Pothole Detection Techniques Using Deep Learning and YOLO Model

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Abstract- *Pothole detection is an essential task in road maintenance and transportation safety, as damaged roads contribute significantly to vehicle damage, accidents, and economic loss. Traditional pothole detection methods, such as manual inspections and sensor-based approaches, suffer from inefficiency, inaccuracy, and high operational costs. With the rise of deep learning and computer vision techniques, automated pothole detection has become a viable solution. This survey provides a comprehensive review of pothole detection systems, focusing on deep learning-based methods, particularly YOLO (You Only Look Once) variants. Multiple versions of YOLO are analyzed for their detection accuracy, computational efficiency, and real-time applicability. Furthermore, this paper compares various studies that have employed deep learning models for pothole detection, highlighting the advantages and challenges of each approach. The paper also discusses GPS-based reporting systems, integration with real-world road maintenance infrastructure, and potential improvements for future research.*

Keywords- Pothole detection, YOLO, Deep Learning, Road Safety, Image Processing.

I. INTRODUCTION

Potholes are a persistent problem in road infrastructure, causing significant risks to drivers, passengers, and vehicles. Poor road maintenance leads to infrastructure degradation, increasing the chances of road accidents and economic losses. According to reports from various transportation departments, pothole-related damages and accidents contribute to thousands of injuries and fatalities annually. Traditional pothole detection relies on manual inspections, vibration-based methods, and laser scanning, which are time-consuming, expensive, and lack scalability. Recent advancements in deep learning and computer vision have paved the way for automated pothole detection using convolutional neural networks (CNNs).

Among various deep learning techniques, YOLO-based object detection models have gained widespreadattention due to their real-time processing capabilities and high accuracy. YOLO models are particularly well-suited for detecting road anomalies such as potholes, cracks, and surface deformations in real-time video streams. The proposed research aims to integrate YOLO variants with GPS tracking and automated reporting systems to enhance pothole detection and maintenance. This survey paper reviews previous studies on pothole detection and compares multiple YOLO versions for performance optimization.

II. LITERATURE REVIEW

Numerous studies have explored pothole detection using deep learning, sensor-based methods, and hybrid approaches. Research has primarily focused on object detection models, including CNNs, Faster R-CNN, SSD (Single Shot MultiBox Detector), and YOLO. Several studies have evaluated the effectiveness of these models in identifying potholes under different environmental conditions.

Chandra et al. (2025) used YOLOv5 for detecting potholes in drivable areas and achieved an accuracy of 84.5%, highlighting the potential of YOLO-based models in road safety applications.

Boosam et al. (2024) compared YOLOv1, YOLOv2, YOLOv3, YOLOv4, Tiny-YOLOv4, YOLOv5, and SSD-MobileNetV2 for pothole detection. The findings revealed that YOLOv5 achieved the highest mean average precision (mAP) of 95%, making it one of the most efficient models for real-time pothole detection.

Lakshminarayanan et al. (2024) proposed a convolutional neural network (CNN) integrated with IoT-based reporting for pothole identification, enabling real-time monitoring through cloud connectivity.

Gadekar et al. (2024) introduced a sonar-assisted YOLO model for detecting potholes even in waterlogged conditions, providing a novel solution for weather-resistant pothole identification.

Tamagusko and Ferreira (2023) conducted a comparative analysis of YOLOv3, YOLOv4, and YOLOv5 on a dataset of road pavement images, finding that YOLOv4 achieved the highest accuracy while YOLOv5 demonstrated better scalability for real-time applications.

Patthi and Padhy (2023), who developed an optimized deep learning framework integrating Recurrent Neural Networks (RNN) and Grey Wolf Optimization (GWO) to enhance pothole detection accuracy to 98.76% .

This survey highlights the key methodologies, performance metrics, and limitations of previous research while proposing a comprehensive approach using multiple YOLO versions for improved accuracy and real-time processing.

III. PROPOSED METHODOLOGY

The proposed pothole detection system integrates multiple YOLO versions for performance comparison and optimization. The methodology consists of three main components:

A. Pothole Detection Using YOLO

The system employs YOLOv3, YOLOv4, YOLOv5, YOLOv7, and YOLOv8 to detect potholes from real-world road images and video feeds. The models are trained on a diverse dataset containing potholes under different lighting conditions, road textures, and weather scenarios.

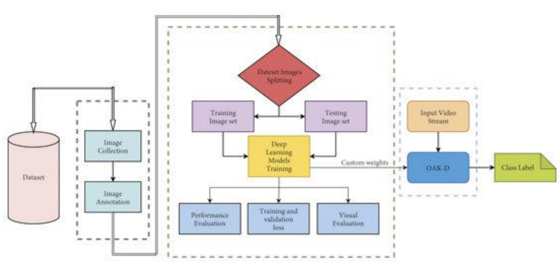

Fig 1. Pothole detection flowchart

B. GPS-Based Localization

Upon detecting a pothole, the system captures the GPS coordinates using an integrated GPS module. The location data is stored along with the image for further processing.

C. Automated Reporting System

The detected pothole information, including its image, confidence score, and location, is sent to an API-based reporting system that alerts road maintenance authorities. The system ensures timely intervention and maintenance.

