



# A Novel Tunnel Inspection Robot

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## Abstract

TUNNEL INSPECTION is a critical task to ensure the structural safety and proper maintenance of underground infrastructures such as railway tunnels, road tunnels, and utility pipelines where human interventions are not possible traditional inspection methods are time-consuming, costly, and expose human inspectors to hazardous environments including low visibility, toxic gases, and confined spaces. To overcome these limitations, this project recommends the design and development of a TUNNEL INSPECTION ROBOT capable of performing inspection tasks. The proposed robot is equipped with sensors and motors such as gas sensors, temperature sensors, metal detectors etc. to detect structural defects, obstacles, cracks, water leakage, and harmful gases inside tunnels. A microcontroller or embedded system processes the sensor data and enables real-time monitoring and control through wired or wireless communication. The robot uses two Arduino Uno Microcontrollers to efficiently runs system operations. The first Arduino handles motion control and distance sensing. The second Arduino is dedicated to environmental monitoring and communication. The DC gear motor provides movement to robot. The Bluetooth Modules enables wireless communication between robot and the operator for remote control

and data monitoring. For visual inspection an ESP32-CAM module is integrated to capture live video and images of tunnel walls which helps in crack detection and structural analysis. To ensure stable power supply for all components buck converters are used to regulate voltage efficiently. The robot's compact and robust mechanical structure allows it to navigate narrow and uneven tunnel surfaces efficiently.

**Keywords:** crack detection; gas sensor; temperature sensor; metal detector; DC gear motors; buck converters



## 1. INTRODUCTION

The Tunnel Inspection Robot was successfully designed and developed to assist in the effective monitoring and inspection of tunnels. The robot demonstrated the ability to navigate through tunnel environments smoothly and efficiently. It was able to capture real-time visual data using the camera module and transmit it to the control station. The sensors integrated into the system effectively detected harmful gases and environmental conditions inside the tunnel. The use of Arduino and wireless communication ensured reliable data transmission and control. The robot reduced the need for human presence in dangerous tunnel conditions, thereby enhancing safety. It proved to be a cost-effective and practical solution for tunnel surveillance and maintenance. The system showed good performance in detecting potential structural issues such as cracks and leakages. Overall, the project successfully achieved its objective of developing a smart and efficient tunnel inspection robot. This technology can be further improved and implemented in real-world tunnel monitoring applications.

## 2. METHODOLOGY

### 2.1. SYSTEM MODEL

The system architecture design based on the circuit diagram consists of four major modules: the Control Unit, Sensing Unit, Actuation Unit, and Communication Unit. The control unit comprises two Arduino Uno boards, where the first Arduino, shown on the left in the diagram, is responsible for motor control and obstacle sensing, while the second Arduino, shown on the right, is responsible for gas sensing, communication, and camera interfacing. The sensing unit includes two ultrasonic sensors for obstacle detection, a gas sensor module for detecting toxic gases in the tunnel environment, and an ESP32-CAM module for live video streaming and crack monitoring. The actuation unit consists of two DC gear motors connected to an H-bridge motor driver (L298N), which controls the movement of the robot in forward, reverse, left, and right directions. The communication unit consists of two HC-05 Bluetooth modules that enable wireless communication between the robot and the operator.

### 2.2. Hardware Assembly and Circuit Integration

All electronic components are connected as per the circuit diagram. The first Arduino Uno is interfaced with the motor driver (L298N) to control the movement of the robot using DC gear motors. The second Arduino Uno is connected to sensors such as gas sensor and Bluetooth module for environmental monitoring and communication. The ESP32-CAM is mounted on the robot for live video transmission and crack detection.

### 2.3. Power Supply Management

A regulated power supply is provided using buck converters to ensure stable voltage to all modules. The motor driver and Arduino boards are powered separately to avoid voltage fluctuations due to motor load. Proper grounding and wiring techniques are followed to minimize electrical noise and signal interference.

### 2.4. Motion Control and Navigation

The robot's movement is controlled using the L298N motor driver, which receives control signals from Arduino. The robot can move forward, backward, left, and right based on commands received via Bluetooth from a remote device (smartphone or computer). This enables manual navigation inside the tunnel.

### 2.5. Wireless Communication Using Bluetooth

The HC-05 Bluetooth module is interfaced with Arduino to enable wireless communication between the robot and the user. A mobile application or serial terminal is used to send control commands and receive sensor data in real time.



## 2.6. Environmental Monitoring

Gas sensors are integrated to detect harmful gases inside the tunnel. If the gas level exceeds a predefined threshold, the Arduino triggers an alert signal, which can be sent to the operator via Bluetooth. This ensures safety during tunnel inspection.

## 2.7. Visual Inspection and Crack Detection

The ESP32-CAM module captures live video footage from inside the tunnel and transmits it wirelessly. The camera is positioned to detect cracks, water leakage, or structural damage in the tunnel walls. The video feed is monitored by the operator in real time.

