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Advanced ROV System for Underwater Inspection

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***Abstract*—Underwater structures such as pipelines, bridges, and tanks require regular inspection to detect cracks and damage before they lead to major failures. Identifying human bodies during underwater search and rescue operations using human divers. However, using human divers for this task is risky, expensive, and difficult in dark, high-pressure, or narrow underwater spaces. This project focuses on designing and building a compact underwater Remotely Operated Vehicle (ROV) capable of carrying out such inspections safely and efficiently. The hardware, including motor and sensor control, is managed by an ESP32 microcontroller built into the ROV and programmed in C++, ensuring fast and reliable real-time operation underwater. Four thrusters allow the vehicle to move forward, backward, upward and downward , enabling navigation through confined spaces. A waterproof HD camera to capture clear footage, while a water-spray mechanism keeps the lens clean of mud and suspended particles. On the software side, Python is used to process the live camera feed for detecting cracks and identifying human bodies underwater, which is especially useful for rescue operations, along with recognizing obstacles such as rocks, pipes, and walls. All detection results and live video are displayed on a monitoring dashboard for the operator.**

Keywords*—Remotely Operated Vehicle (ROV), Underwater Inspection, ESP32, Crack Detection, Human Detection.

I. Introduction

Crack detection in underwater structures and human body detection during underwater search and rescue operations are important applications of underwater inspection systems. Structures like Dams, bridges, pipelines, storage tanks, and ship hulls are often partly or fully submerged, and constant exposure to water, pressure, and environmental wear causes cracks and other damage over time. If such damage goes unnoticed, it can lead to leakage, structural failure, or large accidents, so regular underwater inspection is essential. Inspection has traditionally been done by divers, which is dangerous in dark, deep, or narrow spaces, and limited by the time a diver can stay underwater and by the lack of a live record of what is seen. Remotely Operated Vehicles (ROVs) have therefore been proposed as a safer replacement for divers.

Research on underwater vehicles is wide. Compact vehicles with precise navigation have been built for inspection and emergency-response missions [1]. Model predictive control [2] and gamepad-based steering [3] help keep a vehicle stable and easy to operate, ROVs with cleaning tools have been designed for structures covered by marine growth [4], and sliding mode control with disturbance estimation has been used to hold position against fluid forces [5]. For ship hulls, a ROV has been proposed as a safer replacement for hazardous manual dives [6]. Section II reviews this work and the gap it leaves.

Despite this progress, most existing systems address one aspect of the problem, such as motion control, structural inspection, or task-specific hardware. Visibility is also a persistent difficulty, because mud and suspended particles can cover the camera lens and make the video feed unusable. To the best of our review, none of the surveyed works combines crack detection with human body detection, which is valuable for rescue and search operations, or provides automatic clearing of the camera lens.

This paper presents the design and implementation of a compact tethered ROV that addresses these gaps. Four shrouded thrusters driven by an onboard ESP32 microcontroller programmed in C++ move the vehicle, an HD camera streams live video to a laptop at the control station, and Python-based image analysis detects cracks and human bodies in the stream. A web-based dashboard shows the results and lets the operator control the motors and the spray pump. When the camera view is blocked, a water-spray pump clears the lens automatically.

The contributions of this paper are: (i) a compact ROV prototype with four shrouded thrusters; (ii) integrated crack detection and human body detection on a live video feed; (iii) automatic detection of a blocked camera view with a water-spray response; and (iv) a single dashboard for control, monitoring, and alerts. The rest of the paper is organized as follows. Section II reviews related work and the limitations of existing systems, Section III defines the problem and objectives, Section IV describes the system architecture, Section V explains the methodology, Section VI presents the test results, and Section VII concludes.

II. Related Work

Research on underwater inspection vehicles covers navigation and control, inspection platforms, AI-based detection, and special-purpose hardware. This section reviews the works that relate most closely to the proposed ROV.

