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AI-Based Road Pothole Detection Robot and Driver Assistance System

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Abstract: *Road potholes are a major cause of accidents, especially for two-wheelers, three-wheelers, and older vehicles that lack advanced safety technologies. While modern automobiles equipped with Li-DAR can detect such road defects, most common vehicles on Indian roads do not have this capability. To address this gap, our project proposes a camera-based pothole detection system that identifies pits in real time and records their exact location using GPS coordinates (latitude and longitude). The detected potholes are then mapped and displayed on a mobile application similar to Google Maps, providing users with a visual pothole-alert system. This approach enables early identification of hazardous road surfaces, helping drivers avoid accidents and improving overall road safety.Keywords—Pothole detection, road damage, computer vision, YOLOv5, deep learning, Raspberry Pi, driver assistance, real-time monitoring, 2D Geo-tagged video map, photographic classification.*

Keywords: *Road potholes*

I. INTRODUCTION

Road infrastructure is a fundamental component of safe transportation and a key driver of economic development. Despite continuous improvements in roadway construction, potholes and surface irregularities remain a widespread issue across both developing and developed nations. These defects not only disrupt traffic flow but also pose a significant threat to motorists, leading to accidents, vehicle damage, and frequent congestion. Conventional methods of identifying potholes rely on manual surveys, which are slow, labor-intensive, and often inaccurate due to human limitations.

Maintaining road quality is essential for ensuring public safety and transportation efficiency. Regular monitoring and timely repairs help preserve pavement integrity, enhance driving comfort, and support national economic growth. However, factors such as heavy traffic loads, inadequate drainage, environmental wear, material deterioration, and aging infrastructure continue to accelerate pavement damage. Among the various forms of distress, potholes are particularly problematic due to their rapid development and high risk to road users.

Potholes—formed by repeated surface degradation—can cause serious consequences, including tire damage, misalignment, suspension failure, and fatal accidents. In countries like India, thousands of fatalities each year are linked to pothole-related incidents, especially during the monsoon season when water-filled depressions become difficult to identify. Early and accurate detection of these hazards is therefore critical for preventing accidents and enabling authorities to undertake timely repairs.

To address this urgent need, the present study introduces an AI-driven pothole detection system utilizing advanced YOLO (You Only Look Once) deep learning models for real-time identification and classification. The proposed solution processes road images through a camera-based setup, detects potholes in real time, and records their GPS coordinates along with severity details. The information is then transmitted to an Android application, allowing users and road

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maintenance authorities to visualize pothole locations on an interactive map. This integrated system provides a proactive approach to road monitoring, supporting quicker maintenance decisions and ultimately improving overall road safety.

II. LITERATURE REVIEW:

1. Gap Identified from Reddy et al. (2020) – NodeMCU-Based Pothole Detection
The system developed by E. J. Reddy et al. (2020) uses ultrasonic sensors with a NodeMCU board to detect potholes. Although cost-effective, this approach has notable drawbacks:
-It depends solely on sensor distance, leading to inaccurate results on uneven roads.
-It lacks camera-based detection or deep-learning capabilities.
-It does not capture images, GPS coordinates, or severity information.
-No mobile mapping or real-time user interface is provided.
Resulting Research Gap:
Absence of a visual, AI-based, GPS-integrated pothole detection system suitable for large-scale public use.

2. Gap Identified from Koch & Brilakis (2011) – Vision Tracking for Pavement Assessment
Koch & Brilakis propose a vision-based pavement evaluation system primarily for specialized survey vehicles. This restricts usability for everyday motorists, especially two- and three-wheelers prevalent in India.
Resulting Research Gap:
Lack of a low-cost, camera-based pothole detection system designed for common vehicles.

3. Gap Identified from Hegde et al. (2014) – Pothole Detection and Inter-Vehicular Communication
This study focuses on detection and communication but does not cover a complete workflow involving GPS tagging, cloud storage, and mobile visualization.
Resulting Research Gap:
No end-to-end pipeline combining detection, localization, cloud integration, and user mapping.

