployment by a single operator with minimal preparation time, ensuring longer bottom time and more thorough inspections compared to traditional diver operations (Diver versus Deep Trekker: A Cost/Benefit Analysis, n.d.).

These advantages underscore the pivotal role of ROVs in enhancing safety, efficiency, and effectiveness in a wide spectrum of underwater tasks across various industries.

The disadvantages according to Diver versus Deep Trekker: A Cost/Benefit Analysis (n.d.) include:

1) Lack of Human Judgment:
    a) ROVs lack the adaptability and problem-solving skills that human divers possess, as they are purpose-built for specific tasks and lack the ability to make on-the-spot adjustments or creatively solve unforeseen challenges

2) Limited Battery Life:
    a) ROVs have a finite battery life, which can restrict the duration of their operations underwater compared to human divers who can adjust their dive times based on conditions

3) Reduced Dexterity:
    a) While ROVs can be equipped with robotic arms, they struggle to replicate the fine motor skills and flexibility of human hands, impacting their ability to perform intricate tasks that require precise manipulation or handling of objects

4) Inability to Assess Texture or Weight:
    a) ROVs cannot assess texture or weight underwater, making it challenging for them to perform tasks that require precise manual manipulation or delicate repairs

5) High Initial Investment:
    a) The initial cost of acquiring and operating ROVs can be a barrier, especially for smaller organisations with limited budgets, although the long-term savings may outweigh these upfront costs

### 2.4. ROV Applications and Justifications:

According to Team Blueprint Lab (2022), there are multiple uses of the ROVs according to the industries:

| **Industries** | **Uses** | **Justification** |
|---|---|---|
| Offshore Energy (Wing, Oil and Gas, Hydroelectric) | General Visual Inspection<br>Close Visual Inspections (looking closely at the condition of underwater infrastructure)<br>NDT Inspections<br>Infrastructure Deployment and Recovery<br>Control Manifold Interventions | Ensuring efficient infrastructure inspections and interventions. |
| Military | Submarine Rescue<br>Waterborne Improvised Explosive Device (WIED) Intervention<br>Sea and Limpet Mine Intervention<br>Special Recovery Operations (e.g. Downed Aircraft Recovery)<br>Naval Asset Inspections<br>Hydrography | Enhancing safety in submarine rescue, explosive device intervention, and naval asset inspections. |
| Oceanography and Marine Science | Coral and Marine Life Observation<br>Sample and Sediment Collection<br>Academic Research Applications | Contributing to marine observation, sample collection, and academic research. |
| Inshore Infrastructure (Tanks, Dams, and Waterways) | Condition Assessment and Monitoring<br>Sediment Sampling<br>Removal of Sludge by Dredging<br>Debris Collection | Optimising maintenance in tanks, dams, and waterways through assessments and debris collection. |
| Search and Rescue | Drowned Victim Recovery<br>Forensic Assessment<br>Equipment Recovery<br>Large Scale Search and Documentation | Improving efficiency in victim recovery, forensic assessment, and large-scale search operations. |

| | | |
|---|---|---|
| Commercial Diving and Salvage | Attaching and releasing hooks for equipment installation and recovery<br>Construction and salvage tasks (such as cutting and welding) | Assisting in equipment tasks, construction, cutting, welding, and salvage operations. |
| Aquaculture | Equipment and infrastructure monitoring<br>Rope management and recovery<br>Net Repair<br>Mort Retrieval<br>Cleaning | Enhancing efficiency in monitoring, repair, retrieval, and cleaning in aquaculture settings. |
| Nuclear Decommissioning | Fuel Rod Management<br>Debris Collection and Removal<br>General Visual Inspection<br>Cutting and Recovery<br>NDT Inspections | Playing a vital role in fuel rod management, debris removal, and inspections. |
| Underwater Exploration | General Visual Observation<br>Retrieval of Objects | Providing a valuable tool for general observation and object retrieval. |

