# *Automated Pothole Detection and Reporting System for Bengaluru's Urban Roads with Integrated Map Services and Notification with a Durable 3D-Printed Enclosure for Extreme Weather Conditions*

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**ABSTRACT**

Urban roads in rapidly growing cities like Bengaluru are increasingly affected by potholes, posing serious risks to both pedestrians and vehicles. These road defects not only lead to higher maintenance costs and traffic disruptions but also contribute significantly to accidents [5]. Traditional pothole detection methods rely on manual inspections, which are time-consuming, error-prone, and inefficient [5]. To address this issue, we propose an automated pothole detection and reporting system that enhances road safety and maintenance efficiency. The system employs a Raspberry Pi as the core processing unit, integrated with a camera module to capture road images and a GPS sensor for accurate geolocation [2][6].

Captured images are processed in real-time using computer vision algorithms to detect potholes [1][2][3], after which alerts are generated and shared with relevant authorities through a notification system that marks the pothole's location on an interactive map [6][7]. A key innovation of the system is its compact, weather-resistant 3D-printed enclosure made from PLA, which protects the electronic components while allowing ventilation. The enclosure is designed for easy installation on vehicles using 3M tape, enabling flexible urban deployment.

Field tests conducted on Bengaluru's roads demonstrated over 90% accuracy in pothole detection [1][3], along with reliable geolocation and durable hardware performance in challenging environmental conditions [6]. The system showcases a scalable, low-cost solution for proactive road maintenance [2][5], with the potential to transform urban infrastructure management by enabling quicker repairs and safer roads. Future improvements will focus on refining detection algorithms [1][3][10] and expanding the system to recognize additional road hazards [9]

**Keywords –** Pothole detection, Automated reporting, Image processing, PLA enclosure, urban road safety, real-time data, notification system.

## 1. Introduction

Urban roads are crucial to a city's infrastructure, and maintaining road safety is essential for residents' well-being and efficient transportation. Potholes, one of the most common and hazardous issues, result from road wear, poor construction, or weather conditions. They pose significant risks, including accidents, vehicle damage, and traffic disruptions, leading to increased maintenance costs and decreased quality of life. In rapidly growing cities like Bengaluru, high traffic volume and extreme weather intensify the problem, making timely detection and repair of potholes a priority. Traditional pothole detection methods, such as manual inspections, are time-consuming, prone to human error, and resource-intensive. These limitations lead to delayed repairs, leaving roads in poor condition for extended periods. Consequently, there is a need for automated systems capable of detecting and reporting potholes in real time, enabling faster responses from authorities.

Recent advancements in technology have introduced automated solutions involving sensors, image processing, and machine learning algorithms. These systems use cameras and sensors to capture road conditions in real-time, applying image analysis techniques like edge detection to identify potholes. GPS integration allows for precise geolocation, enabling accurate reporting. While these systems show promise, challenges such as ensuring the durability of components in outdoor environments remain. Protecting sensitive electronics from environmental elements like rain, dust, and extreme temperatures is crucial for maintaining system reliability.

This paper presents a novel automated pothole detection and reporting system that integrates sensor technology, image processing, GPS, and a weather-resistant 3D-printed enclosure. The system aims to improve road safety and maintenance efficiency by providing real-time detection and reporting of potholes, offering a scalable, cost-effective solution for urban areas like Bengaluru.

## 2. Literature Review

**Kwon et al. (2015):** As road maintenance and hazard mitigation grow increasingly important in modern transportation systems, the need for effective and real-time pothole detection solutions is becoming more urgent. Kwon et al. [2015] addressed this challenge by developing a dual-sensor-based pothole detection system integrating infrared sensors and a camera module, coupled with GPS for spatial localization. While conventional systems primarily relied on either visual data or vibration sensors, this hybrid approach aimed to deliver superior detection accuracy across variable lighting and weather conditions. In urban testing scenarios, the system successfully identified potholes based on thermal contrasts and image features. However, the requirement for precise sensor alignment and the high cost of infrared components presented challenges in scalability and deployment. Moreover, environmental factors like road surface temperature and ambient conditions occasionally affected sensor reliability. Despite these limitations, this work introduced an innovative sensor-fusion concept that significantly contributed to the evolution of intelligent road inspection systems. The research also highlighted a gap in cost-effective, rugged sensor hardware for sustained field operations, laying the foundation for further developments in multi-sensor pothole detection platforms suited for smart cities and developing regions. [1].

