KULLIYYAH OF ENGINEERING
DEPARTMENT OF MECHATRONICS ENGINEERING

Assignment Report

Underwater and Aerial Robots
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(Section 1)

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INTRODUCTION

Underwater robotics technology involves the design, development, and deployment of autonomous or remotely operated vehicles (ROVs) for exploration and tasks in underwater environments. These robots are equipped with sensors, cameras, and manipulators, allowing them to perform various functions such as mapping the seabed, inspecting underwater infrastructure,and even performing maintenance tasks.

The significance of underwater robotics in marine exploration and industry is profound. Firstly, it enables researchers and scientists to access and explore regions of the ocean that are difficult or dangerous for humans to reach .This allows for the discovery of new species,advancing our understanding of marine environments and biodiversity.

In industry, underwater robotics plays a crucial role in tasks such as offshore oil and gas exploration, pipeline inspection and maintenance, underwater construction, and environmental monitoring. These robots can perform these tasks more efficiently and cost-effectively than traditional methods, reducing the risk to human divers and minimising environmental impact.

ROVs (remotely operated vehicles) are a type of underwater robot used for various purposes, including exploration, research, and industrial tasks. These vehicles are typically tethered to a control ship or platform on the surface, allowing operators to remotely control their movements and operations from above water.

AUVs (Autonomous Underwater Vehicles) are unmanned underwater robots designed to operate independently without direct human control. Unlike ROVs, AUVs do not require a tether to a surface vessel for communication or power, making them autonomous in their operations. These vehicles are equipped with sensors, navigation systems, and onboard computers that allow them to navigate, collect data, and perform tasks underwater without human intervention.

USVs, or Unmanned Surface Vehicles, are autonomous or remotely operated vessels that navigate on the surface of water without a human crew onboard. These vehicles can be controlled remotely from a shore station or a manned vessel, or they can operate autonomously following pre-programmed routes or responding to environmental cues.

ROV (Remotely Operated Vehicles)

Figure 1 shows model of ROVs called Subastian (https://schmidtocean.org)

ROVs typically have a cylindrical or streamlined body, often made of strong materials like aluminium or titanium to withstand high-pressure environments. The shape is optimised for hydrodynamics to minimise drag and facilitate efficient movement underwater. ROVs are equipped with thrusters or propellers that provide propulsion and manoeuvrability. These thrusters are strategically placed to allow the vehicle to move in all directions. Most ROVs are tethered to a control system on the surface by a long cable, which provides power and communication. This tether allows operators to remotely control the ROVs.It also equipped with a variety of sensors, including depth sensors, altimeters, sonars, and conductivity/temperature sensors. These sensors provide valuable data about the underwater environment. ROVs are controlled by operators using a joystick or computer interface from a control station on the surface. Lastly, ROVs are powered by onboard batteries or through the tether from the surface vessel. Battery-powered ROVs have limited endurance and typically require periodic recharging, while tethered ROVs can operate continuously as long as they remain connected to the surface vessel.

Table 1: Summary of ROV categories

Class	Capability	Power (hp)
Low cost small ROV/ mini or micro ROV	Observation(<100 meters)	<5
Small ROV (Electric)	Observation (<300 meters)	<10
Medium (Electro/ Hydraulic)	Light/ Medium Heavy Work (<2,000 meters)	<100
High Capacity Electric	Observation/Light Work (<3,000 meters)	<20
High Capacity (Electro/ Hydraulic)	Heavy work/Large Payload (<3,000 meters)	<300
Ultra-Deep (Electric)	Observation/Data Collection (>3,000 meters)	<25
Ultra-Deep (Electro/Hydraulic)	Heavy Work/Large Payload (>3,000 meters)	<120

Advantages of Rovs are:
No time constraints (power supplied on board a different vessel) .Able to cover wide areas (relative to capacity of human divers). Mobility allows close-up examination of sea bed Deployment areas less restricted than towed video. Can be used in areas with submarine obstacles. Some models are able to collect benthic(the ecological region at the lowest level of a body of water such as an ocean or a lake) samples

