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DESIGN AND DEVELOPMENT OF REMOTELY OPERATED VEHICLE TO ASSESS THE WATER QUALITY IN AQUACULTURE AREA

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Abstract

Aquaculture has been recognized as a sector that can assist to diversify the Brunei economy from relying on the oil and gas industry. Previous research has indicated that water quality in aquaculture settings is a major limiting factor; thus, it is important to examine and determine the influencing elements that would harm them. However, traditional methods of assessing water quality are unsafe, expensive, labor-intensive; and the sampling measurements may not represent the overall aquaculture areas. Thus, alternative method in collecting the samples is applied using Remotely Operated Vehicle (ROV). In this paper, the design of an innovative ROV equipped with sensors, cameras, and lighting systems in conducting in-situ measurement of the main water quality parameter are presented. The main objective of this ROV is to increase the safety of humans working in difficult-to-access underwater in obtaining measurements with a probe or to collect samples and analyze them in a laboratory. Temperature, dissolved oxygen (DO), nitrate, ammonia, and pH of water are among the assessed parameters. The sensors attached to ROV will take measurements at 15 sample waypoints in existing aquaculture areas. The data gathered may also be utilized to interpret the spatial distribution of measurements in the aquaculture areas. This project is expected to increase the productivity of Brunei aquaculture industry in the new future.

Keywords*: Aquaculture; Oil and gas; ROV; Water quality; In-situ measurement*

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INTRODUCTION

It is interesting to know that 52% of fish for human consumption in the world comes from aquaculture (*FAO Fisheries Division - Yearbook of Fishery and Aquaculture Statistics*, 2018). This means half of our seafood not being captured by the fishermen from the sea or river but being collected from the fish farms. Harrel (2019) define aquaculture as the breeding, rearing, and harvesting of fish, shellfish, plants, algae, and other organisms in all types of water environments for any commercial, recreational, or public purpose. The breeding, rearing, and harvesting of plants and animals takes place in all types of water environments including ponds, rivers, lakes, the ocean and man-made "closed" systems on land. It is a global industry with increased importance in battling the challenges of the food supply in the future (Håstein et al., 2006).

Through aquaculture growth, consumers from low to high income nations have benefited from year-round availability and access to aquatic foods, which are rich in protein and micronutrients. The sector produces far more than fish, shellfish, and algae for direct human consumption. It also generates products used in food processing, feed, fuels, cosmetics, nutraceuticals, pharmaceuticals, and a variety of other industrial products, and it contributes to a range of ecosystem services (Naylor et al., 2021). In Brunei Darussalam, the agriculture, fishing and forestry used to be the major economic contributors until the 1920s when oil and gas resources were first discovered and the country's economy has been almost entirely dependent on fossil fuel production ever since (Ndah et al., 2017). The aquaculture has been identified as one of the sectors that can contribute to the diversification of the Brunei economy away from the reliance on the oil and gas industry. This diversification of the economy has been introduced as one of the three main goals of Brunei in Wawasan Brunei 2035. The overall fishery production shows a positive trend with aquaculture contributed to the growth from BND10 million in 2015 to BND32 million in 2020. Furthermore, seafood has been one of the principal sources of protein for the people of Brunei Darussalam. The per capita fish consumption in Brunei Darussalam is one of the highest in the region, which is about 47 kilograms per person, (Department of Fisheries, 2018) lesser 2kg behind Japan who famous with sushi and sashimi. Thus, aquaculture is an important sector in the world and Brunei in producing source of protein for human consumption and need to have much good research on.

In aquaculture, the water quality is the main factor that need to be checked in all stages; before, during and after the construction and operational of an aquaculture farm. The water quality does not only affect the animal, but also environment and people. Zhang et al.(2020) mentioned that the water quality in aquatic environments is deemed as a main limiting factor, it is necessary to assess the water quality and environmental conditions in marine aquaculture areas and find out the main influencing factors that will damage the water quality environment. There are four major categories of water quality concerns that affect aquaculture cultivations, namely, (1) physical parameters, e.g., pH, temperature, dissolved oxygen, and salinity, (2) organic contaminants, (3) biochemical hazards, e.g., cyanotoxins, and (4) biological contaminants, i.e., pathogens (Su et al., 2020). The water quality monitoring in aquaculture area is often done manually by the authorities or farmer in periodical time and have traditionally been collected using devices such as Nansen bottles, Van Dorn samplers, or syringes. These devices are usually actuated using a messenger dropped from the surface on the line, a bottom-induced trigger, or a powered servo (for large sampling cassettes) (Benson et al., 2019). The water quality monitoring that is done manually tends to be impractical, requires high worker wages, and has a high human error rate (Komarudin et al., 2021). While, Betancourt et al. (2020) mentioned that the process of manually collecting water samples in fish farms is time consuming, and the manual inspection of net-cages could be challenging due to the turbidity of the water. If only few samples are taken, these will not representing the overall aquaculture farm because the parameter may differ by the sample location being taken. Plus, by the time the results were out, the parameter may change, and the remedy action will be not accurate.

