International Journal of Computational Science and Engineering Research
ISSN: 3107 -8605 (Online) , http://www.ijcser.com/
Regular Issue , Vol. 2, Issue. 2 (April – June), 2025 , Pages: 41 - 47
Received: 28 January 2025 ; *Accepted:* 29 April 2025 ; *Published:* 29 June 2025
https://doi.org/10.63328/IJCSER-V2RI2P9
Original Paper : Applied Research – Compare and Contrast Research Paper

Robotic Innovations Revolutionizing Exploration of Earth's Oceanic Depths

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Abstract: Recent technology breakthroughs have created new opportunities for researching the ocean in ways never seen before. Underwater robotics will be covered in this presentation, covering remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) with advanced sensors and manipulators. These robots assist us in overcoming problems like as severe pressure, darkness, and harsh conditions in the deep ocean. They've granted us access to remote and undiscovered ocean places, which is the focus of our seminar: underwater exploration .The event addresses a wide range of applications, including deep-sea exploration and marine archaeology, as well as environmental monitoring and assistance for sectors such as oil and gas. Technological difficulties like as propulsion systems, communication protocols, and operational obstacles that are vital to the robots' smooth functioning are also discussed. The importance of collaboration among marine biologists, geologists, engineers, and computer scientists will be emphasized. This partnership adds to our understanding of the ocean's intricate ecosystems.

Keywords Underwater robotics, ROVs and AUVs, deep-sea exploration, advanced sensors, marine applications.

1. Introduction

Humanity has always been fascinated by and in awe of the vast and unknown marine depths of Earth. These far-flung and unexplored regions, which make up more than 70% of our planet's surface, are full with mysteries just waiting to be discovered. However, the ocean's depths have mainly remained unexplored by humans for ages. The deep sea's crushing pressures, intense temperatures, and total darkness have presented unsurmountable obstacles to conventional exploration techniques.

However, behind the surface, a significant transformation has occurred in recent decades as a result of the persistent growth of technology. This oceanic exploration of Earth's depths is a significant project with far-reaching implications for our planet and species, rather than merely an intellectual exercise or a quest for novelty. Because the seas store so much heat and carbon dioxide, they are critical to climate management. They are home to a staggering variety of living species, many of which are yet unnamed and little understood. Furthermore, the seas give critical resources to human communities all around the world, such as seafood and minerals. Despite their importance, deep oceans remain one of our world's least explored and understood places. Because of the union of robots with oceanography, scientists, researchers, and explorers now have an unprecedented chance to explore the depths of the seas and conquer difficulties that previously thought insurmountable. As this expedition has advanced to the vanguard of marine research, a number of cutting-edge robotic systems have emerged, each one tailored to certain tasks and situations. This robotic revolution is being led by autonomous underwater vehicles (AUVs) and remotely operated vehicles (ROVs). ROVs are surface ships that can dive to large depths, record and recover high-definition video, collect samples, and perform a range of other activities with agility and accuracy. AUVs, on the other hand, run independently of humans, traveling pre-programmed routes and carrying out tasks. Because they allow researchers to do research in previously inaccessible places, these vehicles have become indispensable instruments for oceanographers, marine biologists, geologists, and archaeologists.

The wreckage of the RMS Titanic was discovered, and this is one of the most well-known instances of ROV research. The "Alvin" ROV was instrumental in 1985 in helping to locate and take pictures of the luxury ship that ended tragically and had been abandoned for more than 70 years on the ocean below. This ground-breaking operation demonstrated the potential of ROVs to

ISSN: 3107 - 8605 (Online) , http://www.ijcser.com/ , Vol. 2, Issue 2 , 2025, https://doi.org/10.63328/IJCSER-V2RI2P9

reveal the mysteries of the deep while also offering insightful information about the last moments of the ship. In addition to shipwrecks, ROVs have completely changed how we think about deep-sea ecosystems. Through filming organisms that survive in harsh environments like frigid seeps and hydrothermal vents, scientists have found species that were previously undiscovered and acquired understanding of how remarkably adaptable life is on Earth. By studying these alien habitats, ROVs like "Hercules" and "Jason" have helped scientists learn more about biology, chemistry, and geology. Because of their endurance and independence, AUVs have also significantly advanced oceanic exploration.