Disadvantages of Rovs are:
Depth range limited by length of umbilical cable. Equipment needs a hard boat to operate. May be unable to access very shallow waters. Equipment is very expensive and not widely available. May be difficult to employ in areas with strong water currents. Sampling is non-random for example areas for observation and is selected by the operator.
(Problem Identification for Underwater Remotely Operated Vehicle (ROV): A Case Study 2012)

One of field work for ROVs is ROVs are extensively used for inspecting underwater infrastructure such as pipelines, cables, offshore platforms, and ship hulls. Their high-definition cameras and manoeuvrability allow for detailed visual inspections, identifying defects, corrosion, or damage without the need for human divers. ROVs are preferred in these applications due to their ability to operate at depth, in confined spaces, and in hazardous conditions, minimising risk to human divers. With direct power supply it is suitable for long operation jobs but it has a limited distance as the tether cable is around 50m- 150m.

AUVs (Autonomous Underwater Vehicles)

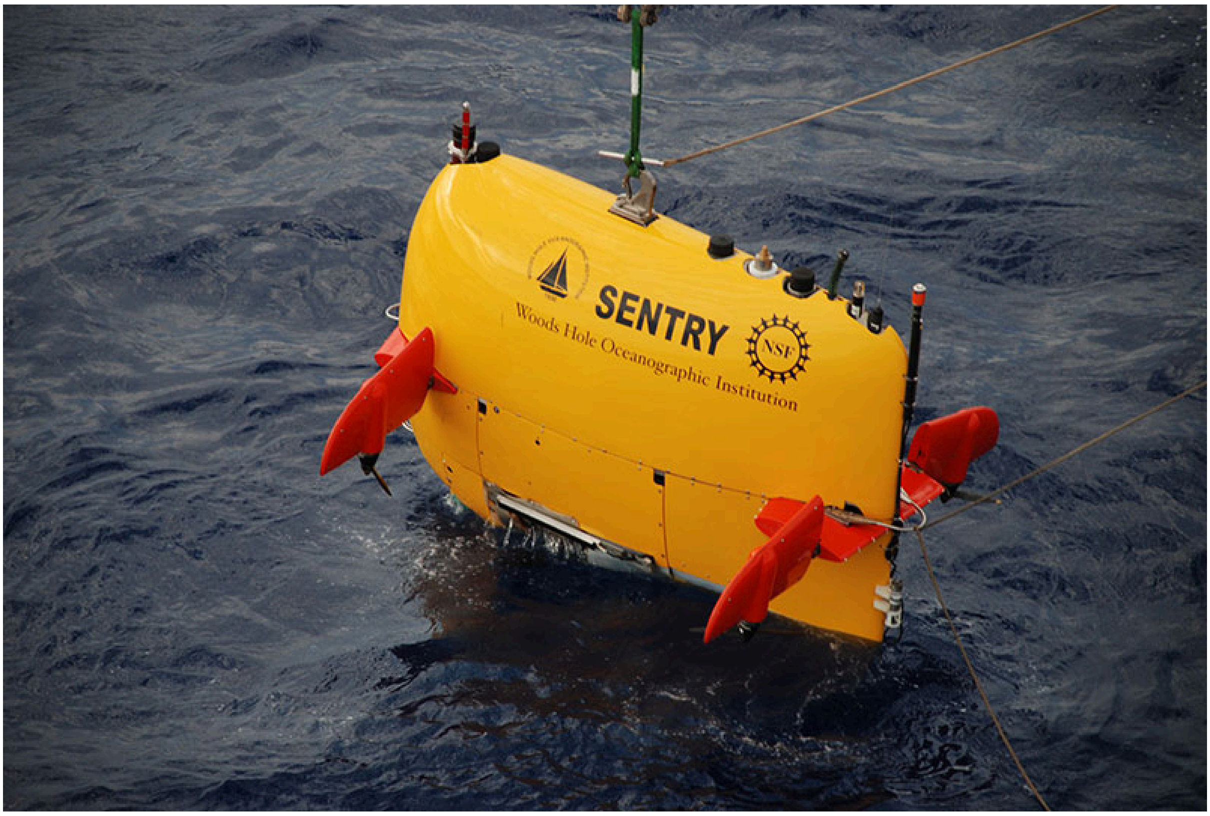

Figure 2 shows AUVs use for marine expedition (https://oceanexplorer.noaa.gov)

