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AI based underwater Remotely Operated Vehicle (ROV) for Inspection and surveillance

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Abstract: Underwater inspection and surveillance are essential in marine research, dam structure monitoring, underwater pipeline inspection, defence surveillance, and search-and-rescue operations. Conventional inspection methods rely heavily on human divers, which involve high operational risk, limited working duration, and significant cost. Industrial-grade underwater robotic systems are available; however, they are often expensive and not easily accessible for academic or small-scale applications. This paper presents the design, development, and implementation of an Artificial Intelligence (AI) Based Underwater Remotely Operated Vehicle (ROV) intended for real-time surveillance and inspection. The system integrates a waterproof mechanical structure, multi-directional thruster system, embedded microcontroller-based control unit, high-definition underwater camera, and an AI-based object detection module. The proposed ROV enables stable underwater navigation, real-time video transmission, and intelligent detection of underwater objects and anomalies. The hardware prototype is developed at an approximate cost of ₹60,000, making it significantly more affordable than industrial systems. Experimental testing in shallow freshwater environments demonstrates reliable manoeuvrability, stable video streaming, and effective AI-assisted monitoring.

Keywords: Underwater ROV, Artificial Intelligence, Object Detection, Embedded Systems, Surveillance, Marine Robotics, Real-Time Monitoring.

I. INTRODUCTION

The underwater environment remains one of the least explored yet most critical domains for environmental monitoring, infrastructure inspection, and defence applications. Underwater structures such as dams, bridges, pipelines, and ship hulls require regular inspection to ensure structural integrity and safety. Traditionally, underwater inspection is carried out by trained divers. However, diving operations are hazardous, time-limited, and influenced by factors such as water depth, turbidity, temperature, and pressure. Moreover, diver-based inspection increases operational cost and risk. Remotely Operated Vehicles (ROVs) provide a safer alternative by enabling operators to monitor underwater environments from the surface. Conventional ROVs mainly provide remote navigation and video streaming. However, with the integration of Artificial Intelligence (AI), underwater systems can perform intelligent tasks such as object recognition, obstacle detection, and anomaly identification. This paper proposes an AI-Based Underwater ROV designed for surveillance and inspection applications. The system aims to provide a cost-effective, modular, and scalable solution suitable for academic research and real-world deployment.

II. LITERATURE REVIEW

Underwater robotic systems have evolved significantly over the past decades. Early ROV systems were primarily designed for industrial offshore operations, focusing on deep-sea exploration and oil pipeline inspection. These systems are robust but expensive and complex. Recent research has explored the integration of computer vision and machine learning techniques with underwater vehicles. AI based detection methods such as convolutional neural networks (CNNs) [9].have been used for underwater object recognition and marine species identification. However, many existing AI-integrated systems require high computational power and specialized hardware, increasing overall cost. There is a need for a compact, affordable underwater ROV system capable of performing intelligent monitoring without industrial scale investment. The proposed system addresses this gap by integrating embedded control with AI-based image processing in a cost-effective prototype.

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III. SYSTEM OVERVIEW

The proposed AI-Based Underwater ROV system is designed as a modular and scalable robotic platform intended for surveillance and inspection in shallow water environments. The system integrates mechanical design, embedded electronics, propulsion control, real-time communication, and artificial intelligence processing into a single compact architecture.

The complete system is divided into three major functional subsystems:

- **A.** Mechanical Subsystem
- **B.** Electronic Control Subsystem
- **C.** AI Processing and Monitoring Subsystem

The underwater unit consists of a waterproof frame containing thrusters, camera module, embedded controller, battery system, and motor drivers. The surface control unit consists of a monitoring interface and operator control mechanism.

The system architecture ensures:

- **i.** Stable underwater mobility
- **ii.** Continuous power supply
- **iii.** Real-time video transmission
- **iv.** AI-based detection capability
- **v.** Operator-controlled navigation

The integration of AI enables the system to move beyond passive video streaming and perform intelligent surveillance tasks.

