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Research paper

Development of A Novel Autonomous Underwater Vehicle for Offshore Inspection and Maintenance

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Abstract

Because they make underwater inspections, data collecting, and better maintenance practices possible, underwater vehicles have helped aquaculture grow. Underwater vehicles also make it easier to collect subsea data, which allows researchers to improve aquaculture practices and take part in projects that aim to achieve food security. Designing, creating, and testing underwater devices for net cage maintenance and inspection in aquaculture plants is the goal of this project. Second-order wave theory (Second-order wave theory is a mathematical model capturing nonlinear wave interactions, improving accuracy in predicting complex ocean wave patterns critical for offshore operations.) adds the theory of "bound waves," or secondary waves caused by nonlinear interactions in the original wave field. This further makes wave prediction complex, as it allows more realistic wave profiles, like ocean waves with more gradual troughs and steeper crests, to be simulated. The accuracy given by second-order wave theory renders it most helpful in crucial circumstances, as it is able to model nonlinear effects. It is routinely used to predict extreme waves, such as rogue waves, that are dangerous to ships and offshore platforms. Further, this theory is critical in detailed structural analysis since knowing the exact wave forces exerted on a structure can be the difference between failure and survivability. As a result, a tool manipulator is shown, and its electrical integration, manipulator capabilities, and fundamental design ideas are examined. Successful missions from experimental evaluations conducted in Greek fish farms in Kefalonia attest to the underwater vehicle models' efficacy and operating capabilities. The concluding remarks summarize the main conclusions drawn from this investigation, discuss their ramifications, and provide insights into potential future directions for subaquatic robotics.

Keywords: *Autonomous Underwater Vehicle; Offshore; Inspection; Maintenance; Marine; Underwater.*

1. Introduction

Autonomous underwater vehicles (AUVs) with artificial intelligence (AI) methods are transforming offshore infrastructure inspection, maintenance, and repair [1]. This encompasses a cutting-edge, two-armed AUV for challenging maintenance and inspection activities, incorporated within a reliable IT infrastructure. This infrastructure facilitates effective information exchange with plant operators and offers easy-to-operate system control and monitoring [2]. Inspection and maintenance are essential for offshore infrastructure safety, e.g., wind turbines and oil and gas production plants. However, the work done underwater is not only costly and complicated, but it also puts the divers who do it at serious risk [10] [13]. The state of maritime assets is already being monitored by remotely operated underwater vehicles, or ROVs [3]. There is, nevertheless, a increasing tendency towards longer-term submerged operation, referred to as "sub-sea resident AUVs". These autonomously operate while submerged but at the same time provide for the possibility of being remotely controlled under certain circumstances [4].

Under the auspices of the DFKI robots Innovation Center, a group of top businesses and academic institutions from the domains of IT, robots, drive technology, and offshore have taken a significant step in this direction with the Mare-IT project [8]. This includes a new two-arm AUV that can function remotely and independently. It can also be used to repair and maintain underwater structures because it has two integrated manipulators [6]. Beyond Mare-IT, global efforts in AUV development are advancing rapidly. Japan's JAMSTEC has deployed the Urashima AUV for deep-sea exploration, achieving significant endurance milestones. Similarly, NOAA in the United States operates AUVs for offshore infrastructure inspections and environmental monitoring, demonstrating international commitment to advancing autonomous underwater systems. Furthermore, the partners are offering a robust IT infrastructure that facilitates easy control and underwater monitoring of the robot, as well as seamless information exchange with plant operators and integration with current business procedures [5].

Fig. 1: Autonomous Underwater Vehicle.

The Body Caudal Fin (BCF) propulsion enhances speed and efficiency for long-distance AUV travel, making it well-suited for offshore inspections over Median Paired's flapping fin propulsion in terms of speed and long-distance movement because to its ability to displace the fish's center line. The BCF body and caudal fin type of swimmer has a streamlined body shape which is advantageous in the expected long-distance travel among wind turbines because it has good mobility with a flexible body, especially because wind farm inspection is the main application of RoboFish [16].

Over the last few decades, autonomous underwater vehicles (AUVs) have been a key subject at many conferences. Still, writings on the applications of AUV technology are still dispersed throughout the literature. Peer-reviewed scientific literature, professional publications, and the websites of organizations and businesses are all publishing new papers. In a number of chapters authored by experts in respective domains, this book integrates technology and applications. The breadth of current advancements in AUV design, construction, and operation is definitely beyond the purview of these chapters.

