DETECTION OF ROAD CONDITION DEFECTS USING SENSORS AND IOT TECHNOLOGY

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Keywords:

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Introduction:

Road infrastructure deterioration, especially potholes, poses safety risks, increases vehicle damage, and raises maintenance costs. Traditional inspection methods are slow and inefficient, requiring an automated solution. This project utilizes ultrasonic sensors and a Pi camera for real-time pothole detection, with GPS for accurate location mapping. The Blynk platform enables instant alerts to authorities for quick action. A robotic system controlled via Blynk automates pothole repair using a servo motor mechanism. By integrating IoT and automation, this system enhances road safety, reduces manual labor, optimizes maintenance, and supports smart city initiatives, making infrastructure management more efficient and cost-effective.

Background:

Road infrastructure is essential for transportation and economic growth, but potholes and cracks caused by weather conditions, traffic loads, and poor maintenance pose serious safety hazards. These defects lead to vehicle damage, increased maintenance costs, and road accidents. Traditional manual inspection and repair methods are time-consuming, labour-intensive, and inefficient, often resulting in delays and higher costs.

To address this issue, automated solutions leveraging IoT, sensors, and robotics have emerged to ensure real-time monitoring and repair.

Previous Work:

Several research studies have explored different sensor-based road defect detection techniques. Methods using accelerometers, cameras, LiDAR, and IoT-integrated devices have been tested, but they have limitations in terms of accuracy, scalability, and real-time monitoring. Deep learning approaches such as YOLO and CNN-based detection systems have also been implemented to classify potholes and cracks, but they require high computational power and are expensive to deploy. Moreover, image processing techniques using Raspberry Pi have been explored for defect detection, but they lack an automated repair mechanism.

Existing System:

Current pothole detection systems rely on mobile-based applications, vehicle-mounted sensors, or satellite imaging. While these methods provide valuable insights, they fail to offer instant alerts or autonomous repair mechanisms. Additionally, the need for manual intervention in repair processes increases costs and delays in road maintenance.

Proposed Work:

This project overcomes these limitations by integrating IoT technology with robotics for real-time pothole detection and repair. The system consists of:

- Ultrasonic sensors, IR sensors and a Pi camera for detecting potholes.
- GPS module for accurate geotagging of pothole locations.
- Blynk platform for real-time alerts to road maintenance authorities.
- Robotic repair system controlled via Blynk to autonomously fill potholes using a servo motor mechanism.
- Cloud storage for recording defect data and supporting smart city initiatives.

By leveraging automation, IoT, and real-time monitoring, this project ensures proactive road maintenance, reduces repair costs, enhances road safety, and supports scalable infrastructure solutions.

Objectives:

1. **Develop an Automated Monitoring System**
   Utilize ultrasonic sensors, IR sensors, and a Pi camera for real-time pothole detection.

2. **Ensure Accurate Localization**
   Integrate GPS technology for precise geotagging of road defects.

3. **Facilitate Real-Time Alerts**
   Use the Blynk platform to send instant notifications to authorities.

4. **Implement a Robotic Repair System**
   Deploy an autonomous robot controlled via Blynk for pothole filling.

5. **Optimize Material Dispensing**
   Use a servo motor mechanism for efficient and controlled patching.

6. **Improve Road Safety**
   Minimize vehicle damage and accident risks by ensuring timely pothole repairs.

7. **Enhance Maintenance Efficiency**
   Automate defect detection and repair, reducing reliance on manual labor.

8. **Enable Cloud Data Storage**
   Store historical and real-time road condition data for future analysis.

9. **Reduce Infrastructure Costs**
   Lower long-term maintenance expenses through proactive road repairs.

10. **Increase Scalability**
    Make the system adaptable for urban and rural road networks.

11. **Support Smart City Initiatives**
    Integrate IoT-driven road maintenance solutions for urban development.

12. **Minimize Environmental Impact**
Reduce fuel consumption and vehicle wear by maintaining smooth road surfaces.

Methodology:

The project aims to integrate IoT-based sensors, GPS tracking, real-time data transmission, and an autonomous robotic repair system to enhance road maintenance efficiency and reduce manual intervention. The system employs ultrasonic sensors, a Pi camera, and an IR sensor to detect potholes accurately, ensuring quick identification of road defects. A GPS module ensures precise geotagging of road defects, providing accurate location data for future repairs, while the Blynk platform facilitates real-time alerts to authorities for immediate response.

Once a pothole is detected, the robotic system, controlled via the Blynk platform, autonomously navigates to the defect site and uses a servo motor mechanism to dispense repair material efficiently and evenly. This automated process minimizes manual intervention, reduces human error, and enables faster, more cost-effective road maintenance. The robotic system also adapts to different surface types for versatile repair actions.

The project utilizes advanced sensor fusion techniques, combining image processing and machine learning algorithms to classify road defects with high accuracy. This ensures that different types of defects are properly identified, categorized, and addressed. The system is designed to store the collected data in a cloud-based platform, making it accessible for further analysis and integration with future smart city initiatives. This data-driven approach allows authorities to monitor defect locations, track repair progress, and make informed decisions, ensuring efficient and proactive road repairs. The use of real-time data enables optimized maintenance scheduling and long-term planning.