IV. DESIGN AND PROPULSION SYSTEM

The mechanical design plays a critical role in ensuring structural stability and buoyancy control. The frame is designed using lightweight yet durable materials to withstand underwater pressure and resist corrosion.

A. Frame Design

The frame structure:

- **i.** Houses all electronic components securely
- **ii.** Maintains neutral buoyancy
- **iii.** Protects internal circuitry from water exposure
- **iv.** Provides mounting points for thrusters and camera

Neutral buoyancy is achieved by balancing the weight of the internal components with the displacement volume of the frame. Proper sealing techniques are applied to prevent leakage.

B. Thruster Configuration

The ROV uses multiple DC underwater thrusters arranged strategically to allow multi-directional movement:

- **i.** Forward and backward motion
- **ii.** Vertical (upward and downward) movement
- **iii.** Lateral stabilization

The propulsion system allows smooth manoeuvrability and precise control in underwater environments.

C. Microcontroller Unit

A microcontroller is used as the main control unit. It:

- **i.** Processes operator commands
- **ii.** Controls motor driver circuits
- **iii.** Regulates thruster speed
- **iv.** Manages power distribution

The microcontroller is programmed using embedded C/Python-based control logic.

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D. Motor Drivers

Motor driver circuits are used to:

- **i.** Control direction of thrusters
- **ii.** Adjust speed using PWM (Pulse Width Modulation)
- **iii.** Prevent overcurrent conditions

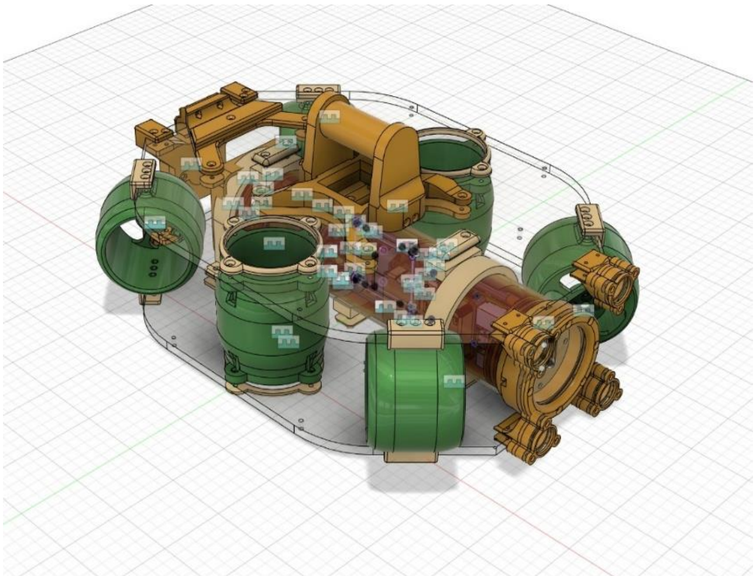

Fig 3.1: Hardware design of ROV

The electronic subsystem controls propulsion, communication, and power management.

E. Power System

The system uses a rechargeable battery pack capable of providing sufficient operational duration. Proper voltage regulation ensures stable performance of electronic components.

F. Communication System

A tether cable is used for:

- **i.** Power supply
- **ii.** Real-time video transmission
- **iii.** Control signal communication

