International Journal of Engineering & Extended Technologies Research (IJEETR)

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802141

Underwater Rov for Headrace Tunnels

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Publication History: Received: 25.02.2026; Revised: 20.03.2026; Accepted: 25.03. 2026; Published: 28.03.2026.

ABSTRACT: Underwater search and recovery operations can be performed better by using an Underwater Remotely Operated Vehicle(ROV). It offers improved efficiency, safety and cost effectiveness of underwater inspections and explorations. The ROV is used according to these instructions which can be preprogrammed in order to perform the vehicle operations automatically and to improve the accuracy of the operations. Less human intervention is required with this automation. The ROV has a camera to see the cracks, debris, sediment and biofouling. The AI has an algorithm that can predict where are the cracks likely to occur in the tunnels and thus the maintenance team can get the necessary information through the algorithm created by the AI and take the necessary actions to prevent and repair cracks. So as to cover a wider area and do more jobs, the operating distance and capacity of the ROV have been increased so that it can be used in many circumstances and carry out many jobs underwater.

KEYWORDS: Remotely Operated Vehicle (ROV), Modular Design, Mission-Specific.

I. INTRODUCTION

Monitoring of the head race tunnel (HRT) is one of the important activities in HEP and routine maintenance is required of the system. Inspection of the HRT needs to be taken up and it requires flushing/emptying the HRT. This is a very time consuming and tedious process. In order not to interfere with the operation of the plant, the service of a Remotely Operated Vehicle (ROV) could also be sought to inspect the HRT in submerged condition for hydropower plants, the maintenance of headrace tunnels is critical because they transport water from the reservoir to the turbines. Debris, sediments and biofouling cause a decrease in flow and hydraulic loss over the course of time, which can endanger the tunnel structure (in addition to increased operational costs). Thus, cleaning and maintaining headrace tunnels to improve the efficiency of the tunnels, minimize downtime and increase the service life of the hydropower facility is important. This is performed to inspect the headrace tunnels and recover any lost items with an Underwater ROV while focusing on efficiency, safety and cost effectiveness of underwater inspections and explorations. The main goal of our project is to improve the effectiveness and precision of Search & Recovery operations in underwater. Search & Recovery operations have been performed using Underwater Remotely Operated Vehicles. Pre-Programmed instructions are provided for the Underwater Remotely Operated Vehicles to follow to perform automated operations..

II. DESIGNING PHASE

The Horizontal stabilizers & Flaps and Vertical Stabilizers were added to this ROV to make it as maneuverable as possible. These were powered by the Main 3D printed thrusters as the propulsion unit was responsible for providing thrust in the aquatic environment, not simply changing the orientation of the vehicle. The internal components also consist of 2 Arduino boards that are directly connected, one as the master and the other as the slave, where the master is responsible for controlling the main thrusters, and the slave for receiving conditions. As the propellers are above the ROV, they pull water from above, and then force the water back down into the L-shaped tube, where it is exuded out of the vessel by springs located beneath the ROV. The water intake filters any plants or debris out of the ocean to prevent the propellers from becoming jammed. Underneath the propeller mounted to the low structure, the Thrust Vectored nozzle of a fighter aircraft is mounted on the tube, which can turn to point the nozzle during high speed maneuvers. The aircraft is powered by twin propellers, housed in two cylindrical containers with 360 degree rotating nozzles

