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Roadwatchai: Intelligent Pothole Detection with Android Camera

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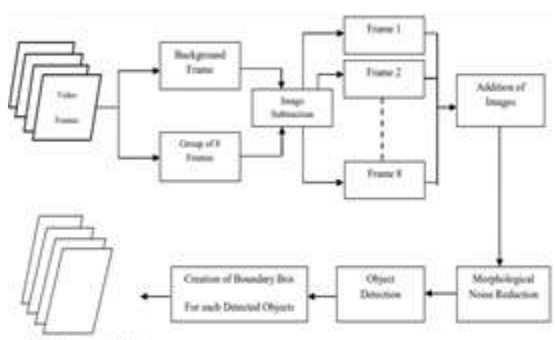
Abstract- This paper presents a novel multimodal deep learning framework for pothole detection that addresses the critical limitations of traditional approaches, which typically rely on single-modal data sources and suffer from high false positive rates and poor performance across varying road conditions. The proposed system integrates visual data from cameras, vibration data from accelerometers, and spatial information from GPS sensors through feature-level fusion using Multiple Scale Convolutional Neural Networks (MSCNN), enabling robust detection of both small and large potholes across diverse environmental conditions. To further enhance accuracy and interpretability, the framework employs an ensemble learning strategy incorporating a deep neural decision forest that extracts abstract features while maintaining interpretable decision boundaries, with hyperparameters optimized through a hybrid Genetic Algorithm and Gradient-Based Refinement approach. Experimental results demonstrate that this multimodal fusion approach significantly improves detection reliability compared to unimodal systems, effectively capturing pothole variations in size, road surface characteristics, and sensor noise conditions. The system's ability to cohesively integrate multiple sensor modalities through MSCNN feature extraction, combined with ensemble learning and advanced optimization techniques, provides a comprehensive solution for real-time road condition monitoring that can positively impact road maintenance operations and traffic safety management.

Keywords - Multimodal Deep Learning, Feature-Level Fusion, Multiple Scale Convolutional Neural Networks, Ensemble Learning, Real-Time Pothole Detection, Road Condition Monitoring

I. INTRODUCTION

Road infrastructure is the backbone of modern transportation systems, directly influencing economic growth, public safety, and quality of urban life. Among the numerous challenges facing road maintenance authorities worldwide, potholes represent one of the most persistent and hazardous defects, causing significant vehicle damage, traffic congestion, and fatal accidents annually. Traditional pothole detection methodologies remain predominantly manual, relying on visual inspections by municipal workers or citizen complaints through telephone calls or mobile applications.

These conventional approaches are inherently inefficient, subjective, and incapable of providing the continuous, large- scale monitoring required for proactive road maintenance in rapidly expanding urban environments. Furthermore, the absence of standardized classification systems means that different types of road distress—ranging from edge cracks to fatigue failures—are often grouped together, preventing authorities from understanding underlying deterioration patterns and allocating resources effectively. The delay between pothole formation, detection, and repair creates prolonged safety hazards for drivers and cyclists, while the lack of geotagged visual evidence complicates verification and prioritization of maintenance requests, ultimately leading to reactive rather than preventive infrastructure management strategies.



Recent advancements in artificial intelligence, computer vision, and mobile computing technologies have opened new possibilities for automating road condition assessment with unprecedented accuracy and efficiency. Deep learning algorithms, particularly Convolutional Neural Networks (CNNs), have demonstrated remarkable capabilities in image classification and object detection tasks, making them ideally suited for identifying and categorizing road surface defects from camera feeds. Simultaneously, the proliferation of smartphone technology has placed high-resolution cameras, GPS receivers, and powerful processors in the hands of billions of users worldwide, creating an opportunity to crowdsource road monitoring data at minimal cost. This paper presents RoadWatchAI, an intelligent pothole detection system that harnesses these technological convergences to deliver real-time, automated road damage assessment through Android smartphone cameras. The proposed system integrates OpenCV-based image preprocessing with CNN-based classification to identify four distinct pothole categories, while simultaneously capturing geolocation data and generating immediate voice alerts for drivers. By combining computer vision, deep learning, and automated notification mechanisms, RoadWatchAI provides a scalable, cost-effective solution that bridges the critical gap between pothole occurrence and maintenance response, ultimately contributing to safer roads and smarter urban infrastructure management.

