BIS ENERGY AND ENGINEERING

Volume 1 2024 | DOI: 10.31603/biseeng.85
5th Borobudur International Symposium on Science and Technology (BIS-STE) 2023

UNIMMA PRESS
UNIVERSITAS MUHAMMADIYAH MAGELANG

Low-cost remotely operated vehicle equipped with underwater pH measurement for water quality assessment

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Abstract
The construction of a Remotely Operated Vehicle (ROV) has become crucial because it should be strong enough to withstand high water pressure, it makes the price of ROV become high. The need for water quality assessment is also increasing due to it will improve quality of human life. In this paper, we propose a low-cost ROV equipped with a pH sensor for Water Quality Assessment by using six DC motors and a microcontroller as the primary control system. Motor movements are governed using a joystick, which serves as the reference input for the PID control. Additionally, this ROV is equipped with a depth sensor to maintain its depth. Through the conducted tests, this ROV has demonstrated the capability to dive to a depth of 2 meters, with a dive duration of 5 minutes. The proposed ROV is expected to be an alternative solution for developing a low-cost water quality assessment robot.

Keywords
pH measurement, water quality, low cost vehicle

Introduction
Water quality is a critical factor in determining the well-being of human life. Since the onset of industrialization worldwide, there has been rapid growth in manufacturing and the use of synthetic chemicals in agriculture and livestock farming to enhance food production. Many of these activities have led to contamination of water sources, primarily due to substances such as residual insecticides and herbicides from agricultural fields to industrial waste discharged into lakes [1][2].

pH value is one of the parameters used to assess water quality in specific environments to determine compliance with established standards. In Indonesia, Government Regulation No. 82 of 2001 sets forth quality standards for pH values in bodies of water, highlighting the significance of pH measurement in assessing water bodies [3]. Furthermore, pH value is a critical parameter to consider when selecting water

Published:
October 20, 2024

Selection and Peer-review under the responsibility of the 5th BIS-STE 2023 Committee

treatment techniques, as the initial pH of water significantly affects the effectiveness of the chosen water treatment process.

The realm of technology has evolved diversely, ranging from large-scale innovations like aircraft technology to minuscule advancements in biotechnology. The early utilization of technology by humans marked the transformation of natural resources into tools that facilitated human labor. Present-day technological advancements progress at an astounding rate, evident through the plethora of innovations that have emerged. The rapid development of technology has translated into the automation of numerous tasks that were once manually performed, ultimately simplifying processes and conserving time and energy. Currently, technology is deeply integrated into almost every aspect of daily human life [4].

Over the past decade, research into Remotely Operated Vehicles (ROVs) for underwater exploration has gained significant attention and development. This shift is primarily driven by the need to reduce human risk associated with underwater activities [5]. Many industries have gradually transitioned from manned submersibles to unmanned underwater robotic vehicles or ROVs. In addition to enhancing safety, ROVs offer a more cost-effective and efficient alternative for underwater research and exploration [6]. Most ROV systems developed are designed for remote control operation using remote control devices or other equipment. Recently, several ROVs and Autonomous Underwater Vehicles (AUVs) have been developed for environmental parameter measurement and monitoring [7].

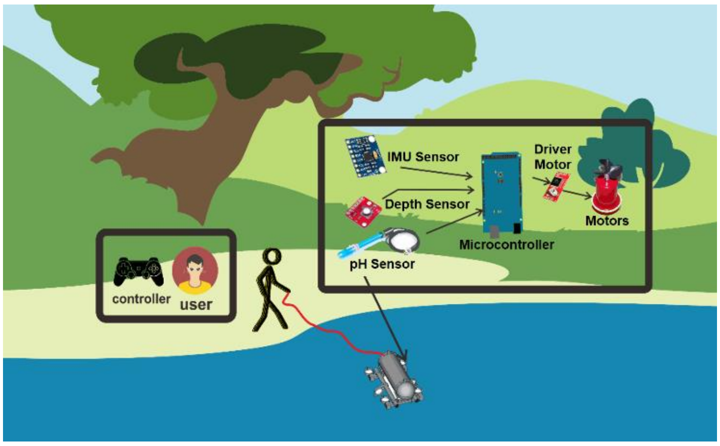
In Indonesia, ROVs are a burgeoning technology but have not received adequate attention, despite being ideally suited to the country's maritime geography. These robotic marine devices have the capability to observe underwater objects, providing a convenient means for humans to study various marine resources without the need for diving [8].