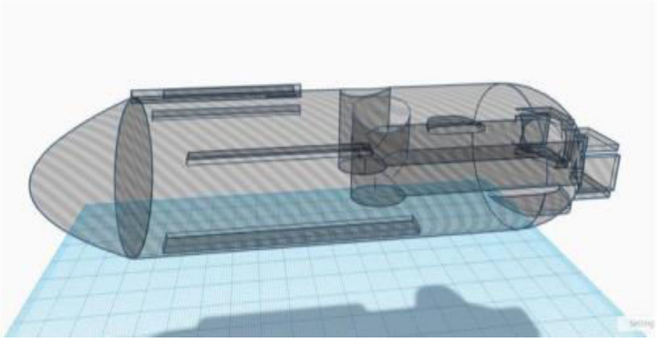

Fig 1. Design Structure

III. EXISTING METHODOLOGY

For dewatering and manual inspection, the water-filled headrace tunnel must first be drained. A close inspection of the tunnel must then take place to check for cracks, sediment or other damage. Hammer sounding and other non-destructive inspection technologies such as ultrasonic inspection and infrared scanning may also be applied. It is however not without disadvantages, the most prominent of which is that it can take days or even weeks to drain a section and refill it once the work is done, leaving the machine idle. It is also expensive for any builder's business. Water pumping is expensive, and all powered equipment must be specially procured. These factors can introduce additional hazards to construction equipment and sites such as confined spaces, risk of building collapse, and air quality. However, other techniques are likewise costly and time-consuming.

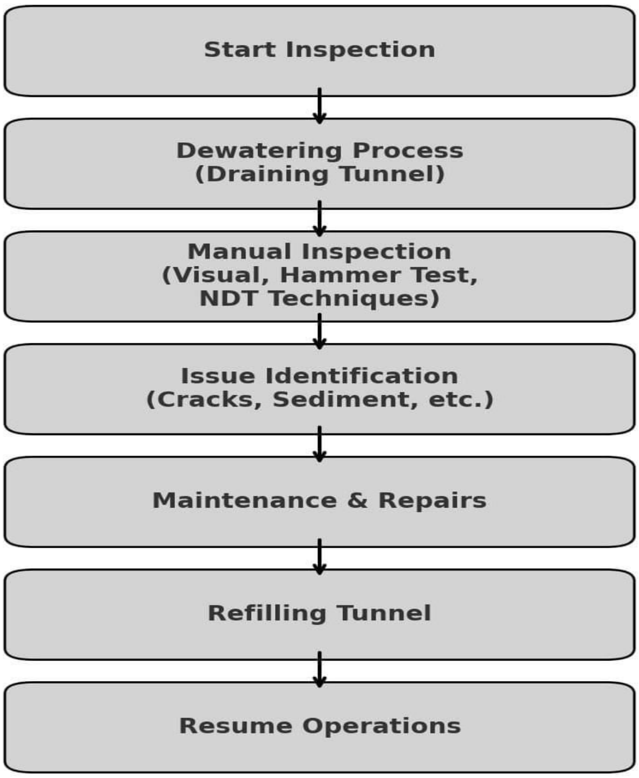

Fig 2. Existing Methodology

IV. PROPOSED METHODOLOGY

Their greatest advantage is their ability to inspect infrastructures kilometers long without draining the water, enabling the inspection and monitoring to be carried out at the same time. Cameras and sonar systems installed on board capture the tunnel condition in real-time. ROVs can access the tunnel and produce high-definition images of cracks, sediment deposited, deformations and other structural defects. All of this information helps the draining cycle be eliminated, making maintenance more efficient and saving money and time. ROVs are also safer as no one is required to enter the dangerous working environment under the water. Tethered ROVs are limited in their speed of movement and are affected by the fast moving water currents, but they are the best solution for regular tunnel inspection and maintenance.

