

Webcam Based Foreign Object Debris (FOD) Detection System to Support Airside Inspections with Image Processing

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ABSTRACT

Ensuring that airside areas are free of Foreign Object Debris (FOD) is a critical activity in aviation, as FOD poses a significant threat to aircraft operations during takeoff and landing. This study aims to enhance FOD detection at Sultan Mahmud Badaruddin II Airport in Palembang by developing an automated detection system that utilizes image processing technology in combination with the YOLO algorithm. Traditional FOD detection methods rely heavily on manual inspections, which are often hampered by blind spots, time constraints, and human error. The proposed webcam-based system significantly improves accuracy and speed in identifying foreign objects, thereby contributing to flight safety by effectively reducing the presence of FOD on runways. By facilitating real-time detection, this research seeks to enhance operational safety, minimize risks of aircraft damage, and reduce costly delays, while also alleviating the burden on personnel. Utilizing the Research and Development (R&D) method based on the Borg and Gall model, the study progresses through seven stages. The developed technology successfully detects four types of FOD with reasonable accuracy: bird carcasses up to 5 meters away, paper up to 3 meters, and both metal and aggregate up to 2 meters. Feedback gathered from surveys distributed to airport technicians reveals a very satisfactory response regarding the device's performance. Ultimately, this technology aims to minimize the risk of FOD-related accidents, ensuring optimal safety for passengers and aircraft alike.

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1. Introduction

With the economy's recovery after the pandemic in Indonesia, the aviation industry has gradually increased [1]. This recovery can be observed from the increase in air passenger numbers, both domestic and international [2]. According to the Central Bureau of Statistics, in October 2023, the number of passengers departing on domestic flights reached 5.3 million people [3]. Advances in aviation technology and the increase in airlines have made flight options more affordable and accessible [4].

As the demand for aviation services increases, airports must provide passenger services that guarantee safety and security [5]. To comply with safety standards, airports perform routine airside inspections [6], as mandated by Ministry of Transportation Regulation Number 33 of 2022. This ensures that airports adhere to aviation safety standards set by civil aviation authorities [7]. One key

activity involves ensuring that airside areas are clear of Foreign Object Debris (FOD), such as debris on the runway, taxiway, and apron [8].

Foreign Object Debris (FOD) refers to any foreign object that may pose a threat to aircraft operations, particularly during takeoff and landing [9]. The significance of FOD detection in aviation cannot be overstated, as it plays a crucial role in ensuring the safety and efficiency of airport operations [10]. Studies have shown that FOD incidents can lead to severe accidents, resulting in significant financial losses and jeopardizing passenger safety [11]. Therefore, effective FOD management is essential for maintaining operational integrity and minimizing risks at airports [12].

The study focuses on improving Foreign Object Debris (FOD) detection on airport runways and other operational areas, particularly at Sultan Mahmud Badaruddin II Airport in Palembang. The research aims to enhance the current manual inspection process, which is prone to human error due to limited visibility and coverage, especially in low-light conditions or adverse weather [13]. The primary objective is to develop an automated FOD detection system using image processing technology combined with the YOLO algorithm to detect and classify FOD more efficiently.

Existing research and practices in FOD detection mostly rely on manual inspections, which have limitations such as blind spots, time constraints, and human error. In addition, existing technologies such as radar systems and electromagnetic sensors have been employed to enhance FOD detection [14]. However, these solutions often suffer from high operational costs and limited effectiveness in certain environmental conditions [15]. The current gap is the absence of a more affordable and effective image-based detection system. This study addresses this gap by introducing a webcam-based FOD detection system that improves accuracy and speed in identifying foreign objects.

Webcams have been increasingly utilized in various surveillance applications, proving their effectiveness in real-time monitoring and incident detection. Studies have highlighted the successful deployment of webcam systems in traffic monitoring and security surveillance, where image processing algorithms have enabled prompt detection of anomalies [16]. The adaptability and cost-effectiveness of webcam technology because it contribute directly to improving flight safety by reducing the presence of FOD on airport runways. By introducing an automated system that detects FOD in real time, the research enhances operational safety, reduces aircraft damage risks, and minimizes costly delays. Moreover, the implementation of this technology helps reduce human workload while ensuring more comprehensive FOD coverage on airside areas, thus minimizing the risk of missed detections during manual inspections.