## 2.8. Data Collection and Analysis

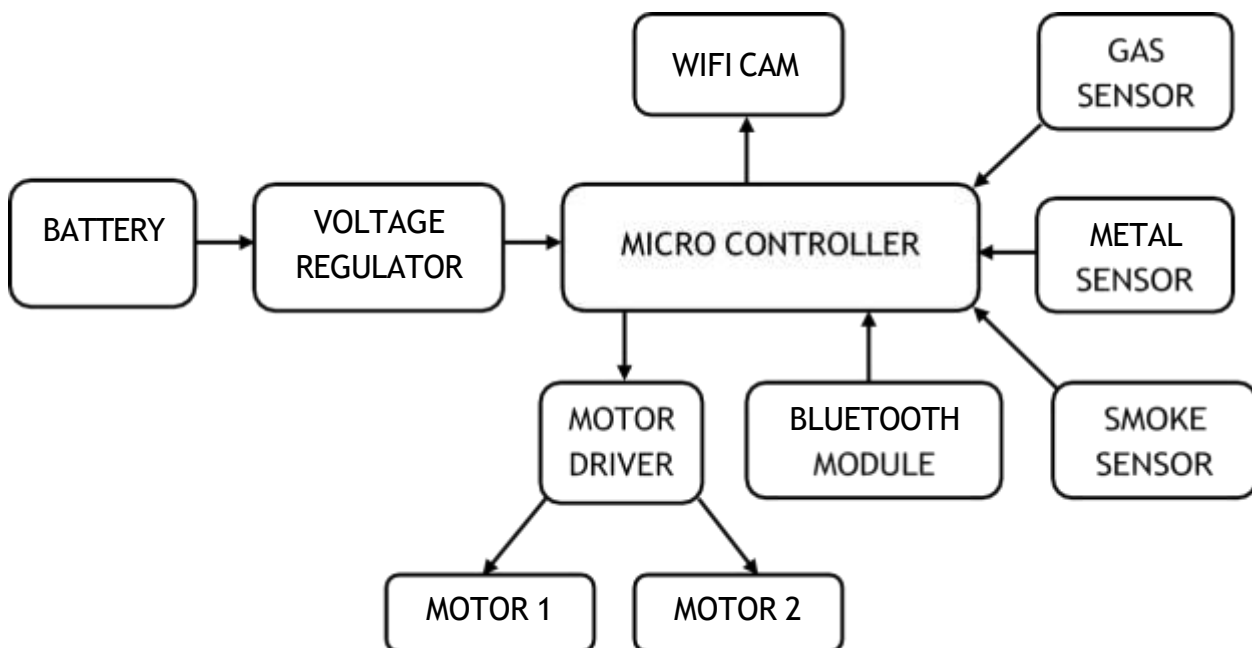
Sensor data (gas levels, obstacles, and visual feed) are collected and analyzed by the operator. The recorded data helps in assessing the tunnel's condition and identifying maintenance requirements.

## 2.9. Testing and Validation

The assembled robot is tested in a simulated tunnel environment. Different scenarios such as obstacle presence, gas leakage, and low visibility are tested to evaluate the performance and reliability of the system. Necessary modifications are made based on test results.

## 2.10. 10. Final Deployment

After successful testing, the robot is deployed for real-time tunnel inspection. The system provides a safer, efficient, and cost-effective alternative to manual.



## RESULTS AND DISCUSSION

The developed Tunnel Inspection Robot was successfully designed, fabricated, and tested for its intended purpose of monitoring and inspecting tunnel environments. The robot demonstrated effective mobility inside a simulated tunnel environment, overcoming uneven surfaces, minor obstacles, and confined spaces. The use of DC geared motors along with a motor driver ensured smooth movement in forward, backward, left, and right directions, allowing the robot to navigate through narrow passages efficiently. The integration of sensors such as ultrasonic sensors enabled the robot to detect obstacles and avoid collisions, improving its autonomy and safety during operation. The gas sensor successfully detected the presence of hazardous gases



such as carbon monoxide and methane, providing real-time alerts that are crucial for ensuring tunnel safety. This feature proves the robot's capability to function in potentially dangerous environments where human presence may be risky. The ESP32-CAM module installed on the robot captured live video footage from inside the tunnel, which was transmitted wirelessly via Bluetooth to a monitoring station. This allowed remote visualization of tunnel conditions, including cracks, water leakage, and structural damages. The image and video quality were sufficient for preliminary inspection and identification of visible defects. The dual Arduino-based control system performed reliably, with one Arduino handling motion control and obstacle detection, while the second Arduino managed sensor data and communication. This distributed control approach improved system efficiency and reduced processing delays. The power management system using buck converters ensured stable voltage supply to all components, preventing damage and ensuring consistent performance. Overall the experimental results indicate that the Tunnel Inspection Robot effectively meets its objectives of surveillance, hazard detection, and structural monitoring. The system proved to be a cost-effective and practical alternative to traditional manual inspection methods.

## CONCLUSION

The Tunnel Inspection Robot developed in this project successfully demonstrates a practical and efficient approach to tunnel surveillance and structural monitoring. The system integrates mobility, sensing, and wireless communication to perform inspection tasks in hazardous and confined underground environments where human intervention is risky and challenging. Through the use of ultrasonic sensors, gas detection modules, and a camera-based visual system, the robot is capable of identifying obstacles, detecting dangerous gases, and capturing real-time images and videos of tunnel conditions. The implementation of a dual Arduino control system and a stable power management unit ensured reliable operation and effective coordination between motion control and data acquisition. The experimental results validate the robot's ability to navigate through tunnel-like environments, gather essential safety-related information, and transmit it to a remote monitoring station. Overall, this project highlights the importance of automation in infrastructure inspection and contributes to enhancing safety, efficiency, and reliability in tunnel maintenance. With further advancements such as autonomous navigation, AI-based crack detection, and improved sensing capabilities, the Tunnel Inspection Robot has the potential to become a fully intelligent and indispensable tool for modern tunnel inspection and disaster prevention systems in the future.

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