4. Gap Identified from PITFREE by Singal et al. (2018) – Mobile Sensor Detection on Indian Roads
The PITFREE system uses mobile phone sensors to detect potholes, but:
-It fails in complex lighting or weather conditions.
-It cannot classify potholes accurately without visual proof.
-It lacks severity estimation and map visualization.
Resulting Research Gap:
Insufficient accuracy and lack of visual deep-learning validation for pothole classification.

5. Gap Identified from Barnwal (2015) – Vehicle Behavior Analysis for Surface Detection
This work detects uneven surfaces using vehicular behavior but does not address:
-Visual identification of potholes
-GPS-based mapping
-Real-time alerts for the public
Resulting Research Gap:
No direct pothole identification or user-facing alert system.

6. Gap Identified from Fernandez-Llorca et al. (2017) – Intelligent Transportation Assist Systems
Their work emphasizes intelligent transportation but not pothole-specific AI models or real-time hazard warning systems for common users.

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Resulting Research Gap:
Absence of a pothole-focused intelligent detection framework.

7. Gap Identified from Krizhevsky et al. (2012) – Deep CNNs (AlexNet)
While AlexNet demonstrated high image classification capability, it is computationally heavy and unsuitable for real-time mobile deployment.
Resulting Research Gap:
Lack of lightweight deep-learning models optimized for pothole detection on smartphones/embedded devices.

8. Gap Identified from Redmon & Farhadi (2017) – YOLO9000
Though YOLO provides real-time object detection, few researchers have adapted it specifically for pothole detection, especially under Indian road conditions.
Resulting Research Gap:
Limited exploration of YOLO-based detection for road damage monitoring.
Conclusion
In this work, a real-time vision-based system for pothole detection and pre-surveillance of road conditions was developed. The system successfully identifies road pits using video feeds, classifies them photometrically, and geotags the locations on a 2D map interface for driver alert and maintenance planning. Integration with toll plaza patrolling vehicles ensures proactive monitoring, reducing accident risks and improving road safety. Experimental results demonstrate the system's effectiveness in accurate pothole detection, timely alert generation, and practical applicability for intelligent transportation and highway maintenance. Future work includes extending the system with predictive analytics for road deterioration and automated maintenance scheduling.

III. PROBLEM FORMULATION

India's road transportation system experiences a significant number of accidents every year due to poor road conditions, among which potholes are one of the leading contributors. Potholes develop due to heavy traffic load, aging pavement, water seepage, and inadequate maintenance practices. These road surface defects often remain unattended for long periods, resulting in severe accidents, vehicle breakdowns, and traffic congestion. During the survey conducted for this project, a real incident was recorded on video where a two-wheeler met with an accident due to a deep pothole. This evidence highlights the urgent need for a reliable, automated, and real-time pothole detection mechanism.
Traditional road inspection methods require manual patrolling, which is slow, costly, and unable to detect potholes promptly, especially on long highway stretches. These manual inspections also depend on human judgment, making them prone to errors and delays. With the growth of smart cities and intelligent transportation systems, there is a pressing need to shift from manual processes to automated solutions that can continuously monitor road conditions.
To address this challenge, the present work formulates pothole detection as a computer vision and deep learning problem. The task involves capturing road images or video streams, processing them in real time, and detecting potholes using advanced object-detection models such as YOLOv3, YOLOv4, and YOLOv5. Each model will be evaluated based on detection accuracy, processing speed, false alarm rate, and robustness under different environmental conditions such as bright sunlight, shadows, night-time, uneven road textures, and water-filled potholes.
Another major requirement is the integration of GPS-based location tagging, which allows the system to pinpoint the exact geographical location of detected potholes. The detected pothole information, along with coordinates, must be uploaded to a centralized database or displayed through an Android application. This real-time visibility can help road authorities schedule timely maintenance, prevent accidents, and improve overall road safety.
Furthermore, the formulation includes designing a lightweight system that can be mounted on vehicles (like bikes, cars, or buses) for continuous monitoring without adding significant cost. The solution must balance speed, accuracy, and hardware efficiency, enabling deployment in practical smart city setups.