2. Review of literature

In order to address the issues caused by diminishing wild fish stocks and satisfy the expanding global demand for seafood, aquaculture is essential. Aquaculture has become a crucial sector for sustainable food production as a result of the world's population growth and the decline of natural fish populations. Among its many benefits are the possibility of localized food production, controlled production environments, and less strain on wild fish populations.

Additionally, aquaculture contributes to food security, economic growth, and job possibilities in many parts of the world.

Blue Transformation seeks to increase aquatic foods' share of global food security by implementing environmentally sustainable policy, practice, and technology innovations. Despite its great value and attention, there are some indications that aquaculture may not last forever. This latter is the main argument in favor of the need to increase the use of robots in the aquaculture industry going forward. Current production techniques must be improved in order for aquaculture to reach its expected relevance. This will involve tackling the industry's various problems with the astute use of technical instruments.

These vehicles can stay underwater for long durations, hover above particular targets, or perform extensive surveys of wide areas [12]. On the other hand, robotic vehicles that can function without human help are known as autonomous underwater vehicles, or AUVs. Depending on their special structural design, these vehicles can move through the water in a variety of ways, such as drifting, driving, or gliding. AUVs can change their mission profile on their own by using environmental information gathered from sensors while they are in operation [11].

HROVs can therefore combine the benefits of two different vehicle types into a single platform, giving them dual capabilities. A critical comparison of ROVs and AUVs highlights their distinct advantages and limitations. ROVs, though tethered, offer real-time human control, making them ideal for precise, short-duration tasks but increasing deployment complexity and costs. AUVs, in contrast, provide superior autonomy, endurance, and reduced human risk, though they face limitations in power supply and real-time adaptability. Wynn et al. (2014) demonstrated that AUVs significantly reduce energy consumption for long-duration missions, while Bellingham & Rajan (2007) emphasized their navigation algorithm advancements.

Study	Vehicle Type	Methodology	Key Findings	Research Gaps
Dalhatu et al. (2023)	ROV	I&M Taxonomy	Heavy-duty manipulators	Limited autonomy integration
Livanos et al. (2018)	AUV	AI-based Navigation for Aquaculture	Enhanced inspections	Offshore reliability untested
Bellingham & Rajan (2007)	AUV	Navigation Algorithms	Robust autonomy	Energy limitations remain
Wynn et al. (2014)	ROV vs AUV	Energy Efficiency Comparison	AUVs reduce long-term energy	Tether management issues remain

They can operate as autonomous underwater vehicles (AUVs) that navigate without human assistance or as remotely operated vehicles (ROVs) that are attached to a surface station so that an operator on the surface can remotely control the vehicle. This makes it easier to conduct precise surveys and samplings and to carry out complex experiments in the ocean. [9]

Furthermore, marine vehicles are employed in intricate jobs and perform more difficult underwater operations using a variety of instruments or manipulators. A Remotely Operated Vehicle (ROV) with a heavy-duty manipulator arm. The mechanical passive arm of the ROV has a nonlinear hydrodynamic model, and this takes into account pertinent attributes and component architecture [7].

Moreover, motion control is a major problem for undersea vehicles, particularly when they are subjected to erratic ocean currents, ambiguous parameters, hydraulic system delays, and thrust capability constraints. Because of the difficulties in the ocean environment, scientists have looked for other solutions. A Remotely Operated Vehicle (ROV) to remove dirt from the surfaces of offshore structures, showing a viable method of overcoming these challenges [15].

Importance of the Study

With its well-organized synthesis of important AUV-related topics, this work makes a substantial contribution to the field of AUV technology. The following significant additions set this study apart from previous research:

- Holistic Integration: The study skillfully incorporates a number of essential elements of underwater robotics, such as sensors, charging systems, navigation algorithms, control systems, and bionic-inspired models. This all-encompassing method enables a sophisticated comprehension of the interrelated elements of AUV technology.
- Cohesive Narrative: This study integrates findings from various disciplines into a coherent narrative, in contrast to many cited articles that concentrate only on particular aspects. This method improves clarity and comprehension by offering a condensed and easily comprehensible summary of developments in underwater robots.
- Development Guidance: The study provides insightful advice for engineers and academics working on the development of AUVs, going beyond individual observations. It offers a road map for an integrated and holistic approach by combining several crucial fields, promoting a thorough comprehension of AUV technology. In the quickly developing field of underwater robotics, this advice is crucial for overcoming the challenges of developing and engineering AUVs.

