Enhancing Underwater Exploration through ROV Design with 3D-Printed Components and Dual Cameras

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I. INTRODUCTION

In the realm of underwater exploration, advancements in remotely operated vehicle (ROV) design have taken a remarkable stride with the integration of 3D-printed components and dual camera systems. This journal focuses on the synergistic marriage of innovative design principles and emerging manufacturing technologies, aiming to propel underwater exploration to new heights. The incorporation of 3D-printed components not only enhances the efficiency of ROV construction but also allows for customized and intricate designs that cater specifically to the challenges posed by diverse aquatic environments. The convergence of robotics, sensor technology, and environmental monitoring underscores the interdisciplinary nature of this research. By delving into the intricate details of underwater ROV advancements, this journal aims to contribute to the broader scientific community's knowledge base, fostering discussions on the potential applications, challenges, and future directions of leveraging ROVs for precise water parameter monitoring. [1]

The dual-camera configuration featured in these ROVs introduces a novel dimension to underwater observation and documentation. By providing simultaneous visual perspectives, these vehicles offer improved spatial awareness and data capture capabilities. This journal delves into the technical intricacies of ROV design, exploring the synergies between 3D printing and dual-camera systems, and elucidates the potential implications of such advancements in revolutionizing our understanding of underwater ecosystems and geological features. [2]

II. BACKGROUND OF THE STUDY

The exploration of underwater environments has long been a challenging endeavor, marked by constraints in technology and design that limit the effectiveness of remotely operated vehicles (ROVs). Traditional ROV designs often face difficulties in maneuverability, adaptability, and cost-effectiveness. Recognizing these challenges, there is a growing need to enhance underwater exploration capabilities through innovative ROV design [3]. The background of this research stems from the imperative to overcome these limitations by integrating cutting-edge technologies, such as 3D-printed components and dual camera systems, into the design and construction of ROVs. These advancements hold the potential to revolutionize underwater exploration by addressing longstanding issues related to customization, versatility, and comprehensive data acquisition.

Moreover, the incorporation of dual cameras is particularly promising for applications beyond traditional exploration. The integration of two cameras provides a simultaneous visual perspective that enhances spatial awareness, a feature invaluable for detecting and monitoring invasive species, especially in delicate ecosystems like coral reefs. This capability becomes crucial in safeguarding marine biodiversity and ecosystems, as dual cameras offer a nuanced and detailed approach to identifying and tracking potential threats. As such, this research not only seeks to advance ROV design but also acknowledges the broader ecological implications, emphasizing the role of these technological enhancements in the preservation and conservation of underwater ecosystems, with a specific focus on detecting invasive species in coral reefs [4].

III. STATEMENT OF THE PROBLEM

Underwater exploration has seen significant advancements with the integration of Remote Operated Vehicles (ROVs) equipped with 3D-printed components and dual cameras. While these innovations hold promise for enhancing our understanding of underwater environments, several challenges remain unresolved. One such challenge is the optimization of ROV design to maximize the effectiveness of 3D-printed components while ensuring durability and functionality in harsh underwater conditions [5]. Additionally, the seamless integration and synchronization of dual cameras pose technical hurdles, including issues related to data transmission, image processing, and real-time monitoring. Addressing these challenges is essential to fully leverage the potential of ROVs for comprehensive underwater exploration and research [6].

The evolution of underwater exploration technology through ROV design featuring 3D-printed components and dual cameras underscores the need for interdisciplinary collaboration and innovative engineering solutions. While 3D printing offers flexibility and cost-effectiveness in component fabrication, ensuring structural integrity and resistance to underwater pressures remains a critical concern [5]. Moreover, the integration of dual cameras requires meticulous attention to synchronization and calibration to facilitate accurate data collection and analysis. Overcoming these challenges will not only advance our ability to explore and study underwater ecosystems but also pave the way for the development of more robust and versatile ROV platforms capable of meeting the diverse needs of marine research and exploration. [7]

IV. OBJECTIVES

To enhance underwater exploration, this ROV aims to improve efficiency with 3D-printed components and enhance detection capabilities using dual cameras, particularly in coral reef environments.

- Investigate the limitations of conventional ROV designs, emphasizing maneuverability and adaptability, and assess the potential improvements achievable through the integration of 3D-printed components for enhanced efficiency in underwater exploration.