A. Navigation, Control, and Steering

Matteo Franchi et al. [1] developed a compact vehicle that fuses Doppler velocity log and fiber-optic gyroscope data with forward-looking sonar for precise navigation.Chengqi Long et al. [2] applied model predictive control to six-degree-

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of-freedom ROV trajectory tracking under ocean currents, and Naoki Motoi et al. [5] combined sliding mode control with disturbance estimation to hold position. Alexander Abdulov and Abramenkov [3] let an operator steer an omnidirectional ROV by tilting a gamepad with an inertial sensor.Nandha Kizor et al. [4] designed a ROV with brush and cutter tools for cleaning and inspecting structures covered by marine growth, and Ali and Arshad [6] built a cylindrical three-thruster ROV with a camera for ship hull inspection. These works concentrate on motion control, steering, and cleaning, and as described none of them detects cracks or human bodies.

B. Inspection Platforms and Task Hardware

Xinyu Bian et al. [7] added a three-degree-of-freedom manipulator to an underwater vehicle to capture targets. Jothikrishna et al. [8] built a ROV with a Raspberry Pi and a Pixhawk controller that streams live video through a tether, but reported low visibility and listed sonar only as future work. Bartlett et al. [9] added a low-cost Doppler velocity log to a Blue ROV for position hold, and Giacomo Picardi et al. [10] built a soft cable-driven gripper for sampling. George Ioannou et al. [11] reviewed technologies for autonomous inspection of undersea infrastructure. Mohd Aras et al. [12] proposed a small four-thruster ROV with an acrylic frame and an Arduino Uno that streams live video for shallow-water inspection, and Mohammed Lawal et al. [13] proposed a solar-powered ROV. Among these, [8] and [12] are the closest to the proposed vehicle, but as described neither detects cracks or human bodies, and neither clears the camera view automatically.

C. AI-Based Detection and Sensing

Zheng et al. [14] combined vision transformer and CNN features with model predictive control to avoid obstacles seen in sonar images. Jamuna et al. [15] detected cracks with underwater cameras and sensors using an improved Retinex model and deep learning. Elmezain et al. [16] built the BB-UWCrack bounding-box dataset, using GAN-generated images, and compared nine detection models. Huang et al. [17] fitted a Blue ROV with multibeam sonar, a Doppler velocity log, and an ultrasonic thickness gauge to inspect steel quaywalls and found finer defects than divers in turbid water. [15] and [16] address cracks only, and as described none of these systems combines crack detection with human body detection or automatic lens clearing.

D. Special-Purpose Platforms and Communication

Jorse Gonzales et al. [18] used manta-ray-inspired soft fins for efficient motion. Yeh et al. [19] measured the tilt of underwater piles with a mini-ROV and sonar, and Mishra et al. [20] used optical and acoustic modems to remove the tether of a hybrid vehicle. These works target special tasks, measurement, and tether-free communication rather than visibility or detection.

E. Research Gap

Table I compares the most closely related systems with the proposed one. To the best of our review, none of the surveyed works combines (i) crack detection, (ii) human body detection, (iii) automatic camera lens clearing, and (iv) a single dashboard for control and monitoring in one compact vehicle. This is the gap that the proposed ROV is designed to fill.

TABLE I
COMPARISON OF SELECTED RELATED WORKS

Ref.	Key feature	Limitation
[8]	ROV with live video over a tether	Low visibility; no detection described
[12]	Small four-thruster ROV with Arduino Uno and live video	No detection or lens clearing.
[15]	AI crack detection with underwater cameras and sensors	Crack detection only with poor visibility, no human detection.
Proposed	Crack and human detection, automatic lens clearing, web dashboard	Tested only in a small pool.

III. PROBLEM IDENTIFICATION AND OBJECTIVES

A. Problem Identification

Underwater inspection by divers is risky and difficult. Visibility in water is poor, and mud or suspended particles can block the camera view. Detecting cracks in such images is challenging, real-time monitoring is often unavailable, and detecting a human body during search operations is difficult.

B. Objectives

The objectives of this work are to:

- To develop a simple underwater ROV for underwater inspection and crack detection using onboard ESP32.
- To enhance safety by reducing the need for human divers.
- To support search operation for detecting human bodies underwater using ROV.