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Thus, the problem is to develop a real-time, automated, GPS-enabled pothole detection system capable of accurately identifying potholes from video or images, reducing manual effort, preventing accidents, and supporting proactive road maintenance planning.

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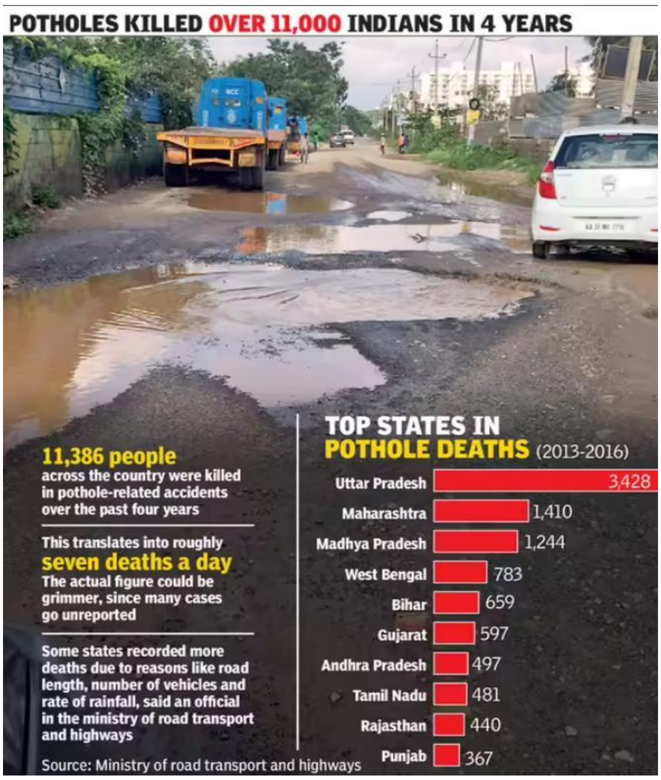

