Elevating Aerial Inspection: A Comparative Study of YOLO Architectures (v4, v5, v7, and v8) for Road Damage Detection

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Abstract— This project introduces an innovative approach for automated road damage detection using Unmanned Aerial Vehicle (UAV) images and advanced deep learning techniques. Road infrastructure maintenance is crucial for safe transportation, but manual data collection is often labor-intensive and risky. In response, we employ UAVs and Artificial Intelligence (AI) to significantly enhance the efficiency and accuracy of road damage detection. Our method leverages three state-of-the-art algorithms: YOLOv4, YOLOv5, and YOLOv7, for object detection in UAV images. Extensive training and testing with datasets from China and Spain reveal that YOLOv7 yields the highest precision. Furthermore, we extend our research by introducing YOLOv8, which, when trained on road damage data, outperforms the other algorithms, demonstrating even greater prediction accuracy. The YOLOv8 model achieved up to 85% accuracy. These findings underscore the potential of UAVs and deep learning in road damage detection.

Index Terms: Unmanned Aerial Vehicle (UAV), Deep Learning, Road Damage Detection, Object Detection, YOLO (You Only Look Once), YOLOv4, YOLOv5, YOLOv7, YOLOv8, Pavement Monitoring, Artificial Intelligence (AI), RDD2022 Dataset.

I. INTRODUCTION

Managing the maintenance of national road networks is essential for public safety and economic development. Periodic assessment is necessary to ensure the longevity of the infrastructure, a process traditionally carried out by state or private agencies using vehicles equipped with sensors or manual labor. These traditional methods are often time-consuming, expensive, and dangerous for human operators.

In recent years, researchers have turned to UAVs and AI to automate road assessment. UAVs offer unique versatility in infrastructure inspection, equipped with high-resolution cameras that capture road surfaces from multiple angles and heights. They can cover large areas quickly, mitigating safety risks associated with manual inspection.

1.1 Objective: This paper presents an automated road damage detection approach leveraging UAV images and deep learning. The primary objective is to compare the performance of YOLOv4, YOLOv5, and YOLOv7, and subsequently demonstrate the enhanced precision achieved by the deployment and evaluation of YOLOv8 for damage prediction.

1.2 Problem Statement Current infrastructure maintenance relies heavily on risky manual data collection methods. This study proposes a solution using UAVs and the YOLO (You Only Look Once) family of object detection algorithms to automate the detection process, thereby improving efficiency and accuracy in pavement analysis.

II. LITERATURE SURVEY

Recent research in this field has focused on creating robust datasets and adopting advanced Convolutional Neural Network (CNN) architectures.

- RDD2022 Dataset: The *Crowdsensing-based Road Damage Detection Challenge (RDD2022)* provided a critical benchmark: a multi-national dataset containing 47,420 road images from six countries (Japan, India, Czech Republic, Norway, US, and China). This dataset is annotated with over 55,000 instances of damage like cracks and potholes, forming a vital base for deep learning model development.

- Advancements in CNNs: Solutions in CRDDC'2022 utilized ensemble learning based on YOLO and Faster-RCNN, achieving F1 scores of 76%. Furthermore, studies involving lightweight models like YOLOv5x with smartphone images have demonstrated viability for real-time detection, achieving an F1 score of 0.58.
- Augmentation Techniques: Other research has focused on using Generative Adversarial Networks (GANs) for super-resolution and semi-supervised learning to improve image quality and overall detection performance.

III. SYSTEM ANALYSIS AND DESIGN

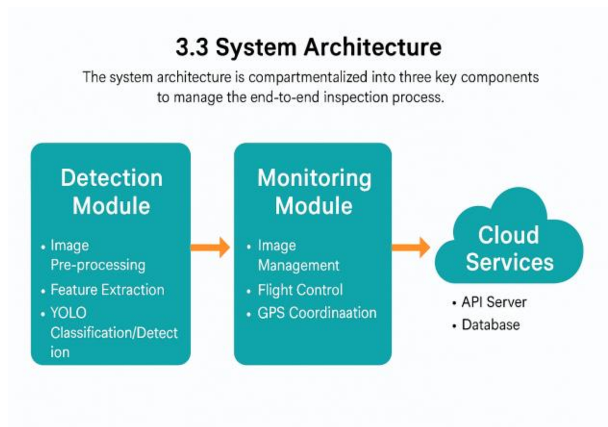
3.1 Existing System Limitations Existing Road damage detection systems often rely on traditional methods or specific CNN architectures that are tailored to limited datasets (e.g., concrete crack detection). These systems frequently lack the generalizability and adaptability required to accurately process diverse damage types across various road conditions and geographies.