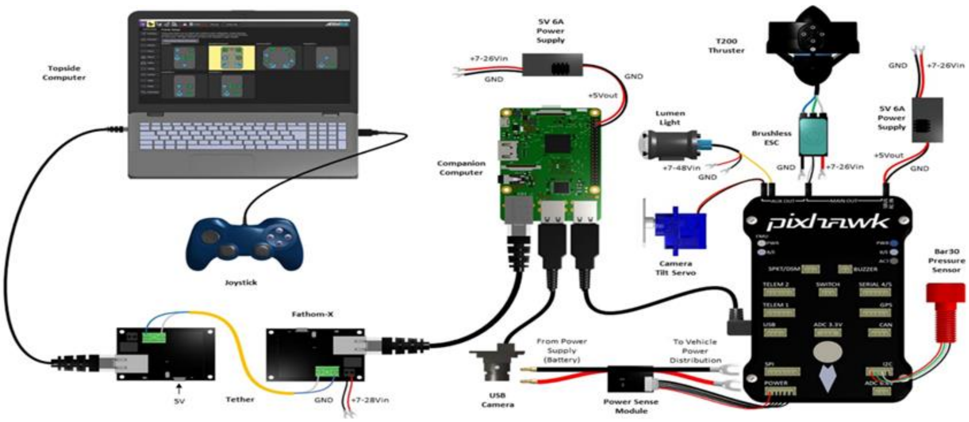

Fig 3.2: Data flow Architecture

V. AI-BASED OBJECT DETECTION AND IMAGE PROCESSING

Artificial Intelligence integration is the core enhancement of the proposed ROV.

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A. Video Acquisition

The HD underwater camera captures real-time video feed, which is transmitted to the surface monitoring system.

B. Image Processing Pipeline

The AI system performs:

i. Frame extraction
ii. Pre-processing (noise reduction, contrast enhancement)
iii. Object detection using trained model
iv. Output visualization

C. AI Model

A machine learning-based object detection algorithm is implemented. The model is trained using underwater image datasets to recognize objects such as:

i. Structural cracks
ii. Obstacles
iii. Submerged objects

The AI module enhances inspection efficiency by automatically highlighting detected objects in the video feed.

VI. METHODOLOGY

The development process followed a structured engineering approach:

A. Requirement Analysis
Identification of surveillance, inspection, and mobility requirements.
B. Mechanical Design
CAD modelling and buoyancy analysis.
C. Hardware Fabrication
Assembly of frame, thrusters, and waterproof enclosure.
D. Embedded Programming
Development of control logic for thruster movement.
E. AI Model Training
Preparation of training dataset and performance optimization.
F. System Integration
Integration of hardware, communication, and AI processing.
G. Testing and Validation
Performance evaluation under controlled freshwater conditions.

This systematic approach ensured reliability and modular scalability.

VII. EXPERIMENTAL RESULTS AND PERFORMANCE EVALUATION

The prototype was tested in shallow freshwater environments with depths up to 8–10 meters.

A. Mobility Performance
i. Stable forward and vertical movement
ii. Smooth directional control
iii. Balanced buoyancy

B. Video Transmission
i. Clear HD video output
ii. Minimal latency
iii. Stable communication via tether

C. AI Detection Performance
i. Successful object identification
ii. Real-time detection capability
iii. Improved monitoring efficiency

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D. Operational Duration
i. Continuous operation up to 45 minutes per charge
ii. Stable voltage supply throughout testing

The experimental results validate the system's feasibility and performance reliability.

VIII. ADVANTAGES OF THE PROPOSED SYSTEM

i. Cost-effective hardware (₹60,000)
ii. AI-assisted real-time monitoring
iii. Enhanced safety compared to diver-based inspection
iv. Modular and scalable architecture
v. Suitable for educational and inspection applications

X. CONCLUSION

The AI-Based Underwater ROV for Surveillance and Inspection has been successfully designed, developed, and tested. The integration of artificial intelligence significantly improves the functionality of conventional ROV systems by enabling intelligent object detection and enhanced situational awareness.

The developed prototype demonstrates stable underwater mobility, effective communication, and reliable AI-assisted monitoring at an affordable cost. The system proves that intelligent underwater robotic platforms can be developed within academic environments while maintaining industrial relevance.

XI. FUTURE SCOPE

Future improvements may include:
i. Autonomous navigation using sensor fusion
ii. Integration of sonar and depth sensors
iii. Deep learning-based advanced classification models
iv. Wireless underwater communication techniques
v. Cloud-based data storage and analytics
vi. Deployment in deeper and more complex aquatic environments

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