ROBUST HUMP AND POTHOLE DETECTION USING DEEP LEARNING FOR ENHANCED ROAD SAFETY

***Project Reference No.:** 48S_BE_4929*

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Keywords:

Road Anomaly Detection, DL model, Pothole and Hump Detection, Real Time Monitoring.

Introduction:

The detection of road surface irregularities, such as potholes and speed humps, plays a vital role in ensuring road safety and improving the adaptability of modern transportation systems. These anomalies not only diminish driving comfort but also contribute to vehicle wear and tear, increasing the risk of accidents. As reported by the Indian Society of Structural Engineers (ISCE) in 2021, 43% of major highways in India received a low rating, leading to approximately ₹130 billion in annual vehicle maintenance costs. This highlights the urgent need for efficient and scalable methods to identify and address road surface issues.

Traditionally, road anomaly detection has relied on sensor-based systems involving accelerometers, gyroscopes, or vibration sensors. However, these methods can be limited in coverage, require complex integration, and may not provide precise localization. In this project, we propose a camera-based deep learning approach utilizing the YOLO (You Only Look Once) object detection model to detect potholes and humps directly from real-time video footage. By replacing physical sensors with vision-based analysis, the system offers a cost-effective, accurate, and non-intrusive solution suitable for integration into vehicles or roadside monitoring units.

The model is trained on a curated dataset of road images, enabling it to identify and classify various types of surface anomalies. This approach not only reduces dependency on hardware sensors but also supports smart city development by enabling faster and more intelligent road maintenance planning.

Objectives:

- **To develop a real-time object detection system using deep learning model (YOLO)** that can accurately detect potholes and humps from camera input without relying on physical sensors.

- **To estimate the distance of detected obstacles** from the camera with reasonable accuracy, supporting early warnings, safer navigation, and integration into autonomous vehicle systems.

Methodology:

- **Data Collection:**

  Road data is captured solely using cameras, ensuring a rich set of images under different lighting conditions, weather, and road types. This approach removes the need for additional sensor-based data.

- **Data Preprocessing:**

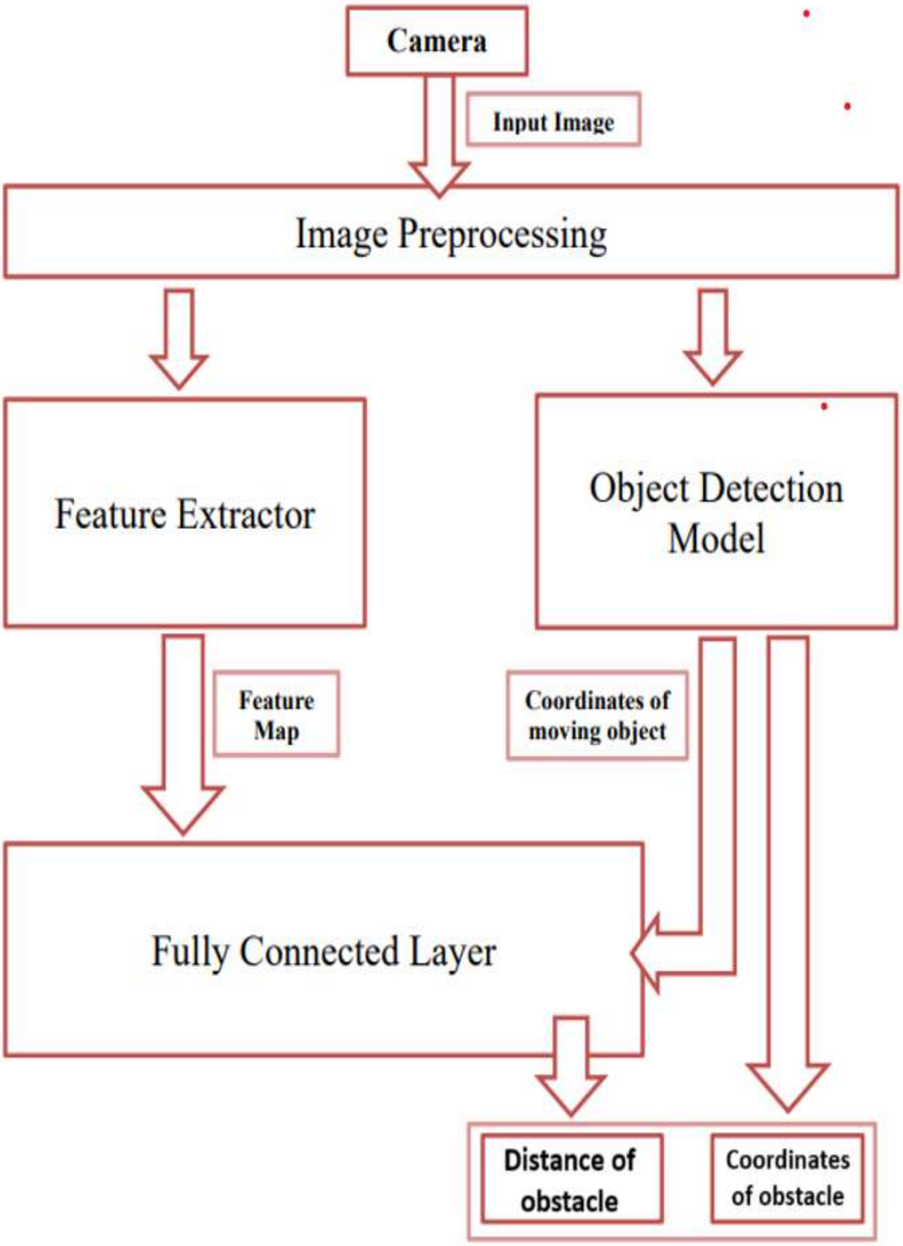
  The captured images undergo preprocessing, including normalization and noise reduction to enhance image quality. Data augmentation techniques like rotation, flipping, and scaling are used to improve model generalization.