To address this issue, we introduced the usage of a Remotely Operated Vehicle (ROV), which is an innovative marine technology that has been employed in the aquaculture industry worldwide, particularly fish farming, for inspection, cleaning, and monitoring of water quality (Betancourt et al., 2020) and today (circa 2021), it has become common to use ROV for such tasks (Føre et al., 2018). An ROV is a Remotely Operated Vehicle that is tethered and under the direct control of a human operator at the surface. The ROV technology has been developed over the past 50 years through military and oil and gas research. This technology has been demanded to the operational models when the US Navy developed the Cable-Controlled Underwater Recovery Vehicle (CURV and CURV II) for rescue and recovery of weaponry in the 1960s (Capocci et al., 2017). In recent years, many commercial companies have made use of a reduction in cost of this technology to develop the affordable underwater vehicles. In detail, ROVs have been used for underwater intervention, repair, and maintenance operations in offshore industries, including oil and gas industries, marine structures, marine sciences, naval defense, marine renewable energy, and scientific purposes (Aguirre-Castro et al., 2019). However, this paper will be presenting the design and development of ROV that can be manufactured locally with its function focusing on as an instrument to assess water quality in safer and effective way.

The rest of this paper is organized as follows: Section 2 describes the design and development of the proposed ROV that can be divided into two aspects; mechanical and electronics. Section 3 presents the proposed experimental procedure in assessing the water quality parameter using ROV and a comparison versus traditional method. Finally, Section 4 summarizes the expected outcome of the paper.

RESULTS AND DISCUSSION

ROV Design and Development

Said et al. (2015) highlighted the important to make a proper design consideration on every aspect of ROV elements as this will produce a cost-effective development of ROV. The components in Figure 1 are the main basic components in ROV that consists of body frame, camera, thrusters, power supply, tether, lighting, sensor and other electronics and mechanicals systems. On this paper, we divide the main component into two categories namely mechanical and electronic.

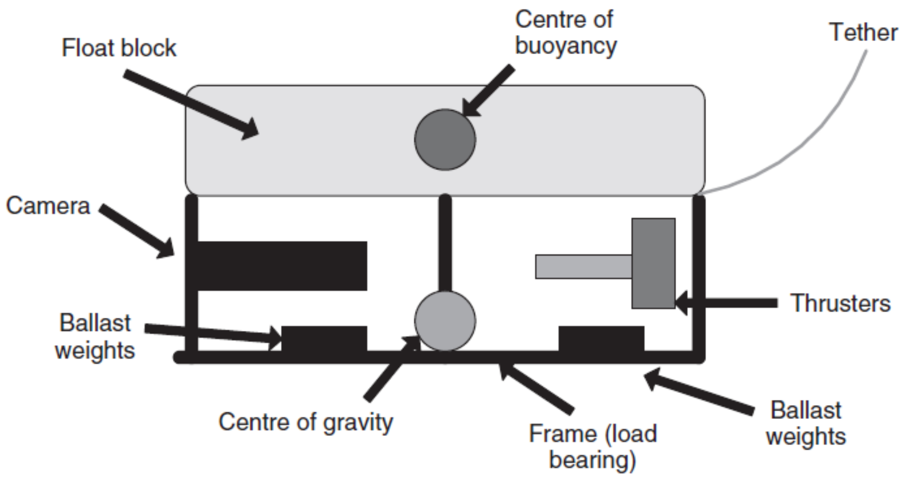

Figure 1: Main Components of ROV (Molland, 2008)

Main Components (Mechanical)

Main Body Frame

The main body frame is the most important part where all the components will be attached to the main body. The ROV design needs to consider the placement of other accessories for each system so that the other equipment can be place at the main body nicely without disturbing or colliding with the other parts. This main body will hold all the system parts and will protects all that instrument from damage due to collision during the operation underwater.