## 3. AUVs (Autonomous Underwater Vehicles):

### 3.1. Design Components

| Design components | | Purpose |
|---|---|---|
| 1 | Structural Framework | AUVs are engineered with a robust structural framework, meticulously designed to withstand the extreme pressures encountered in underwater environments. This structural integrity ensures their resilience and durability during prolonged underwater missions. |
| 2 | Propulsion System | The propulsion system of AUVs is a critical element, typically relying on advanced thrusters for precise three-dimensional manoeuvrability. This section delves into the mechanics of the propulsion system, elucidating how it facilitates the vehicle's movement in the underwater domain. |
| 3 | Buoyancy Control | A detailed explanation of buoyancy control mechanisms is provided, outlining how AUVs regulate their buoyancy to maintain specific depths during operations. This aspect is fundamental to their ability to navigate the water column effectively. |

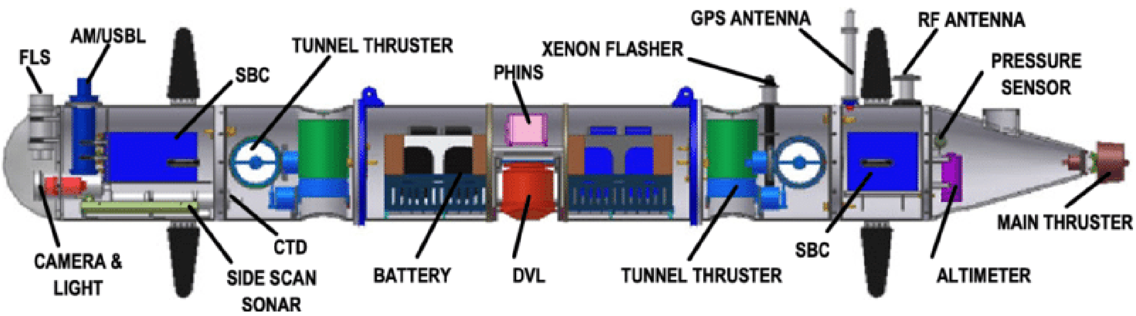


Figure 3: (Shome et al., 2012)

### 3.2. Operational Features

| Operational features | | Purpose |
|---|---|---|
| 1 | Autonomous Navigation | Autonomous navigation is one of the characteristics that set AUVs apart. In contrast to tethered options, this portion examines the technology that allows autonomous operations without requiring real-time control. |
| 2 | Sensor Integration | AUVs are equipped with an array of sensors for diverse data collection purposes. This includes but is not limited to sonars, cameras, and other specialised sensors. The |

| | | |
|---|---|---|
| | | integration of these sensors enhances AUVs' capabilities for scientific research and environmental monitoring. |
| 3 | Endurance and Range | AUV endurance varies based on technology improvements, ranging from hours to months. Additionally, it talks about their operational range, demonstrating how AUVs can be tailored to meet various mission needs. |
| 4 | Mission Execution | The ability of AUVs to carry out pre-programmed missions autonomously is crucial. This entails following specified courses and doing certain duties without direct human interaction, which increases their efficiency in underwater exploration. |

## 3.3. Classification of AUVs

### 3.3.1. Hovering AUvs:

3.3.1.1. Hovering Autonomous Underwater Vehicles (AUVs), exemplified by ABE, Sentry, and Sirius, navigate intricate underwater landscapes with omnidirectional thrusters akin to ROVs. Ideal for precision tasks and seabed imaging, these AUVs carry various sensors, but limited battery capacity constraints operation duration. Despite this, they achieve remarkable precision, following pre-programmed routes and capturing detailed sonar and optical images with high accuracy (*Platform Description*, n.d.).

### 3.3.2. Cruising AUVs:

3.3.2.1. According to Elangovan and T (2020) Cruising Autonomous Underwater Vehicles (AUVs) are a form of AUV specifically intended for efficient survey operations in marine environments. Torpedo-shaped vehicles, powered by a single propeller, may reach speeds of up to 2 m/s and travel vast distances on pre-designed rails . Cruising AUVs are the most common type of AUVs employed in numerous industries since their design prioritises practicality and efficiency for commercial and scientific uses.

