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AquaBot-X: A Cost-Effective ESP32-Based Underwater Drone with Live Streaming and Multi-Thruster Propulsion for Real-Time Exploration

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Abstract: *AquaBot-X is a cost-effective underwater drone designed for real-time exploration and monitoring of aquatic environments. The system is based on dual ESP32 microcontrollers configured as transmitter and receiver, enabling reliable wired communication for underwater operation. User inputs are captured through a control interface and transmitted to the drone, where PWM signals are generated to control four BLDC motors via Electronic Speed Controllers (ESCs). This multi-thruster propulsion system allows precise movement in multiple directions, including forward, backward, ascent, and descent. An IP68-rated camera provides live video streaming, enhancing visibility and remote inspection capabilities. The system is powered by a battery with regulated voltage distribution to ensure stable performance. AquaBot-X offers a compact, low- cost, and efficient solution for underwater surveillance, inspection, and educational applications.*

Keywords: *Underwater Drone, ESP32, BLDC Motor, Electronic Speed Controller (ESC), Real-Time Monitoring, Live Streaming, ROV, PWM Control, Multi-Thruster Propulsion, Tethered Communication.*

I. INTRODUCTION

Keywords: Underwater exploration plays a crucial role in marine research, infrastructure inspection, and environmental monitoring; however, it remains challenging due to limited human accessibility, high operational costs, and safety risks [1]. Traditional inspection methods using divers or bulky equipment are often inefficient and lack real-time feedback, making them unsuitable for continuous monitoring applications [2]. In recent years, the development of remotely operated vehicles (ROVs) has provided an effective solution for underwater operations, enabling safer and more efficient exploration [3].

Advancements in embedded systems and low-cost microcontrollers have significantly contributed to the evolution of compact underwater drones [4]. Among these, the ESP32 microcontroller has gained popularity due to its high processing capability, low power consumption, and support for communication interfaces [5]. Underwater drones typically rely on brushless DC (BLDC) motors for propulsion, as they offer high efficiency, durability, and smooth operation in submerged environments [6]. These motors are controlled using Electronic Speed Controllers (ESCs), which regulate motor speed and direction through Pulse Width Modulation (PWM) signals [7].

A major challenge in underwater communication is the attenuation of wireless signals such as Wi-Fi and Bluetooth, which do not propagate effectively through water [8]. To overcome this limitation, tethered (wired) communication systems are often used to ensure reliable data transmission between the operator and the underwater vehicle [9].

Additionally, real-time video streaming using waterproof cameras enhances the system's capability for monitoring and inspection tasks [10].

This project introduces AquaBot-X, a cost-effective ESP32- based underwater drone designed for real-time exploration and monitoring. The system integrates a multi-thruster propulsion mechanism using four BLDC motors, enabling precise movement in multiple directions [11]. It also incorporates a live video streaming module for enhanced visibility and control [12]. The use of a battery-powered system with regulated voltage distribution ensures stable and efficient operation [13]. AquaBot-X aims to provide an affordable, compact, and reliable solution for underwater applications such as surveillance, inspection, and educational research [14][15].

II. PROBLEM STATEMENT

Underwater environments are difficult to access, monitor, and inspect using traditional methods due to safety risks, high operational costs, and limited visibility. Existing solutions such as diver-based inspection and large-scale underwater vehicles are expensive, complex, and often lack real-time feedback and precise control. Moreover, wireless communication technologies like Wi-Fi and Bluetooth are unreliable underwater, making control and data transmission challenging. Therefore, there is a need to develop a compact, low-cost, and reliable underwater drone capable of real-time monitoring, stable multi-directional movement, and effective communication for efficient underwater exploration and inspection.

III. OBJECTIVES

- To design and develop a low-cost underwater drone for real-time exploration and monitoring.
- To implement a reliable control system using ESP32 microcontrollers for efficient signal processing and communication.
- To achieve smooth and multi-directional movement using BLDC motors controlled through Electronic Speed Controllers (ESCs).
- To integrate a waterproof camera for live video streaming and real-time visual feedback.
- To ensure stable power management and safe operation using a battery with regulated voltage supply.