In this paper, we present the design of a ROV equipped with a pH sensor intended for underwater pH measurement. Conventional methods rely on pH meters that require water sampling, limiting measurement to surface waters only. However, pH measurement needs to be conducted uniformly both at the surface and underwater. With the ROV we have designed, it becomes feasible to measure pH levels evenly both at the water's surface and beneath it.

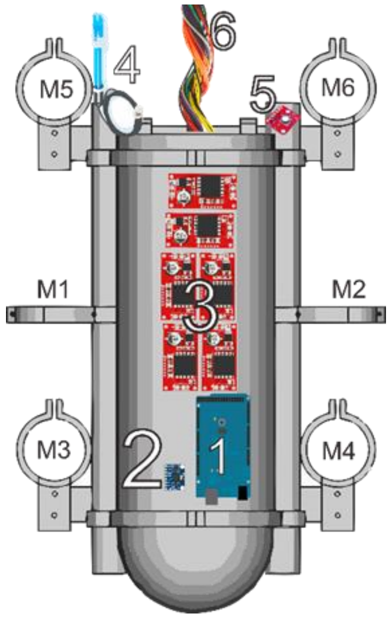
Related Works

In this section, we present a review of related works in the field of Remotely Operated Vehicles (ROVs) designed for water quality assessment and environmental monitoring such as ROVs for Water Quality Data Collection, ROVs for Hydrothermal Plume Detection, IoT-Enabled ROVs for Water Quality Monitoring, and Multi-Sensor ROVs for Oil Spill Detection, Real-Time Water Quality Monitoring ROVs, ROVs for Underwater Ecosystem Characterization, and ROVs for Tunnel Inspection. Several studies have focused on the development and deployment of ROVs equipped with water quality data collection capabilities [9]. These ROVs are designed to gather oceanographic parameters from various aquatic sources in Peru, including rivers, lakes, and oceans. They are equipped with integrated cameras, multi-parameter probes for water quality analysis, and three hydrophones for measuring underwater noise levels. These comprehensive systems allow for thorough and efficient data collection. Another notable application of ROVs involves their use in detecting hydrothermal plumes using chemical sensors [10]. These ROVs are equipped with specialized chemical sensors, such as pH-12, ORP-12, MINIMONE, and ANEMONE, designed to detect and analyse hydrothermal fluid chemistry. The method employed by these ROVs revolves around acoustic detection of hydrothermal plumes, utilizing acoustic Doppler technology for precise identification. Advancements in ROV technology have led to the development of IoT-enabled ROVs for water quality monitoring [11]. These ROVs are controlled remotely and are built around Arduino-based systems. They incorporate sensors for measuring parameters like pH and turbidity. Data collected by these sensors is seamlessly stored in cloud servers, enhancing real-time monitoring capabilities and data accessibility. ROVs have been crucial in the field of oil spill detection and monitoring, featuring a suite of sensors and additional equipment for comprehensive assessments [12]. These ROVs come equipped with sensors measuring temperature, dissolved oxygen (DO), electrical conductivity (EC), and oxygen reduction potential (ORP) to monitor water quality parameters. Additionally, they feature cameras, inertial measurement units (IMUs), pairs of flashlights for illumination, and grippers for sample collection and manipulation. ROVs have also been developed with real-time water quality monitoring capabilities [13]. These ROVs incorporate dissolved oxygen sensors to monitor water quality and feature automated mooring systems for automatic tether rotation. Solar-powered mobile docking platforms supply power to the ROVs, while web-based graphical user interfaces aid in data post-processing and visualization. ROVs have been utilized for underwater ecosystem characterization, incorporating vision algorithms for real-time species tracking [14]. This capability enhances our understanding of underwater ecosystems and their inhabitants. Beyond water quality assessment, ROVs have been employed for the inspection of lengthy tunnels, particularly in conditions involving water and mud, enabling efficient inspections in challenging environments [15]. In summary, these related works demonstrate the diverse applications of ROVs in environmental monitoring and water quality assessment. While many ROV systems have been developed, they often come with substantial production costs.

In this paper, we propose the development of a low-cost ROV equipped with a pH sensor for water quality monitoring, aiming to address cost constraints while maintaining effective data collection capabilities (Figure 1).