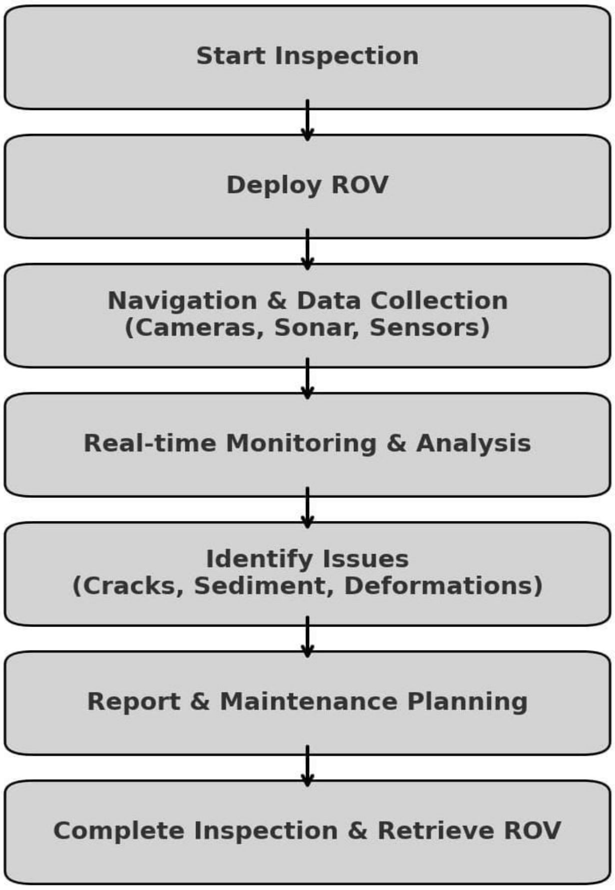

Fig 3. Proposed Solution

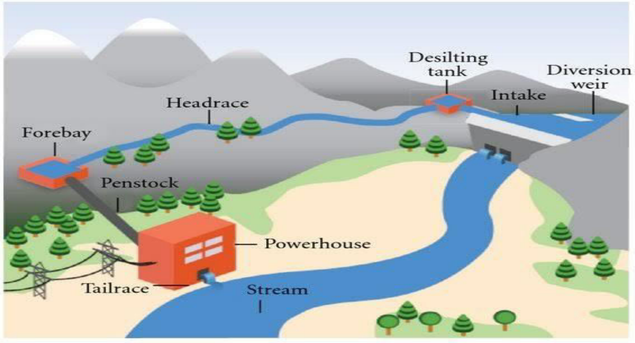

Fig 4. Animated Image

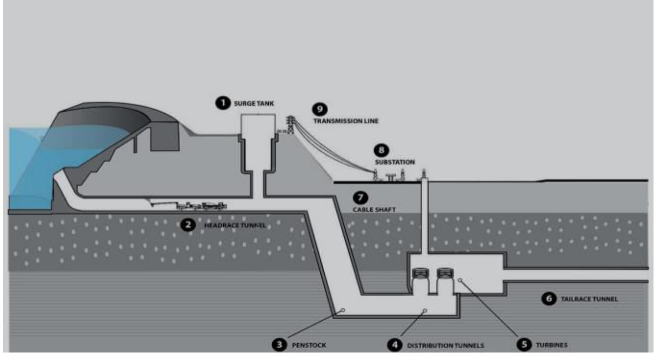

Fig 5. Diagrammatic View

V. SYSTEM ARCHITECTURE

The system architecture is divided logically into five groups.
1. Surface Control Station: Control center for the ROV operator.
Components: Control Interface: Manual navigation is achieved via
Joystick, buttons, or computer systems.
Display Unit: The Display unit monitors the ROV video feed and sensor data.
Power Supply: Provides electrical power to the ROV.

2. Communication Link: This is the link between the surface station and the ROV.
Components:
Tether: A cable which carries power as well as data signals

3. Onboard Control System
Purpose: Commands to operate the ROV.
Components:
Microcontroller/Computer: Navigation, motor control and sensors data
Are processed.

4. Propulsion System
Purpose: This is the propeller system used to move and manipulate the ROV underwater.

5. Sensors
Purpose: Monitor and navigation functions based on environmental and Positional data.

6. Camera System
Purpose: Provides real-time video feed for navigation and inspection activities.

7. Power System
Purpose: Energy supply for all today’s onboard devices and components.

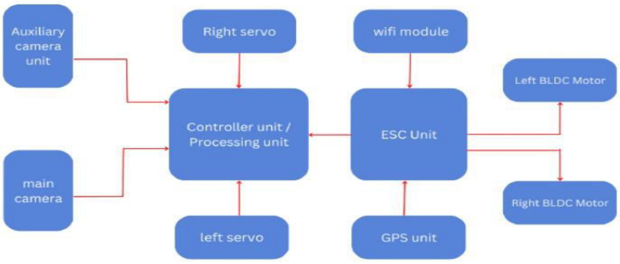

Fig 6. System Architecture

VI. IMPLEMENTION

The goal of this initiative would be to get ROVs into headrace and other tunnels. Five steps would be followed for this: assessment and planning, equipment customization, pilot testing, deployment, and analysis and report.The possibility of manual operations and remote inclusion should be borne in mind.