With amazing accuracy, these vehicles have been used to map the ocean floor, exposing undersea landscapes that were previously obscured from view. Robotics' technical wonders have not only improved our knowledge of the oceans but also created new avenues for the use of the deep sea's abundant riches. Deep-sea mining is one method of obtaining these resources; it offers access to rare earth elements, polymetallic nodules, and ferromanganese crusts that are rich in cobalt. The demand for these minerals, which are necessary for contemporary technologies like cellphones and electric cars, is rising. Deep-sea mining offers a way to meet this demand while lessening the environmental damage caused by conventional terrestrial mining. In the field of deep-sea mining, robotic devices are leading the way in prospecting and extracting mineral reserves. AUVs can be used for high-resolution mapping and mineral prospecting, while ROVs with specialized instruments can gather samples from the ocean floor.

Despite the potential for financial gain, this move toward the exploitation of maritime resources poses significant moral and environmental issues. Another promising area for revolutionizing ocean exploration is the combination of robotic systems with artificial intelligence (AI) and machine learning. Robots can already evaluate enormous volumes of data, spot trends, and come to their own choices thanks to these technologies. Algorithms driven by AI can be used to predict changes in ocean conditions, detect new species, and maximize the effectiveness of exploration projects. Drones using AI algorithms are being used to improve underwater research capacities for marine biology. By using photos and videos that the robots have taken, these algorithms can recognize and categorize marine creatures, which speeds up the process of cataloguing and comprehending the variety of undersea habitats.

2. Literature Review

O'Kane, Jason M. et al. (2022) described in detail how a group of robots divides into two roles. Proximal observers are robots that approach the structure and gather specific information, while distant observers stay at a distance, provide an overview of the mission, and help localize the proximal observers using a cooperative localization framework. To address vision-based localization issues, proximal observers employ a unique robust switching model-based/visual inertial odometry.

Lijing Cao et al. (2022) elaborated on the design of the underwater exploration robot based on the project's actual requirements, and presents a control approach for the underwater exploration robot based on neural networks to optimize the PID control parameters.

Gang Maa et al. (2020) discusses the application of a self-healing mechanism (SHM) to keep underwater robotic vehicles (URVs) structurally intact during flooding occurrences. The research looks at the effectiveness of sodium polyacrylate, a superabsorbent polymer (SAP), in sealing damaged regions in a URV's hull and preventing excessive water infiltration. The research shows that SHM may quickly seal leaks, restore buoyancy, and limit damage in underwater robotic structures by evaluating the stability and water accumulation in the URV before and after applying SHM.

Zhonglu Lin et al. (2023) elaborate on the design and execution of an agile amphibious robot inspired by the mudskipper, a highly adaptable amphibian. To attain great propulsion efficiency, this creative robot employs fish-like movement underwater and legged locomotion on land. The collaboration of the pectoral and caudal fins significantly improves the robot's motion.

Simone Tani et al. (2023) presented a novel navigation system for autonomous underwater vehicles (AUVs) that uses stereo vision to estimate linear velocity. A dependable navigation system is essential for AUVs doing inspection and monitoring activities. The purpose of this framework is to show the effectiveness of using a stereo camera as a linear velocity sensor to improve AUV navigation. The approach combines attitude and depth measurements with linear velocity estimates derived from optical data using a stereo Visual Odometry (VO) algorithm.

Hakon Teigland et al. (2022) examines the role of remotely operated vehicles (ROVs) in underwater structural inspection, maintenance, and repair (IMR). Despite massive efforts to automate the operation of ROVs in recent decades, the control and operation of work class ROVs for performing IMR interventions is still carried out by a team of at least two expert ROV pilots.