The Illustration System



The Mechanical Design

Figure 1. The proposed system

Methods

In this section, we will elucidate the stages of designing the underwater remotely operated vehicle (ROV). The design of the ROV is divided into three steps: mechanical design, electronic design, and software design. The first step involves mechanical design. The mechanical design commences with the primary body design, which consists of an acrylic cylinder with a diameter of 10 Cm and a length of 25 Cm, featuring a 5-millimeter-thick acrylic wall. The primary body of the robot is then affixed using the 3D printer-generated design. To reinforce the framework, small 1/2-inch pipes and aluminum components are incorporated as structural supports for the robot. The pH sensor is positioned on the exterior rear section of the robot to collect pH data in specific aquatic environments. The illustration of our system is depicted in Figure 1 (a). This system is divided into two main parts: the user part and the ROV part. In the user part, there is a user (or operator) and a controller responsible for remotely operating the robot from the surface. In the robot part, the primary body houses all electronic components. Within the primary body, there are the Arduino Mega microcontroller, the IMU sensor MPU6050, the motor driver VNH2SP30, and the buck converter circuit. Several electronic components are required to be submerged in water, including DC motors, the pressure sensor MS5803, and the pH sensor. The mechanical design of the proposed ROV is depicted in Figure 1 (b). It is powered by six DC motors, each of which is controlled and commanded by an individual motor driver VNH2SP30. Four of these motors are utilized for vertical movement, enabling both upward and downward motion, while the remaining two motors facilitate forward and backward propulsion.

The control system employed in this system is the PID (Proportional-Integral-Derivative) controller, chosen due to the utilization of a DC motor. User command inputs, consisting of pitch, roll, yaw, and depth, are transmitted from a remote controller to a microcontroller. This microcontroller is equipped with an IMU MPU6050 sensor to ascertain the roll, yaw, and pitch of the remotely operated vehicle (ROV) and is also equipped with a depth sensor, the MS5803. The PID controller's output is conveyed to the VNH2SP30 motor driver as a response to the user's transmitted commands. The used PID controller is used in Figure 2.

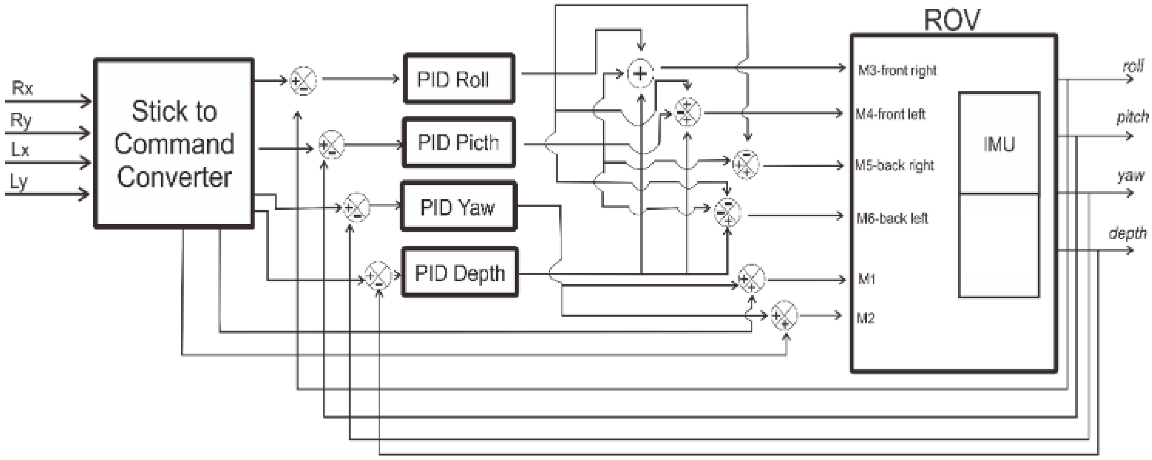


Figure 2. The used PID controller

The ROV is constructed primarily from acrylic tubes to form the robot's main body. The acrylic tube has a diameter of 10 cm, a thickness of 5mm, and a length of 25 Cm. Several components are 3D printed using PLA material. Additionally, aluminium with dimensions of 2x1 Cm and ½ Iinch pipes are used to create the robot's structural framework. At the bottom of the robot, a pair of 1½-Iinch diameter pipes are attached to serve as legs and provide stability. The mechanical design of the proposed ROV is depicted Figure 3.