3.3.2.2. Torpedo Shape:
The streamlined shape improves hydrodynamic performance and lowers drag for more effective water movement.

Figure 4:

3.3.2.3. Single Propeller:
During survey missions, cruising AUVs can traverse large regions thanks to their single propeller, which may reach speeds of up to 2 m/s.

3.3.2.4. Optimised for Survey Operations:
These unmanned aerial vehicles (AUVs) are designed to do certain jobs, like swiftly and precisely gathering data along pre-established paths.

3.3.2.5. Commercial and Scientific Use:
Cruise autonomous underwater vehicles (AUVs) are widely employed in scientific studies pertaining to marine biology, geology, and oceanography, in addition to their frequent use in commercial applications.

## 3.4. Advantages and Limitations of AUVs

Benefits and Drawbacks of AUVs for Data Collection and Underwater Exploration although autonomous underwater vehicles (AUVs) have several benefits for data collecting and underwater exploration, their operating capabilities are limited.

### 3.4.1. Disadvantages:

3.4.1.1. Limited Energy Capacity:
AUVs' limited operating range and endurance due to their energy capacity provide difficulties for long-term missions that need substantial data collecting.

3.4.1.2. Communication Challenges:

Unlike land-based vehicles, AUVs face difficulties in communication underwater as they cannot rely on GPS or radio signals for navigation and communication

3.4.1.3. Complexity and Risk:
Some perceive AUVs as expensive, complex, and risky to use compared to conventional towed instruments for ocean surveys

3.4.1.4. Hardware Failure:
AUVs are susceptible to hardware failures such as battery life issues, communication failures, and motor malfunctions that can impact their performance during missions

3.4.2. Advantages:

3.4.2.1. Data Quality and Cost-Effectiveness:
AUVs provide high-quality data at a lower cost, making them valuable for geophysical surveys in oil and gas exploration

3.4.2.2. Efficiency and Coverage:
AUVs can cover vast areas quickly, making them efficient for search and rescue missions and exploration tasks that require extensive coverage

3.4.2.3. Endurance:
AUVs can operate for long periods without refuelling or recharging, enhancing their utility in prolonged underwater missions

3.4.2.4. Versatility:
AUVs are versatile tools used in oceanographic research, environmental monitoring, marine conservation, offshore infrastructure inspection, underwater maintenance, resource exploration, mine disposal, and anti-submarine warfare

### 3.5. AUV Advantages over ROVs and USVs in Diverse Applications

According to *What Is an AUV? : Ocean Exploration Facts: NOAA Office of Ocean Exploration and Research* (n.d.), when it comes to underwater exploration and data collecting, AUVs are far superior to ROVs and USVs.

| Application | | Purpose |
|---|---|---|
| 1 | Deep-sea Exploration | AUVs can reach deeper water than boats, human divers, or many tethered vehicles, making them ideal for deep-sea exploration |
| 2 | Deep-sea Exploration | AUVs can operate independently of humans, allowing them to stay underwater for extended periods without the need for human intervention |
| 3 | Mapping and Surveying | AUVs are used for seafloor mapping, creating maps of the ocean floor, and recording environmental information, making them valuable tools for oceanographic research |
| 4 | Hazard Identification | AUVs can identify hazards to navigation, such as shipwrecks and geologic formations, providing valuable data for maritime safety and environmental management |
| 5 | Sustainable Research | AUVs are less expensive than research vessels but can complete identical repeat surveys of an area, making them a cost-effective and sustainable option for long-term research projects |

## 4. AUVs (Autonomous Underwater Vehicles):

The design of USVs incorporates features like autonomous navigation systems, efficient propulsion mechanisms, and onboard equipment tailored for specific applications. According to Kolev et al. (2021) and Galway (2008).

