Design and Development of a 3D-Printed Educational Underwater ROV for Marine Robotics Learning

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Abstract— This paper presents the design, development, fabrication, and testing of an underwater Remotely Operated Vehicle (ROV). This study designs and develops a four-degrees-of-freedom (DOF) system to execute basic underwater tasks. The ROV has compact dimensions of 50 cm × 30 cm × 20 cm and is designed to evaluate sensor performance and overall electronic integration. The system demonstrates effective sensor integration, the working principles of propellers, and the design of both the propeller and the base structure of the ROV. Experimental testing confirms the functionality and feasibility of the proposed design.

Index Terms— Underwater ROV, 3D printing, marine robotics, mechatronics, student project, buoyancy control.

I. INTRODUCTION

Several works on ROVs have demonstrated their application in ocean research. Past research has focused mainly on structural design and material choices to optimize underwater performance. Underwater ROVs are generally equipped with a camera for live recording, sensors to detect obstacles, lights for clear underwater vision, thrusters and robotic arms to facilitate underwater operations. The ROV can have a maximum of 6 degrees of freedom.
Material is a major factor corresponding to the propulsion system and the size of the desired ROV. A good material with the right buoyancy properties provides stability to the vehicle. The designed prototype ensures strength, the ability to withstand pressure up to a maximum diving depth of 100 m, and appropriate safety factors.
Underwater Unmanned Vehicles (UUVs) reduce the need for human assistance in deep or challenging underwater environments, thereby enhancing safety and operational efficiency. Underwater unmanned systems are classified into two groups: Autonomous Underwater Vehicles (AUV) and Remotely Operated Vehicles (ROV).

II. GENERAL SPECIFICATION

The underwater ROV is a scaled robot with compact dimensions of 50 cm × 30 cm × 20 cm. The entire system weighs approximately 7.2 kg. The design presents 2 degrees of freedom to move independently in two possible directions. The main controller used for this prototype is the ESP32 S3.

III. MECHANICAL DESIGN

A. Chassis Design

The ornamental design for the underwater ROV is characterized by a substantially modular cuboidal chassis of hollow PVC tubes featuring a plurality of elbow joints disposed on the edges of the cuboid. A thick rectangular base is positioned at the line of the center of gravity, with vertically aligned cuboidal supports and semi-circular brackets attached to the frame with a plurality of screws and optional bolts.

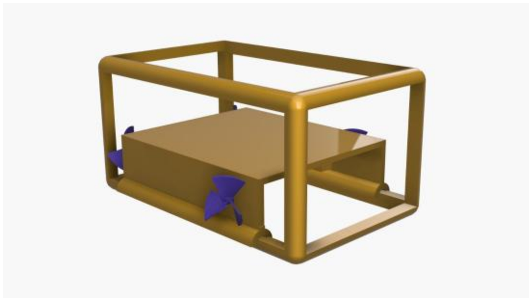

Fig. 1. CAD Model of the Underwater ROV

B. Base Stabilization

To stabilize the rectangular base, a sheet of acrylic or metal is attached to the base using a plurality of screws along the diagonals and the center line of the base from the center.

C. Enclosure Design

The posterior side has an enclosure near both posterior edges with screw holes for support. Each lateral side has its own enclosure positioned in line with the third quadrant of the overall length of the cuboidal chassis. Both the posterior and lateral enclosures are built using a base plate to support the motors, with the back open, and a separate plate attached using multiple screws to provide an airtight seal.

D. Mounting and Wiring

The cuboidal chassis includes wire routing mounts for the sensors and LED lighting. Four propellers are used: two for forward and backward motion, and two for right and left motion. The propellers are mounted on the sides of the ROV. The designed 2-DOF ROV can move independently in two possible directions in two-dimensional space.

IV. HYDRODYNAMIC MODEL AND CONTROL

A. Hydrodynamic Model

The motion of the ROV underwater is influenced by hydrodynamic forces comprising thrust and drag. Thrust generated by the propellers is proportional to the square of the propeller rotational speed:

$$F = kV^2$$

where F is the thrust force (N), k is the thrust coefficient, and V is the propeller rotational speed (rad/s). The drag force acts opposite to the direction of motion:

$$Fd = \tfrac{1}{2}\rho CdAv^2$$

where Fd is the drag force (N), ρ is the fluid density (kg/m^3), Cd is the drag coefficient (dimensionless), A is the cross-sectional area facing the flow (m^2), and v is the velocity relative to the water (m/s).