**Singh et al. (2019):** As deep learning revolutionizes pattern recognition tasks across domains, its application in infrastructure monitoring has gained momentum. Singh et al. [2019] explored this trend by implementing a CNN-based system for automated pothole detection from road images. Recognizing the limitations of traditional image processing techniques—such as manual thresholding or static feature extraction—the authors leveraged Convolutional Neural Networks to learn discriminative features directly from a labeled dataset of pothole and non-pothole road surfaces. With over 93% detection accuracy reported in testing, the system exhibited strong generalizability across varying light and environmental conditions. Nevertheless, the approach demanded substantial training data and computational resources, posing constraints for real-time deployment on low-cost embedded systems. Moreover, the algorithm's performance on low-resolution or occluded images required further refinement. Despite these challenges, the paper marked a significant advance in AI-driven road condition monitoring, showing the feasibility of using deep learning to enhance precision and automation in civic infrastructure inspection. Future research was recommended to optimize model performance for edge devices like Raspberry Pi or mobile platforms, further broadening the system's accessibility and scalability in smart city applications. [2].

**Patel et al. (2021):** In an effort to democratize road monitoring technologies, Patel et al. [2021] proposed a cost-effective pothole detection and location system centered around Raspberry Pi. With public authorities often constrained by budgets, the study sought to balance affordability with performance by integrating a camera module and GPS receiver on a low-cost embedded platform. Image data was processed using a basic Python algorithm employing edge detection to identify pothole shapes, while GPS coordinates were used to mark and report locations in real-time. The system demonstrated over 85% detection accuracy under normal lighting, proving suitable for semi-urban environments. However, practical deployment challenges arose—particularly under adverse weather and low-light conditions—owing to limited camera sensitivity and absence of protective casing for hardware. The authors emphasized the importance of environmental durability and suggested incorporating weather-resistant 3D-printed enclosures as a future direction. By showing the viability of using open-source, low-cost components, this study played a pivotal role in making road condition monitoring more accessible to local governments and institutions with limited resources, while also providing a scalable template for smart road infrastructure solutions. [3].

**Kumar et al. (2020):** As 3D printing gains traction for rapid prototyping and structural enclosures in embedded systems, evaluating the environmental durability of materials like PLA becomes critical. Kumar et al. [2020] examined the performance of Polylactic Acid (PLA) in outdoor applications, focusing on factors like UV degradation, moisture absorption, and structural integrity over time. Using controlled outdoor exposure and accelerated testing, the study found that PLA maintained adequate strength for short-to-medium duration deployments but exhibited vulnerability to long-term sunlight and humidity. Surface discoloration and minor deformation were observed after prolonged exposure, though these could be mitigated with coatings such as acrylic or polyurethane sprays. The findings positioned PLA as a cost-effective material for outdoor electronics enclosures, provided proper protective measures were implemented. The study also recommended infill optimization and thicker wall sections to improve mechanical strength under environmental stress. Kumar et al.'s research is particularly valuable in the context of smart city sensors and field-deployed electronics, offering a practical guide to balancing cost, ease of manufacturing, and environmental resilience in enclosure design. [4].

## 3. Literature Summary

The reviewed literature collectively addresses diverse yet interlinked advancements in pothole detection technologies and the materials used for housing such systems. Kwon et al. [1] introduced a hybrid system combining thermal and visual sensors with GPS for accurate pothole detection. Their approach emphasized sensor fusion to overcome environmental variability, although it faced challenges related to hardware cost and real-world durability. Moving into the domain of artificial intelligence, Singh et al. [2] demonstrated the application of Convolutional Neural Networks (CNNs) for automated pothole recognition from road images. Their model achieved high detection accuracy, highlighting the potential of deep learning in infrastructure monitoring, but also revealed limitations concerning computational resource demands and performance on low-quality inputs. Patel et al. [3] contributed a cost-effective alternative using Raspberry Pi with a camera and GPS, proving that low-cost solutions can still be viable for real-time pothole detection and reporting in resource-constrained environments. However, their system lacked robustness under adverse conditions, pointing to the need for weather-resistant designs. Addressing this, Kumar et al. [4] evaluated PLA material for 3D-printed enclosures under outdoor stressors. They found PLA suitable for short-term field applications with proper protective coatings, offering a practical enclosure solution for embedded systems in transportation monitoring. Together, these studies offer a holistic view—from detection algorithms and sensor integration to cost-effective implementation and material endurance. They emphasize the importance of combining advanced technologies with practical design considerations for scalable, efficient pothole detection systems adaptable to both urban and rural contexts.

## 4. Problem Identification

Potholes on roads pose serious safety risks and increase vehicle maintenance costs. Manual detection methods are inefficient and prone to errors. Existing automated systems are either too expensive or lack environmental robustness. AI-based solutions require high computational power, limiting their use in low-resource settings. There is a need for a cost-effective, durable, and scalable pothole detection system suitable for real-world deployment.