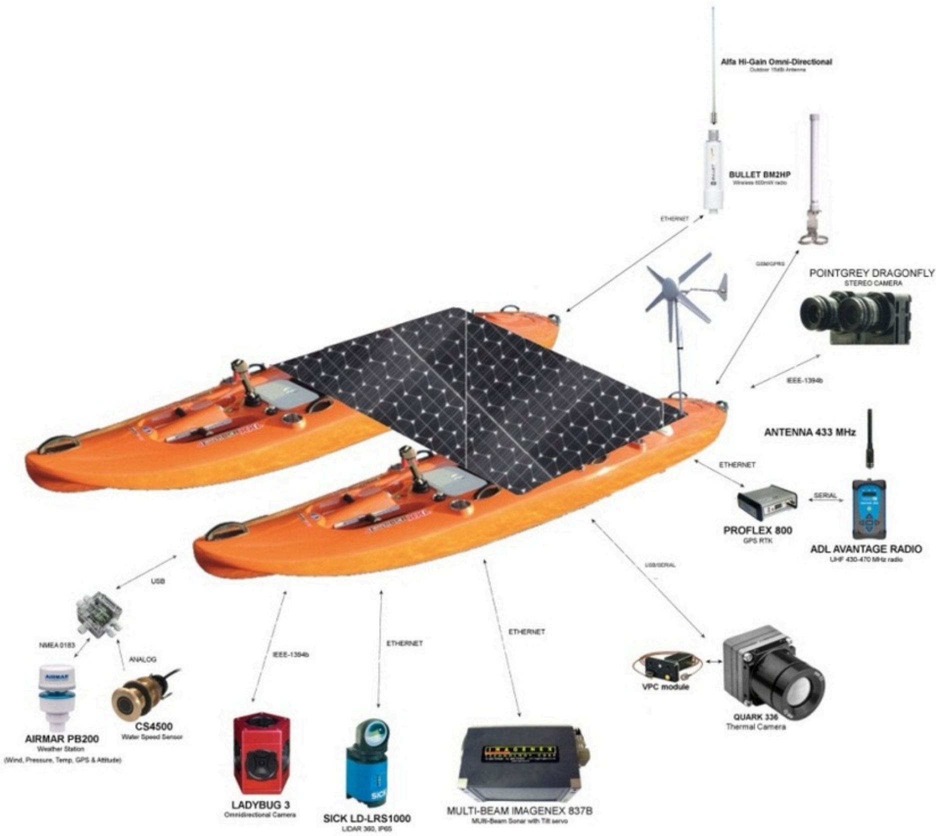


Figure 5: Eduardo Costa Pinto et al. (2013)

4.1. Operational Characteristics:

4.1.1.1. High Speed Missions:
USVs are capable of achieving high speeds during missions in water areas, enhancing their operational efficiency

4.1.1.2. Transportability:
Their small dimensions allow easy transportation between different water bodies, making them versatile for various marine tasks

4.1.1.3. Long-Range Missions:
USVs are suitable for long-range missions due to their developed control and navigation systems that consider Earth's sphericity and ease of calibration

4.1.1.4. Operational Limitations:
USVs may face challenges related to wave interference and weather conditions as their controllers may not account for these factors, impacting their performance in adverse conditions

4.2. Design Features:

4.2.1.1. Architecture:

USVs are designed with a planing hull and an electric propulsion system, making them suitable for various applications like ecological monitoring and cargo missions

4.2.1.2. Onboard Equipment:

USVs are equipped with necessary sensors, communication systems, and control subsystems to enable autonomous navigation and data collection

4.2.1.3. Autonomous Steering System:

This system includes components like an autopilot model, magnetometer calibration, distance calculation, bearing angle calculation, heading angle calculation, steering angle determination, and a steering controller for precise navigation