AUVs typically have a streamlined body shape to minimise drag and optimise hydrodynamics for efficient underwater movement. They are often constructed from lightweight materials such as aluminium or composite materials to achieve buoyancy and withstand underwater pressure.They are propelled by electric motors or thrusters, which are powered by onboard batteries. These thrusters provide propulsion and manoeuvrability, allowing the AUV to navigate underwater in three dimensions. AUVs are equipped with sophisticated navigation systems, including inertial navigation systems (INS), Doppler velocity logs (DVL), and GPS receivers. These systems allow the AUV to accurately determine its position and orientation underwater.AUVs are equipped with a variety of sensors to collect data about the underwater environment. These sensors may include sonars for mapping the seafloor and detecting obstacles, cameras for capturing images and videos, hydrophones for acoustic communication and navigation, and environmental sensors for measuring water temperature, salinity, and other parameters.

AUVs may feature acoustic modems or radio transceivers for communication with surface vessels or other underwater vehicles. This communication enables operators to monitor and control the AUV's mission, receive data in real-time, and adjust mission parameters as needed.A key characteristic of AUVs is their autonomy, allowing them to operate independently without human intervention. AUVs are pre-programmed with mission plans and algorithms to execute specific tasks such as underwater mapping, surveying, or scientific data collection. They can also adapt to changing environmental conditions and obstacles encountered during the mission.AUVs are powered by onboard batteries, which provide the energy required for propulsion, sensors, communication, and other onboard systems. The size and capacity of the batteries determine the endurance and range of the AUV, with some advanced models capable of operating for several days or weeks on a single charge.

AUVs speed, mobility, and spatial range is stronger compared to ROVs.Since ROVs are tethered to the ship, they can draw more power and communicate real-time data. AUVs cannot operate everywhere. They can be influenced by strong currents. They also are less suited for areas that are heavily populated due to acoustic interference, collision risk, and entanglement. AUVs can operate a wide range of times depending on its purpose and payload. They can last over several days. They use different kinds of batteries – some are even solar charged – to power different types of moment or propulsion.

AUVs are particularly well-suited for seafloor mapping and exploration tasks where continuous, high-resolution data collection is required over large areas. Compared to ROVs, which require constant supervision and control from operators on the surface, AUVs can autonomously navigate predefined survey paths while collecting bathymetric data, seafloor imagery, and geological samples. This autonomy allows AUVs to operate efficiently for extended periods without human intervention, making them ideal for mapping and exploring underwater terrain and features such as underwater volcanoes, hydrothermal vents, and deep-sea trenches.