Christophe Domingues et al. (2012) Two Human-Robot interfaces for underwater robot teleoperation are described. This project is part of the Digital Ocean Europe project1, which seeks to digitalize bottom

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areas in 3D imagery using underwater robots (ROVs), and then use this knowledge to create interactive, virtually animated landscapes that are shared online. This research looks at 1) a Web interface installed on an aquatic PC called DOLPHYN and 2) a VR/AR semi-immersive platform. Both interfaces are used for remote undersea research..

Michael Bodi et al. (2015) created a swarm of autonomous underwater vehicles (AUVs) to do these kinds of jobs. These AUVs are controlled by BEECLUST, a honeybee-inspired swarm control system. A swar controlled by BEECLUST demonstrates highly consistent aggregation behavior in a global optimum. BEECLUST is especially adaptive to AUV swarms, according to modeling testing.

Yingchen Yang et al. (2022) describes An autonomous underwater vehicle (AUV) fueled by renewable energy might increase endurance and forward presence while avoiding the need for a logistical tail for fuel. To accomplish this, a wave-powered concept AUV is being created and tested. As its power take-off (PTO) unit, the AUV has a torpedo shape and a completely hull-encapsulated mass-spring-damper system. The AUV surfaces and transforms wave energy to electricity while charging.

Jing Zhou et al. (2023) introduces the Autonomous Underwater Helicopter (AUH). It's intended to explore and investigate the seafloor, where standard underwater vehicles can't reach. The AUH is outfitted with cameras and sensors and can take off, land, and hover near the bottom. It can also link to underwater helipads for power and data transmission, letting it to operate for extended periods of time.

G Santhan Kumar et al. (2018) describes the creation of an Autonomous Underwater Vehicle (AUV) for vision-based tracking. The AUV is designed primarily for marine species research utilizing automated computer vision-based tracking, but it can also be utilized as a platform for seabed photo-mapping owing to its onboard camera and lighting system.

Shenghai Chen et al. (2022) analyzes the performance of a UAV-based mixed Underwater Power Line Communication-Radio Frequency (UPLC-RF) network. In this network, a buoy at sea serves as a relay to send signals from the underwater signal source to the UAV over the PLC link. The UPLC channel is assumed to have a log-normal distribution, and the RF link has a Rician distribution.

Waseem Akram et al. (2022) explored the fault-tolerant route following control issue for an overactuated underwater vehicle with input saturation and rate of change restrictions, actuator flaws, and parametric (mass and inertia) uncertainty. If some of the actuators fail, a robust adaptive control allocation approach capable of reconfiguring control effort distribution among the remaining healthy actuators is suggested. The live estimation of actuator effectiveness and bias fault characteristics is included into the control allocation and reconfiguration unit.

Tianhao Zhang et al. (2020) presented a new deep reinforcement learning (DRL) technique for guiding a fish-like robot down a path that can be a randomly generated Bézier curve. Initially, a modified Central Pattern Generator (CPG) model is used to improve the locomotion control of the fish-like robot. By altering a single control input, the fish can demonstrate a wide range of swimming behaviors.

Eonjoo Kim et al. (2019) presented A curved path following problem for autonomous underwater vehicles (AUVs) driving in a nonuniform ocean current is described. Three-dimensional current velocities were estimated using a high-gain observer (HGO) based on an AUV dynamic model. The current velocities were calculated by subtracting the vehicle's absolute velocity from the observer's estimated relative velocities. The HGO was chosen as a nonlinear estimation algorithm, and the observer gain was computed by solving a Linear Matrix Inequality (LMI) that reflected the estimation error dynamics.

Wenli Yang et al. (2019) presents an image matching technique based on convolutional neural network (CNN) to aid in the navigation of an Autonomous Underwater Vehicle (AUV) in the absence of external navigation aids. which can jointly optimize the representation of the input data based on the similarity measure employed.