4.3. The advantages and challenges of using USVs in marine research and industrial applications.

Due to their autonomy and affordability, unmanned surface vehicles (USVs) are revolutionising marine research and industry. However, these vehicles also face issues related to environmental adaptability and payload restrictions. According to Bai et al. (2022), there are several advantages and disadvantages to USVs

| Advantages | Disadvantages |
|---|---|
| **Cost-Effectiveness:** They eliminate expenses related to crew accommodation, salaries, and onboard facilities, leading to significant cost savings. | **Limited Payload Capacity:** USVs typically have smaller payload capacities compared to manned vessels, which may limit the types of sensors or equipment they can carry |
| **Safety:** By eliminating the need for human presence on board, USVs reduce the risk of accidents and injuries | **Limited Endurance:** USVs may have limited endurance due to their battery life or fuel capacity, which can impact their mission duration |
| **Versatility:** USVs can be equipped with various sensors and payloads, making them suitable for a wide range of applications, such as environmental monitoring, oceanographic research, and defence | **Communication Range:** The effectiveness of USVs relies on communication capabilities. Limited communication range may affect their ability to relay real-time data or receive commands in remote areas. |
| **Efficiency:**these vehicles can cover large water areas efficiently, collecting data and conducting surveys with precision. Their autonomous navigation systems contribute to efficient and thorough data collection. | **Regulatory Challenges:** The integration of USVs into maritime operations requires compliance with regulations and standards. Adhering to these guidelines can be a challenge, especially as the technology evolves. |

## 4.4. Optimal Applications of USVs in Marine Fieldwork Scenarios

Unmanned Surface Vehicles (USVs) are being used more often in marine fieldwork for a variety of purposes because of their efficiency, safety benefits, and adaptability. USVs are especially well-suited for marine fieldwork in the following situations

<table>
<tr>
<td>Environmental Monitoring: USVs are ideal for environmental monitoring tasks, such as oil spill detection, water quality assessment, and marine ecosystem studies, due to their ability to collect real-time data and navigate diverse marine environments</td>
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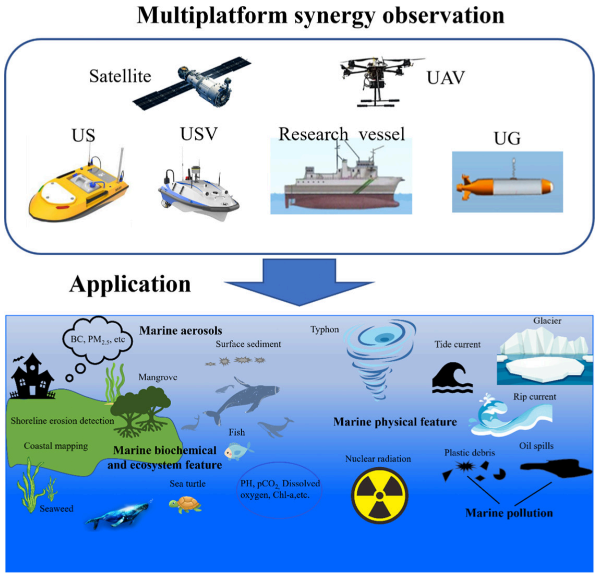

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<tr>
<td>Coastal Protection: USVs can be utilised for coastal protection activities, including monitoring coastal erosion, conducting bathymetric surveys, and assessing shoreline changes, providing valuable insights for coastal management and protection</td>
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<tr>
<td>Security and Surveillance: USVs play a crucial role in security and surveillance operations by patrolling maritime borders, monitoring illegal activities, and enhancing situational awareness in sensitive marine areas</td>
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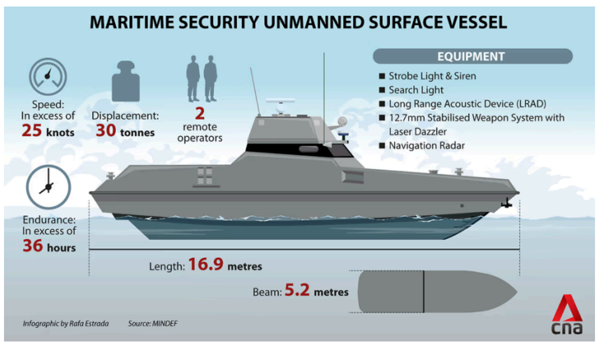