Image Source: Times Of India 1

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IV. SYSTEM DEVELOPMENT

4.1. Block Diagram:

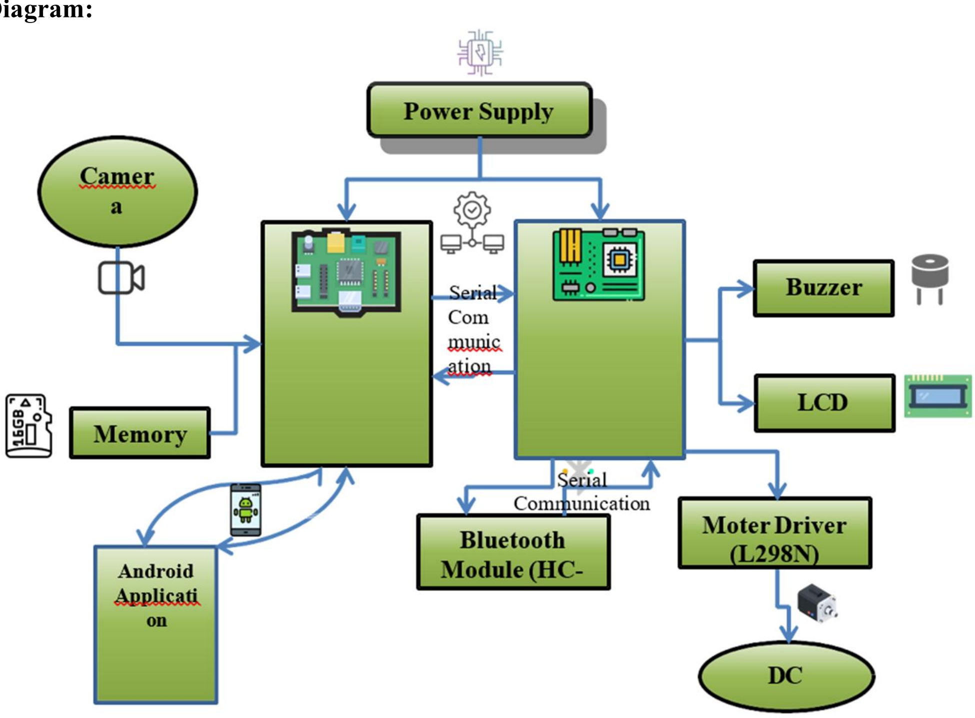

Fig.4.1. Block Diagram of System

The developed system uses both Raspberry Pi and Arduino Uno boards, combining their strengths to perform monitoring, processing, control, and automation tasks efficiently. A regulated power supply is used to deliver the required voltage and current to all the units, ensuring reliable performance throughout the system.

Power Supply

This module provides stable electrical power to every component, including the Raspberry Pi, Arduino Uno, sensors, and peripheral devices. It maintains proper voltage regulation, allowing the system to operate safely and continuously without fluctuations.

Raspberry Pi

The Raspberry Pi functions as the main computational unit. It handles tasks related to image processing and decision-making. The Pi is connected to the Camera Module, capturing real-time images or video for analysis. Processed results or raw data are stored in the Memory Unit.

Additionally, the Raspberry Pi exchanges information with the Arduino Uno, sending commands or receiving system updates. It also supports wireless communication with the Android Application for monitoring or control.

Camera Module

The camera continuously captures visuals of the environment. These images or video streams are forwarded to the Raspberry Pi, where they are processed for detection, analysis, or monitoring. This module is essential for real-time vision-based functionalities.

Memory Module

The memory unit stores captured images, processed data, and system logs. This storage helps in future analysis, system evaluation, and record keeping.

Arduino Uno

The Arduino acts as the action controller of the system. It receives instructions from the Raspberry Pi or Android app and operates LCD display, buzzer, and motor driver. The Arduino also interfaces with the Bluetooth Module (HC-05) for wireless communication.

Bluetooth Module (HC-05)

This module establishes a wireless link between the Arduino and the Android application. It enables the user to send commands, receive alerts, and monitor the system remotely through Bluetooth connectivity.

Android Application

The Android app offers a simple and interactive user interface. Through the app, the user can monitor system status, view alerts, and send control signals. Communication takes place either through Bluetooth (via Arduino) or through Wi-Fi (via Raspberry Pi), depending on the system architecture.

LCD Display (16×2)

The LCD screen displays essential system information such as real-time readings, alerts, and operational messages. It provides immediate visual feedback to the user.

Buzzer

The buzzer generates sound-based alerts to notify

1. System Initialization

the user of warnings, detected issues, or important events. Motor Driver (L298N)

The motor driver receives control signals from the Arduino and controls the DC motor's operation. It supports forward and reverse motion and allows the system to adjust the motor speed as required.

DC Motor

The DC motor performs mechanical movements such as actuation, rotation, or propulsion, depending on the system's purpose. It operates based on instructions coming from the motor driver.

Once the system is powered on, all the hardware units—such as the Raspberry Pi, Arduino Uno, camera module, and communication interfaces—begin their initialization process. Each module loads its configuration settings and prepares for continuous operation.

2. Image Capture / Data Acquisition

A camera installed on the vehicle constantly records live video or captures images of the road ahead. These visual inputs are immediately transferred to the Raspberry Pi, which is responsible for processing and analyzing the data.

3. Image Pre-processing

Before detection starts, the raw images undergo a series of enhancement steps to improve accuracy:

i. Images are resized to fit the input dimensions of the YOLO model.

ii. Unwanted noise is filtered out, and contrast is adjusted.

iii. The images are converted into the required color format (RGB or grayscale).

iv. Brightness and sharpness adjustments are applied to highlight pothole-related features.