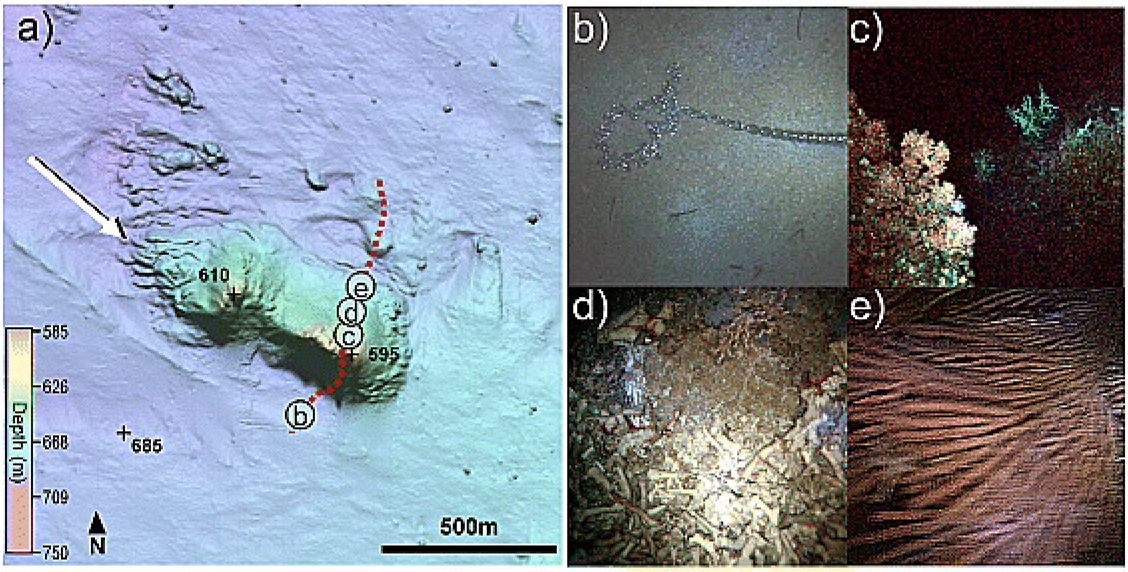

Figure shows floor mapping image (https://agupubs.onlinelibrary.wiley.com)

USVs (Unmanned Surface Vehicles)

USVs come in various hull designs, including monohulls, catamarans, and trimarans, each offering different advantages. The hull is typically constructed from lightweight materials such as fibreglass, aluminium, or composite materials to achieve buoyancy and withstand the rigours of the marine environment.

USVs are equipped with propulsion systems that provide thrust and manoeuvrability. These propulsion systems may include electric motors, diesel engines, or hybrid propulsion systems powered by onboard batteries or fuel tanks.USVs are equipped with navigation systems that enable autonomous or remote operation. These systems may include GPS receivers, inertial navigation systems (INS), radar, and sonar for precise positioning, route planning, collision avoidance, and obstacle detection.USVs are equipped with communication systems that enable remote control and data transmission. These systems may include satellite communication links, radio transceivers, and wireless networks for exchanging commands. Real-time communication capabilities allow operators to monitor and control the USV's operations and receive data updates in real-time.USVs can be equipped with a variety of sensors and payloads tailored to specific mission requirements. These sensors may include cameras, thermal imaging systems, radar, lidar, sonar, and environmental sensors for collecting data on water quality, weather conditions, and marine life. USVs are powered by onboard batteries, diesel generators, or hybrid power systems. Electrically powered USVs typically rely on rechargeable batteries for propulsion and onboard systems, while diesel-powered USVs use fuel tanks to power engines and generators.USVs can operate autonomously or under remote control, depending on the mission requirements. Autonomous USVs are pre-programmed with mission plans and algorithms to execute specific tasks, such as navigation, data collection, and obstacle avoidance, without human intervention. Remote-controlled USVs are operated by operators onshore or from a control station on another vessel, who can monitor and adjust the USV's operations in real-time.

A USV that integrates MBES technology could be a reliable solution to generate underwater terrain maps since it removes the need for an operator and enables new capabilities over existing techniques. The potential use of field robotic systems in environmental data collection is increasing as costs reduce, sensing capabilities are enhanced, and human life can be at risk. USVs are a reliable option for scientific research, environmental missions, reservoir and lake exploration, and ocean resource exploration. The new generation of water vehicles offers significant advantages over traditional surveying methods, for example, high mobility and low cost. Moreover, USVs are a precise and lightweight solution for hydrographic applications since they provide lower operation investment, improved personnel safety, extended operational range, greater autonomy, and increased flexibility in sophisticated environments, including muddy, harsh, and dangerous missions. However, USVs face some challenges, like the development of fully autonomous vehicles in highly dynamic water environments. Additionally, most existing USVs are confined to experimental platforms, comprised primarily of relatively small-scale USVs with limited autonomy, endurance, payload capacity, and power outputs

USVs in maritime surveillance operations, where continuous monitoring of coastal areas, ports, and shipping lanes is essential. They can patrol surface waters autonomously or under remote control, detect and track vessels, monitor maritime traffic patterns, and identify potential security threats such as illegal fishing, piracy, or smuggling.In all parts of the world the increasing volume of maritime threats and the rise of non-traditional border security risks pose a challenge to finite traditional maritime security capabilities. Wide-area surveillance capability has been developed to identify more traditional national security threats using a mix of air, sea and space assets to provide broad maritime domain awareness (MDA).

Figure shows AutoNaut USV for surveillance

Comparison and Selection Criteria

ROVs are tethered underwater robots controlled remotely from the surface. They typically feature cameras, lights, sensors, and manipulator arms for underwater tasks.AUVs are autonomous underwater robots that navigate independently without direct human control. They feature onboard sensors, navigation systems, and propulsion for autonomous operation. USVs are autonomous or remotely operated surface vessels designed for operations on the water's surface. They feature propulsion systems, navigation systems, and communication systems for autonomous or remote control.