B. Control Model

The control system is based on a feedback mechanism to maintain stability and achieve desired movement. A Proportional-Integral-Derivative (PID) controller adjusts the output according to the error between desired and actual values:

$$U(t) = Kp\cdot e(t) + Ki\int e(\tau)d\tau + Kd\cdot de(t)/dt$$

where U(t) is the control output, e(t) is the error (Desired Depth – Actual Depth), Kp is the proportional gain, Ki is the integral gain, and Kd is the derivative gain.

C. Working Principle

The motion of the system is obtained by controlling the rotation of the propellers. By varying the speed and direction of rotation, the robot can move in different directions, enabling controlled navigation and stability in underwater conditions.

V. ELECTRONICS ARCHITECTURE AND CONTROL ARCHITECTURE

A. Hardware Layout

The hardware components of the ROV are mounted on the base platform. The main controller ESP32 S3 is placed on a breadboard and connected to the motor driver and sensors through wired connections. The motor driver controls the DC motors (thrusters), which are mounted on the base of the vehicle. An LED strip is mounted on the chassis to provide clear vision underwater.

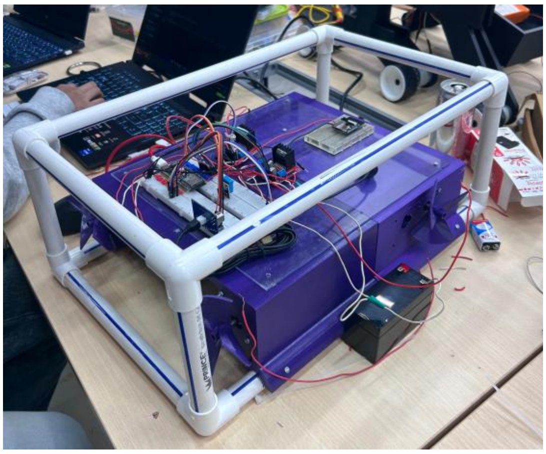

Fig. 2. Fabricated Prototype of the Underwater ROV

B. Components

Component	Function
ESP32 S3	Controls the overall system
ESP32 CAM	Used for live streaming
DHT11	Measures surrounding humidity
BMP280	Measures temperature & pressure
Ultrasonic Sensor	Detects nearby obstacles
12V Battery	Powers the motors
L298N Motor Driver	Operates the motors
12V DC Motor	Drives the propellers

Table I. Hardware Components of the ROV

C. Control System

The control system is managed by the ESP32 S3 controller, which processes the signals and controls the motion of the thrusters. An ESP32 CAM records live underwater footage. The L298N motor driver receives signals from the ESP32 and regulates speed. Sensors detect temperature, pressure, and distance between the robot and nearby obstacles.

VI. SENSOR INTEGRATION

Ultrasonic Sensor: Measures the distance between the ROV and nearby obstacles. The sensor transmits ultrasonic waves and measures the time taken for the reflected signal to return, which is used to calculate the distance.

Humidity Sensor (DHT11): Measures the surrounding environmental conditions including relative humidity.

Pressure Sensor (BMP280): Measures the pressure of the surrounding water, helping to monitor environmental conditions and estimate operational depth.

VII. FUTURE WORK

The current ROV prototype successfully demonstrates a 2-DOF functional system with efficient sensor integration. The following upgrades are planned:

Advanced Propulsion Systems: Upgrade from 12V DC motors to brushless DC (BLDC) motors for higher performance, increased torque, and better reliability.

Improved Navigation and Stabilization: Adding an IMU sensor will provide precise orientation and acceleration measurements, enabling advanced closed-loop stabilization.

Controller Architecture Expansion: More powerful microcontrollers will provide sufficient bandwidth for high-rate IMU data collection, PID calculations on multiple motors, and live video streaming.

Increased Degrees of Freedom: Future redesign will expand to 6 DOF by adding thrusters for pitch and roll control, enabling full omnidirectional movement.

Autonomous Capabilities: Machine learning algorithms will be implemented to enable autonomous navigation and underwater environment mapping.

VIII. CONCLUSION

This paper presented the design, development, and testing of an underwater Remotely Operated Vehicle (ROV). The system demonstrates sensor integration, propulsion, and control using the ESP32 S3. The robot performs basic movement and operates sensors for environmental monitoring and obstacle detection. Sensor integration includes ultrasonic, humidity, temperature, and pressure sensors. The use of 3D printed base and propellers provides a cost-effective yet lightweight structure maintaining the structural strength of the ROV.

ACKNOWLEDGMENT

The authors would like to thank the Department of AI and Robotics, Atlas SkillTech University, Mumbai, for providing laboratory facilities and continuous support throughout this project.

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