This stage ensures the detection model receives clean and optimized input.

4. Pothole Detection Using YOLO

i. The refined images are fed into the YOLO (You Only Look Once) deep learning model.

ii. YOLO analyzes each frame in real time and identifies potholes present on the road.

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iii. The model marks detected potholes with bounding boxes and assigns confidence values, indicating the probability of correct detection.

5. Coordinate Mapping and Pothole Classification

i. The exact location of each detected pothole within the image frame is recorded.

ii. If a GPS module is available, the real-world coordinates (latitude and longitude) of the pothole are also captured.

iii. The system categorizes the potholes by severity—small, medium, or severe—based on their dimensions and appearance.

6. Data Logging and Storage

All detection-related data—such as images, pothole coordinates, classification results, time stamps, and GPS locations—are saved in the Raspberry Pi's memory unit.

This stored information can later be analyzed, used for maintenance scheduling, or uploaded to cloud-based platforms.

4.2 Flowchart

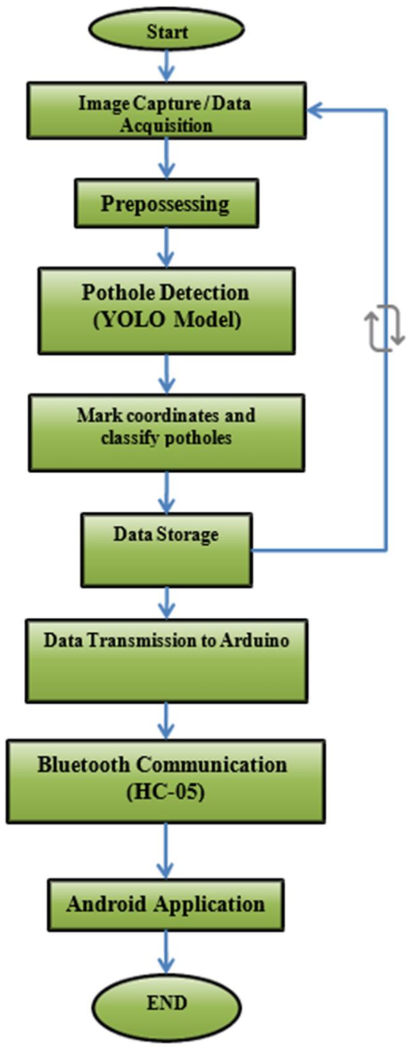

Fig.4.1. Flowchart of the System

7. Data Transfer to Arduino Uno

The Raspberry Pi sends the summarized detection results (e.g., pothole found, severity classification, alert status) to the Arduino. The Arduino is responsible for executing control outputs and generating user notifications.
action, preventing accidents and improving road safety.

8. Bluetooth Communication via HC-05

i. The Arduino communicates with the Android mobile application through the HC-05 Bluetooth module.
It transfers information such as: ii.Detected pothole alerts iii.Severity and category iv.GPS-based location data v.Status updates