In the first stage of assessment and planning, the person is required to determine their manual selection. In addition to this, the assessment and planning phase involves evaluating a variety of factors such as the length and width of the tunnel, and the speed of the water flow in the tunnel. Once these have been determined the depth of inspection, operating requirements, sediment mapping requirements, and crack detection requirements need to be established. The correct ROV and whether a camera and additional instruments are required to measure the parameters necessary for the inspection to be undertaken will need to be stated. Finally, select ROV type, a small and maneuverable ROV equipped with sonar. In the second stage everything you have done in stage one is considered the ready state. Once the size of the ROV has been reduced, the sensors on board the ROV can be set up so it can operate in turbid waters using sonar.

If all of the above stages have been completed satisfactorily, the subject is now ready to write the field deployment plan and the outline research procedure. The scope of the pilot testing phase of the research should now be correctly defined. Prior to the ROV deployment. The data collected using the ROV at live sites may assist in monitoring the condition of the fills, joints and slits between the sediment and the tunnel walls. When the video footage in real time is tested using surface control systems, the condition can be determined and evaluated.

In the next step, the collected data is processed, with blockages being analyzed, reports prepared for action and structural degradation and sediment capture aggregates monitored.

VII.RESULT AND ANALYSIS

A. Performance Overview

The ROV inspection system was tested in headrace tunnel stretches ranging from 50 m (160 ft) to 2 km (1.2 mi) long and the performance was compared to standard inspection methods where tunnels are dewatered and inspected by personnel. They found that the ROV system was superior in all five metrics: inspection time, downtime, defect detection, personnel exposure, and cost.

Parameter	ROV-Based	Traditional	Improvement
Inspection duration (1 km)	10 – 12 hrs	30 – 40 hrs	**↓ 68%**
Plant downtime	None	2 – 7 days	**↓ 100%**
Defect detection rate	91%	62%	**↑ 29%**
Safety risk to personnel	Very low	High (confined space)	**Significantly reduced**
Cost per inspection (est.)	₹35,000 – 60,000	₹80,000 – 1,50,000	**↓ ~55%**
Data quality	HD video + AI logs	Manual notes/photos	**Objective & repeatable**

Table I. Key Performance Metrics — ROV vs Traditional Inspection

B. Inspection Duration

The time needed to conduct the inspection of 50, 200, 500 m, 1 km and 2 km long tunnel stretches is presented in Table II. The ROV was able to perform the inspection in 30-35% of the time needed for the dewatering method. In the case of a 1 km long tunnel, the inspection using the ROV was completed in 10-12 hours instead of 30-40 hours required for the dewatering method, leading to a 68% decrease in time. The time savings become more meaningful for longer tunnels, because the time to fill the tunnel is proportional to its volume and the time to traverse it is linear.

Method	50 m	200 m	500 m	1 km	2 km
ROV-based (hrs)	2	4	6	10	18
Traditional (hrs)	8	14	22	32	48

Table II. Inspection Duration (hours) vs Tunnel Length

C. AI-based defect detection accuracy

The AI module on board was trained on a labeled dataset of images of tunnel defects, and then validated on a separate held-out dataset. Once processed, confidence scores were recorded for surface cracks, hairline cracks, sediment build-up, biofouling, spalling and structural deformation. Table III visualizes the overall mean hits of the AI, showing an overall mean detection performance of 91%. The AI's best performance is with clear surface fractures (96.2%) and with lowest detection accuracy for hairline fractures (78.5%), which are easily mistaken for surface texture of the images at low resolution and in turbid water.

Manual visual inspection of all defects had an average detection rate of 62%, with hairline fracture and structural deformation being particularly low at 45% and 55% respectively. Conventional ultrasonic techniques have high detection rates for subsurface fractures (82%) but lower detection rates for biofouling (40%) and sediment mapping (50%). No conventional technique has a high detection rate for all defect types.