Daniela De Palma et al. (2018) describes two navigation filters intended for a geotechnical surveying Autonomous Underwater Vehicle (AUV). Both a Luenberger observer for the vehicle's kinematic model and an enhanced Kalman filter for its dynamic model are addressed. The filters combine data from a Global Positioning System (GPS), a compass, a gyro, a depth meter, and acoustic range measurements. The concept also makes use of a thruster model that maps low-level actuator commands to vehicle surge velocity.

V. Djapic et al. (2018) The Diver Navigation and Imaging System (DiNIS) is described as a small, capable, integrated underwater hand-held diver navigation system. DiNIS provides a full suite of commercial underwater navigation sensors for waypoint navigation, Intelligence, Surveillance, and Reconnaissance (ISR), bathymetry, and underwater pictures.

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Simon Sirega et al. (2019) Discusses the design and mathematical modeling of the ITB-HAUG (Institut Teknologi Bandung Hybrid Autonomous Underwater Glider). The ITB-HAUG functions as both a glider and an Autonomous Underwater Vehicle (AUV), with distinct propulsion and control systems. The dynamic interaction, kinematics, and energy consumption of the mathematical model in a dynamic context are evaluated using MOOS-IvP simulation.

Moon G. Joo et al (2019) Examines A controller for an underwater glider is shown. An underwater glider is a torpedo-shaped autonomous underwater vehicle with movable batteries and an adjustable buoyancy bag. Two PD controllers regulate the elevator/rudder angles, while a LQR controller maintains the zigzag vertical movement required for gliding. The LQR controller regulates both the pumping speed into the buoyancy bag and the movement speed used to find the battery.

Dongqi Gao et al. (2022) Discusses about A UUV with a hybrid propellor that combines a screw propeller and four bio-inspired flippers. Through flapping motions, these flippers create propulsion and lateral forces, while the screw propeller adds extra push for fast cruising. This design enhances agility while remaining fast. The flipper motions were meticulously adjusted for normal sailing needs, and a control system based on central pattern generators (CPGs) was used to provide rhythmic locomotor signals. To correct for route deviations, a feedback control technique was also implemented.

Satja Sivev et al. (2018) provides an overview of underwater robot manipulator systems, highlighting its use for subsea interventions across several offshore industries. It provides a thorough evaluation of commercial and prototype underwater manipulators, with a focus on design, capabilities, and qualities, as well as a full comparative comparison.

Satja Sivev et al. (2018) discusses how ROVs with hydraulic manipulators are widely used for subsea intervention. Manipulators are teleoperated and slaved to pilot held master arms using camera feedback from the scene. While common for offshore oil and gas, a unique strategy is required for difficult applications in waves or currents. It describes the development of robot arm visual servo control systems used in manufacturing, as well as their transfer and adaptation to underwater hydraulic manipulators.

Yang Cong et al. (2021) discusses Underwater robot technologies are critical for marine resource exploration and autonomous manipulation, and numerous advances have been made with essential indicators (for example, dive depth and navigation range). However, due to the complexity of the underwater environment, cutting-edge sensing technologies cannot meet all of the needs of underwater observations.

Yizhuo Mu et al. (2021) discusses robotic fish route planning and path following control issues. To avoid obstacles while swimming in a complex environment, a path planning system based on the beetle swarm optimization (BSO) method is created. When the robotic fish acquires the intended course, this approach examines the influence of the robotic fish's volume and motion limits on the path planning job, which can reduce collision risk while satisfying the constraint of the smallest turning radius. A multilayer perception-based model was used to develop the best path-following controller control approach. predictive control (MPC) is used, and the objective function of the optimal control is dynamically updated according to the route curvature.