4.3. Circuit Diagram:

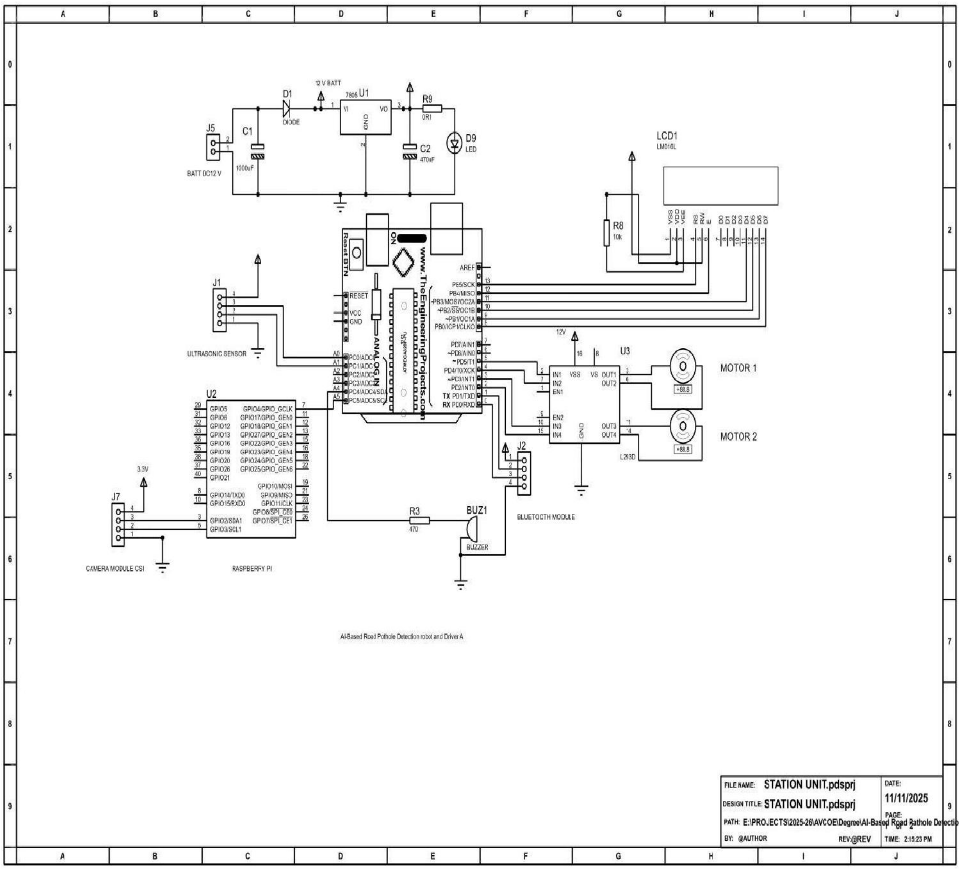

Fig.4.3. Circuit Diagram of System

This ensures users receive immediate notifications while traveling.

9. Android Mobile Application

The Android app acts as the user interface for the system. It:
i. Displays pothole alerts in real time
ii. Shows captured images and detection details
iii. Marks pothole locations on a map iv.Provides severity classification
v.Allows users or authorities to submit maintenance requests or add additional comments
The app helps both drivers and road authorities take timely.

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V. ADVANTAGES

- Helps drivers avoid sudden shocks or accidents by giving instant pothole alerts.
- Authorities get accurate pothole locations, reducing time spent searching for damaged road sections.
- Can be easily mounted on cars, bikes, buses, or robots, making it flexible for real-world use.
- Reduces vehicle maintenance costs by helping drivers slow down before hitting potholes.
- Works continuously and creates a live record of road conditions, useful for maintenance planning.

VI. LIMITATIONS

- Camera may not detect potholes properly in nighttime, rain, fog, or muddy roads.
- The system needs regular cleaning of the camera lens to avoid dust or water blockage.
- Bluetooth range is limited, so data sharing distance is short.
- Requires stable power, so long-duration monitoring needs a good battery or vehicle supply.
- May misidentify shadows or road cracks as potholes if the environment is too complex.

VII. CONCLUSION

The developed AI-based pothole detection system successfully identifies road defects in real time and provides reliable alerts for drivers and authorities. By combining a camera module, Raspberry Pi, Arduino, and YOLO detection algorithms, the system offers a practical method for monitoring road conditions during actual driving. It reduces the need for manual inspection, saves time, and helps prevent vehicle damage by warning users before reaching a pothole. With GPS tagging and mobile connectivity, the system also supports quicker maintenance response and contributes to improving overall road safety. Overall, the project demonstrates a cost-effective, scalable, and real-world solution for smarter road infrastructure.

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