3. Materials and methods

For improved output, lower emissions, and improved operational security, the vast majority of producers and inventors are looking at remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) as one of their chief investment strategies [14].

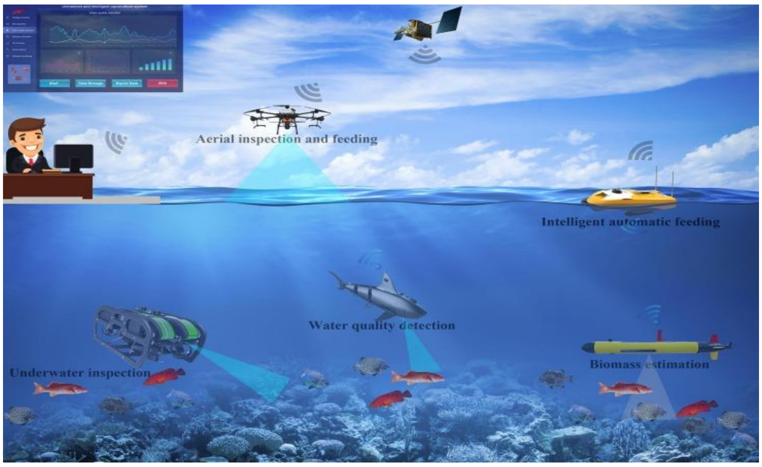

Fig. 2: Underwater Robot.

In the offshore energy sector, where are the newest hotspots for ROV and AUV use? The most recent remote robotics initiatives and technologies are shown below, along with the locations of their launch.

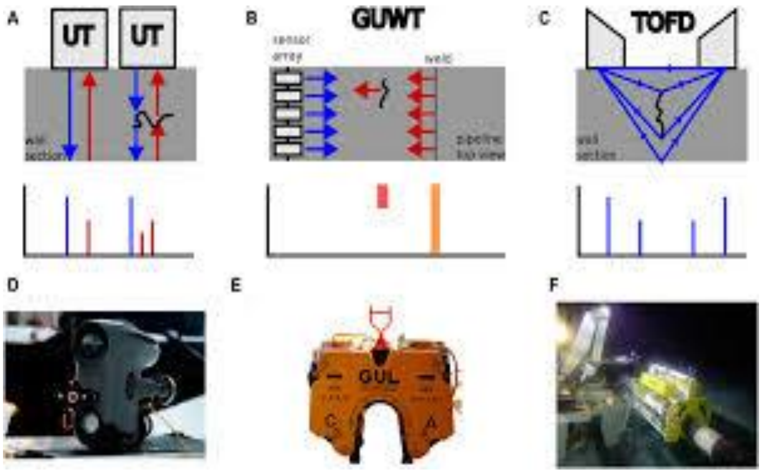

Fig. 3: Autonomous Underwater Robots.

This new generation of intervention AUV is capable of being placed free in the water column and comprises two deep-sea gripping modules installed on the bottom, enabling it to hold objects underwater. The Cuttlefish has an innovative design and AI-based control system that enable it to manipulate its buoyancy and center of gravity while sinking, and any direction stably. A fiber optic connection can be used to control the vehicle in a hybrid mode, also known as supervised autonomy, in addition to completely autonomous operations. When performing crucial work on undersea structures, the hybrid mode enables people to step in and remotely operate the AUV. The platform is outfitted with an assortment of environmental perception sensors, such as sonar sensors, cameras, laser scanners, and magnetometers, as well as manipulators.

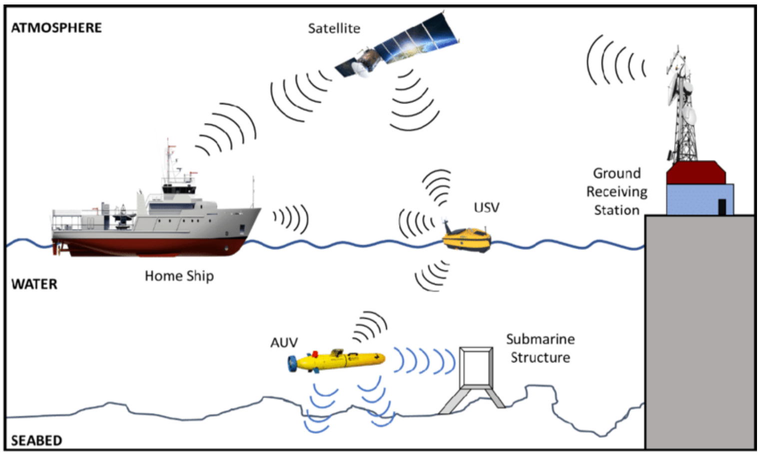

Fig. 4: AUV and ASV.