ROVs can operate at various depths, from shallow coastal waters to deep-sea trenches, depending on their design and capabilities. Some advanced ROVs can operate at depths exceeding 6,000 metres. AUVs can also operate at various depths, with some models capable of diving to depths of several thousand metres. However, their operational depth may be limited compared to ROVs, particularly in extreme environments such as deep-sea trenches. USVs operate on the water's surface and do not dive underwater. Their operational depth is limited to surface-level operations, typically in coastal waters, lakes, rivers, and other surface water bodies.

ROVs are remotely operated and require constant supervision and control from operators on the surface. They are not fully autonomous and rely on real-time communication through a tether for operation.AUVs are autonomous and can operate independently without direct human control. They are pre-programmed with mission plans and algorithms for autonomous navigation, data collection, and task execution.USVs can operate autonomously or under remote control, depending on the mission requirements. They are capable of autonomous navigation, obstacle avoidance, and data collection, but can also be controlled remotely by operators onshore or from a control station on another vessel.

ROVs are equipped with cameras, sensors, and manipulators for visual inspection, data collection, and manipulation of objects underwater. They are well-suited for tasks such as underwater inspections, maintenance, and scientific research.AUVs are equipped with sensors and instruments for collecting data on water parameters, marine life, seafloor topography, and other environmental factors. They are well-suited for tasks such as oceanographic research, underwater mapping, and environmental monitoring. USVs are equipped with sensors and instruments for collecting data on surface water parameters, maritime traffic, environmental conditions, and other surface-level factors. They are well-suited for tasks such as maritime surveillance, environmental monitoring, and hydrographic surveying.

ROVs can be expensive to operate due to the need for specialised support vessels, equipment, and trained personnel for operation and maintenance. Costs can vary depending on the complexity of the ROV and the scope of the mission. AUVs can be cost-effective for certain missions due to their autonomous operation and ability to collect data continuously over large areas. However, initial investment costs for AUVs can be high, and ongoing maintenance and support costs may also be significant.USVs can be cost-effective for certain missions due to their versatility, autonomy, and ability to operate in various environmental conditions. They typically have lower operating costs compared to ROVs and AUVs, as they do not require specialised support vessels and can be deployed from shore or other surface vessels.

In choosing suitable autonomous vehicles, the criteria

ROV considers the depth range required for the project. ROVs are suitable for both shallow and deep-water operations, with some models capable of operating at extreme depths exceeding 6,000 metres.Evaluate the depth capabilities of the AUV. While AUVs can operate at various depths, their operational depth may be limited compared to ROVs, particularly in extreme environments such as deep-sea trenches.Since USVs operate on the water's surface, they are not suitable for underwater operations and are limited to surface-level tasks in coastal waters, lakes, and rivers.

Consider the level of autonomy required for the project. ROVs are remotely operated and require constant supervision and control from operators on the surface.Assess whether autonomous operation is necessary for the project. AUVs are autonomous and can operate independently without direct human control, making them well-suited for long-duration missions and tasks requiring continuous data collection.Determine whether autonomous or remote-controlled operation is needed. USVs can operate autonomously or under remote control, depending on the mission requirements.for selecting an ROV, AUV, or USV for specific types of marine fieldwork and research projects.

Case Studies

Case Study 1: Effective Use of an ROV in Underwater Inspection and Maintenance

Scenario: A company specialising in offshore oil and gas exploration and production needs to inspect and maintain underwater pipelines and infrastructure in deep-sea environments.

Vehicle Selection: The company selects an ROV due to its ability to perform precise visual inspections and manipulate objects underwater. The ROV chosen for the project has high-definition cameras, lights, sonar systems, and manipulator arms for performing maintenance tasks.

Impact on Project Outcomes: The ROV enables the company to conduct detailed visual inspections of underwater pipelines, platforms, and other infrastructure without the need for human divers. It provides high-quality imagery and real-time video feeds to operators on the surface, allowing them to identify defects, corrosion, and other issues accurately. The ROV's manipulator arms allow for the repair and maintenance of underwater equipment, minimising downtime and ensuring the continued operation of offshore assets. Overall, the effective use of the ROV improves safety, efficiency, and cost-effectiveness in underwater inspection and maintenance operations.