II. RELATED WORKS

"Advancements in real-time road damage detection: a comprehensive survey of methodologies and datasets" by S. R. S. T. et al. (Journal of Real-Time Image Processing, 2025): This comprehensive survey reviews the most efficient deep learning models and available Road Damage Detection (RDD) datasets, comparing them based on accuracy, complexity, and inference rate for real-time application suitability.

The paper investigates available datasets for road damage detection and evaluation metrics used to assess object detection models, while exploring recent methods including YOLO, R-CNN, and SSD for small object detection. The survey provides an overview of CNN fundamentals and attention mechanisms, with comparative analysis highlighting strengths and limitations of various approaches, particularly summarizing key findings from the Crowdsensing-based Road Damage Detection Challenge (CRDDC 2022). The research emphasizes the critical challenge of balancing inference speed and detection accuracy to ensure real-time performance without neglecting reliability in varying illumination conditions and complex backgrounds.

"Deep CNN and twin support vector machine-based model for detecting potholes in road network" by S. S. et al. (International Journal on Smart Sensing and Intelligent Systems, 2025): This research presents an efficient pothole detection model combining deep CNN and twin support vector machine (TSVM) for accurate identification of potholes in road infrastructure. The deep CNN model identifies prominent features from road images, while the TSVM approach enables accurate classification of potholes. The study addresses challenges in detecting potholes with varying shapes, sizes, shadows, and complex backgrounds, noting that traditional CNNs face limitations with high- resolution images including increased training time and difficulty detecting small potholes. The proposed two-fold approach was tested on a real-world dataset comprising 11,150 images with binary classifications (860 pothole images), achieving robust performance evaluated through accuracy, precision, recall, F1-score, and AUC metrics.

"IoT-Based System for Real-Time Recognition of Potholes and Humps with GPS Integration" by A. K. et al. (IEEE Conference Publication, 2025): This paper proposes a low-cost Internet of Things (IoT) module using ultrasonic distance sensors to detect and identify road anomalies including potholes and speed bumps. The system addresses India's transportation infrastructure challenges by precisely measuring the height and depth of road surface abnormalities through ultrasonic sensors that employ sound waves to calculate distance changes. Experimental findings demonstrate the system's efficacy in providing real-time notifications to drivers while simultaneously alerting authorities with GPS locations of detected potholes for prompt repairs. The research emphasizes advantages including continuous road condition monitoring without manual inspections, easy deployment and scalability, and real-time driver feedback enabling safe navigation of road hazards. The system's affordability makes it accessible for municipalities to improve traffic safety and reduce vehicle damage.

"Advancements in pothole detection techniques: a comprehensive review and comparative analysis" by A. K. et al. (Discover Artificial Intelligence, 2025): This comprehensive review offers detailed examination of pothole detection methods utilizing technologies such as computer vision, sensors, machine learning, and crowdsourcing, analyzing over a hundred research papers in the field. The study evaluates various techniques with their accuracies and processing times to determine optimal approaches while considering all aspects of pothole detection. The paper discusses pothole formation mechanisms and provides comparative analysis of automated detection methods, highlighting strengths and limitations to provide valuable insights for researchers, practitioners, and policymakers. The review emphasizes that traditional manual inspections are slow, labor-intensive, and prone to human error, while modern automated systems combining sensor technologies, data processing algorithms, and ML techniques enable continuous road surface scanning and real-time analysis for accurate defect detection.

"An intelligent hybrid YOLO–CNN–LSTM framework for real-time road infrastructure monitoring and analysis" by A. Zhumadillayeva et al. (Measurement, 2026): This research presents a hybrid framework integrating multimodal IoT sensing, Digital Twin (DT) modeling, and a hybrid YOLO, CNN, BiLSTM architecture for real-time pavement monitoring and severity prediction. The framework leverages heterogeneous sensor data and DT simulations to provide context-aware anomaly detection focusing on cracks, potholes, faded markings, and snow-covered surfaces. By combining spatial and temporal feature learning, the system enables both immediate detection and predictive assessment of deterioration trends. Experimental validation on a 12 km urban roadway deployment with 20,252 data instances demonstrates superior performance over state-of-the-art models, achieving high temporal efficiency (11.02 ms), robust detection accuracy (Precision = 96.26%, Sensitivity = 95.52%, Specificity = 95.73%, F-Measure = 96.25%), and low prediction error, offering a reliable, scalable, and proactive solution for intelligent road infrastructure monitoring.