The innovative aspect of this research lies in its use of image processing technology combined with the YOLO algorithm for automated FOD detection. This method is more cost-effective than traditional radar or sensor systems and provides more accurate detection across different distances. The real-time capability of the system allows for continuous monitoring of airport runways, significantly reducing the risk of FOD being overlooked. The approach offers a novel, efficient, and scalable solution for airports looking to improve FOD detection while maintaining safety standards at a lower cost.

2. Method

2.1. Design of Research

In this research, we used the Research and Development method, better known as R&D [17]. This method is used to produce specific products and test the effectiveness of these products. R&D is a series of processes or steps to develop new products and improve existing products so they can be accounted for. According to Borg and Gall, there are ten stages of research and development. This research has included 7 stages of 10 stages because Referring to the limited time available for conducting this research, the research and development steps were restricted to the seventh step, which is the product testing phase. This limitation aims to ensure that the research process can be completed thoroughly and on time so that the results obtained remain valid and reliable to support the main objectives of this research.

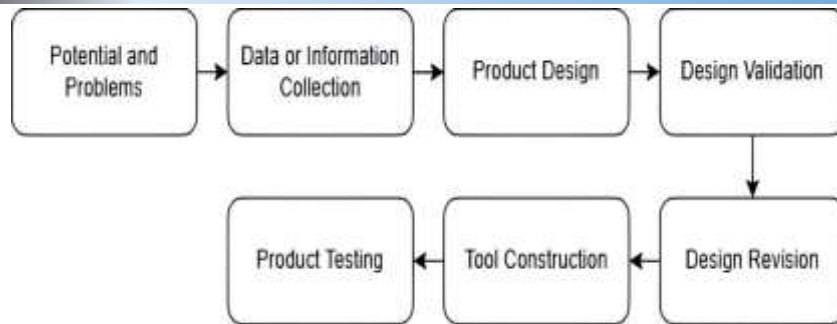


Fig. 1. Research Flowchart Borg and Gall.

2.1.1. Potential and Problems

The first step in developing this application is to conduct a needs analysis. The needs analysis carried out includes preliminary observation activities. The potential in this writing and development lies in the maintenance aspect of the Airside Maintenance Infrastructure & Accessibility (AMIF) unit, with support for developing technology at Sultan Mahmud Badaruddin II Airport to facilitate the main tasks of Airside Maintenance Infrastructure & Accessibility (AMIF) technicians during airside inspections. Although inspections are currently carried out manually by relying solely on visual observation, which can potentially lead to human error, a Foreign Object Debris (FOD) detection system needs to be innovated to ensure greater accuracy in keeping the runway clear of FOD. Therefore, the author is interested in developing a FOD detection system based on webcam image processing. The analysis of potential and problems is presented in a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis.

2.1.2. Data or Information Collection

Information collection is carried out factually and can serve as material for planning a specific product that meets existing expectations. At this stage, the author collects data that forms the basis for designing the FOD detection system.

2.1.3. Product Design

Product design is a series of steps to understand and plan an item that can be used effectively, in line with its function, comfort, and aesthetics, thereby increasing its value and benefits to users. Product design includes the specifications of the tool, the basic working principles of the system.

2.1.4. Design Validation

The validation process is conducted through a Focus Group Discussion (FGD), where the researcher presents the research process and the advantages of the design that were previously discovered. Validation is conducted in an FGD attended by employees of Sultan Mahmud Badaruddin II Airport in Palembang who are experts in their fields.

2.1.5. Design Revision

After the product is planned, it is validated through a Focus Group Discussion (FGD) with experts and other professionals to identify its weaknesses. These weaknesses are then addressed by revising the design.