While conducting teleoperation operations, there is a virtual co-pilot created by DFKI's department of Cognitive Assistance Systems that assists human controllers at the control station. Using a Microsoft HoloLens, the virtual co-pilot can be used as an independent, transportable interface, e.g., on a ship, or in addition to the control station.
Natural speech interaction can be used to configure alerts and present sensor data and measured values. Voice commands can also be used to manage the AUV and its cameras, and when combined with eye tracking, data on the infrastructure components the user is now viewing can be obtained. Additionally, throughout the expedition, it is possible to establish your own spoken words and use them as aliases, such as for camera or docking positions.

4. Results and discussion

Eight similar thruster drives are installed on the AUV, and when combined, they allow for extremely accurate motions that are necessary for docking with underwater structures.

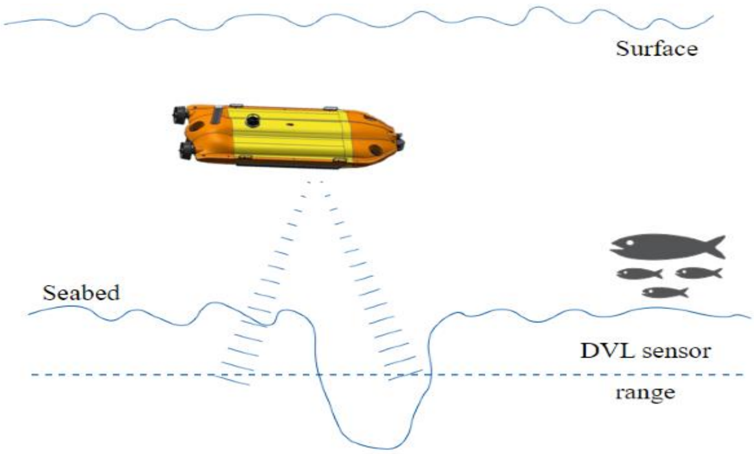

Fig. 5: Self Attention Mechanism.

Figure 5 illustrates the self-attention mechanism integrated into the AUV's control architecture, enabling adaptive decision-making and enhancing autonomous navigation in dynamic underwater environments. SAP looked explored how and when autonomous systems, like AUVs, may be included into cloud-based IT infrastructures in Mare-IT. The management shell permits easy addition or substitution of additional systems from third parties with very little integration effort.

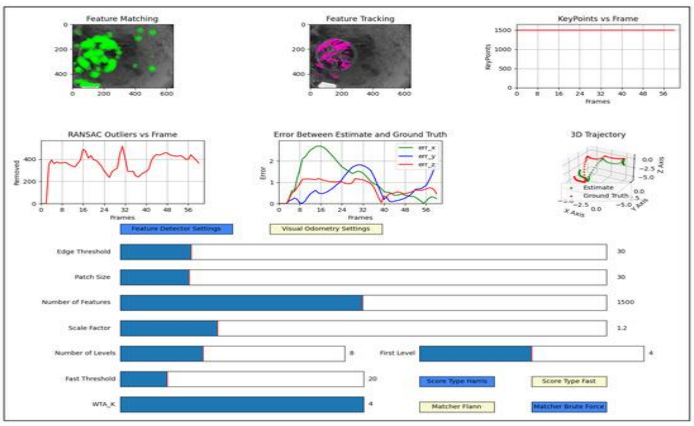

Fig. 6: Python Matplotlib GUI Showing the Statistics of ORB Features.

Figure 6 displays the real-time GUI interface developed for mission monitoring, providing operators with intuitive control and diagnostic insights during AUV deployment. The world's premier integrity management solutions provider built four measurement technologies for Autonomous Underwater Vehicles (AUVs) to examine subsea infrastructure. To guarantee data transfer from the robot to the central control center via the water column, a communication buoy was also created. All four measurement technologies have been successfully accomplished by ROSEN for the AUV, significantly advancing autonomous underwater applications of sophisticated sensor systems.

