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# Real-Time Pothole Detection for Vehicles

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***Abstract*— Road safety and infrastructure maintenance are critical aspects of modern transportation systems. Potholes, which form due to continuous vehicular load and weather-induced pavement degradation, pose severe threats to vehicle performance and passenger safety. Traditional manual inspection methods for pothole detection are inefficient, labour-intensive, and often delayed, leading to increased maintenance costs and accidents. This paper presents a real-time pothole detection system for vehicles using computer vision and machine learning. The system employs a vehicle-mounted camera that captures live road video, which is analysed using deep learning algorithms—specifically the YOLO object detection framework—to accurately identify potholes of varying sizes. Detected potholes are highlighted with bounding boxes, and their width and length are measured to determine severity levels categorized as minor, moderate, or severe. The system also integrates GPS functionality to record and transmit the location of potholes to maintenance authorities for proactive road repair. Experimental testing demonstrates that the proposed model achieves reliable real-time detection even under diverse lighting and environmental conditions, ensuring improved road safety, reduced vehicle damage, and efficient maintenance scheduling. The proposed model achieved an accuracy of 89%, demonstrating strong robustness and generalization across different road textures and environmental settings. The lightweight design allows smooth real-time processing, making the system suitable for on-vehicle deployment without requiring expensive sensors. By combining efficient object detection, dimension estimation, and geotagging, the system contributes toward smart transportation development and supports data-driven decision-making for urban infrastructure management.***

***Keywords*— Computer Vision, Deep Learning, Pothole Detection, Real-Time Monitoring, Road Safety, Smart Transportation, YOLO.**

## I. Introduction

Road transportation plays a vital role in economic growth and public safety but deteriorating road conditions—especially potholes—pose serious hazards to vehicles and commuters. Potholes are depressions formed on road surfaces due to heavy traffic loads, water seepage, and material fatigue.

They can lead to accidents, vehicle damage, and traffic congestion if not detected and repaired promptly. Traditional pothole detection relies on manual inspection, which is time-consuming, costly, and prone to human error. With advancements in artificial intelligence and computer vision, automated detection using machine learning offers a faster and more reliable alternative. Deep learning models such as YOLO (You Only Look Once) have shown excellent performance in object detection tasks, making them suitable for real-time pothole recognition.

This paper proposes a real-time pothole detection system that analyses live video captured by a vehicle-mounted camera. The system identifies potholes, measures their size, classifies severity levels, and alerts both drivers and authorities through integrated GPS-based reporting, thereby improving road safety and supporting intelligent transportation systems.

Beyond safety concerns, potholes impose significant economic burdens on transportation infrastructure. Repeated exposure to such defects accelerates wear on vehicle components such as tires and suspension systems, leading to costly repairs for drivers and larger financial demands on road maintenance authorities. Additionally, sudden action performed by drivers to avoid potholes can disrupt traffic flow and increase accident risks. These challenges underline the importance of automated road monitoring systems that can operate continuously and detect defects accurately without relying on slow, inconsistent manual inspections.

Recent developments in deep learning and edge computing have made it possible to deploy fast and efficient road-anomaly detection systems using affordable hardware. YOLO-based detection models enable high-speed inference from live video, while compact GPU-enabled devices support real-time processing even during vehicle motion.

When combined with GPS-based geotagging and automated reporting, these technologies allow pothole information to be captured, localized, and communicated instantly to maintenance authorities.

Building on these advancements, the proposed system delivers a lightweight, scalable, and practical solution for real-time pothole detection, suitable for both urban and highway environments.

## II. Literature Review

Recent research has explored a wide range of sensing and deep learning techniques to improve pothole detection accuracy, reliability, and real-time performance. Camera–LiDAR fusion models such as those proposed by Cai et al. [1], Faisal and Gargoum [2], Karukayil et al. [6], and Xu et al. [15] provide highly precise 3D measurement using point clouds, but the need for expensive sensors and complex calibration limits their suitability for low-cost deployment. Several works emphasize real-time image-based detection using deep learning, particularly YOLO variants. Saleh et al. [3], Shahdadpuri et al. [4], Kamalakannan et al. [5], Bhavana et al. [7], Ruseruka et al. [8], Paramarthalingam et al. [9], Ding and Tang [10], Ling et al. [11], and Rout et al. [14] demonstrate the effectiveness of YOLO for fast and accurate pothole recognition under dynamic road conditions. Their findings directly influence our project, which adopts the YOLO approach for real-time video-based pothole detection due to its superior speed and lightweight architecture. Studies using CNN and transfer learning models—Swain et al. [12] and thermal-based systems by Aparna et al. [16]—highlight alternative detection methods but remain less efficient for high-speed vehicle scenarios. IoT-based or sensor-driven approaches such as those by Kadu et al. [17], Yuvaraj [18], Egaji et al. [19], and Sharmila et al. [20] introduce low-cost detection using ultrasonic sensors, accelerometers, and smartphones; these works inspired the GPS-based geotagging and alert reporting adopted in our system, though the visual-only detection in our model avoids the need for additional hardware. Several studies also focus on cloud integration, VANET communication, and digital twin frameworks [3], [5], supporting distributed road monitoring—concepts that motivate our project's automated reporting mechanism.