IV. PROPOSED SYSTEM ARCHITECTURE

Fig. 1 shows the block diagram of the ROV system. It has two units joined by a tether cable: the control station and the underwater ROV.

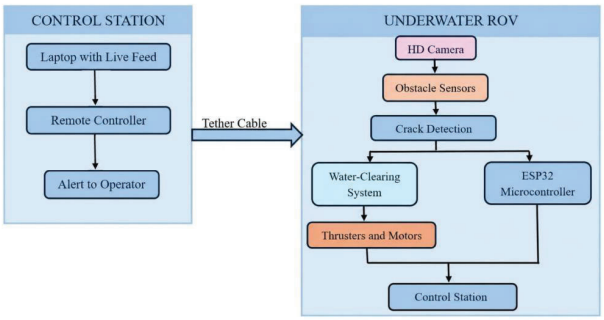


Fig. 1. Block diagram of the proposed ROV system.

A. Control Station

A laptop displays the live video feed and the dashboard. The operator uses the remote controller on the dashboard to send movement and pump commands to the vehicle through the tether cable, and the operator is alerted when a crack or a human body is detected. A manual control box with push buttons and relay modules.

B. Underwater ROV

The ROV carries the HD camera, the obstacle sensors, the water-clearing system, the ESP32 microcontroller is built into the ROV's sealed enclosure and acts as onboard controller .It drives the thrusters and the spray pump and reports status back to the control station through the tether. Fig. 1 groups crack detection with the vision chain to show the order of

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processing; in the prototype, the Python detection program runs on the laptop that receives the video.

C. Dashboard

The control and monitoring interface is a web-based dashboard (Fig. 2) that runs in a browser on the laptop. It lets the operator select the camera source, connect or stop the camera, save the current image, and drive the horizontal and vertical motors. The spray pump has On, Off, and Stop buttons and an Auto Spray mode that turns the pump on when the camera view is blocked or muddy. A live detection stream shows overlay text with crack and human confidence, pump status, and a timestamp, and a status panel lists the detection result, camera status, crack and human counts, stream and detection frame rates, and confidence values.

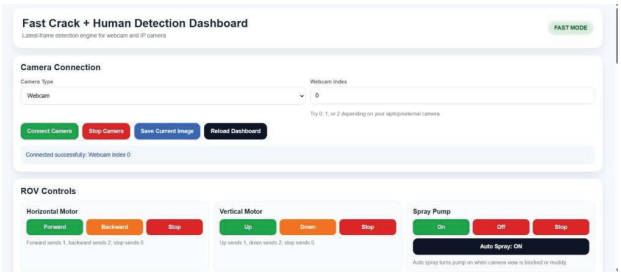


Fig. 2. Control section of the web-based dashboard.

V. Methodology

The working of the system is summarized by the flowchart in Fig. 3. After the operator starts the vehicle with the remote control, the live video feed is checked for a blocked view. If suspended particles or another obstruction are found, the spray pump washes the lens and the feed is checked again. Otherwise the system checks for obstacles and either adjusts the path or continues. The feed is then checked for a crack or a human body. If either is found, an alert and the image are sent to the operator, the mission is marked complete, and a report is sent. If nothing is found, the loop returns to the live video feed.

