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A Survey on IOT-Based Pothole Detection System using YOLO V7-DSA Algorithm

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Abstract: Road surface irregularities, including potholes and speed humps, pose major problems for modern transportation networks by reducing traveler safety, damaging vehicles, disturbing traffic movement, and increasing repair expenses. Traditional road inspection mainly depends on manual checking, which is time-consuming, costly, and difficult to apply consistently across large road areas. Recent developments in artificial intelligence, computer vision, and sensor-based systems have made it possible to automatically detect and categorize road defects with immediate response capability. This survey presents the main techniques used for pothole and hump identification, such as image-based methods, machine learning approaches, deep learning models, smartphone sensing systems, and camera–LiDAR integrated frameworks. These methods are examined based on detection accuracy, processing speed, hardware needs, and suitability for real-world deployment. Common benchmark datasets, evaluation measures, and practical difficulties such as poor lighting, weather variations, occlusion, and insufficient training samples are also discussed. In addition, the paper outlines existing research gaps and new directions, including edge intelligence, connected vehicles, and smart city applications. The review suggests that deep learning and sensor fusion techniques generally achieve better results than conventional methods, although challenges related to cost, scalability, and dependable real-time operation still remain. Overall, this work provides a useful reference for researchers and developers involved in smart road monitoring and safer transportation solutions.

Keyword: Pothole Detection, Road Surface Monitoring, Smart Transportation, Internet of Things (IoT), Deep Learning, YOLO, ESP32, Computer Vision, GPS Tracking, Cloud Computing, Real-Time Monitoring, Road Safety

I. INTRODUCTION

Road transport is an essential part of economic development, everyday travel, and social interaction. The condition of road infrastructure has a direct impact on passenger safety, ride comfort, fuel usage, and vehicle repair expenses. Over time, roads face continuous stress from heavy traffic, changing temperatures, rainfall, poor drainage, and aging materials, which can result in defects such as potholes, cracks, depressions, and speed humps. Among these issues, potholes are widely regarded as one of the most dangerous because they may damage vehicles, increase the chance of accidents, and lower road dependability.

Conventional road inspection usually relies on manual surveys or dedicated inspection vehicles. While these methods can locate damaged areas, they require considerable manpower, time, and cost. In addition, manual evaluation is often subjective and may not deliver uniform results across large road networks. With growing urbanization and increasing traffic volume, the demand for automatic, reliable, and scalable road monitoring systems has become more important than ever.

Recent advancements in artificial intelligence, computer vision, and embedded sensing technologies have significantly improved road defect detection. Devices such as cameras, smartphones, accelerometers, LiDAR units, and GPS modules are capable of collecting road data continuously. Machine learning and deep learning algorithms then process this data to recognize anomalies in real time. Techniques including Convolutional Neural Networks (CNNs), YOLO detectors, transformer-based models, and sensor fusion systems have achieved encouraging results in identifying potholes and humps under challenging road conditions. These solutions are particularly useful for advanced driver assistance systems, self-driving vehicles, and smart city applications.

Even with this progress, several issues remain unsolved. Changes in lighting, weather, shadows, road markings, sensor disturbances, and limited labeled datasets can reduce the dependability of detection models. Moreover, some highly accurate methods require expensive devices or significant computational resources, which limits their use in low-cost environments. This survey provides a detailed review of pothole and hump detection methods introduced in recent years. Existing approaches are grouped into image processing, machine learning, deep learning, vibration-based sensing, and multi-sensor fusion categories. The study also compares available datasets, evaluation criteria, benefits, drawbacks, and real-world applications of these methods. Finally, current research gaps and future directions for developing robust, affordable, and intelligent road monitoring systems are discussed.