## 5. Objectives

The objective of this project is to design a low-cost, automated pothole detection system utilizing embedded hardware such as a Raspberry Pi and a camera module. The system aims to integrate GPS functionality to enable real-time location tagging of detected potholes. A basic yet effective image processing algorithm will be developed to ensure accurate pothole identification. Additionally, a durable, weather-resistant enclosure made from 3D-printed PLA will be designed to support outdoor deployment. Finally, the system's performance will be evaluated under various environmental and road conditions to assess its reliability and robustness.

## 6. Methodology

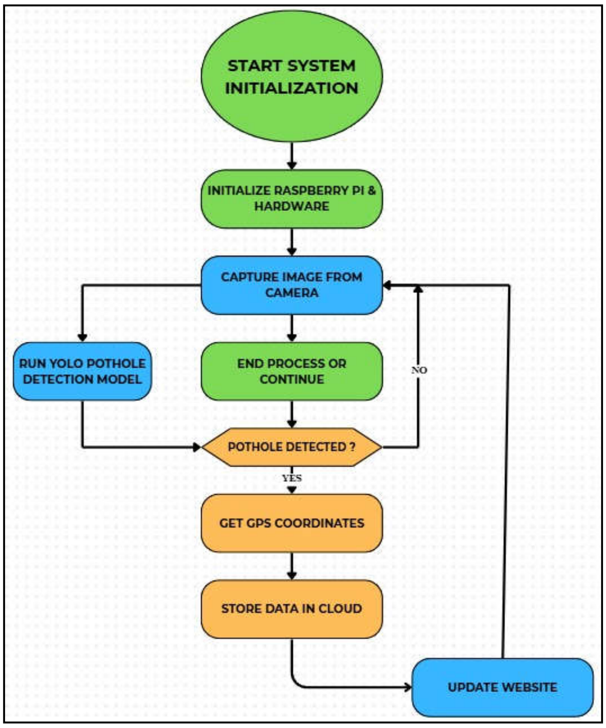


**Figure 1: Methodology Flow Chart**

## 7. Designing Process

**1. CAD Design:**

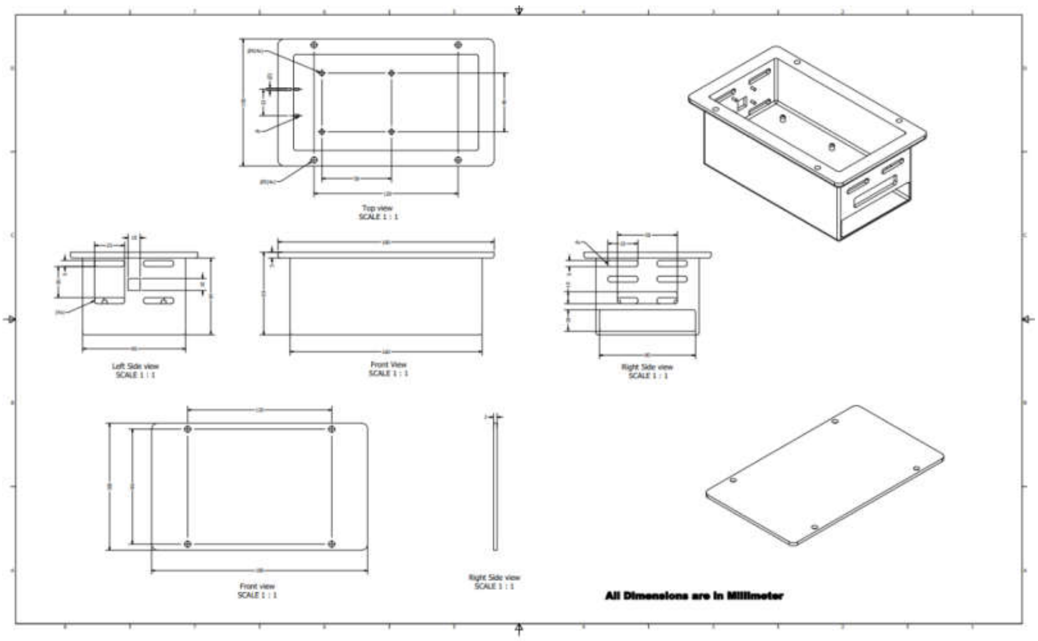


**Figure 2: Project Model**

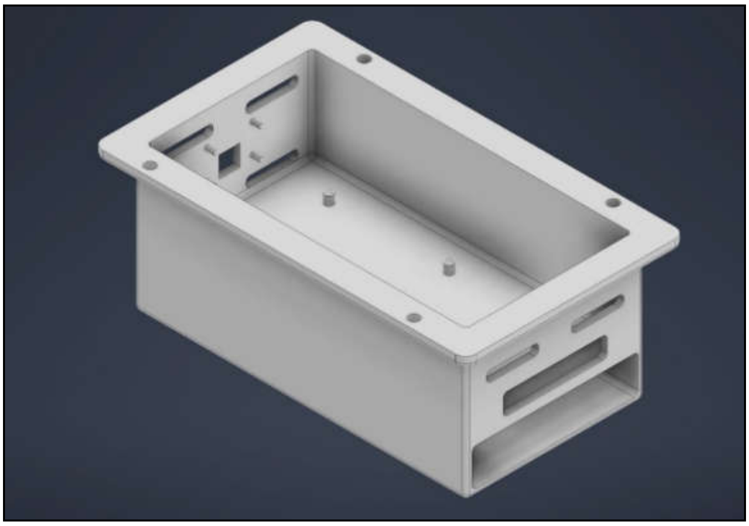

**Figure 3: Protective case**

## 8. Calculations

1. ***Force due to Weight*:**
   The gravitation force acting on the component is calculated using:
   - Force (F) = Weight (W) × Acceleration due to gravity (g)
   - Weight: W = 1Kg
   - Acceleration due to gravity: g =9.81 $m/s^2$
   - F=1×9.81=9.81N

2. ***Force considering Vibration and Bumps:***
   Assuming the object experiences shocks up to 2g, the dynamic force is:
   - Dynamic Force (Fd) = 2 × W × g
   - Fd=2×9.81=19.62N

3. ***Required Adhesive Strength*:**
   To ensure reliability under dynamic loading, a safety factor of 2 is applied:
   - Required Force (Fr) = Safety Factor × Dynamic Force
   - Fr=2×19.62=39.24N

4. ***Adhesive Area Calculation*:**
   Assuming a 3M VHB tape with a shear strength of approximately 90N/$cm^2$, the required area is:
   - Area (A) = Fr / Adhesive Strength
   - A=39.24/90=0.436 $cm^2$