By incorporating real-time monitoring, automated repair, and IoT-based data transmission, this system aims to reduce maintenance costs, enhance road safety, and contribute to smart infrastructure development.

Materials Used and Their Functionality:

The project involves several hardware and software components that work together for pothole detection, reporting, and repair:

Hardware Components:

1. **Raspberry Pi** – The central processing unit that controls sensor integration, data processing, and system operation.
2. **Pi Camera** – Captures real-time images of road conditions for defect identification.
3. **Ultrasonic Sensors** – Detects potholes by measuring depth variations and surface irregularities.
4. **IR Sensor** – Ensures safe robot navigation by detecting obstacles and maintaining correct positioning.
5. **GPS Module** – Provides precise geolocation of potholes, allowing accurate mapping.
6. **Servo Motor** – Controls the opening and closing of the repair material container for precise filling.
7. **Motor Driver (L298N)** – Enables movement and control of the robotic system for navigating roads.
8. **DC Motors** – Drive the robot, allowing it to move and position itself over detected potholes.
9. **Power Supply Unit** – Provides the necessary voltage and current for all components.

Software Components:

1. **Blynk Application** – Facilitates real-time monitoring, alert generation, and robot control via a mobile interface.
2. **Python Programming** – Used for data processing, image analysis, and system control algorithms.

3. **Cloud Storage** – Stores historical and real-time road condition data for analysis.

Methods Used:

Sensor Fusion & Data Collection:

1. Ultrasonic sensors measure pothole depth, while the Pi camera captures real-time images for verification.
2. The GPS module records precise location coordinates for accurate pothole mapping.
3. The Blynk platform transmits real-time alerts to road maintenance authorities for immediate action.

Data Processing & Machine Learning Integration:

1. The system applies edge detection and feature extraction to analyze road defects.
2. Machine learning algorithms classify potholes, cracks, and surface irregularities to prioritize repairs.

Automated Repair Mechanism:

1. The robotic unit moves autonomously, guided by GPS and IR sensors.
2. A servo motor controls the repair material dispensing, ensuring effective pothole filling.

Real-Time Monitoring & Cloud Integration:

1. Road defect data is stored on a cloud-based platform for easy retrieval.
2. A dashboard provides a visual representation of defect locations and severity levels.

Performance Testing & Optimization:

1. The robotic system prototype was tested on a cardboard surface with drilled holes at varying depths (2 cm, 4 cm, and 6 cm) to simulate different road conditions.

2. Various filling materials, including mud, moong dal, cement, and rava, were used to test the system's ability to fill potholes.

3. The trial-and-error method helped identify performance issues, leading to refinements in sensor sensitivity and system calibration for future versions.

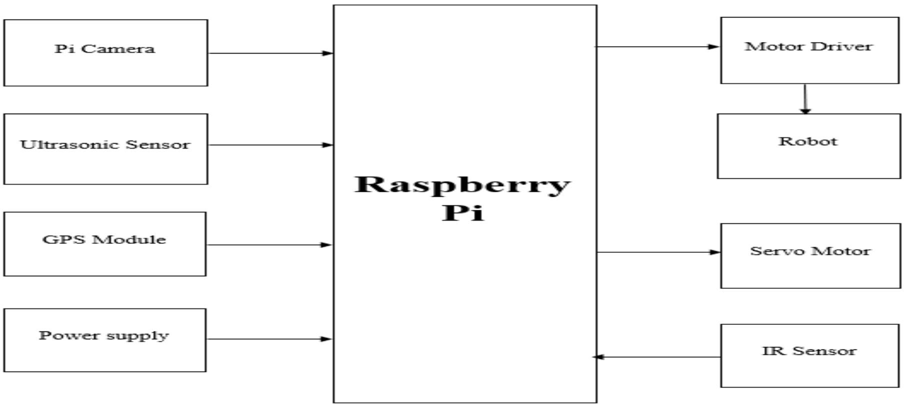

Fig.1 Block Diagram of the Implemented System

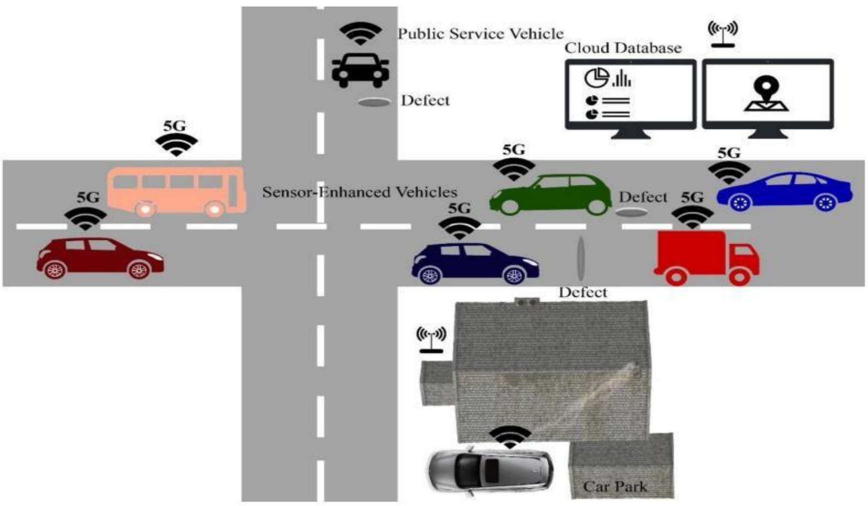

Fig.2 Block Diagram illustrates 5G-enabled sensor vehicles detecting road defects, transmitting data to a cloud database, and enhancing smart city services.