- Examine the drawbacks of single-camera systems in ROVs and explore the advantages of dual cameras, specifically for increased spatial awareness and the detection of invasive species in environments like coral reefs, aiming to advance and revolutionize underwater exploration capabilities.

V. RELATED STUDIES

In a 2017 study by Schillachi et al., an open-source solution for rapid prototyping and customization of underwater drones was proposed. In Section II, they introduce 3D-printable models compatible with hardware components from low-cost underwater drone markets, such as BlueRobotics and OpenROV. These models facilitate easy customization of propellers, ballast, and hydrodynamic configurations, thereby reducing the overall cost of the final product. Consequently, a functional prototype utilizing the proposed models was implemented. Additionally, the study details the hardware and software solutions adopted in the functional prototype. [7]

Underwater robotics necessitate components capable of enduring repetitive stresses, maintaining stringent tolerances, and achieving precise dimensional accuracy to enable assemblies that seal tightly with O-rings, devoid of any imperfections like bumps, ridges, lines, or printing artifacts. Traditionally, such specifications are met through metal machining or injection molding, but outsourcing to providers proves costly and time-consuming, often taking weeks or months. Lewis and Treloar explore 3D printing as a viable alternative, allowing for the design, prototyping, and testing of parts that emulate the qualities of injection-molded or machined plastics. [8]

VI. METHODOLOGY

This methodology outlines the steps taken to design, develop, and test a Remotely Operated Vehicle (ROV) for underwater exploration. The ROV integrates 3D-printed components for customization and cost-effectiveness, along with a dual-camera system to enhance visual data collection and operational efficiency.

A. *Conceptual Design*

Fig. 1. 3D design of the underwater ROV

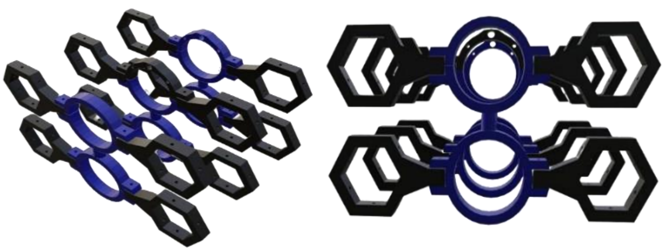

Fig. 2. 3D design of the drone frame structure

Fig. 3. 3D design of the end caps

Fig. 4. 3D design of the thruster and propeller

Fig. 5. 3D design of the holder

The 3D components utilized in this study were designed and fabricated using Blender, a free and open-source 3D computer graphics software tool set compatible with Windows, MacOS, BSD, Haiku, and Linux. The specific parts created included the drone frame structure, propellers, thrusters, end caps, and holders. These components were printed using PETG filament on an Ender 3 V1 3D printer. This methodology ensured high precision and durability of the parts, which are crucial for the functional performance of the drone.

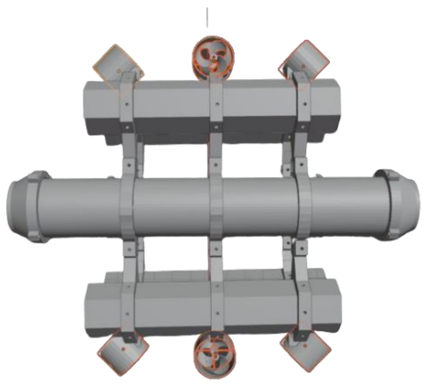

Fig. 6. Thruster Configuration

Marine propellers, essential for underwater drones, provide propulsion and maneuverability against water resistance. The thrusters used in the drone are based on Blue Robotics' T100 design and manufactured with A.B.S. filament material treated with acetone vapor smoothing. Each thruster integrates an A2212 brushless D.C. motor, waterproof and efficient, responsible for propelling the attached propeller and enabling precise drone movement. This motor choice is favored for its compact size, durability, and minimal maintenance needs. Thruster placement allows the drone to achieve five degrees of freedom: forward/backward motion (surge), sideways motion (sway), vertical motion (heave), rotation around the vertical axis (yaw), and rotation around the longitudinal axis (roll). The Electronic Speed Controller (E.S.C.) controls motor speed based on signals from the Pixhawk autopilot board.