Structural Materials

Material selection during ROV construction also affects the strength integrity and buoyancy of an ROV. Thus, the construction materials need to be selected properly. The selection of material depends on the desired operating depth of the ROV. Typical materials used in assisting the buoyancy of the ROV are metal and plastics. The metal can be classified into aluminum and steel where the aluminum has the greater advantages compared to the steel in term of weight ratio and availability (Moore et al., 2010). However, the steel is easier to be machining and welding compared to the aluminum that need special process to weld. There are also several types of plastics that suitable to be used as the frame such as Acrylonitrile-Butadiene-Styrene (ABS), Polyvinyl Chloride (PVC) and acrylic. All these three plastics have the strong durability with light weight and corrosion resistance.

Thrusters

The energy requires to control the ROV motion through the water by using propulsion force is called thrust. The most common method to generate thrust are using the rotating propellers. The ROV design employs a limited range of possible thrust direction. The ROV weight and buoyancy can cause the vertical position and movement and its can be control by using thrust that directed vertically (Christ & Wernli, 2013; Moore et al., 2010). However, the thrust directed horizontally can make the ROV to move forward or backward, turn right or left and spin in horizontal plane. So, the thruster is the simple propeller that attached to the waterproof electric motor that helps the movement of ROV.

Propulsion System

The main element that needs to be emphasized in designing a ROV is the propulsion system (Joochim et al., 2016). The propulsion system needs to have a high thrust-to-physical size/drag and power input ratios. Every component of the propulsion system needs to be selected carefully as the more thruster's power required, the heavier the propulsion system on the ROV will be. The thruster needs to arrange properly so that the ROV can move perfectly without affecting the stability under water. The thruster placement act as the main character that will affect the performance of the ROV. Commonly, the development of mini class ROV is using three thrusters or four thrusters with different placement while the work class of ROV can be more than five thrusters because of the size and weight (Christ & Wernli, 2013). The basic placement for three thruster version is one located centrally and oriented vertically, to move the ROV up and down, while other two thrusters in horizontal direction that to drive horizontal movement including forwards, reverse and turns. For four thruster arrangement, it is like three thruster's modification with additional one thruster in horizontal in X-axis. This will make the ROV can be turn quickly.

Stability Underwater

The stability underwater refers to the tendency of the ROV to bring back to upright position whenever its accidently tipped by other disturbance or the pushing power of the thruster, or the swirling water from a crashing wave (Leonard, 1997). The main parameter for ROV stable under water is the physical distance center of gravity (CG) and center of buoyancy (CB) which can determine the moment arm and determine the torque produce of the ROV. The moment arm is the perpendicular distance of CG and CB from buoyancy force or weight of ROV. The relation of moment arm and torque is based on this equation, $T = Fr$ where, T is torque, F is force applied to ROV and r is the moment arm (White, 2011). When the ROV is tilted one sided or others, the moment arm will produce and creates the torque that can stable back the ROV. The greater torque produce, the quickest time to bring the ROV back in upright position . The ROV is stable when the CB and CG is vertical in line with each other, so that, there will be zero moment arm. If the ROV have shorter moment arm, there will produce smaller moment arm and torque, means the ROV will take longest time to bring it back to upright position. However, the longer moment arm will make the moment arm become longer, and enough torque produce to stabilize back the ROV.

Buoyancy Underwater

The buoyancy can be defined as the tendency of the something to floats in water. Based on Archimedes' Principle, the magnitude of the buoyant force that acting on an abject is equal to the weight of the fluid displaced by the object (White, 2011). This principal has been used for under water vehicle such as submarine that can float and sink in the water. The buoyant force is the upright force that make the object to floats (Love et al., 2003). Based on Figure 2, when the object weight is smaller than the weight of water its displaced, the buoyant force will overpower the weight and the object will float on the surface of water. This situation is called as positive buoyancy. However, the negative buoyancy occurs when the object weight is greater than the weight of water its displaced, so the weight of object will overcome the buoyant force and make the object sink. If the buoyant force is equal to weight of objects, the object will hang motionless in mid-water and it's called neutral buoyancy. This is how the underwater vehicle can float in water without using expending energy.