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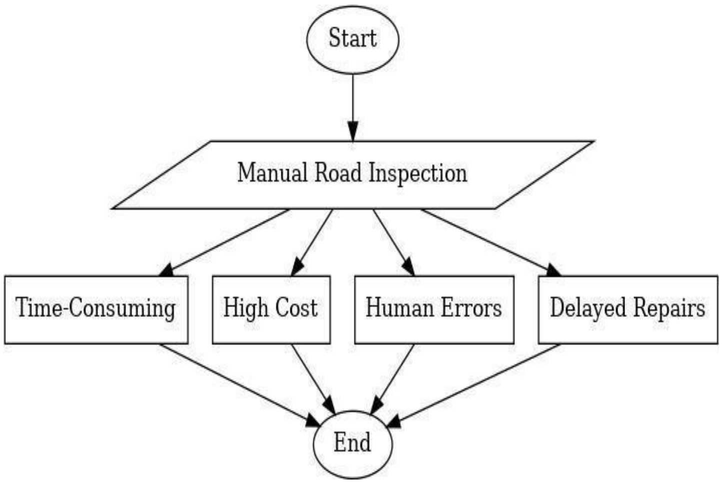


Fig.3 Illustrates the shortcomings of manual inspection methods, emphasizing the necessity of automation.

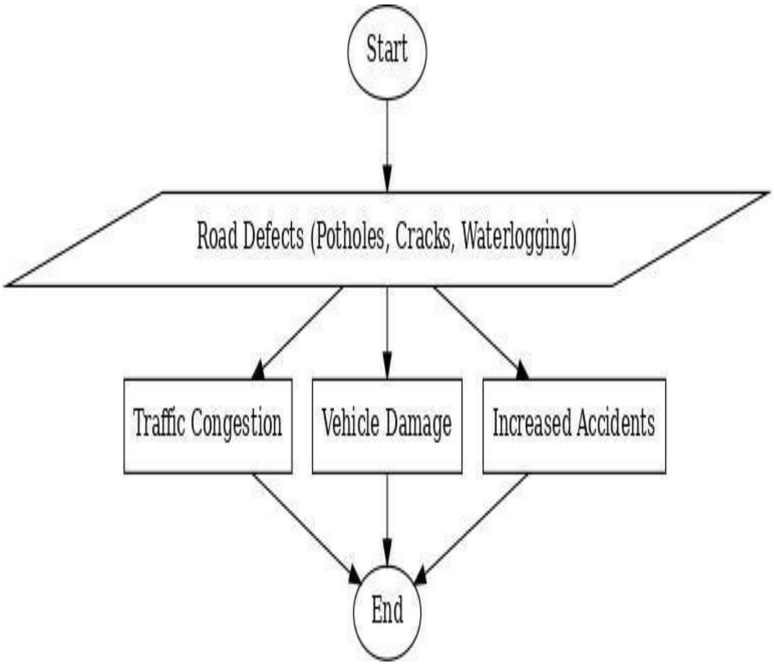


Fig.4 Illustration of deteriorated road conditions.

