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Deep Learning Based- Pothole Detection

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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, including YOLOv3, YOLOv4, YOLOv5, YOLOv7, and YOLOv8, 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.

How to Cite This Article

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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 widespread attention 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.

Potholes are one of the most critical and persistent challenges in road infrastructure management, particularly in developing countries where rapid urbanization and heavy traffic loads accelerate road surface deterioration. These road anomalies not only degrade the quality of transportation but also pose severe safety hazards to drivers, passengers, and pedestrians. Potholes can lead to vehicle damage, increased fuel consumption, traffic congestion, and, in severe cases, fatal accidents. According to various transportation authority reports, pothole-related incidents account for a significant proportion of road accidents each year, resulting in substantial economic losses and human casualties.

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.

Gerasimos Arvanitis et al. (2024) Proposed a saliency-based pothole detection system combined with Augmented Reality (AR) to improve driver awareness. The method identifies important regions in road images using saliency techniques. It also uses distributed cooperative processing for better detection performance. The system is useful for real-time smart transportation applications.

Yifan Pan and Xianfeng Zhang (2018) Developed a UAV-based pothole and crack detection system using multispectral imagery. The approach uses ANN and SVM for classification of road defects. It enables large-scale road monitoring by capturing aerial images. This method improves coverage compared to traditional ground inspection.

Amel Ali Alhussan and Doaa Sami Khafaga (2022) Proposed a hybrid model combining SVM and CNN for pothole classification. The approach uses transfer learning and optimization techniques to improve accuracy. It is suitable for intelligent transportation and self-driving systems. The model enhances feature extraction for better detection.

Dong Chen (2022) Introduced a real-time pothole detection system based on vibration analysis. The method combines reflectometry and sensor data from moving vehicles. It helps in generating road condition maps for smart cities. This approach supports continuous monitoring of road surfaces.

Rui Fan (2020) Proposed a vision-based detection method using disparity transformation and surface modeling. The system applies techniques like RANSAC and Otsu thresholding. It improves road surface analysis and pothole detection accuracy. The approach focuses on modeling road geometry effectively.

Siti Fairuz Mat Radzi (2025) Developed an advanced pothole detection system using an improved YOLOv7 model. The approach enhances feature extraction and attention mechanisms. It enables real-time detection using UAV-based systems. This method improves performance in intelligent road monitoring. 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.

Proposed methodology

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

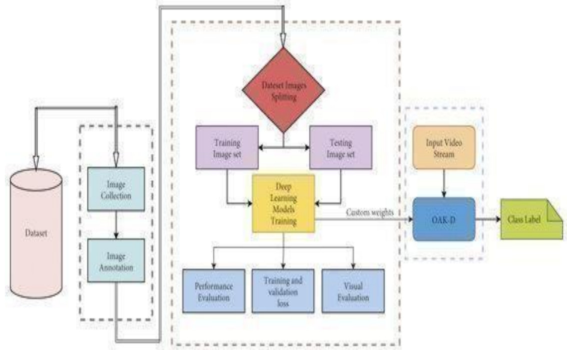

Fig 1. *Pothole detection flowchart*

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.

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.

Comparative analysis

The following table provides a comparison of different pothole detection studies: The comparative analysis of various pothole detection techniques highlights the diversity of approaches used in recent studies. Arvanitis et al. (2024) proposed a saliency-based detection method integrated with Augmented Reality and cooperative processing, achieving improved real-time visualization and situational awareness. Pan and Zhang (2018) utilized UAV-based multispectral imaging along with ANN and SVM, achieving effective large-scale road monitoring and broader coverage. Alhussan and Khafaga (2022) developed a hybrid CNN and SVM model with transfer learning, achieving enhanced feature extraction and classification performance for intelligent transportation systems. Chen (2022) introduced a vibration- based detection approach using reflectometry and sensor data, achieving efficient real-time road condition mapping in smart cities. Fan (2020) focused on a vision-based technique using disparity transformation and surface modeling, achieving improved road geometry analysis and accurate pothole detection. Additionally, Radzi (2025) proposed an advanced YOLOv7-based model with enhanced feature extraction and attention mechanisms, achieving efficient real-time detection in UAV-based systems. Overall, deep learning-based methods, particularly YOLO variants, demonstrate strong performance in real-time detection and scalability, while UAV and sensor- based approaches contribute to efficient large-scale monitoring and smart infrastructure development.

Fig 2. *Pothole detection on Roads*

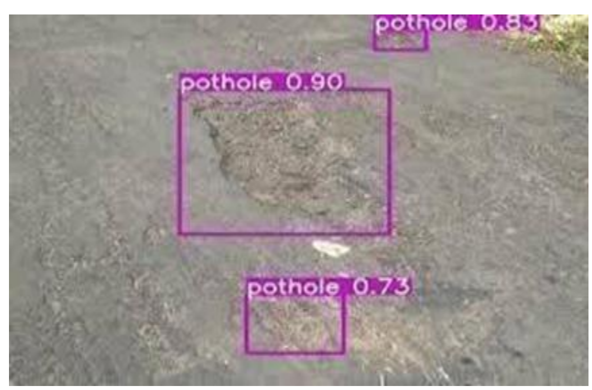

Fig 3. *Pothole detection on Roads*

The comparative study of existing pothole detection techniques reveals significant differences in methodology, performance, and practical applicability. Vision-based approaches, particularly those using deep learning models, demonstrate superior capability in extracting complex spatial features from road images, enabling accurate detection of potholes with varying shapes, sizes, and textures. Among these, YOLO-based models stand out due to their single-stage detection architecture, which allows faster inference compared to traditional region-based methods. In contrast, machine learning approaches such as SVM and ANN rely heavily on handcrafted features, making them less adaptive to complex real-world scenarios. UAV-based detection systems provide extensive coverage and are highly effective for large-scale monitoring; however, their performance depends on image resolution, altitude, and environmental conditions. Sensor-based methods, including vibration analysis and reflectometry, offer an alternative approach by detecting road anomalies through physical signals, making them suitable for integration with moving vehicles and smart city infrastructure. Additionally, hybrid models that combine deep learning with sensor inputs enhance detection reliability by leveraging both visual and physical data. Another key aspect of comparison is scalability, where deep learning models deployed on edge devices or cloud platforms enable continuous monitoring over large road networks.

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)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

6)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

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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