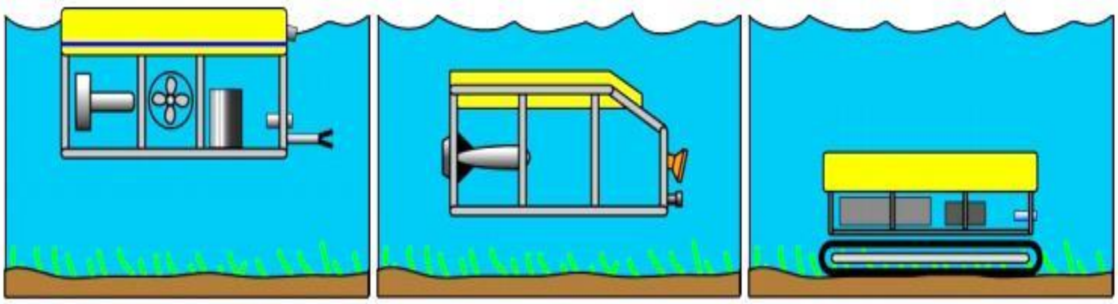

Figure 2: Positive, neutral, and negative buoyancy

Main Components (Electronics)

Camera and Underwater Lights

Camera and lighting will be part of the monitoring system for the ROV. The lights are important to provide a clear view through the camera. The position of the lights relative to the camera need to be considered to produce a good quality video during underwater observation (Moore et al., 2010). The underwater camera become wide availability and easier to purchase due to trending technology nowadays. The GoPro is one of the top branded cameras that widely used for recording extreme activities with high quality video. The GoPro can be buy together with its protective housing and waterproof case for underwater application (*HERO10&9 Black Protective Housing + Waterproof Case | GoPro*, 2021). So, the durability and waterproof of this camera is commonly being used for underwater inspection.

Tether Cable

Another important element that needs to be considered in designing an ROV is the selection of tethering management system (TMS). The selected TMS needs to be able to provide sufficient power in operating the ROV from its electrical source as well as transmitting video and data to the surface (Christ & Wernli, 2013). The electrical components such as electronic circuit, camera, lighting, thruster, and controller will be connected via the tether cable to the main power from the ground. The tether also will be transferring the data obtained from the ROV. This is called two-way communication from the ground and ROV. Another aspect in selecting TMS is the cable used should be strong enough for the purpose of recovering the ROV in case of emergency. The Fathom Tether is one of a high-quality tether cable designed specifically for ROVs and other subsea applications. It is neutrally buoyant, has 350 lb. breaking strength, and is embedded with water-blocking fibers to seal any leaks. The diameter of the tether cable should smaller as possible to make sure the drag effect of tether cable is smaller and to avoid the power loss of the thruster because the effect of the tether cable during the operation especially at the deeper region (Moore et al., 2010).

Power Supply

Power supply is one of the most important parts that need to make a vehicle working properly. As example, the cars need a battery as power supply to start the engine, without the battery the engine car cannot be running, and car will become motionless. The energy stored need to be converted to other forms, either before or after distribution such example the chemical energy stored in gasoline must be converted to electrical energy before it can be used to electrical components in vehicle. Similar goes to the underwater vehicle that need the energy before it can work properly. The power demands that need to be consider in an underwater vehicle is propulsion system and monitoring system. These two systems need the biggest power so there become the main consideration that need to be evaluate from the potential power system in designing ROV. The other electronic component also important and can be included in measuring power demand. Hence, the power supply needs to have enough power to make ROV works. The Table 1 shown the example of power requirement for *ROVing Otter* that designed by students of California State University, Monterey Bay (Moore et al., 2010; *ROVing Otter Technology*, 2009).

Table 1: Sample Power Requirement of Small ROV

Devices	Number	Power per device (watt)	Total maximum power (watt)
Thruster motor	4	9	36
Video light	2	25	50
Wireless ethernet network switch	1	5	5
Network video camera	2	1.5	3
Camera tilt motor	1	9	9
Sensors and other electronics	several	negligible	negligible
Total			103 watts

Control and Monitoring System

This is the important system in ROV that consists of hand controller and video monitor. The hand controller has been used to control the maneuverer and movement of ROV. The video monitor will display the ROV view and the information of the sensor on computer interface that connected to the Surface Control Unit. Normally, the hand controller that controlling ROV is using the CPU Joystick such as Play Station 4 controller with some modification and connected to electronic circuit. By using Graphical User Interface (GUI), the ROV can be control through the computer, because GUI is a program that enable connect the person with computer through symbol, visual metaphors and pointing device to translate the computer language and make the command for ROV. Ayob et al. (2013) had been develop a GUI for controlling and monitoring mini ROV system using MATLAB.