II. LITERATURE SURVEY

1) Gerasimos Arvanitis et al.: [1] (2023): Proposed a 22 cooperative pothole detection framework that combines LiDAR sensing with saliency map analysis to identify potholes. The system also integrates augmented reality (AR) visualization and vehicle-to-everything (V2X) communication to improve driver awareness and road safety. The advantage is enhanced situational awareness through intelligent visualization and connected vehicle communication. The limitation lies in expensive sensing hardware and the possibility of driver distraction due to AR overlays.
2) Karukayil et al [2] (2022): Karukayil et al.: Deep Learning Enhanced Feature Extraction of Potholes Using Vision and LiDAR Data for Road 4 Maintenance [4] (2024): Proposed a camera–LiDAR fusion system using YOLO-based detection and 3D point cloud reconstruction. The framework estimates pothole area, volume, and depth, while GNSS data is used for mapping pothole locations. The advantage is rich geometric analysis with accurate detection and location-aware maintenance support. The limitation lies in expensive LiDAR hardware and the need for careful sensor calibration.
3) X. Huang et al. [3] (2023): Introduced a lightweight real-time pothole segmentation model designed for efficient deployment. The framework uses EADE and GCA modules to improve feature extraction and segmentation accuracy while maintaining faster inference speed. The advantage is low computational cost with real-time detection capability on resource-limited devices. The limitation is sensitivity to environmental variations and dependence on high-quality training datasets.
4) A. Dhiman and R. Klette [4] (2020): Presented a comprehensive study of pothole detection methods using stereo vision, 3D reconstruction, image processing, and deep learning approaches. The work highlighted the growing importance of AI techniques for improving road damage detection performance. The advantage is broad analysis of multiple detection strategies and comparison of modern approaches. The limitation is that many reviewed methods remain affected by weather conditions and lack standardized datasets.
5) N. Bhavana et al. [5] (2024): : Proposed a YOLOv8-based pothole detection model with edge segmentation techniques for accurate real-time recognition. The method achieved very high reported accuracy and The was advantage designed is for fast detection deployment speed with in strong practical accuracy road in monitoring real-time systems. applications. high The limitation lies in sensitivity to lighting changes and the need for image preprocessing.
6) S. Saleh et al. [6] (2024): Developed a smart pothole detection architecture that combines edge computing, Internet of Vehicles (IoV), and digital twin technology. The system provides ultra-low latency alerts and enables intelligent monitoring of road infrastructure. The advantage is fast response time with scalable intelligent transportation support. The limitation is the requirement of complex infrastructure and continuous network connectivity.
7) L. Li et al. [7] (2024): Proposed a pothole segmentation framework using crowdsourced road datasets and an improved Mask R-CNN model. The method utilized diverse training data to improve segmentation quality and generalization across multiple road conditions. The advantage is strong segmentation accuracy with the benefit of large-scale community-generated datasets. The limitation is dependence on dataset quality and possible generalization issues in unseen environments.
8) A. Wang et al. [8] (2024): Introduced a two-stage pothole detection pipeline using YOLOX for object localization and DSASNet for detailed segmentation. The integration of 2D and 3D information The improved is recognition better detection precision accuracy and pothole detailed boundary segmentation extraction. output. advantage and The limitation is higher computational demand and the need for larger annotated datasets.
9) K. VramanaReddy et al. [9] (2025): Presented an Internet of Things based system for automated pothole detection and road condition monitoring using embedded sensors and wireless communication modules. The framework detects potholes through vibration or motion sensing devices mounted on vehicles and transmits the location data to a central server for maintenance planning. By integrating GPS and cloud connectivity, the system enables real-time reporting of damaged road segments and supports efficient municipal response. The proposed solution offers a low-cost and scalable approach for smart city road maintenance. The advantage is economical deployment with automated pothole reporting and real-time location tracking. The limitation lies in lower accuracy compared with vision-based systems and possible false detections caused by vehicle movement or uneven roads.
10) S. F. M. Radzi et al. [10] (2025): Developed a UAV-assisted pothole detection system using an enhanced YOLOv7 model integrated with C3ECA and DSA modules for real-time aerial road inspection. The proposed algorithm improves feature extraction, attention learning, and detection capability for identifying potholes from drone-captured images under varying road and environmental conditions. By using UAV platforms, the system can cover large road networks quickly and collect high-resolution inspection data without interrupting traffic flow. Experimental evaluation demonstrated high detection accuracy and efficient real-time performance for large-scale infrastructure monitoring. The advantage is rapid large-area road inspection with

accurate aerial pothole detection and reduced manual survey effort. The limitation lies in dependence on weather conditions, UAV battery constraints, flight regulations, and operational costs.

III. METHODOLOGY

The proposed intelligent pothole detection system is designed to identify road surface irregularities instantly using low-cost sensors, wireless communication, and cloud-based intelligence. The framework combines sensing hardware, embedded processing, artificial intelligence, and monitoring tools to create an efficient solution for road condition analysis and alert generation. The complete workflow is divided into four major stages: data acquisition, local processing, cloud intelligence, and monitoring with notifications.

A. Data Acquisition Using Sensors and GPS

The first stage of the system focuses on collecting road condition data while the vehicle is in motion. Multiple sensing components are integrated to capture different physical characteristics of the road surface.