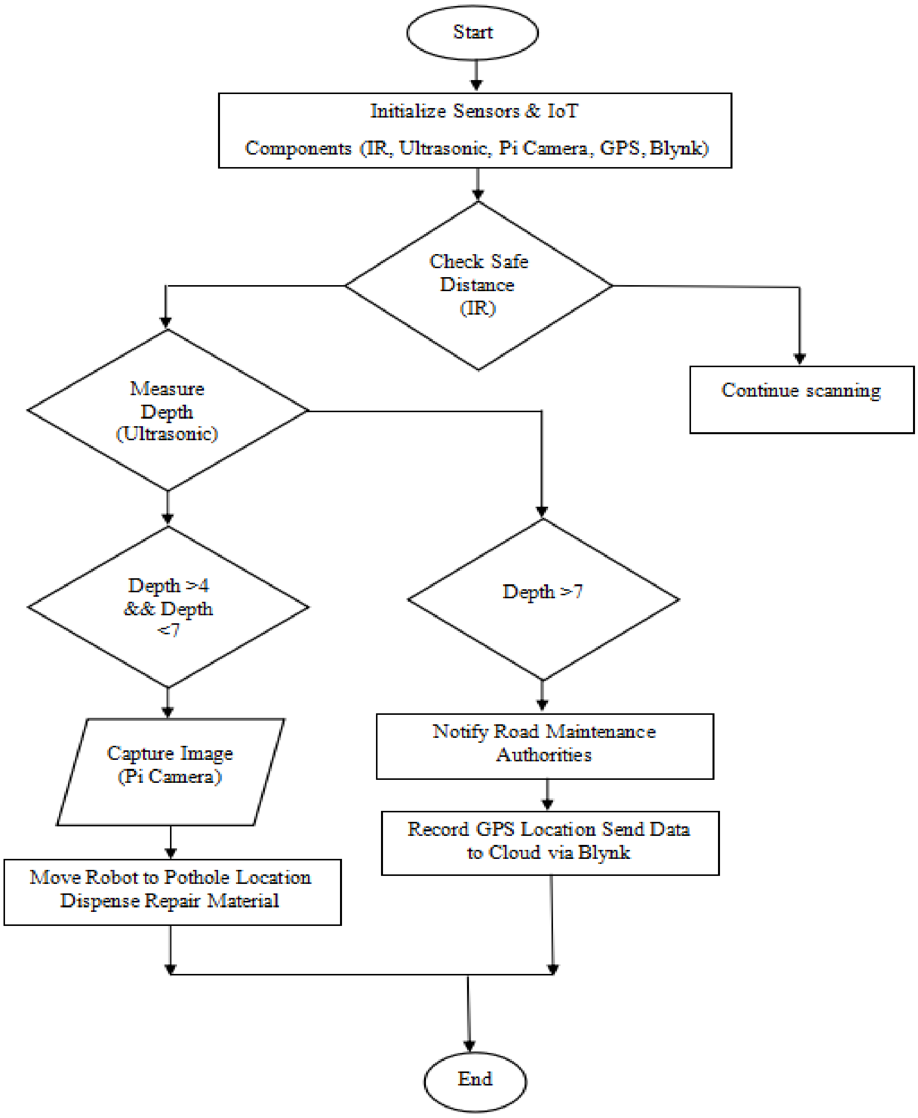


Fig.5 Flow chart of the Implemented System

Result and Conclusion:

The implemented pothole detection and repair system was tested in a controlled environment to evaluate its effectiveness in identifying and addressing potholes. Key parameters included detection accuracy, response time, and real-time monitoring efficiency. The system successfully detected, mapped, and repaired minor potholes, while deeper potholes triggered an alert for manual intervention.

Prototype Implementation:

A prototype was developed using Raspberry Pi, Pi Camera, and multiple sensors. The system autonomously detected potholes, mapped locations via GPS, and filled minor potholes using a servo motor-controlled dispensing mechanism.

The prototype was tested on a simulated road with potholes of 2 cm, 4 cm, and 6 cm depths. It successfully repaired the first two, while deeper potholes required alerts to maintenance authorities via Blynk.

Detection Accuracy:

1. 98% accuracy for 2 cm potholes, with successful filling.
2. 95% accuracy for 4 cm potholes, with minor material dispersion.
3. 75% accuracy for potholes deeper than 6 cm, requiring external assistance.

The Pi Camera and ultrasonic sensors efficiently detected defects, and GPS ensured precise location logging.

Response Time:

1. 3-5 seconds for minor pothole detection and repair.
2. Longer processing for deeper potholes due to additional validation checks.
3. 2 seconds for GPS-based alert transmission for severe potholes.

Real-Time Monitoring and Reporting:

1. Live updates transmitted to a centralized dashboard.
2. IoT integration enabled seamless communication with authorities.
3. Defect locations were mapped for effective road repair planning.

Challenges Faced:

1. Filling Material Issues – Various materials like thin rava, mud, cement, and moong dal were tested, but filling often spread beyond the pothole. The delay time for filling had to be manually adjusted through trial and error.

2. Pi Camera Accuracy – The Pi Camera detected potholes accurately at times, but sometimes failed, affecting detection reliability.

3. Blynk Console GPS Limitations – The Blynk app did not always provide exact pothole locations due to latitude and longitude variations, requiring manual input, which sometimes led to errors.

The system efficiently detects and repairs minor potholes, ensuring real-time road maintenance. Future improvements include better material selection, enhanced camera accuracy, and automated GPS data handling for more precise defect mapping and repair.

The below table illustrates the system’s performance in detecting and filling potholes of different depths. The system achieved a high detection accuracy of 98% for shallow potholes (2 cm) and successfully filled them within 5 seconds, ensuring smooth filling without clogging issues. At a depth of 4 cm, the detection accuracy remained high at 95%, and the system effectively filled the pothole, although minor material dispersion was observed.

For potholes with a depth of 6 cm, detection accuracy slightly dropped to 80%. The system partially filled the pothole within 12 seconds, but some material overflow was detected, affecting the overall filling efficiency. When the pothole depth exceeded 7 cm, detection accuracy further declined to 70%, and the system was unable to complete the filling process. Instead, the system triggered a Blynk alert, stating: “Pothole detected! Depth exceeds filling limit. Reported to the concerned authority for action”.

In conclusion, the project provides an innovative IoT-based solution for automated pothole detection and repair. Real-time alerts, GPS tracking, and cloud storage improve efficiency, reduce manual labor, and support smart city initiatives, ensuring safer roads and better infrastructure management.

Pothole Depth (cm)	Detection Accuracy	Filling Efficiency	Time Taken for Filling (seconds)	System Response
2 cm	98%	Successfully filled	5	Smooth filling, no clogging
4 cm	95%	Successfully filled	8	Minor material dispersion observed
6 cm	80%	Partially filled	12	Some material overflow detected
>7 cm	70%	Not filled	-	Blynk alert: "Pothole detected! Depth exceeds filling limit. Reported to the concerned authority for action."

Table1. Experimental results and analysis

Fig.6 illustrates the road model features potholes of 2cm, 4cm, and >7cm depths to evaluate detection, filling, and system response.