IV. LITERATURE SURVEY

1. Rex 2: Design, Construction, and Operation of an Unmanned Underwater Vehicle
Year: 2009
Publication: MIT (Master's Thesis)
This paper focuses on designing a low-cost unmanned underwater vehicle (UUV) with a tethered communication system. It enables real-time control and data transmission using a surface float connected to the vehicle. The system integrates thrusters, sensors, camera modules, and control units, making it suitable for underwater exploration. The study emphasizes cost-effectiveness, modular design, and ease of deployment, which are highly relevant for ESP32-based underwater drones.

2. A Survey of Underwater Vehicle Navigation: Recent Advances and New Challenges
Year: 2006
Publication: Johns Hopkins University / IEEE (Survey Paper)
This paper reviews modern navigation techniques for underwater vehicles, including IMUs, Doppler sonar, acoustic sensors, and pressure sensors. It highlights the role of sensor fusion and advanced algorithms in improving positioning accuracy. The study also discusses challenges like real-time navigation and environmental disturbances, which are important for developing reliable underwater drones with live streaming and control systems.

3. Oceanic Challenges to Technological Solutions: A Review of AUV Path Technologies in Biomimicry, Control, Navigation, and Sensing
Year: 2024

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Publication: IEEE Access

This paper provides a comprehensive review of recent advancements in autonomous underwater vehicles (AUVs), focusing on navigation, control systems, and sensing technologies. It discusses biomimicry models, adaptive algorithms, and sensor integration for efficient underwater exploration. The study highlights the importance of multi-disciplinary approaches and identifies gaps such as propulsion and communication integration, which are crucial for real-time ESP32-based underwater drones.

4. AUV Localisation: A Review of Passive and Active Techniques

Year: 2022

Publication: International Journal of Intelligent Robotics and Applications

This paper reviews localization techniques used in underwater vehicles, categorizing them into passive and active approaches. It explains methods like Extended Kalman Filters, particle filters, and acoustic positioning systems for accurate position estimation. The study emphasizes the importance of reliable localization for autonomous operations, which is essential for underwater drones performing real-time monitoring and navigation.

5. A Survey on Unmanned Underwater Vehicles: Challenges, Enabling Technologies, and Future Research Directions

Year: 2023

Publication: Sensors (MDPI Journal) This paper discusses the overall architecture and enabling technologies of UUVs, including communication systems, propulsion, control algorithms, sensing, and energy sources. It highlights challenges such as signal loss underwater, high energy consumption, and navigation complexity. The paper also explores multi-thruster propulsion and advanced control techniques, making it highly relevant for designing cost-effective underwater drones with live streaming capabilities.

Comparison Table

Author & Year	Method Used	Advantages	Limitations
Owens (2009)	Tethered UUV with surface communication & multi-thruster system	Low cost, real-time communication, easy deployment	Limited mobility due to tether, dependency on surface unit
Kinsey et al. (2006)	Sensor-based navigation (IMU, Doppler sonar, acoustic systems)	High navigation accuracy, improved control	Complex system integration, expensive sensors
Hasan et al. (2024)	AUV path planning using AI, biomimicry & adaptive control	Efficient navigation, advanced sensing & autonomy	Lacks full system integration, high computational complexity
Maurelli et al. (2022)	Localization using EKF, particle filters, acoustic positioning	Accurate position estimation, supports autonomy	Error accumulation, dependency on external aids
Wibison o et al. (2023)	Integrated UUV system (propulsion, sensing, communicatio n)	Comprehensiv e system design, multi- thruster support	Communicati on issues underwater, high energy consumption

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IV. WORKING OF SYSTEM

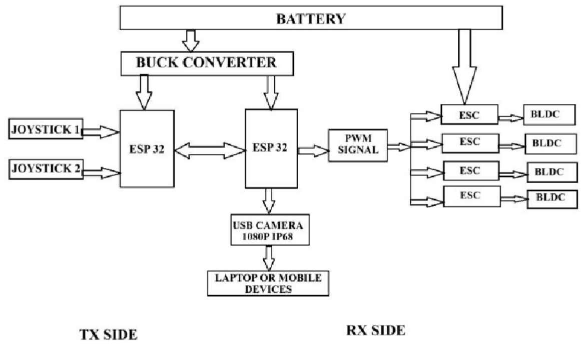

Fig 1: Design of the system

1. Power Supply Initialization & System Initialization The system is powered using a battery supply, which provides power to the ESP32, ESCs, and BLDC motors. All ground connections are made common to ensure proper circuit operation.