B. Hardware Description

Dual cameras are crucial in furnishing image frames for control and subsequent image processing. The Pixhawk autopilot is responsible for acquiring telemetry and sensor data from the drone and transmitting this information to the Raspberry Pi. An integral power sensing module interfaces between the battery and electronics, offering analog current and voltage sensing. This module, linked to the Pixhawk autopilot, processes data emanating from it. The drone system transmits all sensor and telemetry information to the user by enabling the Raspberry Pi to manage data routing through a rope connected to mission control. Brushless DC motors, driven by an E.S.C., receive input signals from the Pixhawk. Power for the entire system is supplied by a 12.6 V, 30 Ah lithium-ion battery pack.

C. Software Description

The researchers relies entirely on open-source software solutions to control the drone. They have selected Raspbian as the operating system for the Raspberry Pi 5 and have installed ArduSub 6 on the PX4 Pixhawk. ArduSub, developed by BlueRobotics and derived from the ArduCopter code, now forms part of the ArduPilot project. It offers a comprehensive range of functionalities including feedback stability control, depth and heading hold, and autonomous navigation using pre-programmed trajectories.

For communication, they have adopted MAVlink as the protocol. To facilitate dive control and mission planning, they use QGroundControl, an open-source application initially developed for the Pixhawk Project. QGroundControl is widely utilized in various research centers and by a growing community to manage aerial, terrestrial, and underwater drones effectively.

Fig. 7. Front view 3D design of the underwater ROV

The drone incorporates two cameras strategically placed for specific functions. One camera, situated inside the drone's lower hull, provides live video feed essential for real-time visual data and drone control. This setup allows for immediate operational insights and image analysis. The cameras are crucial for facilitating control and image processing tasks. The Rapoo C260 USB Full HD Webcam, chosen for its high-resolution capabilities and smooth 60Hz frame rate, captures clear 1920x1080p video and 2-megapixel photos. Its flexibility, including a 270-degree rotation capability and an 8-inch USB extension cord, ensures optimal positioning for desktop or laptop use.

VII. Results and Discussion

The integration of 3D-printed components and dual cameras has significantly enhanced the capabilities of the remotely operated underwater vehicle (ROV) designed for underwater exploration. This section presents the outcomes and discussions based on the performance and functionality of these key innovations, along with the initial testing and subsequent marine deployment.

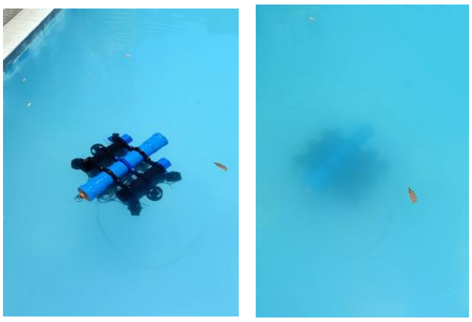

Fig. 8. Initial Testing at Imus, Cavite

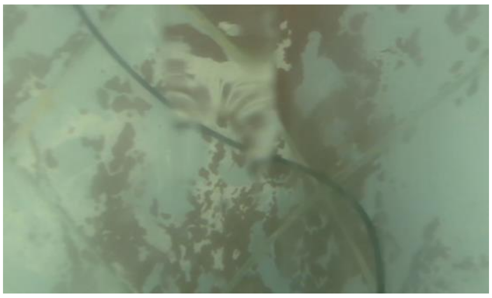

Fig. 9. Drone footage captured during pool testing at Imus, Cavite

Initial testing in a controlled 5-foot pool focused on assessing the durability and performance of 3D-printed components, particularly for leakage and pressure resistance. During these tests, some leakage issues were identified, prompting the researchers to reinforce critical areas such as endcaps with resin epoxy. This modification effectively addressed the leakage concerns and ensured the integrity of the ROV's structural components during subsequent operations.

The structural enhancements made with resin epoxy in 3D-printed components significantly improved the ROV's stability and durability under varying water pressures. This reinforcement contributed to maintaining structural integrity during dives and maneuvering challenges encountered during underwater exploration. The customized design of 3D-printed parts facilitated precise integration of sensors and other equipment, optimizing the ROV's maneuverability across five degrees of freedom.

Fig. 10. Final Deployment in marine environment at Brgy. Guis-guis, Sariaya, Quezon

Fig. 11. Drone footage captured during deployment at Brgy. Guis-guis, Sariaya, Quezon

The deployment at Brgy. Guis-guis, Sariaya, Quezon marked a successful validation of the ROV's capabilities in real marine environments. The ROV reached depths of up to 5 meters, demonstrating robust performance and functionality of its dual cameras. Positioned strategically within the ROV's lower hull, these cameras provided clear, high-resolution video streams essential for navigation and environmental assessment. The cameras' reliability in capturing detailed images and videos under varying light and water conditions underscored their effectiveness in supporting underwater research and monitoring efforts.

