Advancements in Underwater ROV Technology for Monitoring Water Parameters through TDS, pH, and Temperature Sensors

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I. INTRODUCTION

In recent years, the field of underwater remotely operated vehicles (ROVs) has witnessed significant advancements, particularly in the realm of precise monitoring of water parameters. [1] This journal explores the cutting-edge developments in Underwater ROV Technology, focusing on its role in monitoring Total Dissolved Solids (TDS), pH levels, and temperature in aquatic environments. As concerns for water quality and ecosystem health escalate, the demand for sophisticated tools that can provide accurate and real-time data becomes paramount. This study delves into the latest innovations in sensor technology integrated into ROVs, offering a comprehensive examination of their capabilities and contributions to enhancing our understanding of water dynamics. [2]

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]

II. BACKGROUND OF THE STUDY

The critical importance of monitoring water parameters in aquatic environments has become increasingly evident due to escalating concerns about water quality, pollution, and their impact on ecosystems. Traditional methods of water quality assessment often lack the precision and real-time capabilities required to address these concerns comprehensively [3]. The deployment of underwater remotely operated vehicles (ROVs) equipped with Total Dissolved Solids (TDS), pH, and temperature sensors presents a promising solution to this challenge. The background of this research stems from the need for advanced technologies that can provide accurate, continuous, and detailed data on crucial water parameters, fostering a more proactive approach to environmental conservation and management.

Historically, limitations in underwater monitoring tools have hindered the acquisition of nuanced information about water quality dynamics. This journal aims to address these limitations by examining the recent advancements in ROV technology tailored for precise water parameter monitoring. By delving into the historical context of water quality assessment and the existing challenges, this research endeavors to establish a foundation for understanding the significance of the proposed technological innovations in advancing our capability to monitor and safeguard aquatic ecosystems [4].

III. STATEMENT OF THE PROBLEM

The burgeoning interest in underwater Remote Operated Vehicles (ROVs) for monitoring water parameters, specifically Total Dissolved Solids (TDS), pH, and temperature, has prompted significant advancements in technology [5]. As our understanding of aquatic ecosystems deepens, the need for accurate and real-time data collection becomes paramount. Traditional methods of water parameter monitoring are often cumbersome, limited in scope, and can pose logistical challenges, especially in remote or hazardous environments. The advent of sophisticated sensors and cutting-edge ROV technology offers a promising solution to overcome these limitations. However, despite the strides made in this field, there remains a critical gap in research and development concerning the integration, calibration, and deployment of these sensors on underwater ROVs. Addressing this gap is imperative for unlocking the full potential of underwater ROVs in enhancing our ability to monitor and safeguard water quality [6].

Efforts to streamline the integration of TDS, pH, and temperature sensors into underwater ROVs face technical and operational hurdles. Calibration precision, data accuracy, and sensor reliability are crucial factors requiring attention. Furthermore, the design and engineering of ROVs must adapt to effectively accommodate these sensors, considering factors such as power consumption, sensor placement, and communication capabilities. Addressing these challenges is essential to unlock the full potential of underwater ROVs for advancing our understanding of aquatic ecosystems and ensuring reliable water parameter monitoring [7].

IV. Objectives

In addressing the limitations of current water monitoring approaches, this study aims to evaluate the potential enhancement of real-time precision in aquatic parameter assessment through the integration of Total Dissolved Solids (TDS), pH, and temperature sensors within underwater remotely operated vehicle (ROV) technology.

- Evaluate current water monitoring limitations and explore the integration of TDS, pH, and temperature sensors in underwater ROV technology to enhance real-time precision in aquatic parameter assessment.
- Investigate challenges in monitoring TDS, pH, and temperature, striving to advance ROV technology for more effective and detailed water quality assessment in diverse underwater environments.