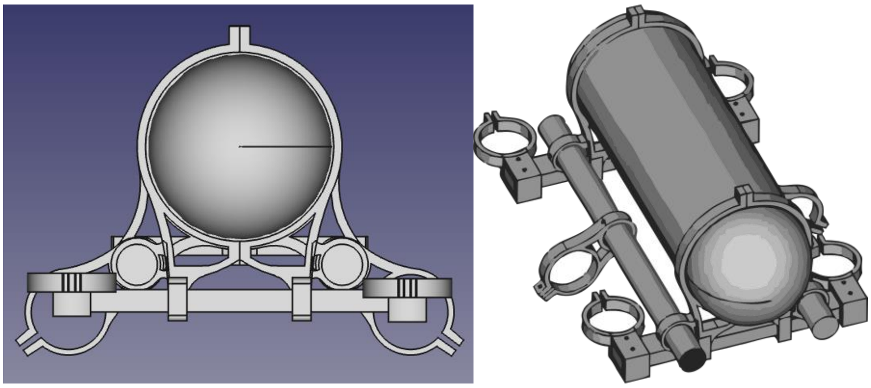


Figure 3. Mechanical Design of The Proposed ROV

During its motion, the robot employs a total of 6 motors for underwater propulsion, with 4 motors facilitating vertical movement and 2 motors enabling horizontal motion. Motor 1 is positioned on the right-hand side horizontally, while motor 2 is located on the left-hand side horizontally. Motor 3 is situated at the front-right position, and motor 4 is positioned at the front-left. Motor 5 is placed at the rear-right, and motor 6 is situated at the rear-left. The motor arrangement is illustrated in the following diagram. Motors M1 and M2 are installed horizontally, while motors M3, M4, M5, and M6 are installed vertically. The motors configuration is shown in Figure 4.

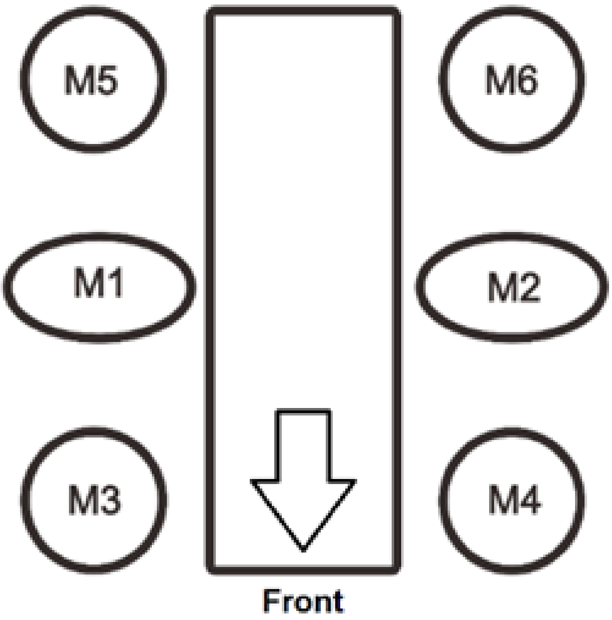


Figure 4. Motors Configuration

Result and Discussion

The proposed ROV has been successfully realized, as depicted in the Figure 5. The readings from the pH sensor required regression (y=2.793+0.01x) to ensure the accuracy of the pH values obtained as shown in Figure 6. The pH sensor has an error of 6.1%. The ROV was tested for lifting an object with a weight of 1 Kg, and an ascending velocity of 13.157 Cm/s was obtained. The depth sensor has an error of 1-3 Cm.

Figure 5. The realized ROV

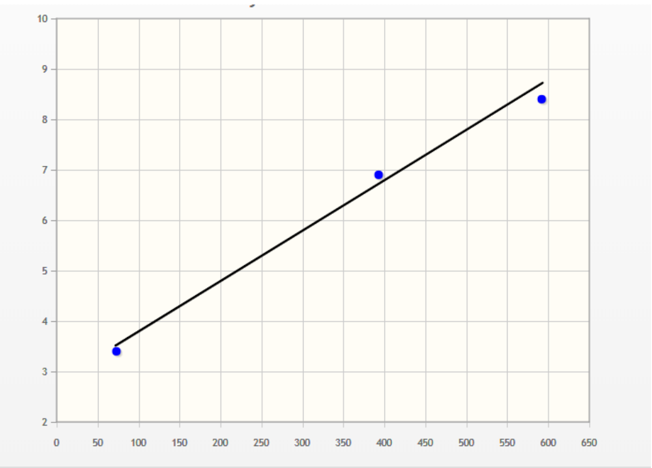


Figure 6. The regression of pH sensor shows how accurate the sensor

We also tested the movement of our ROV by monitoring all motors as shown in Figure 7, Figure 8, Figure 9. It shows all motors worked well to respond to the roll and pitch movements.