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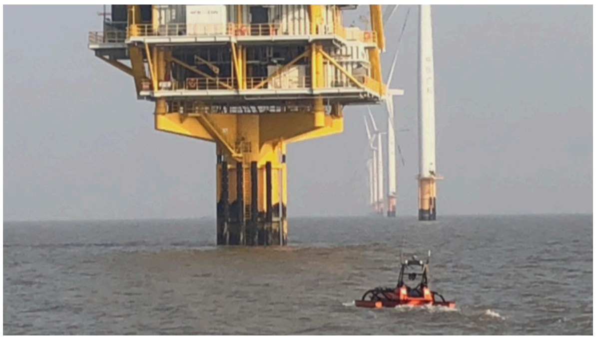
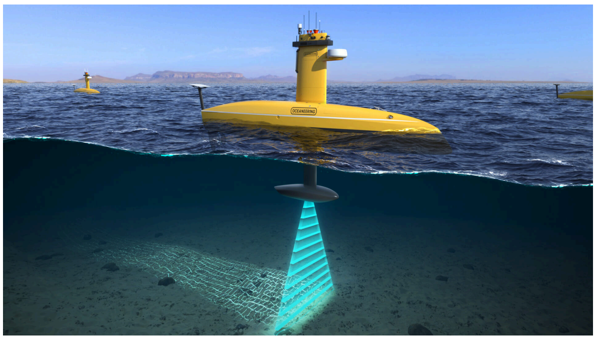
|---|---|
| **Offshore Operations:** USVs are well-suited for offshore operations like pipeline inspection, offshore platform monitoring, and subsea infrastructure maintenance, offering cost-effective solutions for routine inspections and maintenance tasks |  |
| **Scientific Research:** USVs are extensively used in scientific research applications to study oceanographic processes, marine biodiversity, underwater habitats, and climate change impacts on marine ecosystems, providing researchers with valuable data for analysis and decision-making |  |

## 5. Comparison and Selection Criteria:

### 5.1. Exploring Unmanned Marine Vehicles: A Comparative Analysis

The choice of Unmanned Marine Vehicles (UMVs) is crucial for a number of applications in the field of marine technology. The following is an improved subheading that compares ROVs, AUVs, and USVs according to technology, autonomy, operational depth, data gathering capacity, and cost-effectiveness:

| | ROV | AUV | USV |
|---|---|---|---|
| Technology: | -Controlled by Tether<br>-Manipulator Arms | -Fully Autonomous | -Surface Navigation |
| Operational Depth: | -Varied Depth | -Varied Depths | -Surface Operations |
| Autonomy: | -Operator-Dependent | -High Autonomy | -Varied Autonomy |
| Data Collection Capabilities: | -Versatile Sensors<br>-Real-time Feedback | -Sensor Payload<br>Data Storage | -Surface Sensors<br>Communication Platforms |

| | | | |
|---|---|---|---|
| Cost-Effectiveness: | -Higher Costs<br>-Skilled Operators | -Moderate Costs<br>-Reduced Operating Costs | -Cost-Effective<br>-Reduced Crew Requirements |

5.2. Criteria for selecting an ROV, AUV, or USV for specific types of marine fieldwork and research projects.

1. Environmental Monitoring:
   a. AUVs:
      i. AUVs equipped with sensors for measuring water quality parameters are valuable for environmental monitoring due to their autonomous navigation and long-endurance capabilities. They can collect comprehensive datasets over large areas, contributing to the assessment of marine ecosystem health.
   b. USVs:
      i. USVs can serve as platforms for deploying and operating sensors for environmental monitoring. While they may lack the autonomy of AUVs, their stable platform and remote operation capabilities enable efficient data collection in coastal and nearshore environments.