V. Related Studies

In 2020, a study conducted by Moriya et al., used aquatic vehicles to monitor large areas and classification of water bodies based on environmental indicators. different monitoring setups consisting of different types of underwater drones combined with water quality sensors and cameras were tested in the field for applications in water management and environmental monitoring activities, and efforts were made to involve water managers in the different stages of research. [8] The drones are either tethered, with a real-time video feed, or controlled wirelessly via radio signals: operational depth restricted to a maximum of 5 m water depth. Some of the tested models allow features such as the ability to set a fixed depth and/or a fixed direction that is automatically maintained through the self-adjustment of the speed of the thrusters, based on the real-time processing of the onboard pressure sensor and compass. The combination of underwater drones with a variety of equipment allowed the collection of high-frequency multi-dimensional ata of multiple environmental and water quality parameters, and to obtain visual insights into underwater environments and ecosystems. The underwater drones were able to dive and collect data at multiple water depths on the water column, generating three-dimensional datasets. These were used to obtain depth profiles and maps at specified water depths. Sensors have a response time of a few seconds, which means that the drone had to descend in small steps, to allow the sensors to stay for some time at each desired depth.

In 2015, a study conducted by Hidalgo et al., proposed the design and implementation of ROV-based acquisition system designed for water quality monitoring through the acquisition of oceanographic parameters of Peruvian water resources. The presented prototype is developed to be used as a research platform and as a measurement tool for the Peruvian Institute of the Sea (IMARPE—Instituto del Mar del Perú) in order to extend its capabilities on oceanographic parameters monitoring. [9]

VI. Methodology

This study utilized an advanced underwater Remotely Operated Vehicle (ROV) equipped with cutting-edge sensors to monitor critical water parameters. The ROV featured a modular sensor suite comprising an Analog Total Dissolved Solids (TDS) sensor, an Analog pH meter sensor, and a Waterproof Temperature Sensor DS18B20, each meticulously calibrated to ensure high accuracy across diverse aquatic environments. The conceptual framework of the study is illustrated in Figure 1, which delineates the input parameters, the processes undertaken by the system, and the anticipated outputs.

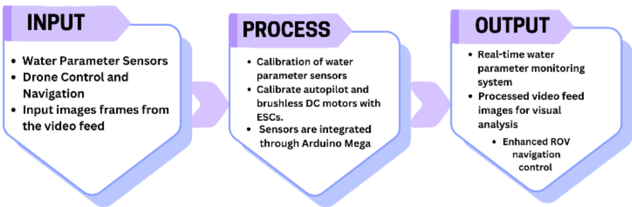

Fig. 1. Conceptual Framework of the Study

A. *Hardware Development*

Operating a remote-controlled underwater vehicle and water parameter sensors necessitates specific knowledge and skills. Additionally, the required hardware components must be assembled and calibrated. This process involves constructing the drone and calibrating its motors and sensors. The outcome will be a remotely operated underwater vehicle equipped with sensors for monitoring water parameters, including T.D.S., pH, temperature, and other supplementary sensors.

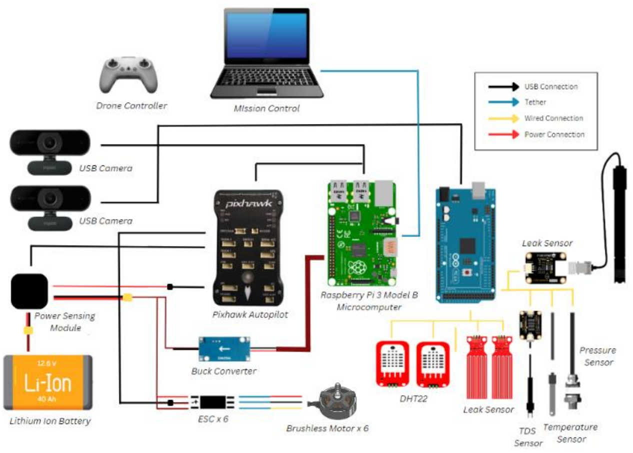

Fig. 2. Schematic diagram of the Electronics Hardware System

The system gathers data from four primary sources: the Pixhawk Autopilot with an Inertial Measurement Unit (IMU) for telemetry data, thrusters, cameras for live video feed, and various sensors that monitor water quality parameters such as temperature, pH, and total dissolved solids (T.D.S.). The Pixhawk autopilot is responsible for acquiring telemetry and sensor data from the drone and transmitting this information to the Raspberry Pi. The Arduino Mega processes data generated by the onboard sensors. These three components establish connectivity with the Raspberry Pi via a USB connection.