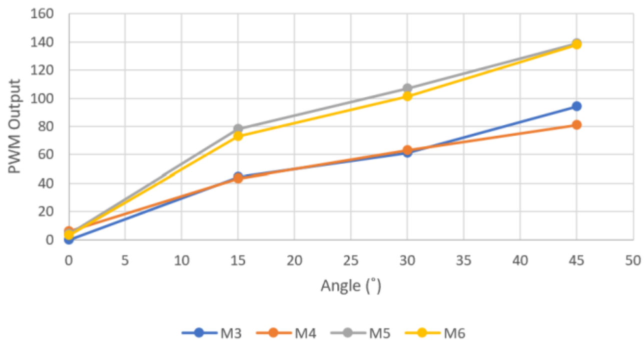


Figure 7. Motor Responses of Negative Pitch

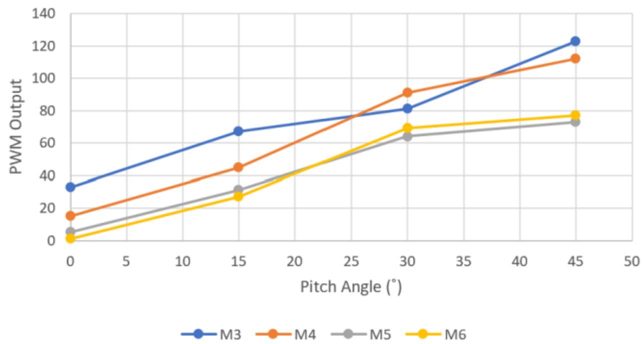


Figure 8. Motor Responses of Positive Pitch

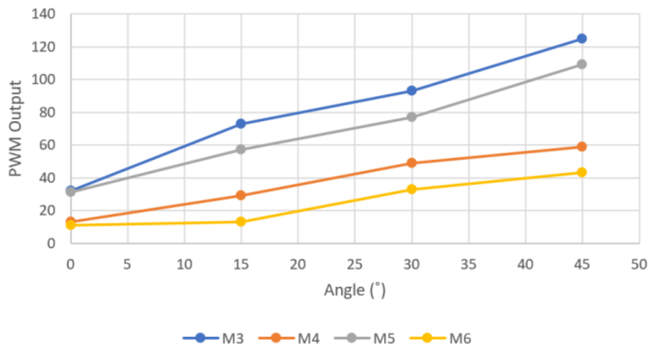


Figure 9. Motor Responses of Positive Roll

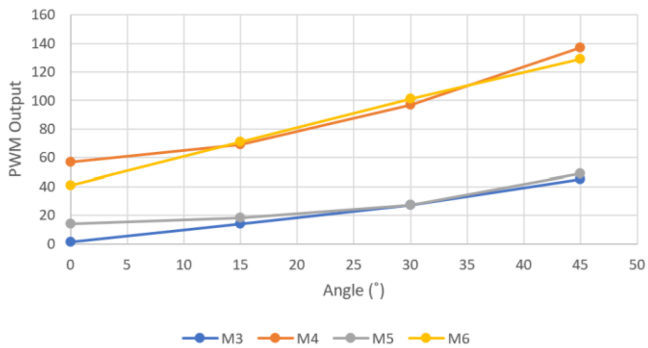


Figure 10. Motor Responses of Negative Roll

From several tests, the specifications of the ROV are as follows.

Dimensions	30 x 28 x 15
Number of Motors	6

Input Voltage	12 Volts
Control Range	0 – 7 m
Maximum Depth	2 m
Weight	4 kg
pH Reading	0-14 + 6.1%
Duration	5 minutes

Conclusion

The conclusions drawn from the testing and analysis of the proposed ROV are (1) the stability of the robot is regulated using a PID controller that receives feedback from the MPU6050 sensor and the MS5803 sensor. The MPU6050 sensor provides feedback in the form of the robot's setpoint position, while the MS5803 pressure sensor is used to record the depth of the ROV and aids in maintaining the robot's stability during vertical movements upward and downward. This sensor detects water pressure, which is subsequently calibrated and converted into ROV depth from the water's surface in Cm. The depth sensor has an error of 0-3 cm. The pH sensor design utilizes a dfrobot pH sensor, and readings taken in Lake 8 at ITS Surabaya exhibit a reading error of 6.1%.

Acknowledgments

This study and its publication were made possible by the financial support provided by the Department of Electrical Engineering at Institut Teknologi Sepuluh Nopember Surabaya in 2023. We extend our sincere appreciation to the Department of Electrical Engineering for their generous support and funding, without which this research and publication would not have been feasible.

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