2. Offshore Energy Infrastructure Inspection
   a. ROVs:
      i. ROVs are commonly used for offshore infrastructure inspection due to their precise manoeuvrability and real-time feedback capabilities. Equipped with high-resolution cameras and manipulator arms, they allow for detailed inspections and maintenance tasks, ensuring the safety and integrity of offshore facilities.
   b. AUVs:
      i. AUVs equipped with imaging sonars are suitable for broad-scale surveys of offshore energy infrastructure. While they may lack the manipulation capabilities of ROVs, their autonomous navigation and long-endurance capabilities enable them to collect valuable data for asset management and maintenance planning.

3. Bathymetric Surveys:
    a. AUVs:
        i. AUVs are ideal for bathymetric surveys due to their autonomous navigation and long-endurance capabilities. They can systematically cover large areas while collecting accurate depth measurements and high-resolution imagery, providing comprehensive seafloor mapping data.

4. Pipeline Inspection and Maintenance:
    a. AUVs:
        i. While AUVs offer autonomous navigation for covering large areas efficiently, they lack the real-time feedback and manipulation capabilities of ROVs. However, their long-endurance capabilities make them suitable for broad-scale pipeline surveys, contributing to cost-effectiveness and data continuity.
    b. USVs:
        i. USVs can support pipeline inspection by deploying and operating sensors in the vicinity of pipelines. Although they lack the manipulation capabilities of ROVs, their remote operation capabilities and adaptability to varying sea conditions allow for efficient data collection and monitoring tasks.
    c. ROVs:
        i. ROVs excel in pipeline inspection due to their precise manoeuvrability and real-time feedback capabilities. With tethered operation, they offer continuous power and communication, enabling operators to conduct detailed inspections and perform maintenance tasks with high accuracy.

## 6. Case Study

| Vehicle | Scenario | Reason for Selection | Impact |
| --- | --- | --- | --- |
| ROV | Inspection of an offshore gas pipeline in the Gulf of Mexico. | Compared to AUVs and USVs, ROVs offer superior manoeuvrability and real-time data transmission capabilities, making them the optimal choice for intricate inspections at significant depths where precise control is essential. | The ROV successfully detected a minor leak in the pipeline, enabling timely repairs and preventing potential safety hazards and costly disruptions. |
| AUV | Mapping the seafloor around the Galapagos Islands for scientific research. | AUVs were selected due to their autonomous operation capabilities, allowing for extended missions without human intervention. This autonomy, coupled with their ability to cover large areas efficiently, made AUVs the preferred choice for mapping remote underwater environments with minimal human involvement. | The AUV collected high-resolution data, revealing previously unknown geological features and marine habitats, contributing to the understanding of the region's unique ecosystems. |
| USV | Monitoring coral reefs in the Great Barrier Reef for environmental conservation. | USVs were chosen for their surface-based operation, minimising disturbance to delicate marine habitats compared to AUVs and ROVs. Their adaptability to shallow waters and ability to navigate close to coral reefs made USVs ideal for environmental monitoring and conservation efforts in sensitive marine ecosystems. | The USV gathered valuable data on reef health, biodiversity, and environmental changes, supporting conservation efforts and ecosystem management in the region. |

## 7. Conclusion

For marine fieldwork, AUVs, ROVs, and USVs each offer distinct advantages depending on the specific requirements of the task at hand. AUVs are most suitable for autonomous underwater exploration and survey missions, particularly in remote or hazardous environments where human intervention is impractical. ROVs excel in tasks that require real-time control and manipulation, such as detailed inspections, sample collection, and infrastructure maintenance. USVs are preferred for autonomous surface operations, including oceanographic research, environmental monitoring, and military missions, where cost-effectiveness, adaptability, and reduced risk to human life are paramount.

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