Case Study 2: Effective Use of an AUV in Oceanographic Research and Mapping

Scenario: A research institute aims to study deep-sea ecosystems and map underwater topography in remote oceanic regions.

Vehicle Selection: The research institute selects an AUV for its ability to operate autonomously and collect data continuously over large areas. The AUV chosen for the project is equipped with multibeam sonar, bathymetric sensors, cameras, and environmental sensors.

Impact on Project Outcomes: The AUV enables the research institute to conduct comprehensive surveys of deep-sea ecosystems and seafloor topography with high precision and resolution. It autonomously navigates predefined survey paths, collecting data on water depth, seafloor features, marine life, and environmental conditions. The AUV's continuous data collection capabilities provide researchers with valuable insights into deep-sea biodiversity, habitat distribution, and geological processes. The detailed maps and datasets generated by the AUV enhance understanding of oceanographic processes and support conservation efforts in remote marine environments.

Case Study 3: Effective Use of a USV in Maritime Surveillance and Environmental Monitoring

Scenario: A government agency responsible for coastal management and maritime security needs to monitor maritime traffic, enforce regulations, and detect environmental threats in coastal waters.

Vehicle Selection: The government agency selects a USV for its versatility, autonomy, and ability to operate on the water's surface. The USV chosen for the project is equipped with radar, AIS transceiver, cameras, and environmental sensors.

Impact on Project Outcomes: The USV enables the government agency to conduct continuous surveillance of coastal waters, monitoring vessel traffic, detecting illegal activities, and enforcing maritime regulations. It autonomously patrols predefined routes, collecting data on vessel movements, maritime activities, and environmental conditions in real-time. The USV's sensors and cameras provide situational awareness to maritime authorities, allowing them to respond quickly to security threats, pollution incidents, and other emergencies. The effective use of the USV enhances maritime security, environmental protection, and resource management along the coast, contributing to safer and more sustainable maritime operations.

In each of these case studies, the selection of the appropriate underwater vehicle (ROV, AUV, or USV) is driven by the specific requirements of the fieldwork scenario and project objectives. The chosen vehicle's capabilities, such as operational depth, autonomy, data collection capabilities, and cost-effectiveness, play a critical role in achieving project outcomes and delivering value to stakeholders.

Conclusion

ROVs (Remotely Operated Vehicles), AUVs (Autonomous Underwater Vehicles), and USVs (Unmanned Surface Vehicles) represent distinct categories of underwater robotics technology. ROVs operate tethered to the surface and are controlled remotely, excelling in precise visual inspections and manipulation tasks. AUVs navigate autonomously without direct human control, enabling continuous data collection over large areas and versatility in oceanographic research and mapping. USVs, on the other hand, operate on the water's surface, offering autonomy or remote control for tasks such as maritime surveillance and environmental monitoring. Choosing the appropriate vehicle type is crucial, as each offers unique capabilities suited to specific applications in marine exploration and research, influenced by factors like operational depth, autonomy requirements, data collection needs, and cost considerations. Careful consideration of these factors ensures the successful utilisation of underwater robotics technology to achieve project objectives effectively and efficiently.

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6. Author links open overlay panelTakumi Matsuda, Highlights•Landing methods and systems for hovering-type AUVs on the seafloor are proposed.•A heading control method, AbstractThis paper aims to provide stable landing methods and systems for hovering-type AUVs (autonomous underwater vehicles) on a seafloor, Wynn, R. B., Schjølberg, I., Yamaguchi, T., Alvarez, A., Rattanasiri, P., Allotta, B., Pugi, L., Yoerger, D. R., Kim, K., Huang, S. W., Nishida, Y., Matsuda, T., Sangekar, M. N., Fujimoto, H., Oshida, A., Wang, S., … Yano, H. (2020, July 11). Landing method of autonomous underwater vehicles for seafloor surveying. Applied Ocean Research. https://www.sciencedirect.com/science/article/abs/pii/S0141118720302637
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