2. Transmitter Side Input (Switch Control) At the transmitter side, DPDT switches are connected to ESP32 GPIO pins configured in INPUT_PULLUP mode. When a switch is pressed → input becomes LOW When not pressed → input remains HIGH The ESP32 continuously checks the state of these switches to detect user commands.

3. Command Detection

Based on switch combinations, the ESP32 identifies movement commands such as:

• Left / Right
• Forward / Backward
• Upward / Downward

These commands represent the desired motion of the underwater drone.

4. Wired Signal Transmission

Since Wi-Fi and Bluetooth do not work underwater, signals are transmitted through a wired (tethered) communication system. The transmitter sends control signals through wires to the receiver ESP32, ensuring reliable communication.

5. Receiver ESP32 Processing

The receiver ESP32 reads incoming signals through GPIO pins. It compares the received command and decides which motors need to be activated.

6. PWM Signal Generation

The ESP32 generates PWM signals to control motor speed:

• 1000 µs → Stop
• 1300 µs → Slow speed
• 1800 → High speed
• 2000 µs → Maximum speed

These signals are sent to the ESC through signal pins.

7. ESC Operation

The Electronic Speed Controller (ESC): Receives PWM signal from ESP32
Converts battery DC power into 3-phase AC supply
Drives the BLDC motor accordingly ESC connections:

• 3 thick wires → Motor phases
• Red & Black → Battery power
• Signal wire → ESP32 GPIO

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8. BLDC Motor Movement (Thrusters)
The BLDC motors rotate based on ESC output. Any order of phase connection works Swapping any two wires reverses direction Multiple motors work together to achieve:
• Forward / Backward movement
• Turning (Left/Right)
• Vertical motion (Up/Down)
9. Directional Control Logic
The ESP32 controls motors in combinations:
• M1 + M2 → Forward
• M3 + M4 → Backward
• Individual motors → Turning
• Vertical motors → Up/Down
This ensures smooth and controlled underwater navigation.
10. Continuous Monitoring Loop
The ESP32 continuously:
• Reads switch inputs
• Sends/receives signals
• Updates motor control
• If no switch is pressed → motors remain OFF
• If switch is pressed → corresponding motor activates instantly

V. SYSTEM DESIGN

1. Overview of the System
The AquaBot-X system is designed as a tethered underwater drone consisting of two main units: the transmitter (control unit) and the receiver (drone unit). The system uses ESP32 microcontrollers for processing and control, along with BLDC motors and ESCs for propulsion. A wired communication link is used to ensure reliable signal transmission underwater, and a waterproof USB camera provides real-time visual feedback.
2. System Components and Design
1. ESP32 Microcontroller (×2)

Fig.2: ESP32 Microcontroller
Two ESP32 microcontrollers are used in the system: Transmitter ESP32: Reads input signals from DPDT switches.
Receiver ESP32: Processes commands and generates PWM signals to control motors.
The ESP32 acts as the main control unit, handling input processing, signal transmission, and motor control.
2. Wired Communication System
Due to the limitation of wireless communication underwater, a tethered wired connection is used between transmitter and receiver.
• Ensures reliable and continuous signal transmission
• Eliminates signal loss caused by water absorption

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3. Electronic Speed Controllers (ESCs ×4)

Fig.3: Electronic Speed Controller (ESC)

Each BLDC motor is connected to an ESC.

- ESC receives PWM signals from ESP32
- Converts DC power into 3-phase AC supply
- Controls motor speed and direction

4. BLDC Motors (×4)

Fig.4: BLDC Motor (Thruster)

Four waterproof BLDC motors act as thrusters.