3. Result and Discussion

The literature reviews provide a comprehensive overview of recent advances and research in underwater robotics, including robot roles and cooperation, design considerations, exploration strategies, structural integrity, control approaches, navigation systems, human-robot interfaces, swarm robotics, energy sources, fault-tolerant control, and path planning. O'Kane et al. (2022) emphasize the distinction between proximal and distant observers, each with their own localization procedures. Cao et al. (2022) describe an underwater exploration robot using a neural network-based control strategy, whereas Maa et al. (2020) focus on structural integrity self-healing mechanisms. Lin et al. (2023) present a mudskipper-inspired agile amphibious robot with fish-like submerged mobility and legged locomotion on land. Tani et al. (2023) present a stereo vision-based AUV navigation system, highlighting the need of accurate navigation in inspection tasks. Teigland et al. (2022) explore the importance of remotely operated vehicles (ROVs) in underwater structure inspection, emphasizing that professional pilots are still required despite automation attempts. Domingues et al. (2012) contribute to the Digital Ocean Europe project by researching human-robot interfaces for underwater teleoperation. Bodi et al. (2015) present the BEECLUST swarm control method for AUVs, demonstrating consistent aggregation behavior. Yang et al. (2022) investigate the concept of a wave-powered AUV for long endurance. Zhou et al. (2023) describe an Autonomous Underwater Helicopter (AUH) for seafloor exploration beyond the capabilities of conventional underwater vehicles. Kumar et al. (2018) create an AUV for vision-based tracking, specifically for marine species research. Chen et al. (2022) investigate a mixed

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Underwater Power Line Communication-Radio Frequency (UPLC-RF) network based on a UAV. Akram et al. (2022) examine fault-tolerant control for underwater vehicles that have been over actuated. Deep reinforcement learning is used by Zhang et al. (2020) to guide a fish-like robot along a randomly generated Bézier curve. Kim et al. (2019) use high-gain observer-based current velocity estimation to investigate curved path following for AUVs in nonuniform ocean currents. Yang et al. (2019) present an image matching strategy for AUV navigation based on convolutional neural networks. De Palma et al. (2018) describe navigation filters for geotechnical surveying AUVs that include multiple sensors and a thruster model. Diver Navigation and Imaging System (DiNIS) for underwater navigation and imaging is introduced by Djapic et al. (2018). Joo et al. (2019) investigate an underwater glider controller, concentrating on buoyancy and battery control. Gao et al. (2022) describe a hybrid propulsor design for a bio-inspired unmanned underwater vehicle (UUV). Sivev et al. (2018) provide an overview of underwater robot manipulator systems, focusing on their applications in subsea interventions. Cong et al. (2021) emphasize the importance of underwater robot technology in the exploration of marine resources. Mu et al. (2021) use the beetle swarm optimization (BSO) algorithm and model predictive control (MPC) to handle path planning and control for robotic fish. The collective literature highlights the broad and developing character of underwater robotics, encompassing a wide range of technological advancements and applications that contribute to the field's continued progress.

4. Conclusion

The literature reviews provide an in-depth look at recent advances in underwater robotics, covering topics such as robot roles and cooperation strategies, control approaches, self-healing mechanisms, biomimicry-inspired designs, navigation systems, human-robot interfaces, swarm robotics, renewable energy integration, fault-tolerant control, and novel applications such as autonomous underwater helicopters. Diverse solutions to issues in underwater exploration, inspection, and intervention have been investigated by researchers, demonstrating breakthroughs in propulsion systems, control algorithms, sensor technologies, and human-robot interaction. From the development of agile amphibious robots inspired by nature to wave-powered autonomous underwater vehicles, the field has shown a consistent evolution toward improving efficiency, autonomy, and flexibility in underwater robotic systems. The literature also emphasizes the ongoing role of human intervention in remotely operated vehicles and teleoperation interfaces, emphasizing the interdisciplinary nature of underwater robotics, where engineering, biology, and artificial intelligence converge to fully realize the potential of these technological advancements for exploring and understanding the underwater world.

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