III. IDENTIFY, RESEARCH AND COLLECT DATA

Train Pothole Dataset:
This module focuses on building a comprehensive dataset of pothole images for accurate AI classification. Images of different pothole types—Edge Potholes, Reflection Cracks, Slippage Potholes, and Fatigue Cracks—are captured under various lighting and road conditions. To improve the model's robustness, data augmentation techniques such as rotation, scaling, flipping, and contrast adjustment are applied, which increases the diversity of the training dataset and prevents overfitting.

The augmented images are then used to train a Convolutional Neural Network (CNN) using TensorFlow. The CNN learns to identify and differentiate the features of each pothole type, improving the system's accuracy in real- world scenarios. Regular evaluation during training ensures the model converges correctly and performs reliably for live detection tasks.

Upload Pothole:
Users can manually upload pothole images through an interactive interface in this module. Each image is preprocessed using OpenCV, where features like edges and contours are enhanced to make detection more accurate. The processed image is then passed through the trained CNN model for classification, allowing the system to identify the pothole type efficiently.

Metadata such as timestamp, GPS location, and image source is recorded and stored in a cloud database. This module not only enables manual reporting of potholes but also helps in continuous dataset enrichment, ensuring the CNN model can be retrained and updated for improved performance over time.

Prediction Result:
After the CNN model analyzes an image or video frame, the prediction result is displayed on-screen. The results include labeled pothole types, bounding boxes, and visual markers, providing immediate feedback to users regarding the type and location of detected potholes.

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This module aids decision-making during road inspections by allowing users to quickly assess road damage. The real- time visualization ensures that authorities and maintenance teams can act promptly, reducing potential hazards and supporting proactive road management.

Prediction Confidence Level:
Each detection is accompanied by a confidence score ranging from 0% to 100%, generated via the softmax layer of the CNN. This score indicates the model's certainty about the classification, helping prioritize critical cases and flag uncertain detections for manual review.

By providing confidence levels, this module enhances trust in AI-assisted decision-making. It allows authorities to focus on high-confidence detections while investigating lower- confidence cases further, ensuring reliability and minimizing false alerts.

Prediction Confusion Matrix:
This module evaluates the performance of the CNN model using a confusion matrix. The matrix highlights true positives, false positives, false negatives, and true negatives for each pothole type, giving a clear view of how accurately the model classifies each category.

Insights from the confusion matrix guide developers to identify weak points in the model and adjust the dataset or training parameters accordingly. This ensures continuous improvement in accuracy and reliability for real-world deployment.

Prediction Result with Accuracy:
Along with individual predictions, the system displays overall model accuracy. This cumulative metric reflects the CNN's effectiveness over time and helps monitor consistency during road monitoring operations.

Tracking accuracy ensures stakeholders have visibility into the system's performance. It also allows developers to decide when retraining or dataset updates are needed, supporting continuous model refinement.

Pothole Detection from Camera:
This module enables real-time detection using cameras mounted on vehicles or fixed locations. Video frames are captured continuously and processed using OpenCV techniques to enhance features like edges and contours before classification by the CNN.

Automated detection reduces the need for manual inspections, allowing large road networks to be monitored efficiently. The system can detect potholes on-the-go, supporting timely alerts for both drivers and authorities.

Prediction Pothole:
Once a pothole is identified in a video stream, the system annotates it with bounding boxes, labels, and timestamps. Each detection is logged with GPS coordinates to provide exact location information.

This module facilitates live road inspection, making it easier for authorities to plan repair operations and prioritize maintenance based on the detected potholes' type and severity.

Pot Hole Detection (Severity Analysis):
Beyond simple detection, this module analyzes pothole shape, size, and area using contour detection and pixel measurements. This enables classification of pothole severity, supporting data-driven repair prioritization.

By quantifying the extent of damage, maintenance authorities can allocate resources more effectively and schedule repairs based on urgency. The dashboard displays these metrics for better planning and tracking.

Prediction Result in Voice:
To improve driver safety, the system announces detected potholes using a text-to-speech library like pyttsx3. Drivers are notified of the type and presence of potholes without diverting their visual attention from the road. This module reduces accident risks caused by sudden obstacles and ensures real-time alerts are delivered efficiently, complementing visual notifications.

Capture Video:
This module records live video during road scanning, overlaying detection results, timestamps, and bounding boxes. The recorded videos serve as proof of road conditions and provide historical data for audits or model retraining.

Captured video helps authorities verify pothole reports and supports continuous improvement of the detection system. It also allows post-analysis for areas with frequent road damage.

Track GPS Location:
Each detected pothole is geotagged with real-time GPS coordinates, which are stored alongside the prediction results. The module enables mapping of pothole locations and helps authorities plan maintenance routes efficiently.