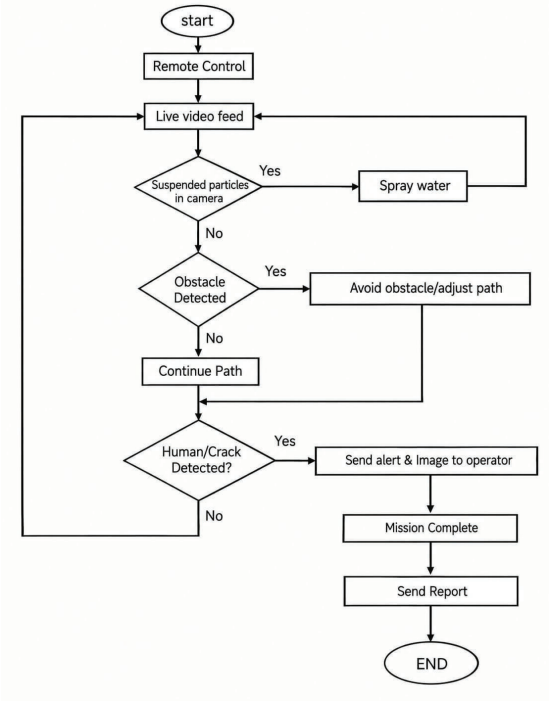


Fig. 3. Flowchart of the operation of the ROV system.

A. Mechanical and Propulsion Build

The vehicle is built on a compact frame with four thrusters, each mounted in a red cylindrical shroud that protects the propeller and guides the water flow (Fig. 4). The thrusters give horizontal and vertical motion, which the dashboard controls through separate horizontal-motor and vertical-motor buttons.

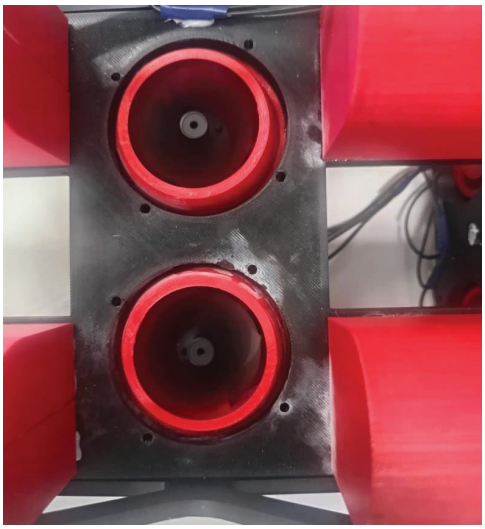


Fig. 4. Thruster assembly of the ROV prototype with shrouds.

B. Embedded Control

An onboard ESP32 microcontroller, programmed in C++ receives movement and pump commands from the dashboard and drives the motors and the spray pump. The dashboard sends 1 for forward or up, 2 for backward or down, and 0 for stop, so each motor group needs only a single command value at a time.

C. Camera Clearing

The video is checked for a blocked view. When mud, suspended particles, or another object covers the lens, the dashboard shows “CAMERA VIEW BLOCKED,” the pump status changes to ON, and water is sprayed on the lens. After the lens is clear, normal monitoring continues as shown in Fig. 3. The operator can also use the pump buttons manually.

D. Detection Pipeline

Video frames are analyzed in Python on the laptop. The detection engine works on the latest frame so that the displayed stream is not held back by detection. For each frame it gives a crack confidence and a human , around a detected crack, and updates the crack and human counts. A detection raises an alert, and the dashboard shows the result and the captured image.

VI. Results and Discussion

The prototype was tested in a small pool. Five cases were run, as shown in Fig. 5: an empty scene, a toy doll used as a stand-in for a human, a real hand, a cracked board, and a blocked camera view. Table II lists the values read from the dashboard for each case, and Figs. 6–10 show the dashboard output.

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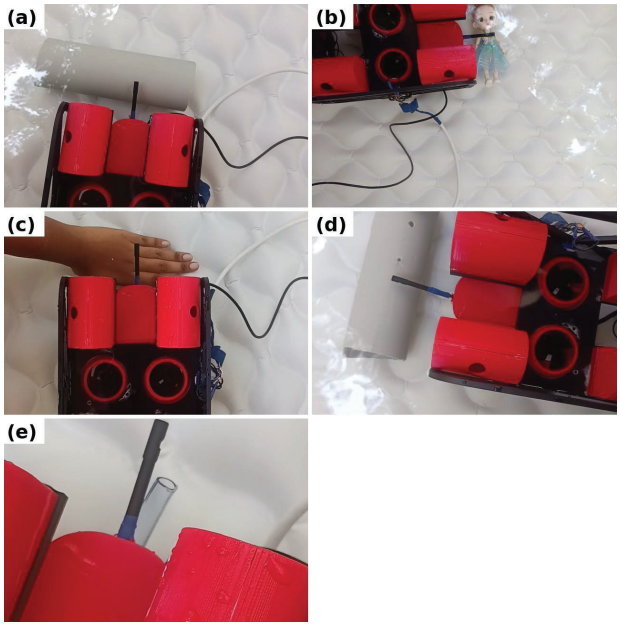


Fig. 5. Test setups: (a) no crack on pipe, (b) toy doll, (c) real hand, (d) cracked pipe, (e) blocked camera.