- Ultrasonic Sensor: Measures the distance between the sensor and road surface. Sudden changes in distance may indicate potholes, bumps, or depressions.
- Vibration Sensor: Detects abnormal shocks and vibrations caused when a vehicle passes over damaged road sections.
- GPS Module: Records the geographical coordinates of the detected anomaly for location-based mapping and reporting.

By combining these sensors, the system captures both physical road deformation and exact position data.

B. Local Processing Using ESP32 Board

The collected sensor values are transmitted to an ESP32 microcontroller, which acts as the central control unit of the system. The ESP32 performs initial data handling and communication tasks.

Its main functions include:

- Reading sensor values continuously
- Filtering noise from raw sensor signals
- Detecting threshold-based abnormal events
- Organizing data packets with time and GPS coordinates
- Transmitting data through built-in Wi-Fi connectivity

Because the ESP32 supports wireless communication and efficient processing, it is suitable for portable real-time IoT applications.

C. AI and Cloud-Based Processing

After local preprocessing, the collected data is sent to a cloud server through Wi-Fi for advanced analysis and storage. Cloud computing improves scalability and enables the use of intelligent algorithms.

The cloud layer performs the following operations:

- Data Storage: Maintains historical records of road conditions
- AI Analysis: Uses machine learning or deep learning models to classify potholes and road anomalies
- Image/Data Processing: OpenCV and TensorFlow-based frameworks can be used for pattern recognition and decision-making
- Severity Estimation: Determines the seriousness of detected potholes based on sensor patterns

Cloud-based architecture allows continuous model improvement and centralized monitoring.

D. Monitoring, Alerts, and Reporting

Once potholes are confirmed, the processed information is displayed through monitoring dashboards, mobile applications, or web interfaces. Authorities and users can access real-time road health information.

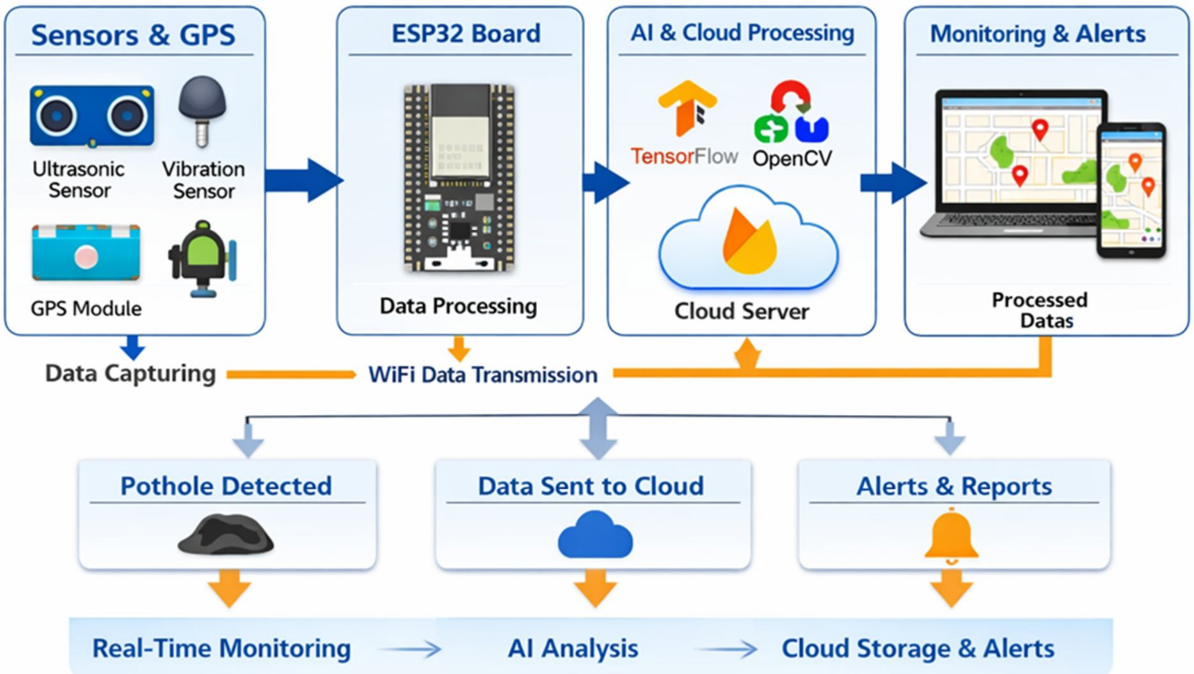
Main outputs include:

- Live pothole location mapping
- Processed road condition data
- Notifications and warning alerts
- Reports for maintenance planning
- Historical trend analysis

This phase ensures that the collected data is transformed into meaningful actions for road maintenance and public safety.