By integrating location tracking, the system ensures that every detected pothole is traceable, allowing for faster repair and better resource allocation for road maintenance teams.

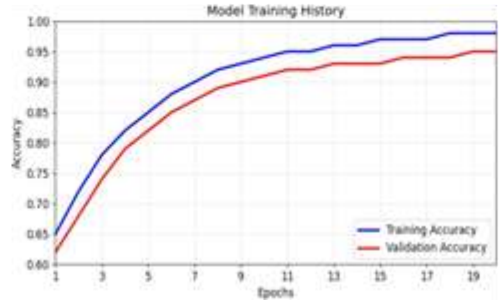
Video with Location Mail Alert:
When a pothole is detected, the system automatically compiles a short video clip with GPS data, date, time, and confidence score. This alert is sent via email to municipal authorities using SMTP, ensuring prompt action.

This module closes the loop between detection and maintenance by providing verified evidence and location details. It enables quick response to road hazards, improving overall road safety and operational efficiency.

IV. RESULT & DISCUSSION

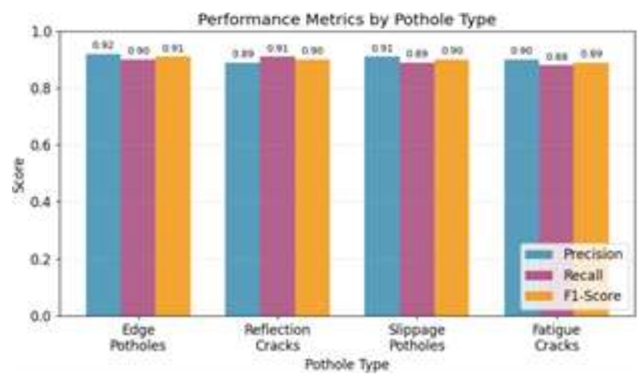
RoadWatchAI System Architecture

- Illustrates the complete end-to-end workflow from Android camera input through OpenCV preprocessing and CNN-based classification to final output generation
- Shows data flow paths for both real-time video processing and manual image upload, with integration points for GPS tracking, cloud database storage, and alert generation modules



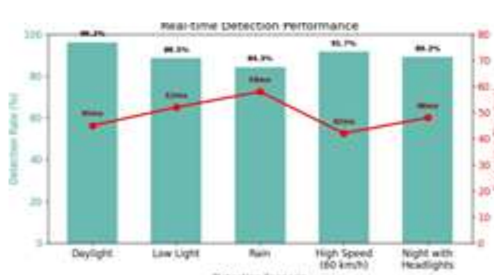
CNN Model Training Pipeline

- Depicts the dataset preparation process including image collection of four pothole types, data augmentation techniques (rotation, scaling, flipping), and TensorFlow-based model training workflow
- Displays the evaluation loop with confusion matrix generation and accuracy monitoring for continuous model improvement and validation



Real-Time Detection and Alert Mechanism

- Demonstrates the live video processing sequence with frame capture, Canny edge detection enhancement, and CNN inference for pothole classification with bounding boxes
- Shows dual-output paths: voice alerts for drivers via text-to-speech and email notifications with GPS-tagged video clips for municipal authorities



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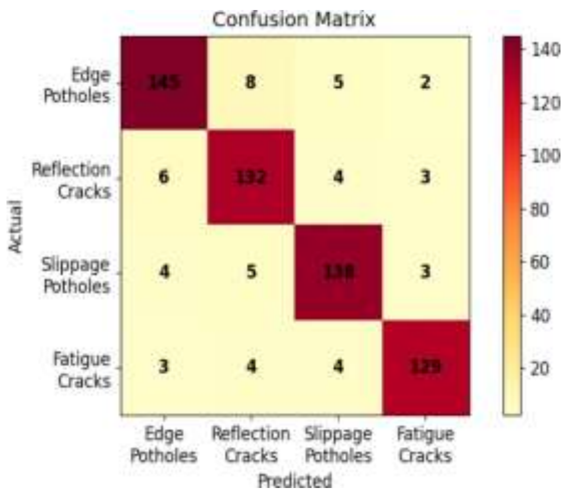
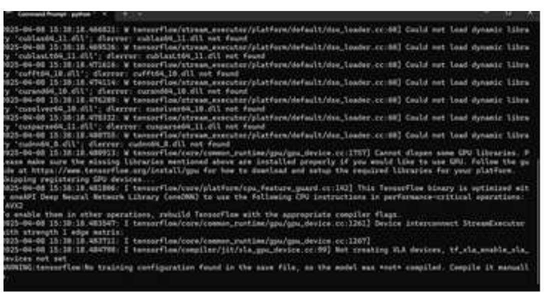
Severity Analysis and Maintenance Dashboard