The sensor integration with the Arduino Mega includes pH, T.D.S., and temperature sensors for monitoring water quality, as well as pressure, DHT22, and leak sensors serving as operational sensors for the drone, connected through connector wires. An integral power sensing module interfaces between the battery and electronics, providing analog current and voltage sensing. This module, connected to the Pixhawk autopilot, processes data originating 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 cable connected to mission control. Brushless DC motors, driven by an ESC, receive input signals from the Pixhawk. Power for the entire system is supplied by a 12.6 V, 30 Ah lithium-ion battery pack.

B. System Testing and Evaluation

To verify the functionality and operability of the hardware and software system, the underwater drone was deployed in several phases within different underwater environments. Each deployment phase tested the drone's capabilities and performance under varying depths, conditions, and objectives. Initially, a shallow pool, 5 feet deep swimming facility at Imus, Cavite, was used to assess the effectiveness of the water seals, test the camera vision underwater, and evaluate the joystick handling of the drone. The drone was equipped with two Rappo C260 cameras for visual data capture and underwater footage recording. However, during preliminary testing in an actual marine environment, the drone encountered a significant issue with unstable connectivity to the QGround control system, which is vital for command input, real-time sensor data reception, and status monitoring. To address this issue, researchers focused on testing the sensors' functionality in a saltwater environment with a stable connection. This challenge required recalibrating the drone's ballast due to the higher density of seawater compared to freshwater, affecting buoyancy. In Area A, 1200 grams were added to the drone's ballast, with 600 grams on the lower right side and 400 grams on the other side. After successful recalibration, the focus can return to evaluating the full performance of the sensors and collecting valuable data from the marine environment in future experiments.

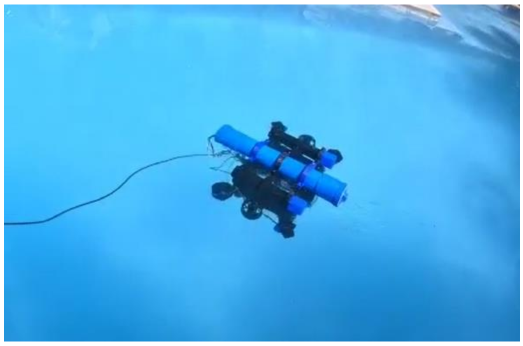

Fig. 3. The underwater ROV during the pool testing.

The subsequent test was conducted in the waters of Brgy. Butong in Taal, Batangas, where the drone was tested at depths ranging from 1 to 3 meters, accompanied by scuba divers. To ensure proper functionality, researchers focused on evaluating sensor performance in a stable saltwater environment. This adjustment required recalibrating the drone's ballast to account for the increased density of seawater due to dissolved salts, which impacts buoyancy. In Area A, an additional 1200 grams were added to the drone's ballast, with 600 grams on the lower right side and 400 grams on the other side. Following successful recalibration, the focus returned to evaluating the full performance of the sensors and collecting valuable marine environment data in future experiments.

Additionally, another deployment took place at Brgy. Guis-guis in Sariaya, Quezon Province, where the drones, accompanied by scuba divers, were successfully tested at depths ranging from 1 to 8 meters.

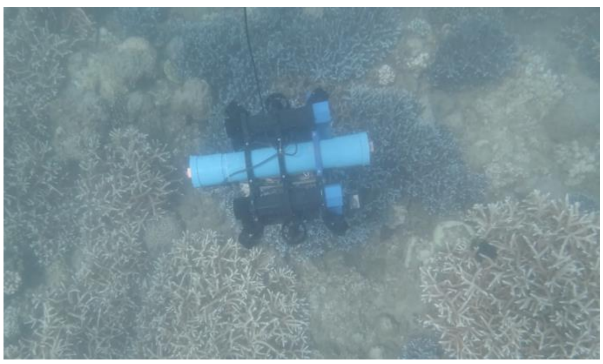

Fig. 3. The underwater ROV during the marine environment deployment at Brgy. Guis-guis, Quezon Provinc

VII. Results And Discussion

A. *Drone's Forward Cruise and Vertical Ascent Speed*

The speed calibration of the Electronic Speed Controllers (ESCs) was carried out using the BLHeliSuite application, a specialized tool for flashing and configuring BLHeli ESCs. The firmware is an open-source version from the BlueRobotics website, identical to the firmware employed in their commercial BlueROV. The throttle settings are specified with a minimum of 28 ppm and a maximum of 228 ppm, index values corresponding to specific pulse widths.

