# Robotic Inspection and Monitoring System for Utility Tunnels

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**Abstract -** In this paper, an automatic robotic inspector for tunnel assessment is presented. The proposed platform is able to autonomously navigate within the civil infrastructures, grab stereo images and process/analyse them, in order to identify defect types. At first, there is the crack detection via deep learning approaches. Then, a detailed 3D model of the cracked area is created, utilizing photogrammetric methods. Finally, a laser profiling of the tunnel's lining, for a narrow region close to detected crack is performed; allowing for the deduction of potential deformations. The robotic platform consists of an autonomous mobile vehicle; a crane arm, guided by the computer vision-based crack detector, carrying ultrasound sensors, the stereo cameras and the laser scanner. Visual inspection is based on convolutional neural networks, which support the creation of high-level discriminative features for complex non-linear pattern classification. Then, real-time 3D information is accurately calculated and the crack position and orientation is passed to the robotic platform. The entire system has been evaluated in railway and road tunnels, i.e. in Egnatia Highway and London underground infrastructure

***Key Words:*** *Raspberry Pi, Arduino Nano, Motor drivers, sensors, Robotic inspection, Tunnel assessment, Crack detection*

## 1. INTRODUCTION

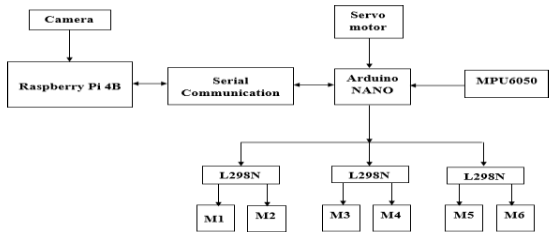
Utility tunnels play a vital role in modern urban infrastructure by accommodating essential services such as electrical cables, water pipelines, gas lines, and communication networks within a single underground system. This centralized arrangement simplifies maintenance and improves service management. However, as urban infrastructure expands, ensuring the safety and reliability of these tunnels becomes increasingly important.Regular inspection is necessary to detect defects such as cracks, corrosion, and water leakage. Traditional manual inspection methods are time-consuming and pose significant risks to human workers due to hazardous conditions like confined spaces, poor ventilation, and harmful gases. To address these challenges, this work proposes a **Robotic Inspection and Monitoring System for Utility Tunnels**. The system integrates robotics, embedded systems, and computer vision to enable safe and efficient tunnel inspection. A Raspberry Pi-based processing unit, along with the YOLO algorithm, is used for real-time defect detection, while an Arduino-based control system manages robot movement and sensor operations.The proposed system reduces human involvement in dangerous environments and enhances the accuracy and reliability of tunnel monitoring.

## 2. WORKING PRINCIPLE

The. The proposed robotic inspection system operates by integrating image processing, artificial intelligence, and robotic control for automated tunnel monitoring. A **Raspberry Pi 4 Model B** captures real-time video using a camera module and processes the frames using a YOLO-based deep learning model deployed through ONNX runtime. The system detects structural defects such as cracks and leakages based on a predefined confidence threshold. During automatic operation, the Raspberry Pi sends movement commands to an **Arduino Nano** via serial communication. The Arduino controls DC motors through an **L298N motor driver**, enabling the robot to navigate inside the tunnel. When a defect is detected, a stop command is issued, halting the robot for detailed inspection. An **MPU6050 sensor** monitors tilt and orientation, allowing a servo motor to stabilize the camera for clear image capture. Additionally, a Flask-based web interface provides real-time video streaming and remote control capabilities. This system ensures safe, efficient, and intelligent tunnel inspection without human intervention.

## 3. BLOCK DIAGRAM

The system consists of a **Raspberry Pi 4B** as the main processing unit, which receives input from the camera module for real-time image acquisition and defect detection. The Raspberry Pi communicates with the **Arduino Nano** through serial communication for motion control.The Arduino Nano acts as the control unit, interfacing with the **MPU6050 sensor** to monitor orientation and with a **servo motor** to stabilize the camera. It controls multiple DC motors through **L298N motor drivers**, enabling the robot to move in different directions.Each L298N driver operates a pair of motors (M1–M6), allowing efficient navigation inside the tunnel. This integrated system ensures coordinated image processing, motion control, and stable inspection.




### 3.1 Arduino Nano

The Arduino Nano is a miniature microcontroller board. It uses the ATmega328P chip, similar to the Uno. Its compact size makes it perfect for projects with limited space. You can program it via USB. It has both digital and analogue input/output pins. Hobbyists and professionals use it for diverse electronic applications. Newer versions add features like Wi-Fi and Bluetooth.

Fig 3.1 Arduino Nano

### 3.2 Raspberry pi

The Raspberry Pi is a tiny, single-board computer. It's designed to be affordable and versatile. It runs on Linux based operating systems. It has a processor, RAM, and various ports. You can connect it to a monitor, keyboard and mouse. It's used for education, hobby projects, and industrial applications. It has GPIO pins for connecting electronic components. It's popular for robotics, media centres and home automation. A large community provides support and resources.