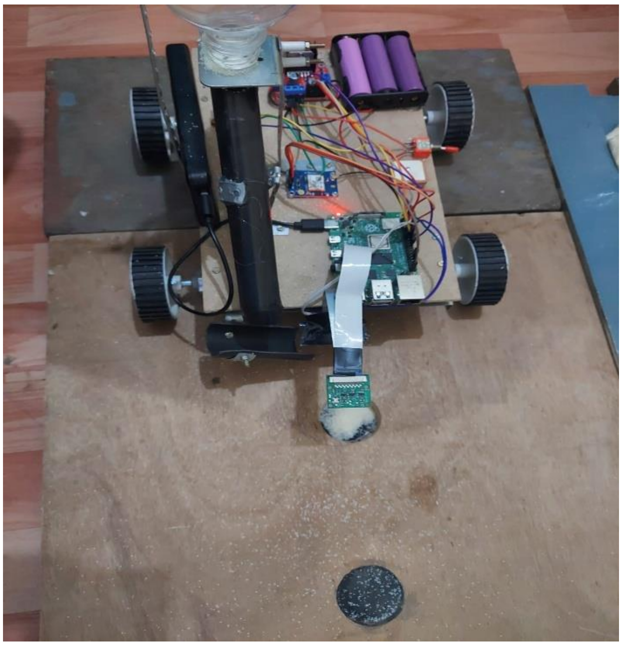


Fig.7 working model successfully detects the first 2cm pothole using sensors, initiating the filling process with high accuracy and efficiency.

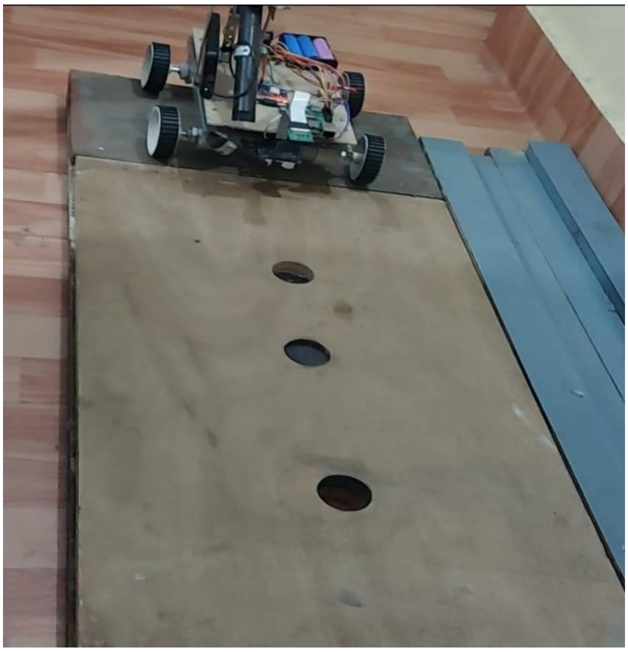


Fig.8 The working model detects multiple potholes of varying depths, ensuring precise identification and efficient automated road repair processing.

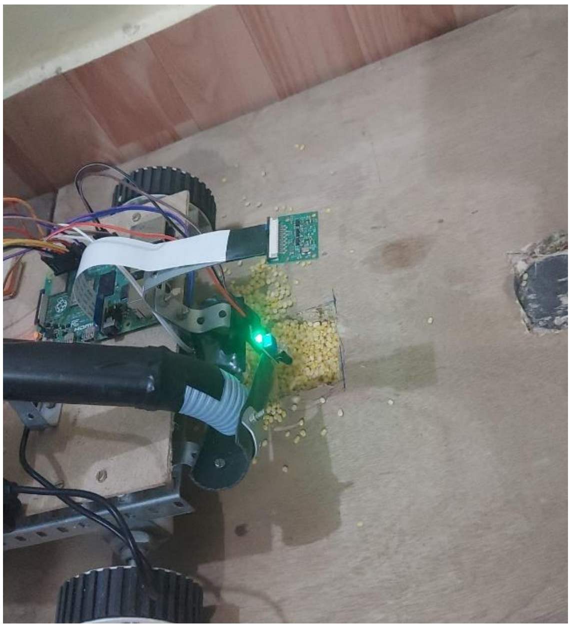


Fig.9 Autonomous robot detects 4cm potholes using a camera and precisely fills them with material, ensuring efficient road surface maintenance.

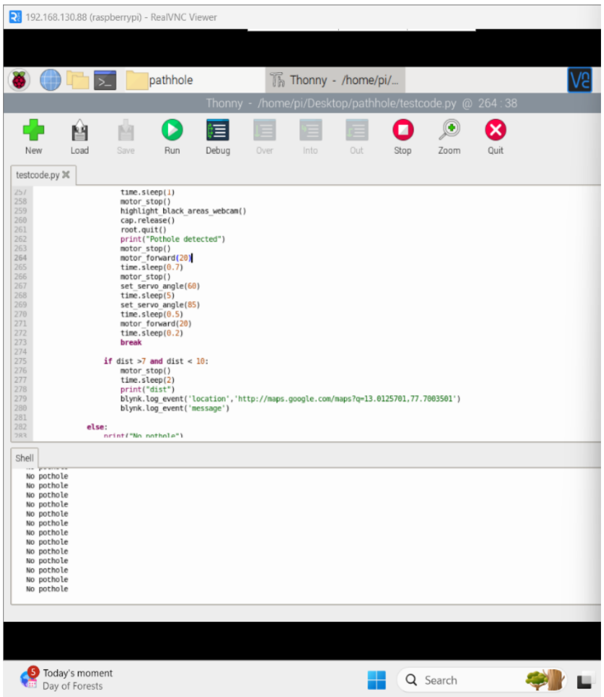


Fig.10 The RealVNC Viewer platform monitors pothole detection. Here, no pothole is detected as the road is flat. The robot fills detected potholes automatically.