E. System Workflow Summary

The overall operation of the proposed model follows this sequence:
Road Data Collection → Sensor Analysis → ESP32 Processing → Wi-Fi Transmission →
Cloud AI Classification → Alert Generation → Real-Time Monitoring



F. Advantages of the Proposed Method

The proposed methodology offers several benefits:

- Low-cost implementation using affordable sensors
- Real-time pothole detection and alerts
- Accurate location tracking using GPS
- Scalable cloud-based storage and analytics
- Suitable for smart city and intelligent transport systems
- Reduced manual road inspection effort

G. Expected Outcome

The system is expected to automatically detect potholes, upload their locations to the cloud, generate timely alerts, and support authorities in prioritizing road maintenance. This improves road safety, reduces vehicle damage, and enables smarter infrastructure management.

IV. DISCUSSION

The reviewed studies and the proposed smart pothole detection framework demonstrate that automated road monitoring has evolved significantly from manual inspection methods to intelligent real-time systems. Earlier approaches mainly relied on visual observation or periodic surveys, which were slow, labor-intensive, and often inconsistent. The integration of sensors, embedded devices, artificial intelligence, and cloud platforms now enables faster and more reliable detection of road surface anomalies.

One of the key observations from the literature is that no single sensing method is sufficient under all road conditions. Camera-based systems provide rich visual information and perform well for visible potholes, but their accuracy may decline under poor lighting, rain, shadows, or occlusion. Vibration-based systems are inexpensive and easy to deploy, yet they may confuse potholes with speed breakers, rough patches, or sudden braking events.

LiDAR-based methods offer accurate depth estimation and geometric analysis, but their high hardware cost limits large-scale deployment. For this reason, recent research increasingly focuses on sensor fusion, where multiple data sources are combined to improve reliability.

The proposed methodology follows this practical trend by integrating ultrasonic sensing, vibration analysis, GPS tracking, local processing through ESP32, and cloud-based intelligence. This architecture balances cost, scalability, and functionality. Ultrasonic measurements help estimate surface depth changes, vibration signals capture dynamic road impacts, and GPS provides precise localization. When these signals are processed together, the probability of false detection can be reduced compared with using a single sensor.

Another important discussion point is the role of edge and cloud computing. Performing basic filtering and event detection on the ESP32 reduces communication overhead and enables quicker local response. At the same time, cloud processing allows storage of large volumes of road data, centralized monitoring, model updates, and advanced analytics. This hybrid approach is well suited for smart city applications where multiple vehicles or devices continuously contribute road condition information.

Despite these advantages, several practical challenges remain. Sensor readings can be affected by vehicle speed, mounting position, suspension type, road material, and environmental noise. GPS accuracy may decrease in dense urban areas or under poor satellite visibility. Wireless transmission depends on stable network availability. In addition, AI models require representative datasets collected from different roads, weather conditions, and vehicle types to generalize effectively. Without sufficient data diversity, system performance may degrade in unseen scenarios.

The survey also indicates that evaluation should not depend only on accuracy. Real-world systems must be judged using precision, recall, latency, energy consumption, maintenance cost, and ease of deployment. A highly accurate model that requires expensive hardware or heavy computation may be less practical than a moderately accurate but scalable solution.

Overall, the findings suggest that intelligent pothole detection is moving toward low-cost IoT devices, distributed sensing, and cloud-assisted decision systems. The proposed framework aligns with this direction by offering an affordable and extensible model for continuous road monitoring. Future improvements can include mobile application integration, severity ranking, predictive maintenance, adaptive thresholds, and federated learning for privacy-preserving model updates.

V. CONCLUSION

Road potholes and surface irregularities remain major concerns for transportation safety, driving comfort, and infrastructure maintenance. Conventional inspection techniques are often slow, expensive, and dependent on manual effort, making them less suitable for large and rapidly growing road networks. This survey examined the evolution of pothole detection methods, including traditional image-based techniques, machine learning, deep learning, vibration-based sensing, LiDAR systems, and multi-sensor fusion approaches.The review shows that intelligent detection systems provide clear advantages over manual inspection by enabling faster, more accurate, and continuous monitoring of road conditions. Camera-based methods are effective for visual recognition, sensor-based systems are economical and easy to deploy, while LiDAR and fusion models offer better geometric understanding and improved robustness. However, each approach also presents limitations related to environmental conditions, computational cost, hardware expense, or scalability.