Fig 3.2 Raspberry Pi

### 3.3 L298N Motor Driver

The **L298N motor driver** is used to control the speed and direction of DC motors by acting as an interface between the controller and motors. It is based on a dual H-bridge IC, enabling independent control of two motors using PWM signals.In this system, the L298N receives control signals from the **Arduino Nano** and drives the robot's wheel motors, allowing movement in multiple directions. It provides the required current and voltage for safe motor operation.

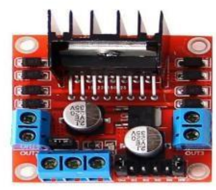


Fig 3.3 L298N motor driver

### 3.4 Servo Motor

A servo motor is a rotary actuator used for precise control of angular position. It operates using PWM (Pulse Width Modulation) signals and consists of a DC motor, gear mechanism, and feedback system for accurate positioning. The servo motor typically provides controlled rotation between 0° and 180°, ensuring stable and precise movement in robotic applications. In the proposed system, the servo motor is used to adjust the orientation of the camera, enabling multi-angle image capture. This improves inspection coverage and enhances the detection of structural defects inside the utility tunnel.


Fig 3.4 Servo motor

### 3.5 LPU6050

The **MPU6050** is a motion tracking sensor that integrates a 3-axis accelerometer and a 3-axis gyroscope to measure acceleration, angular velocity, and orientation. The accelerometer detects linear motion along X, Y, and Z axes, while the gyroscope measures rotational movement.

It communicates with controllers such as Arduino Nano or Raspberry Pi using the I2C protocol for real-time data

transmission. In this system, the MPU6050 is used to detect the tilt and movement of the robot on uneven tunnel surfaces. Based on this data, the controller adjusts the servo motor to stabilize the camera, ensuring level orientation and clear image capture for accurate inspection.

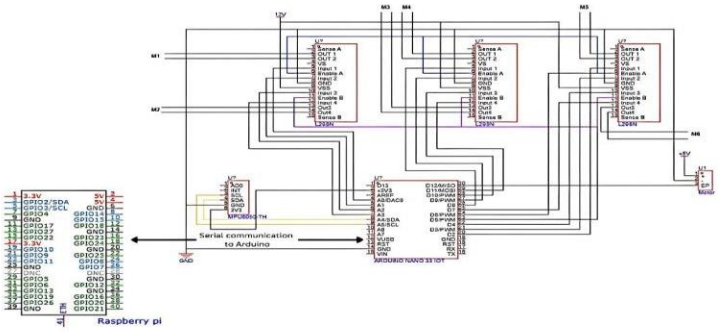
Fig 3.5 LPU6050

### 3.6 Camera Module

The **Raspberry Pi Camera Module** is an image acquisition device used to capture real-time photos and videos. It connects to the Raspberry Pi 4 Model B via the CSI interface using a ribbon cable and consists of an image sensor and lens for visual data capture. It supports high- resolution imaging and continuous video streaming for real-time applications. In this system, the camera captures live video of the tunnel environment, which is processed using the YOLO algorithm for defect detection such as cracks and leakages. The captured data is also streamed to a remote monitoring system for observation and control. The camera enables visual inspection in low-light and confined spaces, improving accuracy, coverage, and real- time monitoring of tunnel conditions..

Fig 3.6 Camera module 4

### CIRCUIT DIAGRAM




## 5 RESULT AND DISCUSSION

The proposed robotic inspection system was successfully implemented and tested for efficient tunnel monitoring and defect detection. The system integrates a Raspberry Pi for real-time image processing and an AI-based YOLO model to identify anomalies such as cracks, severe cracks, and leakage. During operation, the robot moved smoothly using multiple DC motors controlled by an Arduino Nano through motor driver modules, ensuring stable navigation inside the tunnel. Captured video frames were pre-processed and analyzed, and defects were accurately detected when the confidence level exceeded the defined threshold.

Upon detection of anomalies, the Raspberry Pi transmitted a stop command to the Arduino, allowing the robot to pause for detailed inspection and observation. The integration of the MPU6050 sensor and servo motor provided effective camera stabilization, ensuring clear and reliable image capture even on uneven surfaces. Additionally, the system supported real-time video streaming and remote monitoring through a web-based interface, enabling manual control when required. Overall, the system demonstrated reliable performance, improved detection accuracy, smooth mobility, and enhanced safety by minimizing human involvement in hazardous tunnel environments.

## 6 CONCLUSION

The proposed robotic inspection and monitoring system provides a safe, efficient, and reliable solution for utility tunnel inspection, minimizing the need for human entry into hazardous environments. The system integrates a Raspberry Pi for real-time image processing, an Arduino Nano for motion control, and a YOLO-based AI model for accurate detection of defects such as cracks, severe cracks, and leakage.

The robotic platform demonstrates smooth navigation using multiple DC motors and motor drivers, ensuring effective movement inside tunnel environments.

The use of the MPU6050 sensor and servo motor enhances camera stabilization, resulting in clear and consistent image capture even on uneven surfaces. The system also supports real-time video streaming and remote operation through a web-based interface, enabling continuous monitoring and manual control when required. Overall, the proposed system improves inspection accuracy, operational efficiency, and safety. It also provides a scalable solution that can be further enhanced with advanced sensors, autonomous navigation, and improved AI models for smart infrastructure monitoring in the future.

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