Across all works, common challenges include environmental sensitivity, false positives, and limited nighttime performance.

Considering the gaps, our proposed system incorporates the most effective strategies—YOLO-based real-time detection, video-frame processing, pothole dimension measurement, severity classification, and GPS communication—while remaining low-cost, scalable, and suitable for on-road deployment.

## III. System Design And Methodology

### *A. Hardware Components*

The hardware setup of the proposed system includes an NVIDIA Jetson Nano or a laptop equipped with a dedicated GPU (GTX/RTX) to efficiently perform real-time image processing and model inference.

A high-definition USB camera is mounted approximately 30 cm above the road surface at a fixed angle to continuously capture video, ensuring accurate detection and measurement of pothole dimensions. Additionally, SSD or HDD storage is utilized for saving detection logs and captured frames, while Wi-Fi or 4G connectivity supports automatic data transfer and report submission to maintenance authorities.

### *B. Software Components*

The software stack for the proposed system is built using Python 3.8+, with key libraries such as OpenCV for image processing, NumPy and Pandas for data manipulation, and TensorFlow or PyTorch for deep learning model development. The pothole detection component utilizes the YOLO (You Only Look Once) algorithm due to its high speed and accuracy in real-time object detection.

GPS-based location tracking is implemented using the Geopy library, while automatic report generation and emailing are handled through SMTP. Development and testing are carried out in Visual Studio Code and Jupyter Notebook, providing an efficient and flexible environment for implementing and refining the model.

### *C. Methodology*

Data Collection and Preprocessing, Pothole image and video datasets are collected under varying lighting and weather conditions. Preprocessing includes resizing, denoising, and histogram equalization to improve model robustness.

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**Fig. 1 Pothole Dataset**

Model Training, A YOLO-based model is trained on annotated datasets containing pothole and non-pothole images. Training parameters such as batch size, learning rate, and epochs are tuned to achieve high detection accuracy.

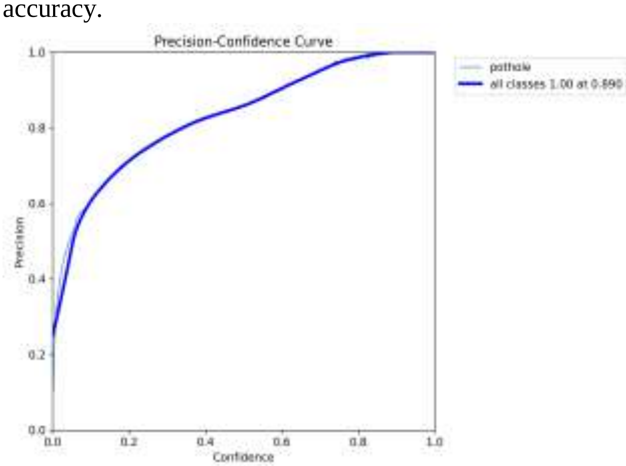


**Fig. 2. Precision–Confidence curve**

The Precision–Confidence curve illustrates the relationship between the model's prediction confidence and the resulting precision during pothole detection. As shown in Fig.2, precision steadily increases as the confidence threshold is raised, indicating that the model becomes more selective and reduces false positives at higher confidence levels. The curve approaches a maximum precision of 1.00 at a confidence score of 0.89, demonstrating that the trained YOLO model produces highly reliable detections when operating at optimal confidence thresholds.

This behavior confirms that the model is well-calibrated and capable of maintaining strong precision across a wide range of confidence levels, which is essential for real-time deployment in road environments where incorrect detections must be minimized. During real-time operation, the live video frames captured by the camera are processed through the trained YOLO model, where detected potholes are highlighted with bounding boxes and their dimensions are calculated using pixel-to-distance calibration. Based on these measurements, each pothole is classified into minor, moderate, or severe severity levels. After detection, the system triggers a dashboard alert for the driver and automatically logs the event with the timestamp, GPS coordinates, and image evidence into a local CSV file, with the option to send the detailed report directly to road maintenance authorities via email.

The modular design ensures scalability for integration with autonomous vehicles, municipal road-monitoring systems, and smart city infrastructure. It achieves a balance between detection accuracy, cost efficiency, and real-time responsiveness.