2.1.6. Tool Construction

In the tool construction phase, the researcher starts the process from planning the model to achieving the desired final product.

2.1.7. Product Testing

The prototype will be tested starting with a range test to ensure the camera successfully detects objects, a test to verify that the webcam's image processing successfully identifies objects in real-time, and a test to assess the size of the objects detected. The results of the tests will show whether the tool works as expected or not.

2.2. Data Analysis Technique

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3. Results and Discussion

3.1. Potential and Problems

The initial step in development is the analysis of potential and problem identification, which aims to determine the necessary supporting system innovations. Based on observations at Sultan Mahmud Badaruddin II Airport in Palembang from October 2023 to June 2024, the author conducts a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis of the situation on the ground.



Fig.2. SWOT Analysis.

3.2. Data or Information Collection

During the field observations, the researcher, accompanied by a technician from the Airside Maintenance Infrastructure & Accessibility (AMIF) unit, obtained the following results:

- Currently, Sultan Mahmud Badaruddin II Airport in Palembang conducts airside inspections twice a day, carried out by a single technician. The first inspection is done in the morning at 05:00 WIB, and the second one is at noon at 12:50 WIB. Sultan Mahmud Badaruddin II Airport has a fairly large airside area, so the technician takes about 30 minutes using a maintenance car.
- The technician inspects the airside to ensure there are no obstacles, such as vehicles or FOD, that could interfere with takeoff and landing processes. The inspection is conducted from the Apron area to the taxiway, then to the runway, and back again if the airside area is clear of obstacles. At

Sultan Mahmud Badaruddin II Airport, FOD detection is still done manually, using the naked eye.

- Although airport technicians can visually inspect the area, the limitations of human observation can result in some FOD being missed or undetected. Small or hidden objects may be difficult to see with the naked eye.

3.3. Product Design

This tool is expected to utilize automation in the form of webcam image processing that can be monitored in real time. Below is the planned list of components and materials to be used in its development.

Basically, this tool operates in a manner similar to the process shown in the image below.

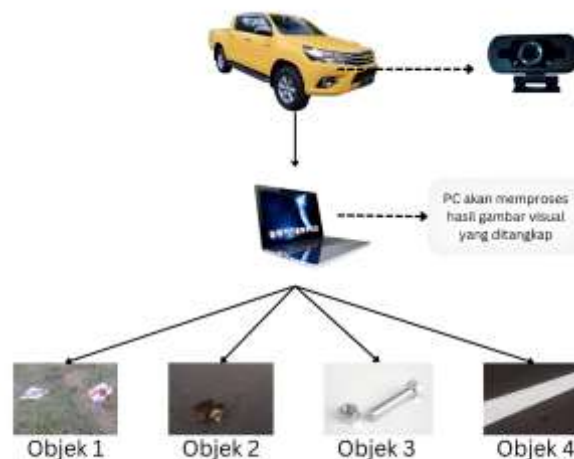


Fig.3. The operational scheme of the tool.

In operating the tool, the camera is activated, and it will capture images in real-time. Once the image is captured, the Mini PC will process the image and predict the detected object. The detected object will be classified into one of the types of FOD (Foreign Object Debris) that have been previously tested in the form of a dataset. There are 4 objects that the tool can recognize: Object 1 is paper waste, Object 2 is a bird carcass, Object 3 is metal, and Object 4 is broken stones or aggregate. Once an object is recognized, a notification will appear on the technician's monitor to alert them to clean the FOD immediately. If no object is detected, the monitor will not display any object detection output.



Fig. 4. Product Design.

The FOD detection system based on webcam image processing is planned to be mounted on the front of the maintenance car. The webcam used has a 1080p resolution to ensure clear image capture. The installed webcam is equipped with an acrylic casing to withstand various weather conditions, whether rain or intense sunlight, which helps extend the webcam's lifespan.

3.4. Design Validation

The Focus Group Discussion (FGD) in this study was conducted to validate and provide input for the revision and trial of the product. The discussion forum was attended by Assistant Maintenance Managers of Sultan Mahmud Badaruddin II Airport.