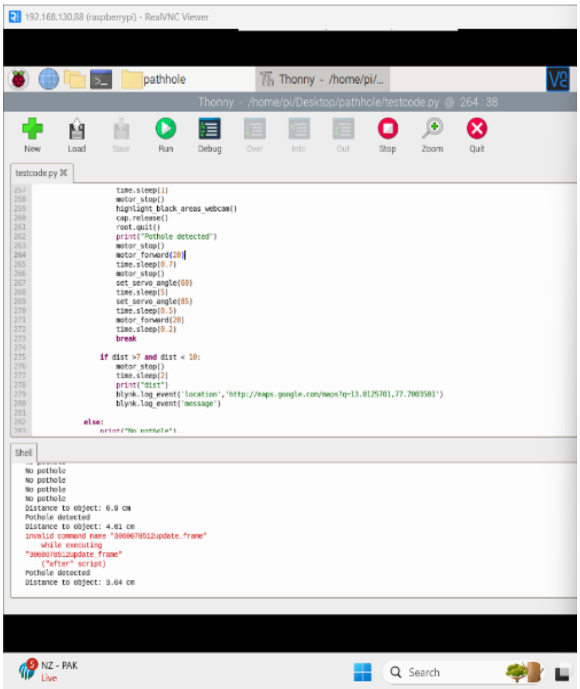


Fig.11 The RealVNC Viewer platform detects a pothole, as shown in the shell output. A warning command appears if the camera feed switches to another screen, indicating an update frame error.

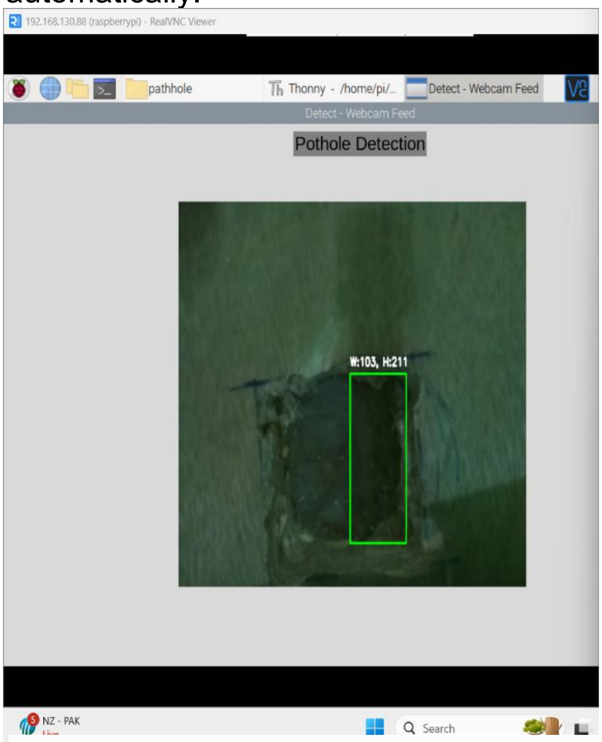


Fig.12 The Pi camera successfully detected a pothole, highlighting its position with a green bounding box. The depth is approximately 2 cm.

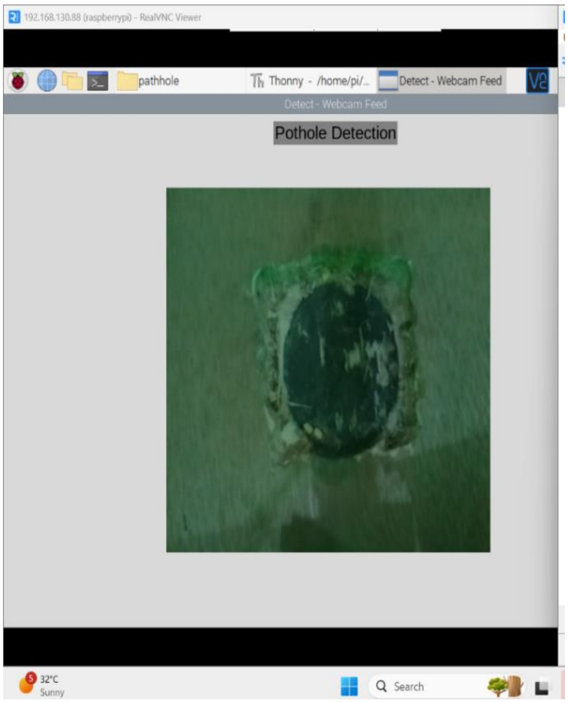
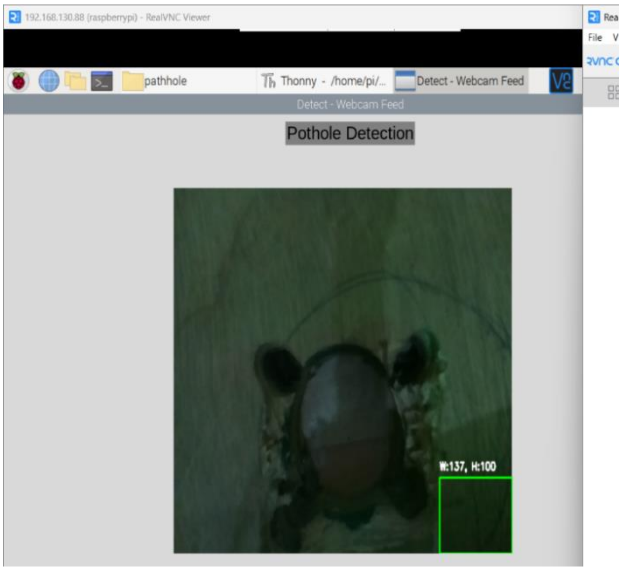