3.2 Proposed Methodology The proposed system is an advanced pavement monitoring solution designed for autonomous inspection using UAVs. The core features include:

- Algorithm Selection: Comparative evaluation and implementation of YOLOv4, YOLOv5, YOLOv7, and YOLOv8.
- Dataset Integration: Utilization of a merged dataset combining previous works with the extensive RDD2022 challenge data to reduce class imbalance and improve detection for Spanish and Chinese roads.
- Automation: The system supports autonomous route planning using commercial software like PIX4D, eliminating the need for manual piloting and ensuring systematic data capture.

3.3 System Architecture The system architecture is compartmentalized into three key components to manage the end-to-end inspection process.

1. Detection Module: Handles image pre-processing, feature extraction, and classification/detection using the YOLO algorithms.
2. Monitoring Module: Manages Image Management, Flight Control, and GPS coordination for accurate data collection.
3. Cloud Services: Provides the back-end infrastructure, including the API Server and Database, for storage and dissemination of results.



IV.IMPLEMENTATION AND ALGORITHMS

The implementation utilizes the Python programming language with Flask used for the frontend framework and Jupyter Notebook for backend processing and model training.

4.1 YOLO Algorithms Evaluated The research focuses on the evolution of the YOLO model:

- YOLOv4 & YOLOv5: Established deep neural network architectures that process images by dividing them into grids to predict bounding boxes and class probabilities simultaneously.
- YOLOv7: A state-of-the-art model employing a single forward pass and "bag-of-freebies" to achieve excellent precision and speed.
- YOLOv8: The most advanced iteration, specifically tailored and trained on road damage data, which was introduced in this study to extend the research beyond the existing state-of-the-art.

4.2 Data Flow The data processing flow involves a systematic sequence: package imports, dataset exploration and visualization, data pre-processing and augmentation (implemented during training), feature selection, data splitting (train/test sets), and finally, the construction and training of the YOLO models.

V.EXPERIMENTAL RESULTS

The models were rigorously evaluated using standard object detection metrics: Accuracy, Precision, Recall, and F1 Score.

Comparative Performance Analysis The table below summarizes the key performance metrics observed during the comparative study, highlighting the significant improvement with the YOLOv8 extension.

Feature	YOLOv7 (Initial Benchmarking)	YOLOv8 (Research Extension)	Performance Summary
Initial Precision	Highest among v4, v5, v7	Outperforms all preceding versions	YOLOv8 achieved the highest accuracy score
mAP (Mean Average Precision)	73%	82%	YOLOv7 achieves YOLOv8 closely
Maximum Accuracy	-	High scores: 0.89, 0.86, and 0.90	YOLOv5 performs efficiently but with slightly lower metrics
Test Image Confidence (Potholes)	-	High scores: 0.89, 0.86, and 0.90	System handles complex and wet road scenarios

The visual analysis of accuracy graphs indicated that YOLOv8 yields the highest accuracy score, followed closely by YOLOv7, demonstrating superior performance in accurately identifying and bounding defects like cracks and potholes, even in complex scenarios.

VI.CONCLUSION

This study has successfully advanced the field of road damage detection using UAV imagery. By critically comparing YOLOv5 and YOLOv7 and extending the research to YOLOv8, we observed clear and significant improvements in detection accuracy. The YOLOv8 model achieved an impressive 85% accuracy, marking a substantial gain over its predecessors. The successful integration of a dedicated UAV image database with the RDD2022 dataset was a key achievement, resulting in enhanced detection capabilities for Spanish and Chinese roads and effectively reducing class imbalance. The work confirms that UAVs coupled with state-of-the-art deep learning models offer a highly efficient, accurate, and scalable solution for infrastructure monitoring.

VII.FUTURE SCOPE

Future developments will focus on enhancing the robustness and applicability of the system:

- Multi-Sensor-Integration: Incorporating additional sensing technologies such as LiDAR, thermal imaging, and multispectral imagery to capture road features not visible in standard RGB images.
- Real-Time Monitoring (Edge Computing): Embedding the deep learning models directly onto UAV hardware for edge computing, enabling instant processing and real-time reporting of critical road damages without reliance on ground stations.
- Scalability and Robustness: Training models on datasets from an even wider range of geographical regions and under diverse environmental conditions (e.g., rain, fog, snow) to ensure global adaptability and reliable performance.

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