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# A SURVEY: POTHOLE DETECTION WITH DEPTH ANALYSIS AND REAL-TIME ALERTS

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## ABSTRACT

Potholes on roads pose significant risks to both drivers and pedestrians, leading to accidents, injuries, and damage to vehicles. Timely detection and repair are essential for maintaining road safety and minimizing these risks. This project proposes a pothole detection system using the YOLO v11 object detection model integrated with the Depth-Anything framework to enhance accuracy by assessing pothole severity through depth estimation. The system captures real-time images and depth maps using a smartphone or vehicle-mounted camera. It classifies road regions as either “pothole” or “normal road,” addressing class imbalance issues through data augmentation and weighted training. The geotagged coordinates of detected potholes are stored in a database and sent to civic authorities for maintenance, while drivers receive real-time alerts with alternate route suggestions. The proposed solution optimizes both detection speed and precision, ensuring high frames per second (FPS) performance. This system can significantly improve road safety by providing accurate, real-time pothole detection and facilitating efficient road maintenance.

**Keywords:** Pothole Detection, YOLO V11, Depth Estimation, Depth-Anything, Real-Time Detection, Machine Learning, Geotagging, Object Detection, Road Safety, Route Optimization, Maintenance Scheduling.

## I. INTRODUCTION

Road networks are essential for efficient transportation, linking cities, towns, and regions. However, potholes—resulting from environmental wear and frequent usage—create significant safety hazards, contributing to accidents, injuries, and vehicle damage. Traditional methods of detecting and repairing potholes are often slow and inefficient, relying on manual checks. This highlights the need for automated systems that can detect potholes in real time, alerting both drivers and authorities for timely response.

This project utilizes advanced machine learning, specifically YOLO v11 for real-time object detection, combined with the Depth-Anything framework for assessing pothole depth and severity. Using images and depth maps captured by smartphone or vehicle-mounted cameras, the system processes data through the detection model and sends real-time alerts to drivers via a mobile app. Additionally, geotagged information is sent to civic authorities to facilitate more effective road maintenance.

The proposed solution tackles challenges like class imbalance, low-light conditions, and resource management, achieving high precision, recall, and FPS performance. By offering alternative routes for drivers and aiding in maintenance planning, this system aims to improve road safety and reduce accident risks.

## II. LITERATURE SURVEY

I.A Books and Websites Reviewed

| Ref. No. | Title | Author(s) | Year | Publisher/Source |
|---|---|---|---|---|
| [11] | Computer Vision: Algorithms and Applications | Richard Szeliski | 2011 | Springer |
| [12] | Deep Learning | Ian Goodfellow, Yoshua Bengio, Aaron Courville | 2016 | MIT Press |
| [13] | YOLO GitHub Documentation | AlexeyAB (GitHub) | N/A | GitHub |
| [14] | Depth-Anything Framework | Depth-Anything | N/A | Depth-Anything |

I.B Real Time stories and Live Survey

| Survey Title | Deailtes |
|---|---|
| **Survey of Road Conditions in India** | Reports a significant increase in accidents caused by potholes, emphasizing the need for accurate and timely detection systems for safer roads. |
| **Field Testing with Autonomous Vehicles** | Real-world tests have demonstrated that integrating depth maps improves pothole detection accuracy, particularly in low-light environments. |