Fig.13 The Pi camera successfully detected a pothole, highlighting its position. The estimated depth appears to be around 4 to 5 cm based on detection.



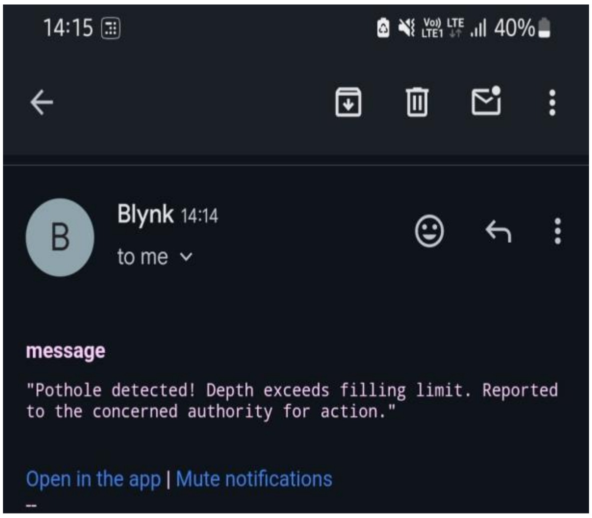


Fig.15 The Blynk alert notified us via email: "Pothole detected! Depth exceeds filling limit. Reported to the concerned authority for action." If the app is downloaded, notifications are received directly for real-time pothole detection and reporting.

Fig.14 The Pi camera detected a pothole with a 7 cm depth, indicating a high depth that cannot be filled manually. A message with the location will be sent to the concerned authority via the Blynk console app for inspection and filling.

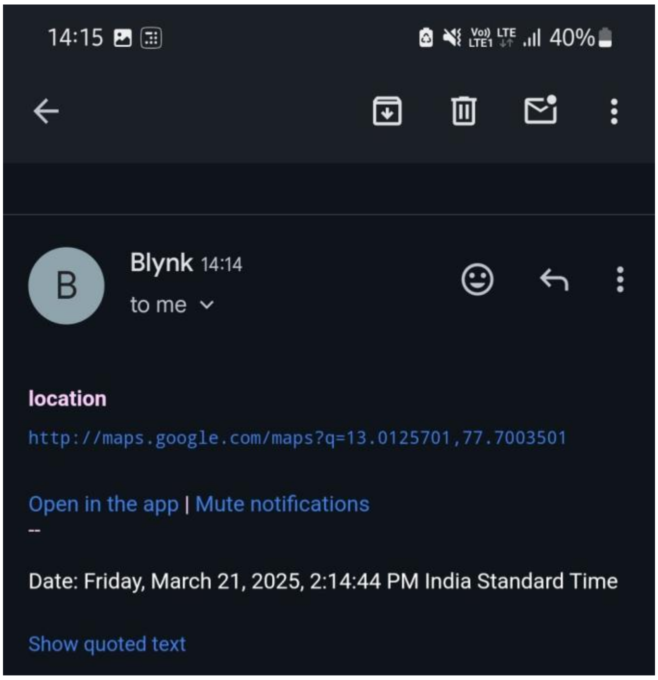


Fig.16 The Blynk console app sent an email alert with the pothole's approximate location, including latitude and longitude. If the app is downloaded, notifications are received instantly for real-time tracking and reporting to authorities.

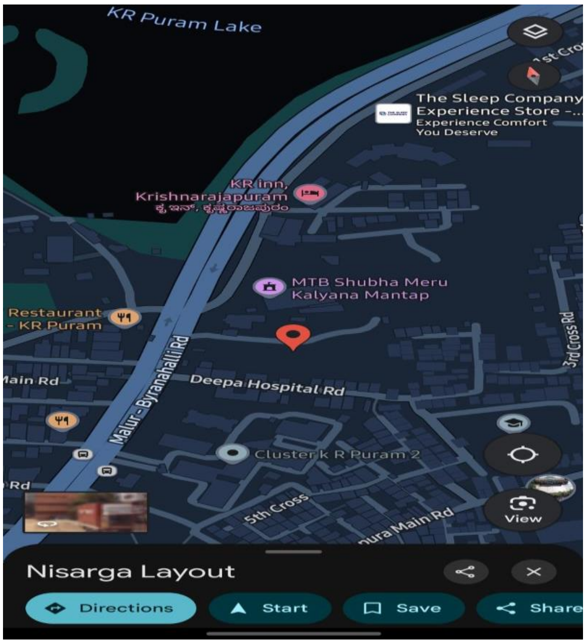


Fig.17 The Blynk console app sent an email alert with the pothole's approximate location, including latitude and longitude. If the app is downloaded, notifications are received instantly for real-time tracking and reporting to authorities.