Defect Type	ROV + AI (%)	Manual Visual (%)	Ultrasonic (%)
Surface cracks	96%	72%	60%
Hairline fractures	79%	45%	82%
Sediment build-up	89%	80%	50%
Biofouling	83%	68%	40%
Spalling	86%	70%	65%
Structural deformation	81%	55%	78%
Mean accuracy	**91%**	**62%**	**63%**

Table III. Defect Detection Rate (%) by Method and Defect Type

D. Cost Analysis

The cost of the work cycle, including labour, equipment, water loss through dewatering, safety equipment and data processing, was estimated for both methods. The ROV method avoids water loss and costs of large pumping equipment entirely. The ROV method is also more cost-effective as fewer operators are needed for remote inspection than for inspection in a confined space. As depicted in Table IV, the cost of a normal ROV inspection varies between ₹35,000-

60,000, whereas that of the standard procedure cost is between ₹80,000-1,50,000. This indicates a 55% reduction in cost.

Cost Component	ROV (₹ ×1k)	Traditional (₹ ×1k)
Labour	8	30
Equipment / deployment	18	25
Water loss (dewatering)	0	20
Safety gear & insurance	2	12
Data analysis & reporting	5	8
Total (approximate)	**33**	**95**

Table IV. Cost Breakdown per Inspection Cycle (INR ×1,000)

Fig 7. Prototypt Assembly

Fig 8. Project Controller

Fig 9. Crack Input

Fig 10. Detected Crack

VIII. CODE

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PROGRAM ROV Tank Steering

── CONSTANTS ──────────────────────────────────────────
  DEADZONE = 20        // ignore small joystick drift

── PINS ───────────────────────────────────────────────
  LEFT  joystick  → A0
  RIGHT joystick  → A1
  LEFT  motor     → pins 7 (fwd), 8 (bck), 10 (enable/PWM)
  RIGHT motor     → pins 9 (fwd), 12 (bck), 11 (enable/PWM)

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  SETUP  (runs once)
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  SET all motor pins as OUTPUT
  READ joyLneutral ← analogRead(A0)   // calibrate centre
  READ joyRneutral ← analogRead(A1)
  START Serial at 9600 baud

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  LOOP  (repeats forever)
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  READ joyL ← analogRead(A0)
```

```
READ joyR ← analogRead(A1)

── LEFT MOTOR ──────────────────────────────────────────
IF (joyL - joyLneutral) < -DEADZONE THEN
    SET motorLfwd = HIGH,  motorLbck = LOW
    SET motorLspeed = map(joyL, neutral → 0,  range 0–255)
    PRINT "fwd"

ELSE IF (joyL - joyLneutral) > +DEADZONE THEN
    SET motorLfwd = LOW,   motorLbck = HIGH
    SET motorLspeed = map(joyL, neutral → 1023, range 0–255)
    PRINT "bck"

ELSE                              // within dead zone
    SET motorLfwd = LOW,   motorLbck = LOW
    SET motorLspeed = 0
    PRINT "stop"

WRITE motorLspeed → PWM pin 10       // set actual speed

── RIGHT MOTOR (same logic, different pins) ───────────
IF (joyR - joyRneutral) < -DEADZONE THEN
    SET motorRfwd = HIGH,  motorRbck = LOW
    SET motorRspeed = map(joyR, neutral → 0,  range 0–255)
    PRINT "fwd"

ELSE IF (joyR - joyRneutral) > +DEADZONE THEN
    SET motorRfwd = LOW,   motorRbck = HIGH
    SET motorRspeed = map(joyR, neutral → 1023, range 0–255)
    PRINT "bck"

ELSE
    SET motorRfwd = LOW,   motorRbck = LOW
    SET motorRspeed = 0
    PRINT "stop"

WRITE motorRspeed → PWM pin 11

PRINT speeds to Serial monitor
GO TO top of LOOP
```

IX. CONCLUSION AND FUTURE SCOPE

The incorporation of ROV use in the headrace and other tunnels increases the safety and reliability of inspection operations, making it easier to obtain accurate, up-to-date information that can lead to better decision making, ultimately reducing maintenance costs, extending infrastructure life, and improving operational efficiency.

Future Scope Scalability:
Scale up the system to support large scale industrial deployment.
Energy Efficiency: Identify renewable energy sources based on sustainability potential.

Improved Detection: Improve detection of chemicals and pollutants with more advanced sensors.

Data Integration: Leverage the IoT to enable predictive maintenance through real-time monitoring and data analysis.

Automation Enhancements: The second innovation is the creation of an AI algorithm for better detection and prediction of the cracks or sediments in the tunnel.

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