TABLE II
TEST CASES AND DASHBOARD READINGS

Test case	Result shown	Crack (%)	Human (%)	Pump
No crack on pipe	NO DETECTION	0.0	0.0	OFF
Toy doll	HUMAN DETECTED: 1	0.0	46.7	OFF
Real hand	HUMAN DETECTED: 1	0.0	71.4	OFF
Cracked pipe	CRACK DETECTED: 2	35.1	0.0	OFF
Blocked camera	CAMERA VIEW BLOCKED	0.0	0.0	ON

With no object in front of the camera, the system reported NO DETECTION, with 0.0% crack and human confidence and the pump off (Fig. 6), so no false detection was seen in this run.

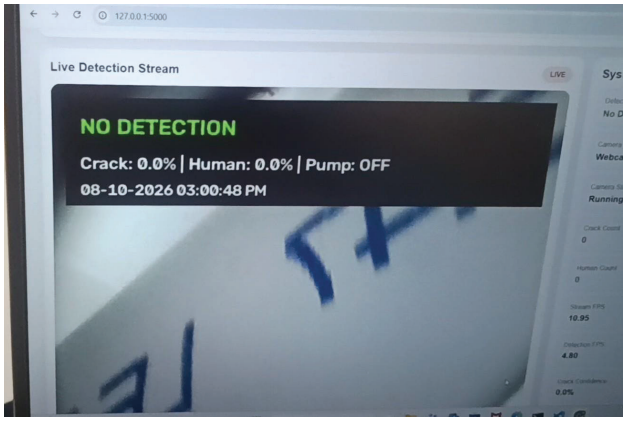


Fig. 6. Dashboard output with no object: NO DETECTION.

The toy doll was detected as a human with 46.7% confidence (Fig. 7), and the real hand with 71.4% confidence (Fig. 8); the status panel showed 76.4% at the moment the hand image was captured. The higher value for the hand suggests that the detector responds more strongly to real human features than to a toy, but one run per case is not enough to conclude this.

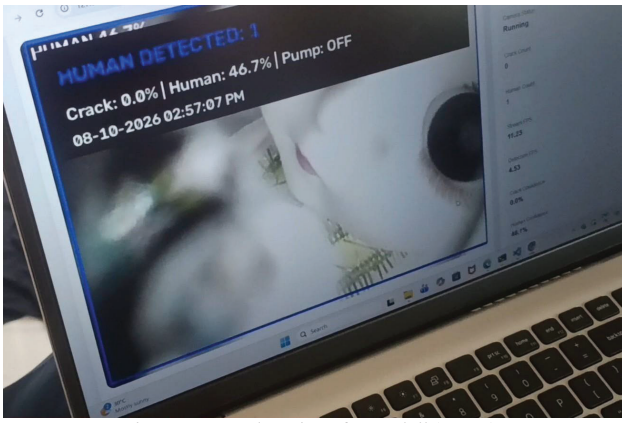


Fig. 7. Human detection of a toy doll (46.7%).