To address these issues, the proposed smart pothole detection methodology integrates ultrasonic and vibration sensors, GPS tracking, ESP32-based local processing, wireless communication, and cloud-based AI analysis. This combination offers a practical balance between affordability, real-time operation, and intelligent decision-making. The system can automatically detect potholes, store location-aware data, generate alerts, and support maintenance authorities with actionable road condition reports.

In summary, automated pothole detection is becoming an essential component of smart transportation and smart city infrastructure. Further studies should concentrate on improving detection reliability under diverse real-world conditions, reducing energy consumption, enhancing low-cost deployment, and developing predictive maintenance systems using large-scale connected data. With continued advancements in IoT and artificial intelligence, road monitoring systems can become more proactive, efficient, and beneficial to public safety.

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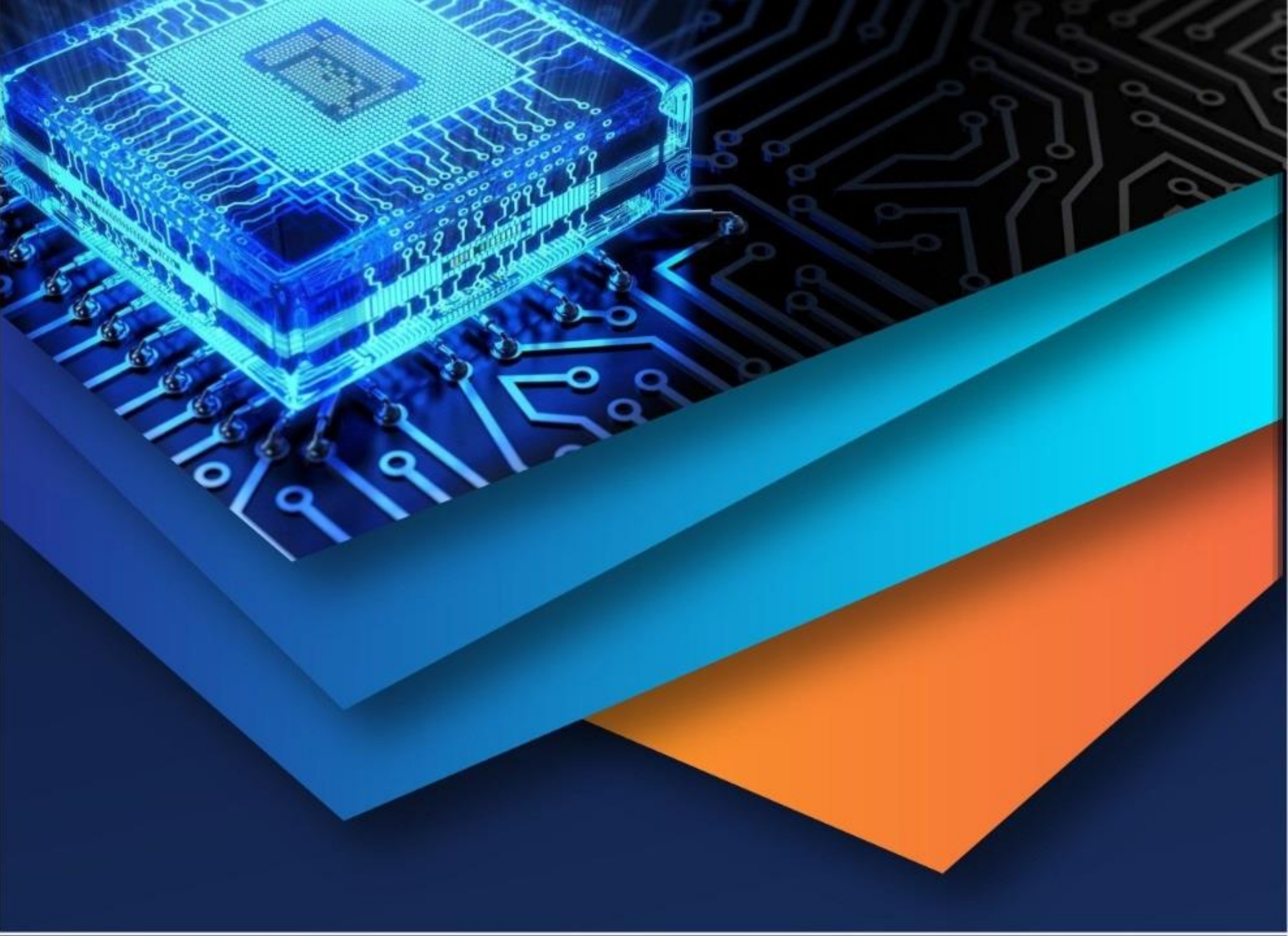

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