The successful integration of reinforced 3D-printed components and dual cameras highlights their critical role in advancing underwater exploration capabilities. These innovations enable researchers to conduct precise and reliable data collection in challenging marine environments. By enhancing maneuverability, stability, and visual capabilities, the ROV proves invaluable for scientific research, environmental monitoring, and infrastructure inspections beneath the ocean's surface.

IX. CONCLUSION

In conclusion, the iterative improvements and successful field deployment of the ROV equipped with 3D-printed components and dual cameras demonstrate significant strides in underwater technology. Addressing initial challenges with resin epoxy reinforcement has strengthened the ROV's performance and reliability, paving the way for enhanced exploration and understanding of marine ecosystems. Future advancements in these technologies promise further innovations in underwater robotics, benefiting diverse applications in marine science and industry.

The development of the remotely operated underwater vehicle (ROV) represents a significant achievement in enhancing capabilities for underwater exploration and environmental monitoring. Utilizing advanced technologies and meticulous calibration processes, the drone's navigation system was finely tuned using QGroundControl to ensure precise orientation and stability underwater. Integration of the USB/IP protocol enabled synchronized dual-camera transmission, enhancing situational awareness and facilitating detailed observation in complex marine environments.

The ROV, designed and constructed with agile 3D-printed components optimized through iterative refinement and expert consultations, exemplifies a cost-effective solution for underwater research. Its robust performance, validated through successful field operations and deployments, underscores its effectiveness in comprehensive environmental assessment and monitoring tasks.

Moving forward, continued advancements in ROV technology promise further innovations and applications, contributing to deeper insights and sustainable management of marine ecosystems. The success of this project highlights the collaborative efforts and interdisciplinary approach essential for pushing the boundaries of underwater exploration and fostering scientific discovery in aquatic environments.

REFERENCES

[1] O. A. Aguirre-Castro *et al.*, “Design and Construction of an ROV for Underwater Exploration,” *Sensors*, vol. 19, no. 24, p. 5387, Dec. 2019, doi: https://doi.org/10.3390/s19245387.

[2] D. Trekker, “Underwater Drone 101 All you need to know,” *Deep Trekker*. https://www.deeptrekker.com/news/underwater-drone-101

[3] “An underwater explorer remotely operated vehicle,” *read.nxtbook.com*. https://read.nxtbook.com/ieee/potentials/potentials_may_june_2023/an_underwater_explorer_remote.html

[4] L. Meng, T. Hirayama, and S. Oyanagi, “Underwater-Drone With Panoramic Camera for Automatic Fish Recognition Based on Deep Learning,” *IEEE Access*, vol. 6, pp. 17880–17886, 2018, doi: https://doi.org/10.1109/access.2018.2820326.

[5] M. Fernandes, S. R. Sahoo, and M. Kothari, “An Open Source, Low Cost, 3D Printed Thruster For Autonomous Underwater and Surface Vehicles,” *IEEE Xplore*, Sep. 01, 2022. https://ieeexplore.ieee.org/document/9965889

[6] Electoviz, “Robot AI Integration: How Deeply Are Deep Learning and Neural Networks Intertwined in Modern Robotics?,” *Electoviz*. https://electroviz.com/microcontrollers/robot-ai-integration-how-deeply-are-deep-learning-and-neural-networks-intertwined-in-modern-robotics (accessed Mar. 12, 2024).

[7] Schillaci, G., Schillaci, F., & Hafner, V., V. (2017, July 20). *A customisable underwater robot*. arXiv.org. https://arxiv.org/abs/1707.06564

[8] 3D printed underwater robotics for deep sea repairs. (n.d.). Formlabs. https://formlabs.com/asia/blog/3d-printed-underwater-robotics-for-deep-sea-repairs/

[9] Boogaard, F., De Lima, R., & De Graaf, R. (2020). Innovative Water Quality and Ecology Monitoring Using Underwater Unmanned Vehicles: Field Applications, Challenges and Feedback from Water Managers. Water, 12(4), 1196. https://doi.org/10.3390/w12041196