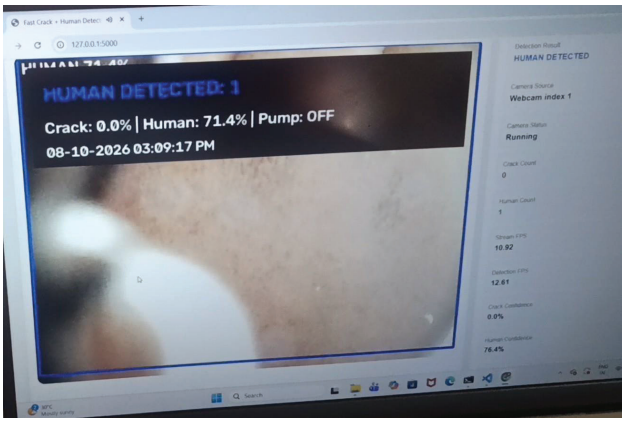


Fig. 8. Human detection of a real hand (71.4%).

For the cracked board, the system showed CRACK DETECTED: 2 with 35.1% crack confidence and drew a bounding box and outline around the crack in the live feed (Fig. 9).

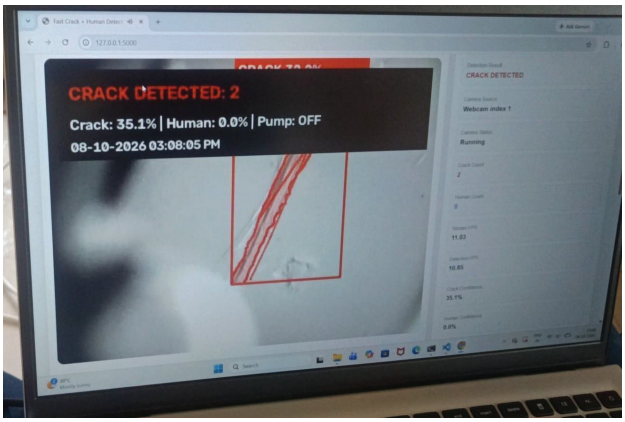


Fig. 9. Crack detection on a cracked board (35.1%).

When the lens was covered with a finger, the dashboard showed CAMERA VIEW BLOCKED and the pump status changed to ON automatically (Fig. 10), which confirms the intended camera-clearing response.

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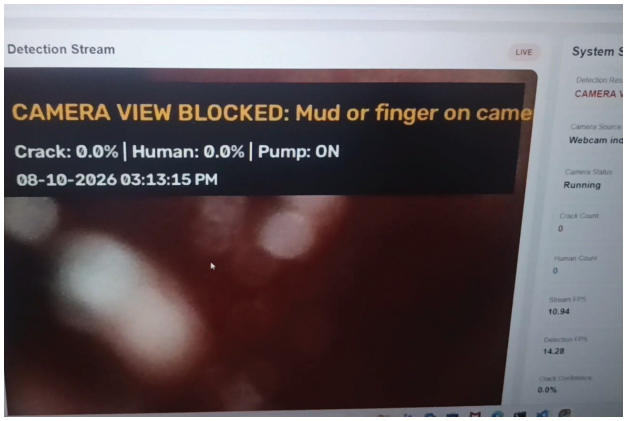


Fig. 10. Blocked camera view with the spray pump switched ON.

These are qualitative single-run tests in a small swimming pool with crack detection ,human body detection has been reported.

VII. Conclusion and Future Scope

This paper presented the design and implementation of a compact tethered ROV for underwater inspection and rescue support. The prototype combines four shrouded thrusters driven by an onboard ESP32 programmed in C++ with an HD camera, a water-spray pump, and Python-based detection of cracks and human bodies, all brought together in a web-based dashboard. In tests in a small pool, the system reported no crack detected on pipe, detected a toy doll and a real hand as human at 46.7% and 71.4% confidence, detected a crack on a cracked board at 35.1% , and switched the spray pump on automatically when the camera view was blocked. These results show that the main functions work together on one platform, although the tests were single runs in a small swimming pool.

In the future, the proposed ROV system can be enhanced by integrating AI-based autonomous navigation to enable automatic path following and obstacle avoidance. A reliable rechargeable battery system can be incorporated to increase the operating time of the vehicle. Variable-speed motor control can be implemented to improve manueuvrability, precise positioning, and inspection efficiency. Additionally, an onboard video recording facility can be introduced to store underwater inspection footage for further analysis, documentation, and monitoring.

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