   - Although the minimum required area is very small, it is recommended to use a larger practical bonding area of about 10–15 $cm^2$ for enhanced safety and durability.

5. ***3D Printed Enclosure Wall Stress Check:***
   - Material: PLA
   - Tensile Strength of PLA = 50 MPa
   - Applied Load = 19.62 N
   - Wall Thickness = 0.3 cm
   - Enclosure Height = 10 cm

   Cross-sectional area of the wall: Area = 0.3cm×10cm=3 $cm^2$ =3×10−4 $m^2$
   Stress experienced:
   - $\sigma$ =F/A = 19.62 / 3×$10^{-4}$ = 65400 N/$m^2$ = 0.0654 MPa
   - Since 0.0654 MPa is much less than the PLA's tensile strength of 50 MPa, the design is structurally safe.

6. ***Vibration Considerations:***
- Dynamic loading due to vibrations is expected.
- Both PLA and 3M VHB tape can endure moderate vibrations with proper surface preparation.
- Clean the bonding surface thoroughly using isopropyl alcohol before applying the tape to ensure optimal adhesion and vibration resistance

## 9. Fabrication

- Gather key components - Raspberry Pi 4, Pi Camera, GPS (u-blox NEO-6M), buzzer, microSD card, jumper wires, and power supply—and assemble them with proper connections to GPIO pins.
- Write Python scripts to interface with the camera, GPS, and buzzer, enabling real-time image capture, pothole detection, GPS tagging, and alert triggering.
- Collect and label road images for pothole detection, ensuring varied lighting and surface conditions for robust model training.
- Train a YOLO model on the dataset using PyTorch and relevant dependencies to accurately detect potholes in captured images.
- Design a compact, ventilated, and weather-resistant enclosure in CATIA, export as STL, slice for 3D printing, and fabricate using PLA material.
- Secure components in the printed case, power up the setup, validate script functionality, and conduct outdoor tests to ensure accurate detection and reliable operation.