- Provide propulsion and movement
- Arranged to enable multi-directional control
- Allow forward, backward, turning, ascending, and descending motion

5. USB Camera (IP68 Rated)

Fig.5: USB Camera

A waterproof USB camera is mounted on the drone.

- Captures real-time underwater video
- Provides visual feedback to the operator
- Helps in navigation and monitoring

6. Power Supply (Lead Acid Battery)

Fig.6: Power Supply Unit

A lead-acid battery is used as the main power source.

- Supplies power to ESCs, motors, and ESP32
- Provides stable and sufficient current for underwater operation
- All grounds are connected together for proper functioning

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VI. RESULTS

The AquaBot-X prototype was successfully designed and tested in a controlled environment to evaluate its performance. The system demonstrated reliable operation of all major components including the ESP32 microcontroller, ESCs, BLDC motors, and wired communication setup.

The multi-thruster propulsion system using four BLDC motors showed smooth and responsive movement. The drone was able to perform basic directional operations such as forward, backward, turning, and vertical motion (upward and downward). The ESCs responded accurately to PWM signals generated by the ESP32, ensuring stable speed control of each motor.

The wired (tethered) communication system proved to be highly effective, providing continuous and uninterrupted signal transmission between the transmitter and receiver units. Unlike wireless methods, no signal loss or delay was observed during operation.

The power supply using a lead-acid battery delivered sufficient current to drive all components simultaneously without noticeable voltage drop. The system maintained stable performance throughout the testing period.

The integration of the underwater frame and wiring setup (as shown in the prototype) was functional, with proper connections between ESCs, motors, and control unit. The arrangement allowed easy control and coordination of all thrusters.

However, minor limitations were observed such as exposed wiring, which may require better insulation and waterproofing for long-term underwater use. Additionally, precise control can be further improved by replacing switches with joystick control.

Overall, the prototype successfully achieved its objective of developing a low-cost, ESP32-based underwater drone capable of controlled movement and reliable operation, making it suitable for basic underwater exploration and educational applications.

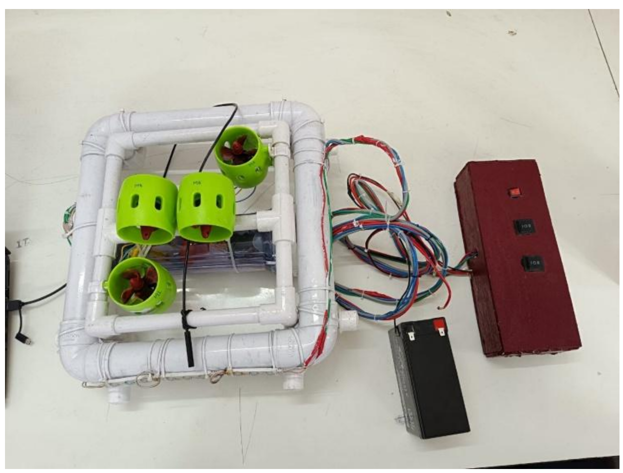

Fig.7.Prototype Model

VII. CONCLUSION

The AquaBot-X underwater drone was successfully designed and implemented as a cost-effective and reliable system for basic underwater exploration. The integration of ESP32 microcontrollers, ESCs, and BLDC motors enabled smooth and controlled multi-directional movement. The use of wired communication ensured stable signal transmission without interruption, overcoming the limitations of wireless technologies underwater. The system demonstrated consistent performance during testing, with effective motor control and proper power distribution using a lead-acid battery. Overall, the project proves that a simple and affordable underwater drone can be developed for monitoring and educational purposes with satisfactory performance.

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VIII. FUTURE SCOPE

The system can be further improved by enhancing its functionality and durability. Advanced control methods such as joystick or mobile-based control can replace switch-based input for better precision. Waterproofing can be improved by enclosing all electronic components in a sealed housing. Additional sensors like depth, temperature, and obstacle detection can be integrated for smarter operation. The inclusion of autonomous features using AI can enable self-navigation and object detection. Communication can also be upgraded using advanced underwater transmission techniques for longer range. These improvements will make the system more efficient and suitable for real-world applications such as marine research, surveillance, and industrial inspection.

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