I.C Algorithm Survey

| Ref. No. | Method | Description | Gap Identified |
|---|---|---|---|
| [1] | CNN-based Deep Learning Model | Uses CNNs for classifying potholes and normal roads. | Lacks depth estimation for pothole severity assessment. |
| [2] | Raspberry Pi with Camera Module | Detects road deformations with Raspberry Pi cameras and logs GPS coordinates. | Struggles in poor lighting conditions and limited real-time performance. |
| [3] | Disparity Map & 3D Surface Modeling | Uses disparity transformation and 3D surface modeling for accurate shape-based pothole detection. | Computationally expensive, limiting real-time applications. |
| [4] | Attention-Based Coupled Framework | Applies few-shot learning to segment road and pothole areas using limited data. | Does not provide real-time alerts or depth information. |
| [5] | Laser Imaging for Severity Measurement | Measures pothole depth using laser imaging, ensuring high accuracy in urban and highway conditions. | Requires specialized laser equipment, limiting widespread use in regular vehicles. |
| [6] | Hybrid Accelerometer and Computer Vision System | Combines accelerometer data and vision techniques to cross-validate pothole detection. | Inconsistent results due to environmental factors affecting accelerometer data. |
| [7] | IoT-Based Smartphone Detection System | Uses IoT and smartphone cameras for real-time video data and GPS location tagging of potholes. | Lacks depth estimation and scalability for larger datasets. |
| [8] | Wavelet-Based Pothole Detection and Classification | Uses wavelet energy fields to detect potholes and classify based on their size and depth. | High computational overhead, reducing real-time effectiveness. |
| [9] | SSD Object Detection on Smartphones | Applies the SSD model for real-time pothole detection using smartphone sensors. | Performance drops significantly in low-light or adverse weather conditions. |

## III. METHODOLOGICAL SURVEY

| Ref. No. | Method Used | Data Used |
|---|---|---|
| **1** | **CNN-based Deep Learning Model** [R. Rastogi & Kumar, 2020] | Dataset of **road images** collected via cameras. Focus on **classifying pothole vs. normal road** regions. |
| **2** | **Raspberry Pi with Camera Module** [Govada & Jonnalagadda, 2020] | Images captured by **Raspberry Pi cameras**. Used for detecting **potholes and cracks** with GPS tagging. |
| **3** | **Disparity Map & 3D Surface Modeling** [Manjunatha HT & Ajit | **3D point cloud data** and **dense disparity maps** for accurate pothole detection using shape-based modeling. |

| | | |
|---|---|---|
| | Dant, 2019] | |
| **4** | **Attention-Based Coupled Framework** [Masihullah et al., 2021] | **KITTI and IDD datasets** for training a **few-shot learning framework** to detect potholes and drivable areas. |
| **5** | **Laser Imaging for Severity Measurement** [Yu & Salar, 2011] | **Laser-scanned images** from highways and urban roads. Used to calculate **depth, size, and severity** of potholes. |
| **6** | **Hybrid Accelerometer and Computer Vision System** [Kandoi et al., 2021] | **Accelerometer readings** from mobile sensors and **camera images** for cross-validation of pothole detection. |
| **7** | **IoT-Based Smartphone Detection System** [Rasyid & Albaab, 2019] | Real-time **video streams** from smartphones combined with **GPS data** for location tagging. |
| **8** | **Wavelet Energy Field Method** [Silvister & Komandur, 2019] | **Images processed using wavelet transformations** to detect and classify potholes based on size and depth. |
| **9** | **Non-Contact Control System for Monitoring** [Lo et al., 2016] | Uses **EEG signals** for healthcare monitoring. Provides ideas for **remote data collection**, adaptable for pothole reporting. |
| **10** | **SSD Object Detection on Smartphones** [Silvister & Komandur, 2019] | **Real-time images and accelerometer data** processed using the **SSD model** for mobile pothole detection. |

## IV. OUTCOMES

The proposed pothole detection system utilizing YOLO v11 and Depth-Anything achieves significant advancements in real-time road safety and automated maintenance management. The key outcomes of this system are:

1. Real-Time Pothole Detection: The integration of YOLO v11 enables accurate pothole detection in real-time, processing images at high frames per second (FPS), ensuring smooth operation on smartphones and vehicle-mounted systems. This allows drivers to be alerted immediately when a pothole is detected on their route.
2. Depth Estimation for Severity Analysis: By incorporating Depth-Anything, the system goes beyond simple detection and estimates the depth of potholes, allowing for classification into various severity levels (e.g., minor, moderate, severe). This helps authorities prioritize the most dangerous potholes for repair.
3. Geotagged Data and Reporting: Each detected pothole is tagged with GPS coordinates, which are logged in a centralized database. This geotagged data can be shared with civic authorities to facilitate timely and efficient maintenance, improving resource allocation and planning.
4. Driver Alerts and Alternate Routes: The system provides real-time alerts to drivers through a mobile application. If a severe pothole is detected, the system can also suggest alternate routes, ensuring the safety and convenience of the commuters.
5. Improved Road Safety: By providing accurate and timely pothole detection, this system reduces the risk of accidents caused by road defects, helping safeguard drivers, pedestrians, and vehicles.
6. Scalability and Efficiency: The system is designed to operate efficiently on low-resource devices such as smartphones, ensuring it can be deployed widely without requiring expensive hardware or specialized equipment.
7. Enhanced Maintenance Planning: With detailed information about pothole locations and severity, authorities can better manage road repairs, reducing both the time and cost associated with manual inspections. This leads to more proactive road maintenance and fewer disruptions for drivers.

## V. CONCLUSION

The proposed pothole detection system using YOLO v11 and Depth-Anything provides a robust solution to the ongoing challenges of road safety and maintenance. By combining real-time object detection with depth estimation, the system offers accurate identification and severity classification of potholes, helping both drivers and civic authorities respond promptly. The geotagging of potholes ensures that road defects are reported efficiently, facilitating timely repairs and reducing accidents caused by poor road conditions.

This solution not only addresses class imbalance and environmental challenges (like low-light conditions) but also ensures scalability, as it can be deployed on low-resource devices such as smartphones. The real-time alerts and alternate route suggestions enhance the driving experience, keeping commuters safe. Moreover, the system's ability to prioritize repairs based on pothole depth helps optimize maintenance planning, leading to better use of resources.

In conclusion, this project demonstrates the potential of machine learning and computer vision technologies in improving road safety. It offers an effective, cost-efficient, and scalable solution that can be integrated with autonomous and manual vehicles, ensuring safer journeys and proactive road maintenance.

## VI. FUTURE SCOPE

The proposed pothole detection system using YOLO v11 and Depth-Anything can be further expanded and improved in several ways:

1. Integration with Autonomous Vehicles: The system can be embedded into autonomous vehicles to improve their navigation by proactively detecting and avoiding potholes in real time.
2. Cloud-Based Data Sharing Platform: A cloud-based dashboard can be developed to store and visualize geotagged pothole data. This platform can allow government authorities and contractors to collaborate effectively and monitor the repair status.
3. Predictive Road Maintenance: Using machine learning models, the system can predict potential future pothole formations based on traffic patterns, weather data, and previous repair histories, helping authorities plan proactive maintenance.
4. Crowdsourcing Data from Multiple Users: The system could enable crowdsourced data collection from multiple drivers, improving the dataset's accuracy and coverage while reducing reliance on dedicated inspection systems.
5. Improved Model Optimization: Further optimization of YOLO v11 and depth estimation algorithms can be explored to enhance performance on low-end devices and reduce power consumption for mobile applications.
6. Integration with Smart City Systems: The system can be linked to smart city infrastructure, enabling automated traffic management and dynamic routing to reduce traffic congestion caused by pothole repairs.
7. Adapting to Other Road Defects: In addition to potholes, the system can be expanded to detect other road issues like cracks, speed bumps, or flooded areas, providing a more comprehensive road monitoring solution.
8. Edge Computing for Faster Detection: Implementing edge computing solutions will allow the system to process data locally on vehicles, ensuring faster alerts and improving real-time performance without depending on internet connectivity.
9. International Deployment: The system can be adapted to suit different geographical regions with unique road conditions, making it applicable in both developing and developed countries.
10. User Feedback and Continuous Learning: Incorporate user feedback from drivers to improve model performance. The system can also update itself using continuous learning techniques from new datasets.

The future development of this system promises enhanced scalability, efficiency, and reliability, making it a vital component of intelligent transportation systems.

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