Conceptual Design

This paper proposes an ROV conceptual design that can operate up to 50 meters depth. The size is limited to 500mm x 500mm x 500mm and has ability to move up and down, as well as having 360-degree rotation. The ROV should be able to operate at slow speed and go up to 1.5 m/s. It should be able to perform monitoring and observation mission using video camera. Special tools including sensors, sonar, sampling device are to be installed in the ROV.

The design consideration was based on the basic requirements of the ROV. All the standards and theories have been taking into consideration. The consideration has followed the design objective which is to develop an ROV that able to assess the water quality parameter. The specification of the ROV can be based on Table 2:

Table 2: Consideration in Designing ROV

No	Consideration		Quantity/Size
1	Dimension	Height	320 mm
		Length	370 mm
		Width	262 mm
2	No of Thruster		3

Four conceptual designs have been hand-sketched for this project. The remarks of every design is concluded in morphology chart in design selection section. All the conceptual design are summarized and evaluated in morphology chart (Figure 3).

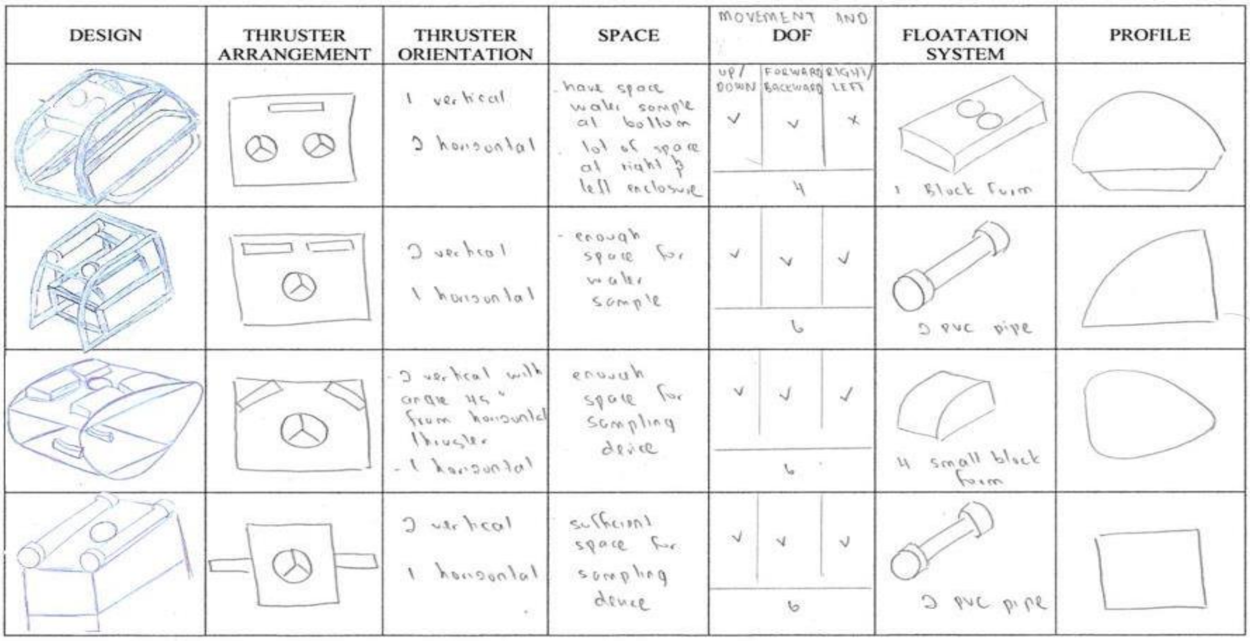

Figure 3: Morphology Chart

The morphology chart enables the designer to integrate components from distinct design concepts into single final design based on preference. The final design will be chosen on these criteria: i) Ease fabrication process, ii) Ability to achieve six degree of freedom and iii) Space provide for all the components and the water sampler space. Based on these criteria, the component of the conceptual designs will be incorporated into a single final design (Table 3) and CAD drawing will be developed by using Solid Works 2018. Thus, the prototype of ROV that suitable for this mission will be constructed following the final drawing.