## IV. WORKING PRINCIPLE

The real-time pothole detection system operates through a sequential pipeline that integrates continuous video capture, deep learning–based inference, and automated reporting. As shown in Fig. 1, the process begins with image acquisition, where a high-definition USB camera mounted approximately 30 cm above the road surface records live video while the vehicle is in motion. This mounting height ensures that potholes and road irregularities fall within a consistent field of view for accurate detection and measurement.

The recorded video stream is then divided into individual frames for analysis. Each frame undergoes preprocessing using OpenCV, which includes resizing, noise filtering, contrast enhancement, and edge sharpening. These operations improve the clarity of road textures and reduce false detections caused by shadows, lighting variations, or uneven pavement conditions. After preprocessing, each frame is passed through a YOLO-based deep learning model specifically trained to detect potholes. YOLO's single-shot detection architecture enables fast object recognition, allowing potholes of different shapes and sizes to be identified in real time with bounding boxes and labels overlaid on the video feed.

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Following detection, the system performs measurement and severity classification. Using calibrated pixel-to-distance ratios derived from the fixed camera height and field of view, the system calculates the length and width of each detected pothole. Based on these measurements, potholes are categorized into three severity levels: minor, moderate, and severe. This classification assists both drivers and maintenance authorities in prioritizing road repairs according to the potential risk posed by each defect.

To support location-based reporting, the system incorporates a GPS module that records the precise coordinates—latitude and longitude—of every detected pothole. When a pothole is identified, a dashboard alert notifies the driver, and detailed information including the pothole's size, severity, image frame, and GPS location is logged into a CSV file. The system can also automatically transmit this data to road maintenance authorities via email for proactive repair planning.

All detection records are stored locally for further analysis. These logs help authorities identify high-risk road segments, monitor patterns of pavement deterioration, and plan timely maintenance interventions. The stored data can also support smart city infrastructure systems by enabling continuous, automated road condition monitoring. Operating entirely in real time with minimal latency, the system enhances driver safety and contributes to efficient, data-driven road infrastructure management.

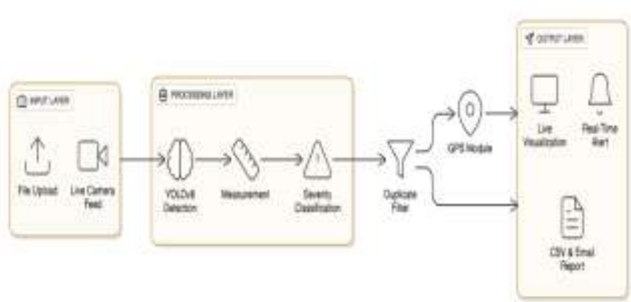


**Fig. 3. Block diagram of the real-time pothole detection system**

## V. RESULTS AND DISCUSSION

The proposed real-time pothole detection system was tested using live road video captured by a vehicle-mounted HD camera. The YOLO-based model achieved an accuracy of 89%, detecting potholes of different sizes with minimal false positives while maintaining smooth performance at 25–30 FPS.

The camera calibration at 30 cm enabled precise measurement and classification of potholes into minor, moderate, and severe categories.

**Fig 4. Result on Day-time**

**Fig 5. Result on Night-time**

The visual outcomes presented in Fig. 4 and Fig. 5 further validate the robustness of the proposed system under different lighting conditions. In Fig. 4 (day-time), the model correctly detects both medium and severe potholes, accurately drawing bounding boxes and calculating their dimensions. The high clarity and contrast of daylight enable precise edge detection and size estimation. In Fig. 5 (night-time), despite low illumination, headlight glare, and uneven lighting, the model successfully identifies a severe pothole and maintains reliable measurement accuracy.

These results demonstrate the system's ability to operate effectively in real-world environments, handling both daytime and nighttime scenarios without significant degradation in performance. GPS integration allowed automatic geotagging and data logging with timestamps for maintenance reporting. The system performed reliably under varied lighting and weather conditions, demonstrating its effectiveness for on-road deployment and smart infrastructure monitoring.

## VI. Conclusion And Future Work

The proposed real-time pothole detection system efficiently identifies and classifies road surface defects using computer vision and deep learning. By integrating a YOLO-based model with a vehicle-mounted camera and GPS, the system detects potholes in live video feeds with an accuracy of 89%, categorizing them into minor, moderate, and severe levels while generating real-time alerts and automatic geotagged reports.

The model performed reliably under diverse lighting and environmental conditions, reducing manual inspection efforts and enhancing road safety. Future improvements include incorporating depth estimation through stereo or LiDAR sensors, optimizing the model for lightweight edge devices, and integrating cloud-based data sharing for large-scale road condition monitoring, thereby advancing toward smarter and safer transportation infrastructure.

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