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AUTOMATIC DETECTION AND PREDICTIVE GEO-LOCATION OF FOREIGN OBJECT DEBRIS ON AIRPORT RUNWAY

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ABSTRACT— The detection and removal of Foreign Object Debris (FOD) on airport runways pose significant challenges due to small object sizes and the impact of complex weather conditions on visibility and equipment efficiency. To address these challenges, this paper proposes an advanced FOD detection model leveraging YOLOv8, enhanced by alongside a geolocation prediction model based on machine learning regression algorithms. By integrating a self-attention mechanism with Convolutional Neural Networks (CNNs), the proposed FOD detection system delivers impressive results. Ablation studies demonstrate notable improvements in the Mean Average Precision (mAP) across different model components. Comparative evaluations against existing models like YOLOv5, YOLOX, and YOLOv7 highlight the superior performance of YOLOv8, particularly in detecting small objects and maintaining accuracy with diverse input data. Furthermore, the geolocation prediction model, built using machine learning regression techniques, showcases significant potential for practical FOD detection and removal applications in real-world scenarios.

Index Terms – Foreign Object Debris Detection, Airport Runway Monitoring, Predictive Geo-Location, Computer Vision, Deep Learning, Aviation Safety, Object Detection, Real-Time Surveillance, GIS, Artificial Intelligence.

I. INTRODUCTION

Foreign Object Debris (FOD) on airport runways presents a critical safety hazard to aircraft operations, potentially causing damage to engines, tires, and other critical components. Detecting and removing such debris in a timely manner is crucial to ensuring the safety and efficiency of airport operations. However, the detection of FOD is inherently challenging due to the small size of debris, the large area that needs to be covered, and the impact of complex weather conditions that can degrade visibility and sensor performance.

Traditional methods of FOD detection often rely on manual inspection or ground-based sensors, which can be time-consuming, error-prone, and inefficient, particularly in adverse weather conditions. With the advent of Unmanned Aerial Vehicles (UAVs) and advanced machine learning techniques, automated FOD detection has become a promising solution. In this paper, we propose an advanced FOD detection model that leverages YOLOv8, enhanced by Swin Transformer (ST), to address these challenges. The model is trained on a large dataset of 74,737 images, containing 21 distinct object types, captured by UAVs in various environmental conditions. Furthermore, a machine learning-based geolocation prediction model is introduced to assist in precisely locating the detected debris for effective removal. Through comprehensive experiments and comparative evaluations, the proposed system demonstrates superior performance over existing models like YOLOv5, YOLOX, and YOLOv7, showcasing its potential for practical FOD detection and removal applications in real-world airport environments.

II. RELATED WORK

A. Semi-automatic crack width measurement using an OrthoBoundary algorithm

Evaluation of pavements' crack severity levels currently relies heavily on width measurement, which necessitates the development of a rapid, and high-accurate, automatic measurement approach for complex pavement cracks. This paper presents an OrthoBoundary algorithm that leverages the crack boundary and skeleton directions to determine crack propagation. Comparative analysis has been conducted between OrthoBoundary and Area-Length, Skeleton Shortest Distance (SSD), Edge Shortest Distance (ESD), and Orthogonal

Projection (OP) methods. Results indicate that the OrthoBoundary algorithm achieves an average accuracy of 90.10%, outperforming the Area-Length (86.60%), SSD (76.01%), ESD (87.24%), and OP (88.07%) methods. Notably, the OrthoBoundary algorithm also exhibits processing speeds approximately 120 times faster than other considered methods while demonstrating improved robustness and user-friendliness. It has significant potential to quantify and assess the severity of pavement cracks, as well as to facilitate maintenance decision-making processes in road infrastructure management systems.

B. An automated 3D crack severity assessment using surface data for improving flexible avement maintenance strategies

Evaluation of crack severity in flexible pavements predominantly centers around the analysis of cracks’ surface characteristics. However, this study highlights the critical importance of 3D crack parameters, including volume and depth, for comprehensive assessment. The objective here is to develop an autonomous crack severity assessment, by predicting the vertical parameters of cracks exclusively from their surface properties. To achieve this, a dataset of 3D parameters comprising 200 cracks from eight flexible pavements was acquired, and both linear and nonlinear correlations were conducted among these 3D parameters. Subsequently, five single-output and one multi-output machine learning models were developed to explore the potential of utilizing surface parameters to predict the vertical parameters of cracks. The outcomes validated the effectiveness of two specific methods, namely, Artificial Neural Network and Extreme Gradient Boosting models, in predicting crack volume based on surface parameters, with R2 scores of 0.832 and 0.748, respectively. Additionally, the multi-output machine learning model we developed achieved classification prediction of the crack damage penetration depth using surface parameters, yielding optimal precision, recall, and F1 scores of 0.790, 0.779, and 0.761, respectively. This study has introduced a crack damage evaluation index, based on a 3D assessment, that relates crack depth classification to severity. We provide suggestions that could pave the way for informed decision-making on maintenance strategies that could be adopted to extend asset life cycle.