- **Model Selection:**

  The YOLO (You Only Look Once) deep learning model is chosen for its ability to detect objects in real-time with high accuracy. YOLO's architecture is ideal for fast, efficient detection.

- **Model Training:**

  A labeled dataset containing annotated images of potholes and humps is used for training the YOLO model. Transfer learning is employed to fine-tune a pre-trained model, improving accuracy with limited data.



- **Real-time Detection:**

  The trained model is deployed on an embedded system or IoT device, processing live video feeds from the camera for real-time pothole and hump detection.

- **Distance Estimation:**

  The system incorporates a distance estimation feature to determine the proximity of detected obstacles, providing vital information for safety alerts, particularly in autonomous vehicle applications.

- **Performance Evaluation:**

  The model's performance is assessed using accuracy, precision, recall, and F1-score metrics to ensure reliable detection and classification of road anomalies.

- **System Testing:**

  The model is tested in real-world scenarios under varying road conditions, ensuring its robustness and ability to function effectively across diverse environments.

Result and Discussion

Various objectives defined for the dissertation work were satisfied based on results discussed in previous chapters. As a summary,

- The model effectively detected potholes, performing well across different road types and lighting conditions.
- Hump detection was accurate, though the model struggled with varying hump shapes and sizes.
- Distance estimation was accurate based on obstacle positioning in the image, but Far-range detection needed improvement.

Results of Hump and Pothole Detection

Image detecting pothole and hump (live example)

Image detecting pothole (live example)

Image detecting pothole

Image detecting potholes

Conclusion:

The proposed system, leveraging the YOLO model for real-time pothole and hump detection, successfully addresses the limitations of traditional detection methods. It accurately identifies road anomalies across different road types and lighting conditions, providing timely insights for road maintenance. Additionally, the system's ability to estimate the distance to obstacles enhances driver safety by offering valuable information for obstacle avoidance, making it a significant improvement over sensor-based detection systems.

Despite its success, the system faces challenges, particularly with varying hump shapes and far-range detection. The detection of road anomalies at longer distances still requires optimization to ensure consistent performance in dynamic driving environments. With further refinement in these areas, the system holds great potential to revolutionize road safety, reduce vehicle maintenance costs, and improve the efficiency of managing road hazards. Continuous improvements in real-time performance and adaptability will be crucial for its broader deployment in smart transportation systems.

Project Outcome & Industry Relevance:

While the system demonstrates the theoretical feasibility of using the YOLO model for real-time pothole and hump detection, its current form is best viewed as a proof of concept. Though preliminary results show potential, the system still faces challenges in accurately detecting humps of varying shapes and in estimating distances consistently. As such, its immediate industry relevance is limited, but it may serve as a foundation for further research or experimental trials in the domain of road condition monitoring.

Working Model vs Simulation/Study:

The project includes a basic working model capable of real-time detection on live camera input, but with limited reliability. While the detection pipeline functions under controlled conditions, its performance in more dynamic or uncontrolled environments is inconsistent. Compared to a polished product, the model remains closer to a study with some working components rather than a fully deployable solution.

Project Outcome and Learnings:

The project provided a learning experience in applying deep learning to a real-world problem, especially in using YOLO for object detection. However, many of the original goals were only partially achieved. While detection was possible in some scenarios, the system struggled with generalization, especially under varied lighting and road conditions. Though the model can calculate the distance, better method of Distance estimation needs to be built. These outcomes highlight the gap between theoretical models and practical deployment, underlining the need for more robust data, better training, and optimized deployment techniques.

Future Scope:

Various objectives defined for the dissertation work were satisfied based on results discussed in previous chapters. As a summary,

- **Long-Range Detection** can be enhanced using multi-scale techniques to improve the model's ability to detect obstacles at various distances, ensuring earlier warnings for distant anomalies. Integrating LiDAR sensors will further improve accuracy by providing detailed 3D depth data, which is especially useful for detecting obstacles in challenging conditions like poor visibility or high-speed driving.
- **Adaptability to Weather Conditions** is crucial for effective detection in diverse environments. Training the model on datasets with various weather scenarios will help improve performance. Incorporating thermal or infrared imaging will enable detection even in low-light or adverse weather conditions, such as fog or rain, where regular cameras may struggle.
- **Vehicle System Integration** will allow real-time detection to trigger alerts for drivers and adjust the vehicle's suspension system to reduce the impact of potholes and humps, ensuring a smoother ride. This integration could also enhance autonomous vehicles by allowing automated responses to detected anomalies.
- **Support for Sensor Fusion** will combine cameras with radar to improve robustness in detection. Radar can complement cameras by detecting obstacles in low-visibility conditions, while the combination of data from both sensors will lead to more reliable and accurate identification of road anomalies.

These future developments will make pothole and hump detection systems more accurate, adaptable, and integrated with vehicle systems, improving road safety and driving comfort.