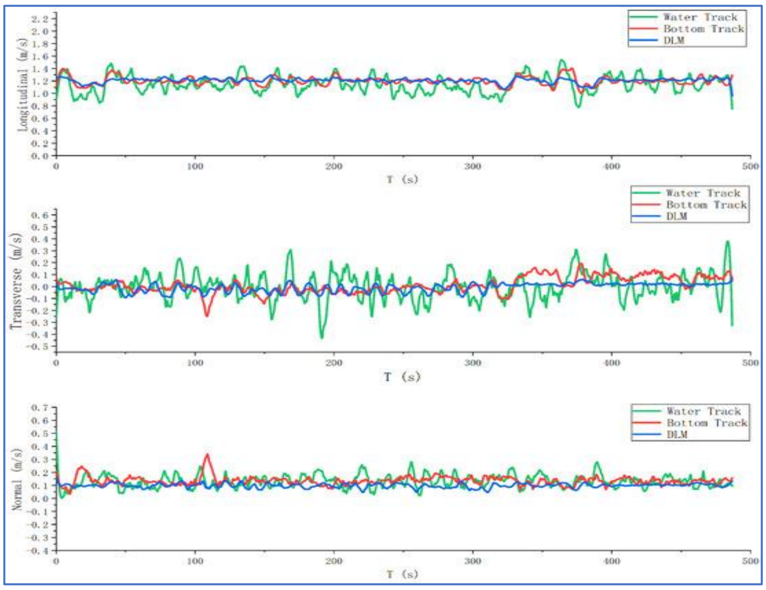

Fig. 7: Velocity Comparison.

Figure 7 compares velocity profiles of different AUV configurations, highlighting the performance benefits of modular propulsion and improved maneuverability for complex subsea tasks. Additionally, this opens up more intricate routes that may shorten trip times. Reduced environmental disturbance is suggested by decreased noise levels and a reduced chance of tangling of continually revolving pieces. Additionally, the multi-actuated system enables maneuverability in challenging settings and flexibility and adaptability when accessing small areas. In addition, the extended body design is amenable to modular structure, allowing increased robustness and survivability through redundancy in the case of individual module loss. The modular architecture also supports extendibility and flexibility, which facilitate simple reconfigurability to suit different mission environments and intervention operations.

5. Conclusion

In summary, the current study examines an HROV used for aquaculture net cage maintenance and inspection. Six degrees of freedom are included in the vehicle's design, and rotational and translational velocities are considered sufficient for examination. The manipulator costs 30 euros to build, whereas the vehicle costs 4050 euros. The vehicle's propellers are covered with 3D-printed protective components, which guarantee its safety. Furthermore, the lack of any potentially dangerous elements on the vehicle's exterior removes the chance of collisions brought on by direct contact with it. Additionally, the open-source nature of the system's components and the great modularity of its hull are responsible for its high scalability and interoperability. Most vehicles' waterproof enclosure, which requires opening seals for hardware adjustments while moving between task activities, is the main barrier to their adaptability and versatility. Nonetheless, this car has the right plugs installed that allow you to switch between connections without having to open the sealed enclosure. This provides the option to add sensors or an underwater tool manipulator on-site. This also holds true for carrying out maintenance tasks.

As discussed above, the aquaculture sector can be greatly improved through the application of underwater robotic devices. The adoption of these systems can enhance productivity and efficiency through cost reduction and safety measures. Aquaculture systems can also enhance fish welfare and health through effective removal of fish mort's and speeding up net repairs. Still, the use of underwater vehicles has particular challenges and detriments to aquaculture, such as high buying prices and maintenance prices, as well as requirements of special training. AUV adoption faces persistent challenges, including high procurement costs, energy limitations, and complex maintenance. Modular designs utilizing 3D-printed components offer promising cost reduction strategies. Additionally, advancements in bio-inspired propulsion, such as Body Caudal Fin (BCF) systems, can improve energy efficiency. Regulatory frameworks governing AUV deployment, especially in offshore energy and aquaculture sectors, require further development to ensure operational safety. Future research should also explore AUV applications beyond aquaculture, including offshore wind farm inspection and marine infrastructure monitoring.

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