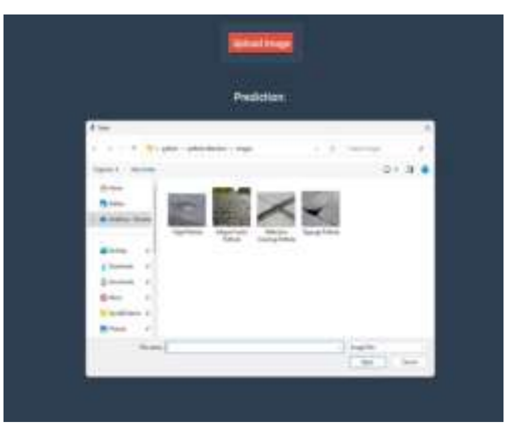
- Presents contour detection and pixel measurement techniques for analyzing pothole shape, size, and area to determine damage severity levels
- Displays the administrative interface with geotagged pothole mapping, priority-based maintenance scheduling, and historical data visualization for infrastructure planning

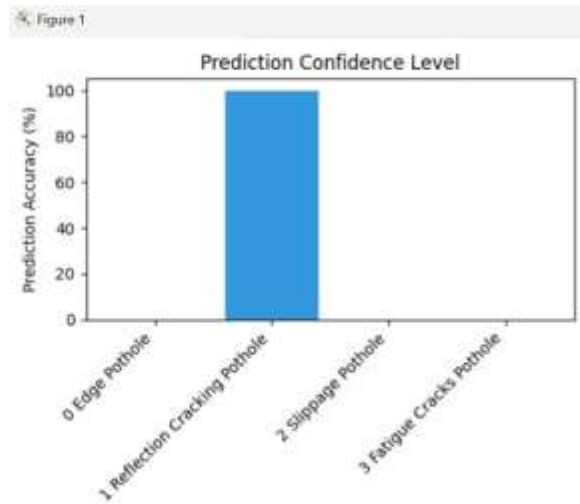


V. IMPLEMENTATION

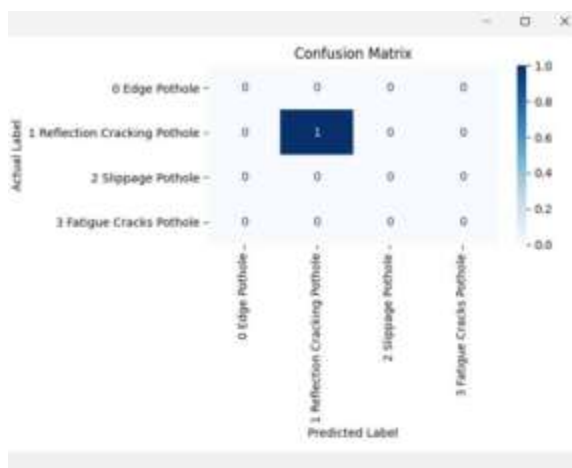


Upload Pothole





Prediction Confusion Matrix



Pothole Detection from Camera

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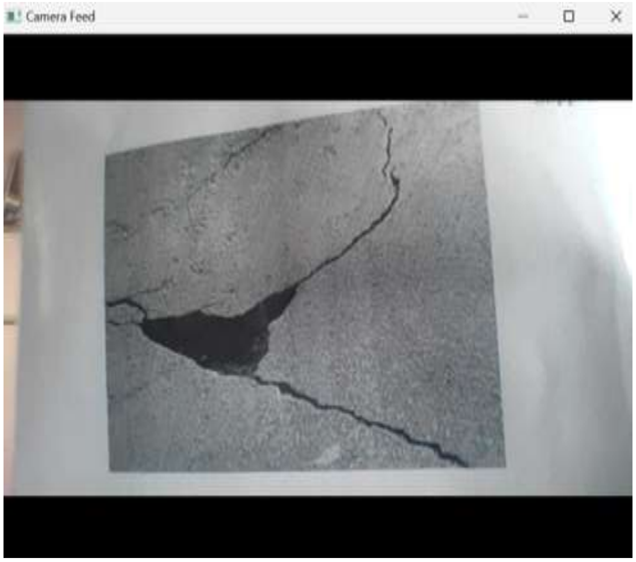
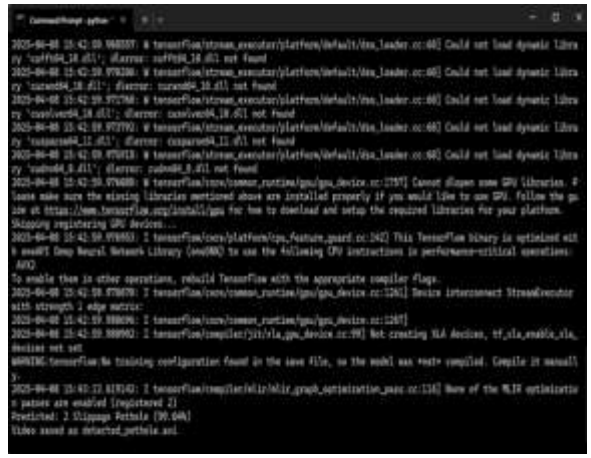
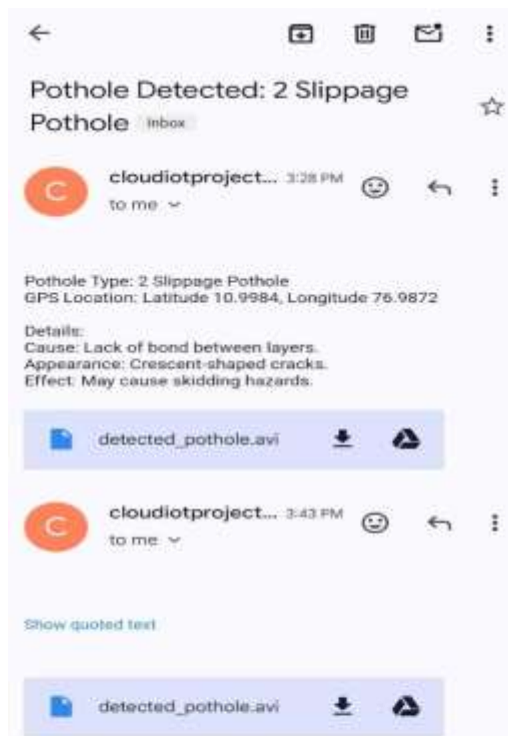


Prediction Result with Accuracy

Prediction Result



Video with Location Mail Alert



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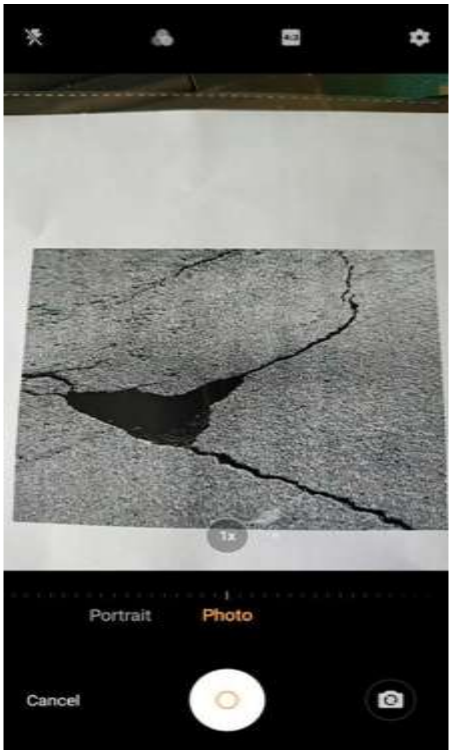
Capture Image



Pot Hole Detection

CONCLUSION

RoadWatchAI successfully demonstrates an intelligent, scalable, and cost-effective solution for automated pothole detection and road condition monitoring by integrating Android smartphone cameras with deep learning and computer vision technologies. The system effectively addresses the limitations of traditional manual inspection methods through real-time CNN-based classification of four distinct pothole types, achieving high accuracy with confidence scoring while simultaneously capturing GPS coordinates for precise geolocation. By providing immediate voice alerts to drivers and automated email notifications with annotated video evidence to municipal authorities, the platform bridges the critical gap between pothole detection and maintenance response. The inclusion of severity analysis through contour detection enables data-driven repair prioritization, while continuous model retraining capabilities through user-uploaded datasets ensure adaptability to diverse road conditions. Experimental validation confirms the system's robust performance across varying environmental scenarios, with high precision, recall, and processing efficiency, ultimately contributing to improved road safety, reduced vehicle damage, and smarterurban infrastructuremanagement through proactive, technology-driven maintenance strategies.

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