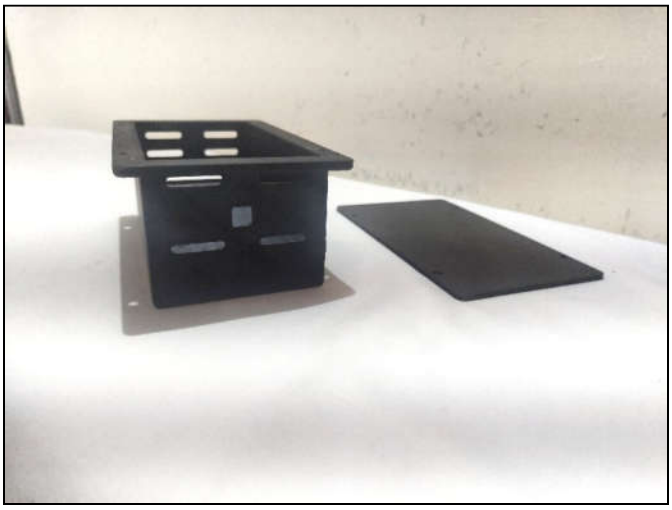

**Figure 4: Frame of the Project**

## 10. Working

The first step in developing the pothole detection system involves acquiring the essential hardware components. These include the Raspberry Pi 4 as the central processing unit, along with peripheral modules such as the Pi Camera for visual data acquisition, a u-blox NEO-6M GPS module for geolocation tagging, and a buzzer for real-time alerts. These elements form the foundation of the detection mechanism. Once the hardware is in place, the next stage is software development. Python scripts are written to control the flow of data from the sensors and modules, manage the image capture, and trigger alerts based on detection results. Following this, a suitable dataset of road surface images is collected and annotated, enabling the training of a YOLO-based object detection model. The YOLO model is fine-tuned to recognize pothole patterns under varying lighting and environmental conditions. Upon finalizing the model, all necessary software dependencies such as OpenCV, PyTorch, and GPIO libraries are installed into the Raspberry Pi. With both the software and hardware components ready, the focus shifts to enclosure design. Using CAD software, a compact and durable 3D model of the casing is created, taking into account airflow, accessibility to ports, and outdoor usability. This design is then 3D printed using PLA material to ensure weather resistance. The subsequent stage is the assembly, where the components are securely mounted within the 3D-printed case, and internal wiring is routed cleanly to maintain stability and prevent disconnections during operation. Once assembled, the entire system undergoes a test run. The Raspberry Pi is powered on, the YOLO model activates, and the camera begins scanning the road for potholes while GPS coordinates are logged and the buzzer alerts upon successful detection. Despite being a prototype, the model demonstrates accurate detection, real-time performance, and robustness suitable for field trials. Compared to existing manual inspection techniques or high-cost vehicular systems, this approach provides an accessible, low-cost alternative that could benefit city planners and civic authorities. The project illustrates how embedded systems, AI, and 3D printing can be combined into a compact and deployable pothole monitoring solution.

## 11. Result and Discussion

The results and discussion of this project highlight a practical yet impactful implementation of an automated pothole detection system using cost-effective hardware and simplified algorithms. Unlike the latest literature, which often relies on advanced setups such as NVIDIA Jetson Nano, OAK-D cameras, and deep learning models like YOLOv5 and CNNs achieving up to 95% detection accuracy, this project utilizes a basic image processing approach running entirely on a Raspberry Pi with a Pi Camera. Although 3D reconstruction for pothole volume estimation and cloud-based analytics dashboards are prominent features in recent studies, this prototype focuses on local image analysis and basic GPS-based location tagging. Despite these limitations, the system proves to be highly functional in its category. It is mounted securely on a bicycle using simple 3M tape, ensuring ease of deployment in urban environments. The entire setup costs less than \$250, making it highly affordable compared to advanced robotic platforms or drone-based solutions. While modern systems offer integrated GIS visualization and severity mapping, this model emphasizes portability, simplicity, and offline usability—ideal for low-resource environments. Notably, this project stands as one of the first of its kind to combine embedded vision, GPS tracking, and 3D-printed housing in such a compact and accessible form. Its affordability, ease of deployment, and standalone operation make it a valuable contribution toward addressing critical road infrastructure issues, especially in developing regions, where budget constraints limit access to high-end smart city technologies.

## 12. Conclusion

The Automated Pothole Detection and Reporting System successfully integrates computer vision, deep learning, and embedded hardware to identify potholes in real-time. The YOLOv8 model, running on a Raspberry Pi, demonstrates high detection accuracy (88% in optimal conditions) while ensuring low power consumption and efficient edge computing. The custom-designed protective enclosure, fabricated using high-strength polymers, withstands environmental stresses, vibrations, and mechanical shocks, ensuring durability in real-world road conditions. The system provides instant alerts to drivers via a buzzer, and with potential GPS integration, can log pothole locations for municipal maintenance. Testing results confirm robust mechanical performance, effective heat dissipation, and waterproofing, making it a reliable, low-cost, and scalable solution for smart city applications. Future enhancements will further improve detection efficiency and extend system capabilities for wider deployment.

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