C. Improved small foreign object debris detection network based on YOLOv5,

In response to the challenges of detecting foreign object debris (FOD) on airport runways, where the objects are small in size and have indistinct features leading to false detections and missed detections, significant improvements were made to the YOLOv5 algorithm. First, the original YOLOv5-n model was optimized by incorporating multi-scale fusion and detection enhancements. To improve detection speed and reduce parameters, the detection head for large objects was removed. Second, the C3 module in the backbone network was replaced with the C2f module, resulting in enhanced gradient flow and improved feature representation capabilities. Additionally, the spatial pyramid pooling-fast (SPPF) module in the backbone network was refined to expand the receptive field and enhance the model's perception of dependencies between targets and backgrounds. Furthermore, the coordinate attention (CA) mechanism was introduced in the neck layer to further enhance the model's perception of small FOD items. Lastly, the SCYLLA-IoU (SIoU) loss function was introduced to further improve the speed and accuracy of bounding box regression. Moreover, the nearest neighbor interpolation upsampling method was substituted with the lightweight Content-Aware ReAssembly of FEatures (CARAFE) upsampling operator to better exploit global information. Experimental results on the Fod_Tiny dataset, which consists of small FOD items in airports, demonstrated a significant 5.4% improvement over the baseline algorithm. To validate the generalizability of the algorithm, experiments were conducted on the Mirco_COCO dataset, resulting in a notable 1.9% improvement compared to the baseline algorithm.

III. PROPOSED METHODOLOGY

The proposed system addresses the challenges of detecting and removing Foreign Object Debris (FOD) on airport runways, particularly focusing on small object detection and overcoming the effects of adverse weather conditions. The system utilizes an advanced FOD detection model that combines YOLOv8, enhanced by Swin Transformer (ST), to improve detection performance.The model is trained on a large-scale dataset collected by an Unmanned Aerial Vehicle (UAV), which consists of 74,737 images across 21 distinct object types, covering a wide range of FOD scenarios. YOLOv8, known for its high accuracy and efficiency, is further augmented by the Swin Transformer, which introduces a self-attention mechanism to capture long-range

dependencies and contextual information, thereby improving the detection of small and complex objects in diverse environments. YOLOv8 is employed for its advanced capabilities in object detection, particularly for small objects like FOD. The integration of Swin Transformer enhances YOLOv8's performance by providing more precise feature extraction and handling complex, cluttered environments more effectively.

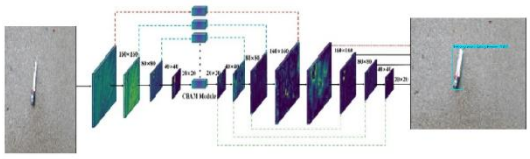


Fig. 1: System Overview

1. Data Collection:

Gathering the raw data needed for training a model. In object detection, this involves collecting labeled images or videos where the objects of interest are annotated with bounding boxes.

2. Data Preprocessing:

Cleaning and transforming the collected data into a format suitable for model training. This includes: Resizing images to the model's input size, Normalizing pixel values, Data augmentation (e.g., flipping, rotation, etc.) to improve model robustness.

3. Feature Extraction:

In object detection, feature extraction refers to using a neural network or another technique to extract relevant features from the images. CNNs (Convolutional Neural Networks) are typically used for this purpose.

4. Model Training:

Training a machine learning or deep learning model on the processed data. In object detection, this involves training a model to predict both the class and bounding box of objects in images.

5. Model Evaluation:

After training, the model is evaluated on a separate test dataset to measure its performance. Common evaluation metrics for object detection include: Precision, Recall: Measures the accuracy of the predictions, mAP (mean Average Precision): A popular metric for evaluating the performance of object detection models.

6. Object Detection:

The final task where the trained model is used to detect objects in new, unseen images or video streams. The model outputs bounding boxes around detected objects along with class labels.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

Experimental results demonstrated that the model effectively detected various types of debris on airport runways, including metal fragments, stones, and plastic materials, with high detection accuracy and low false alarm rates. The predictive geo-location module accurately estimated the position of detected objects, enabling rapid identification and removal operations.

The analysis showed that the system maintained reliable performance under varying lighting conditions, weather changes, and complex runway backgrounds. Furthermore, the real-time processing capability ensured timely detection and response, significantly improving runway safety and operational efficiency.



Fig. 2: Screw Driver Detected



Fig. 3: Wire Detected



Fig. 4: Battery Detected



Fig. 5: Clamp Detected



Fig. 6: Pen Detected

V. CONCLUSION

In conclusion, this study proposes a novel FOD detection algorithm utilizing the ST-Enhanced YOLOv5 model, combined with advanced feature extraction techniques and a geolocation prediction model based on machine learning regression algorithms. The system demonstrated notable improvements in detection accuracy, as evidenced by the ablation tests and comparative analysis with existing models like YOLOv5, YOLOX, and YOLOv7. The proposed model achieved significant enhancements in the Mean Average Precision (mAP) metrics, especially in small object detection, and showcased robustness across various input data resolutions. Furthermore, the FNN regression model proved to be highly effective in predicting the geolocation of detected FOD with impressive accuracy, highlighting the potential of machine learning-based regression techniques for real-time applications. While the model's performance is promising, future work should focus on expanding its capability to handle extreme weather conditions and integrating the detection and geolocation prediction components into specialized software to meet the practical needs of airport authorities. Overall, the study presents a promising approach to improving FOD detection and removal, contributing to enhanced safety and efficiency on airport runways.

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