Table 3: Design Summary

Components	Conceptual Design Chosen
Chassis Design	Design 4
Thruster Arrangement	Design 4
Thruster Orientation	Design 2
Floatation System	Design 2

Water Quality Assessment

In this study, we will develop several sensors and electronic components to form a multi-water quality checker (MQC) that can be attached to the ROV to monitor water quality parameters in situ. The main water parameters to be assessed are including pH, dissolve oxygen, turbidity, total dissolve solid and temperature. We used a commercial multiprobe meter (CMM) to conduct field testing to ensure the correctness of the created system. Then, to validate its dependability, we will compare the in-situ measurements collected from MQC utilizing ROV with the findings of laboratory analysis. Before installing the MQC to the ROV, the preliminary experiments will be conducted to determine whether water quality measurements are consistent between the MCQ and the CMM. The water samples will be collected at the predetermined sampling locations then the measurements will be made at the same time from two different beakers for each water quality parameter.

The experiment will be carried out by taking water samples at fifteen different locations to ensure consistency between ROV and conventional measurements. As illustrated in Figure 4, the number of sample points and their positions will be chosen at random. This being done for more stringent testing of the in situ measurement method (Koparan et al., 2018). At each location, three replicates of water samples will be measured with both MQC and CMM in different depth namely top, middle, and bottom. The mean of the measurements will be used in analysis. The main water quality parameters that will be measured and compared, including pH, Biological Oxygen Demand (BOD), Alkalinity and CaCO3 and total ammonia (NH3). A paired t-test analysis will be used to assess the statistical differences between the main water quality parameter measurements produced by the MQC and the CMM. To determine how precise the MQC measurements are, the percent errors of each parameter will be determined.

Simultaneously, few random samples will be collected and sent to the laboratory in Brunei Darussalam under approved collection and adequate storage conditions. The laboratory will analyze the water samples using standard APHA and EPA methods (Rice & Baird, 2017; U.S. Environmental Protection Agency, 2001; Pitot, 1996).

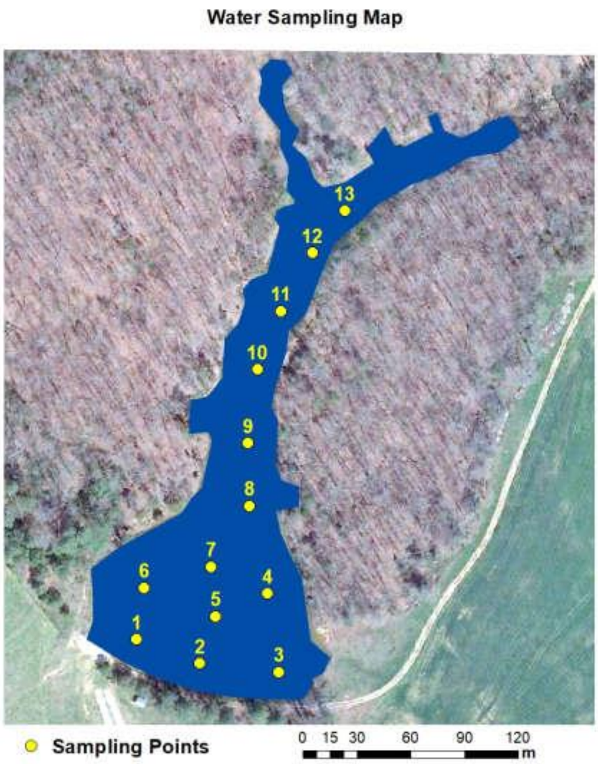

Figure 4: ROV Sampling Waypoints (Koparan et al., 2018)

CONCLUSIONS

This study presents a conceptual design for an innovative ROV used to check water quality. The design prioritizes several essential mechanical and electronic parameters, such as body frame, material types, number of thrusters, power supply, and tethering management system. The process for conducting experiments and analyzing data in the assessment of water quality parameters is also described. The development of a ROV prototype, as well as data collection and analysis from site experiments, will be the focus of future research activities.

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