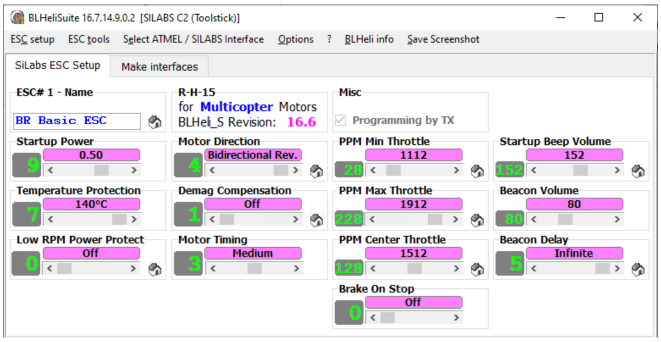

Fig. 4 Speed Calibration of ESCs using BLHeli Suite Application

With the ESCs above configured for each thruster's throttle speed, the drone achieved a speed of 0.576 meters per second for its forward/backward and left/ right movements. The drone performed at approximately 0.152 meters per second for its vertical ascent and descent.

B. *Power Consumption*

The total power consumption can be calculated by summing the power consumption of each component, determined by the product of their rated voltages and maximum current load. An additional 20% allowance is included for contingency. Refer to Table 6 for the Schedule of Electrical/Electronic Loading. The battery pack, rated at 378 Wh, is deemed suitable for the specifications, providing a runtime capacity of 1 to 1.5 hours for the drone.

C. *Water Quality Monitoring Results*

Table 1. Standard water parameter results of seawater from DENR Administrative Order No. 2016-08 (DAO 2016-08)

Parameter	Values
pH	7.0-8.5
TDS	35000 ppm
Temperature	26°C - 30°C

Table 4.1 presents standard water parameters for seawater according to DAO 2016-08 Water Quality Guidelines and General Effluent Standard of 2016. The recommended pH range is 7.0 to 8.5, ensuring aquatic and human safety by maintaining proper acidity or alkalinity levels. Total dissolved solids (TDS) should not exceed 35,000 ppm, encompassing various dissolved substances while ensuring water safety for consumption and industrial use.

Table 2. Actual Data Samples Gathered using Water Quality Meter in Area A

Parameter	Values
pH	7.83
TDS	27300 ppm
Temperature	29.6°C

Table 3. Actual Data Samples Gathered using Water Quality Meter in Area B

Parameter	Values
pH	7.91
TDS	26900 ppm
Temperature	31.5°C

Tables 2 and 3 present the values measured by manual multimeter sensors for pH, TDS, and temperature in water samples collected from Areas A and B, respectively.

In Area A, the recorded values are 7.83 for pH, indicating neutral to slightly alkaline water, 27,300 ppm for TDS, signifying a high concentration of dissolved minerals and salts, and 29.6°C for temperature, which influences the metabolic rates of aquatic organisms and chemical reactions within the water. In Area B, the values depict a pH of 7.91, indicating neutral to slightly alkaline water, a TDS of 26,900 ppm, suggesting a high presence of dissolved minerals and salts, and a temperature of 31.5°C, impacting the metabolic rates of aquatic organisms and chemical reactions in the water. These readings are crucial for assessing environmental conditions and ecological health and ensuring regulatory compliance with water quality standards. Regular monitoring helps in the early detection of pollution sources and the implementation of effective water management strategies.