IV. COMPARATIVE ANALYSIS

The following table provides a comparison of different pothole detection studies:

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Boosam et al. (2024) conducted a comparative study involving YOLO versions 1 to 5 and SSD, where YOLOv5 demonstrated the highest accuracy of 95%, making it the most efficient model for real-time pothole detection. Chandra et al. (2025) utilized YOLOv5 on a drivable area dataset and achieved an accuracy of 84.5%, proving its effectiveness in real-time monitoring applications. Tamagusko and Ferreira (2023) examined YOLOv3, YOLOv4, and YOLOv5, finding that YOLOv4 achieved the highest accuracy, while YOLOv5 demonstrated superior scalability for real-time applications. Lakshminarayanan et al. (2024) integrated CNN with IoT-based monitoring, attaining 92% accuracy on a real-world dataset, which highlights the effectiveness of cloud-connected solutions. Additionally, Gadekar et al. (2024) introduced a sonar-assisted YOLO model capable of detecting potholes in waterlogged conditions, providing an innovative approach to weather-resistant pothole identification.

Fig 2. Pothole detection on Roads

Fig 3. Pothole detection on Roads

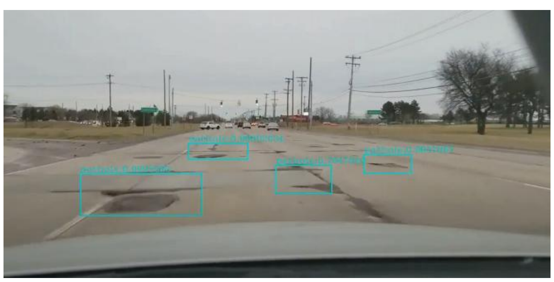

Fig 4. Pothole detection using Car Dashboard

V. DISCUSSION

The analysis of various YOLO variants for pothole detection reveals that YOLOv5 offers the best balance between accuracy and real-time processing speed, making it a preferred choice for real-world deployment. However, YOLOv4 remains highly competitive, especially in terms of precision in detecting smaller potholes. The research findings also indicate that hybrid models combining deep learning with sensor-based techniques (such as sonar and LiDAR) provide additional robustness in challenging conditions, such as low-light environments or waterlogged roads.

A significant advantage of deep learning-based pothole detection over traditional methods is automation, reducing human intervention while improving accuracy and scalability. The integration of GPS tracking further enhances the system's efficiency by enabling real-time geolocation mapping of detected potholes. Additionally, IoT-based reporting mechanisms ensure timely communication with road maintenance authorities, expediting the repair process.

Despite these advantages, the effectiveness of pothole detection still depends on various factors, including dataset diversity, model training efficiency, and real-world implementation challenges. The deployment of such systems in large-scale urban infrastructure requires careful consideration of edge computing solutions, as continuous cloud processing may not always be feasible due to latency and bandwidth constraints.

VI. CHALLENGES AND FUTURE SCOPE

Challenges Faced in Past Studies

1) **Limited and Biased Datasets** – Many studies have trained models on small, region-specific datasets, leading to poor generalization in diverse environments. Models trained on smooth urban roads may struggle to detect potholes on rural or high-traffic highways.
2) **Environmental Variability** – Weather conditions (rain, fog, night-time visibility) significantly impact detection accuracy. Shadows and lighting variations can cause false positives.
3) **Computational Cost** – High-performance models such as YOLOv5 and YOLOv8 require powerful GPUs, making deployment on low-resource edge devices challenging.
4) **Waterlogged and Hidden Potholes** – Traditional vision-based models struggle to detect potholes submerged in water, mud, or covered by debris. Some past studies attempted hybrid solutions using sonar or thermal imaging, but these approaches require additional hardware.
5) **Real-Time Constraints** – Although YOLO models are optimized for real-time inference, processing high-resolution images at scale remains a challenge, particularly for embedded systems like vehicle dashboards.
6) **Integration with Road Infrastructure** – Many past studies focused on detection

alone, with limited research on integration with smart city infrastructure for automatic maintenance scheduling.

Future Scope and Improvements

1) **Enhanced Dataset Collection and Augmentation** – Future research should focus on building larger, more diverse datasets, incorporating images from different lighting conditions, terrains, and weather scenarios. Data augmentation techniques can further enhance model robustness.
2) **Multi-Sensor Fusion** – Combining YOLO-based vision detection with LiDAR, sonar, or thermal imaging can improve pothole identification in challenging environments, such as waterlogged roads or nighttime conditions.
3) **Lightweight Models for Edge Devices** – Optimizing YOLO models for low-power devices using techniques like quantization, pruning, and knowledge distillation will enable real-time inference on mobile phones and in-vehicle cameras.
4) **Integration with Autonomous Vehicles and Drones** – Deploying pothole detection systems in autonomous vehicles and UAVs (unmanned aerial vehicles) for large-scale road monitoring can significantly improve maintenance efficiency.
5) **Predictive Maintenance using AI** – Instead of just detecting potholes, future research should focus on predicting road deterioration using AI and historical data analysis. Machine learning models can help forecast potential road damage before potholes even form.
6) **Real-Time IoT Connectivity** – Enhancing connectivity between detection systems and road maintenance authorities through 5G and IoT frameworks will enable faster and more efficient road repairs.

VII. CONCLUSION

This survey provides a comprehensive analysis of pothole detection methods using deep learning, with a primary focus on YOLO-based object detection models. From the comparison of various YOLO versions, YOLOv5 emerges as the most effective model for real-time pothole detection, balancing high accuracy with computational efficiency. However, YOLOv4 remains competitive in terms of precision, making it suitable for specific applications requiring high detection accuracy.

The integration of GPS-based geolocation and IoT-enabled reporting further enhances the practical applicability of these systems, enabling automated alerts for road maintenance teams. Despite significant advancements, challenges such as dataset limitations, real-time processing constraints, and environmental variability persist. Future research should address these limitations by incorporating multi-sensor fusion, optimizing models for edge devices, and integrating AI-driven predictive maintenance strategies.

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