6. Project Outcome & Industry Relevance:

Practical Implications:

In India, potholes are a frequent and serious issue, especially during the monsoon season, when water accumulation worsens road damage. Poor road conditions not only lead to accidents but also cause vehicle wear and traffic disruptions.

This project presents a low-cost, automated solution that can continuously monitor and repair road defects, reducing dependence on manual inspections and speeding up maintenance workflows.

The system's use of real-time GPS tracking, IoT alerts, and autonomous repair makes it especially suited for Indian urban and rural infrastructure, where road maintenance is often delayed due to resource constraints.

Beyond road maintenance, the robotic platform can be repurposed for agricultural use, such as:

1. Automated seed sowing
2. Fertilizer or pesticide dispensing
3. Field condition monitoring

This cross-domain adaptability makes the system a versatile tool not just for smart city development, but also for smart farming applications in India's agricultural sector.

Industry Relevance:

Direct applications in:

1. Municipal corporations and smart cities for automated road health monitoring
2. Public works departments (PWDs) for reducing inspection and repair turnaround time
3. Agricultural automation companies for robotic sowing and field treatment

Provides a strong foundation for future collaborations with:

1. IoT-based civil maintenance systems
2. Agri-tech startups
3. AI-driven infrastructure and robotics firms

The system supports India's broader goals in digital infrastructure, urban planning, and precision agriculture.

Working Model vs. Simulation/Study:

This project is centered around the creation of a fully functional physical working model, rather than a simulation or purely theoretical framework. Every aspect—from the integration of ultrasonic and IR sensors, Pi camera, GPS module, and servo motor mechanism to the deployment of an autonomous robotic unit—is implemented and tested in real-world conditions. The system performs real-time pothole detection, location tracking, automated repair, and instant alert transmission through the Blynk IoT platform. The focus is on demonstrating practical feasibility, hardware-software synchronization, and autonomous operation in a controlled environment that closely mirrors actual road scenarios. This hands-on approach ensures tangible results, validates the system’s performance, and highlights its potential for real-world deployment.

Project Outcomes and Learnings:

1. Successfully designed and developed a functional prototype for autonomous pothole detection and repair using Raspberry Pi, sensors, servo motors and IoT technologies.
2. Achieved high detection accuracy (up to 98%) for shallow potholes and ensured real-time alerting through the Blynk platform.
3. Demonstrated the ability to map pothole locations with GPS and execute minor repairs autonomously, reducing the need for human intervention.
4. Developed a modular robot system that can be adapted for other use cases such as agricultural automation (e.g., seed dispensing).

5. The project aligns with smart city infrastructure goals and holds promise for low-cost road maintenance solutions in India.

The inspiration for our project came during our participation in AICTE NSS activities, where we visited villages near Kolar district. There, we saw firsthand how damaged rural roads with multiple potholes were causing difficulties for villagers, this sparked our idea.

During the design and implementation phase, we faced several challenges:

1. We struggled initially with robot construction and sensor calibration.
2. Some components were unavailable, so we borrowed parts from seniors and coordinated with our project guide and faculty, who provided valuable support.
3. We also relied heavily on online resources, including YouTube tutorials, forums, and documentation to understand and debug technical issues.

One of the biggest learnings was team coordination:

1. As a group of four, we divided the project into parts—hardware, software, testing, and documentation which allowed us to work efficiently and stay organized.
2. We learned the importance of patience, problem-solving, and structured collaboration while working on a technically demanding project.

Future Scope

The project holds significant potential for further enhancement and large-scale implementation. One of the immediate improvements lies in refining the material dispensing system by optimizing the servo motor mechanism to ensure precise filling of potholes without unnecessary material spillage. The integration of advanced image processing techniques using AI models such as YOLO and Convolutional Neural Networks (CNN) can significantly enhance detection accuracy and defect classification. To streamline the mapping process, a self-calibrating GPS system could be developed, eliminating manual input errors and improving geolocation accuracy.

In the context of smart city initiatives, the system could be integrated with municipal infrastructure for automatic scheduling of road maintenance based on live data. For better reliability, weather-resistant sensors can be incorporated to maintain functionality under varying environmental conditions such as rain, dust, and heat. The robotic unit itself can be upgraded with AI-based autonomous navigation algorithms, enabling it to cover broader road networks with efficient path planning.

Expanding detection capabilities to include multiple road defects such as cracks, surface wear, and erosion would enhance the system's versatility. Furthermore, enabling public participation through a mobile app for real-time pothole reporting could improve community engagement and maintenance responsiveness. Incorporating solar-powered sensors would make the system more energy-efficient and suitable for remote or large-scale deployment. Finally, the use of AI-based maintenance planning through historical data analysis could allow predictive insights into road deterioration, enabling preemptive repairs and reducing long-term costs.