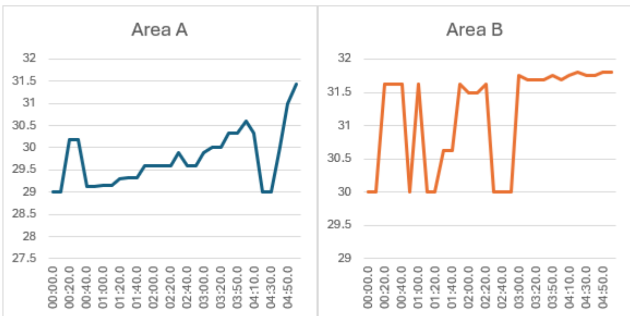

Fig. 4. Temperature Sensor Readings from Area A and B

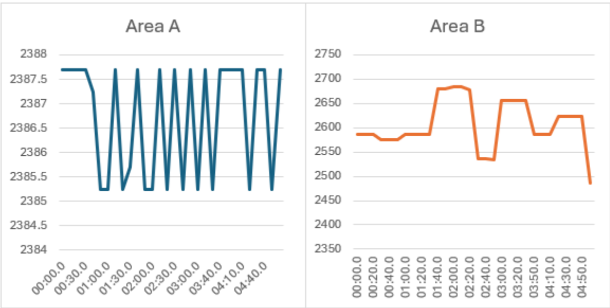

Fig. 5. TDS Sensor Readings from Area A and B

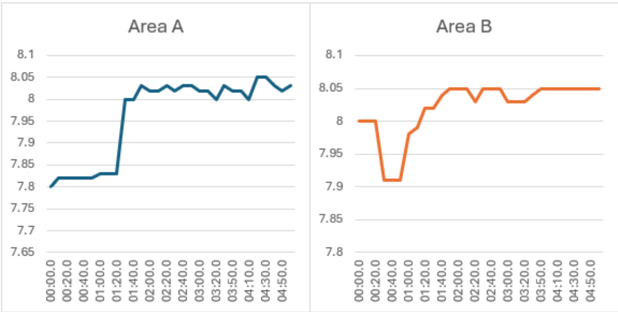

Fig. 6. pH Sensor Readings from Area A and B

The depth of the same Area was measured using the same rope with a weight attached to its end. For area A, the measured Area was 25 square meters, and the depth was approximately 4 meters. In contrast, area B measured 30 square meters and a depth of 5.65 meters.

The deployment areas are classified as Class SA, which are protected waters. Additionally, the fisheries water in these areas is classified as Class 1, according to DAO 2016-08. Comparing the obtained values from Area A and Area B to the standard water parameters for seawater reveals exciting insights. In Area A, the pH level of 8.03 falls within the standard range of 7.0 - 8.5, indicating a slightly alkaline environment conducive to marine life. The Total Dissolved Solids (TDS) concentration of 2385.25 ppm is somewhat lower than the standard value of 35,000 ppm, suggesting a marginally lower mineral content than typical seawater.
Additionally, the temperature of 31°C is slightly higher than the upper limit of the standard range of 26°C to 30°C, indicating suitable thermal conditions for supporting marine ecosystems. Conversely, in Area B, the pH level of 8.00 also falls within the standard range, suggesting a similar alkaline environment to Area A. The TDS concentration of 2585.66 ppm is lower than the standard but higher with Area A. However, the temperature of 30°C in Area B aligns well with the standard range. These comparisons highlight variations in water quality parameters between the sampled areas and standard seawater parameters, emphasizing the importance of localized monitoring for understanding and managing marine ecosystems effectively.

VIII. Conclusion

An advanced water quality monitoring system integrated into the ROV, equipped with sensors to measure total dissolved solids (TDS), pH levels, and temperature. These sensors provide real-time data on water quality, making the ROV an invaluable tool for environmental monitoring and assessment. The drone integrates various microcomputer and microcontroller boards, including the Arduino Mega, Raspberry Pi 3 Model B, and Pixhawk 2.4.8 Autopilot, to efficiently manage its operations and data transmission. Crucial for water quality assessment, the DS18B20 temperature sensor monitors sea temperatures, which are critical to coral health, and alerts when temperatures exceed optimal thresholds of 29-30°C to prevent bleaching. Incorporating TDS measurements is vital for assessing salinity and mineral content. The TDS sensor requires calibration and temperature compensation for accurate readings, as high TDS levels above 2000 ppm can stress corals, highlighting the need for continuous monitoring. The pH sensor, essential for maintaining optimal pH levels (7.7 to 8.4) for coral health, ensures accurate measurements through calibration. Deviations from this range can negatively impact coral calcification and larval settlement. Together, these sensors and systems enable comprehensive monitoring and management of marine ecosystems, supporting coral health and resilience. Integrating these sensors allows for the continuous and precise measurement of critical water parameters, thereby supporting a wide range of applications, from scientific research to pollution management. The ROV's design not only meets the operational requirements for underwater missions but also significantly enhances the capacity for effective marine ecosystem monitoring and management.

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