In conducting the Focus Group Discussion (FGD), the validation results to be implemented in the design revision stage are as follows:

- **Device Placement for Detection Reliability.** The validator provided input that the design of the FOD (Foreign Object Debris) detection system using webcam-based image processing would have a higher reliability if placed in the center of the vehicle rather than on one of the sides.
- **Technical Limitations.** Although it has many advantages, some participants also identified several technical limitations that need further consideration. These include the need for sufficient computational resources to perform real-time image processing and the potential for errors. Currently, the Airside Maintenance Infrastructure & Accessibility (AMIF) maintenance car unit is not yet equipped with a display on the car's dashboard, so the device still needs to be connected to a PC.
- **Aesthetic Enhancements.** Since the device will be placed on the front of the vehicle, a protective casing with materials that can withstand all weather conditions is required.

3.5. Design Revision

The author carried out a product improvement stage by considering input from expert validators on the FOD detection system. Revisions were made to correct errors and shortcomings in the webcam-based image processing FOD detection system based on the suggestions and feedback provided by the expert validators.

Table 1. Design Revisions

Critiques and Suggestions	Before	After
Device Placement for Detection Reliability	The device was placed on the left side of the vehicle	The device is placed in the center of the vehicle
Technical Limitations	The device was connected to the vehicle's PC	The device can be connected to either a Personal Computer (PC) or a Portable Personal Computer
Aesthetic Enhancements	No protection for the device	The device has protective casing
Automated FOD Detection Technology	FOD detection was still manual, relying on the technician's eyesight	An image processing webcam-based FOD detection system is available

3.6. Tool Construction

3.6.1 Dataset Introduction

To distinguish between various types of FOD (Foreign Object Debris), a dataset must be collected. The FOD dataset, containing 400 images, was gathered using an image downloader or Imageye. Seventy percent of the dataset, or 280 images, will be used for training, 20% or 80 images will serve as validation data, and the remaining 10% will be used for testing. This dataset consists of images depicting various types of FOD, with each image labeled according to the type of FOD shown, such as metal, paper waste, bird carcasses, and gravel fragments (aggregates). The dataset has been categorized based on the type of FOD present in the images.

3.6.2 Data Preprocessing

Before training the model, data preprocessing is required. In image processing, preprocessing refers to the steps taken to prepare raw images for easier analysis or further processing. The preprocessing steps include linking and labeling. The labeling process assigns labels to the dataset based on the categories of FOD, such as bird carcass, paper waste, metal, and aggregate fragments,

corresponding to the images. Links are provided to reference the source or location of the image files, allowing the images to be connected to their respective labels.

3.6.3 Training Dataset Evaluation

Training data is used to evaluate the model built with various parameters. The pre-trained model uses YOLOv5. The purpose of the training process is to teach the YOLOv5 algorithm to detect different types of FOD. Training is conducted using the 400 dataset images divided according to the established proportions.

3.6.4 Validation Dataset Testing

Validation testing is conducted using the 400 labeled dataset images. The validation dataset consists of 80 images and is used to assess the accuracy of the model by optimizing its performance after the training process. The purpose of the validation test is to ensure the trained data produces the desired model and to evaluate its performance.

3.6.5 Testing Dataset Evaluation

The testing phase assesses the training results using metrics such as recall, precision, accuracy, mAP (mean Average Precision), and loss. Recall measures the system's ability to re-identify the input dataset by calculating the ratio or success rate in determining whether a sample matches or not. Precision refers to the percentage of correctly predicted positive outcomes during the object-reading process. Accuracy is the ratio of correct predictions (both positive and negative) to the total data. mAP represents the average precision score across multiple repeated readings, used to measure the object detection accuracy in other models. The training data is used to train and build the model.

3.7. Product Testing

3.7.1 Accuracy Test of The Device

Training evaluation is the process of measuring how accurately the object detection model performs. In this evaluation, we aim to understand how well the model can correctly detect objects and how accurately it can identify objects within images or videos.

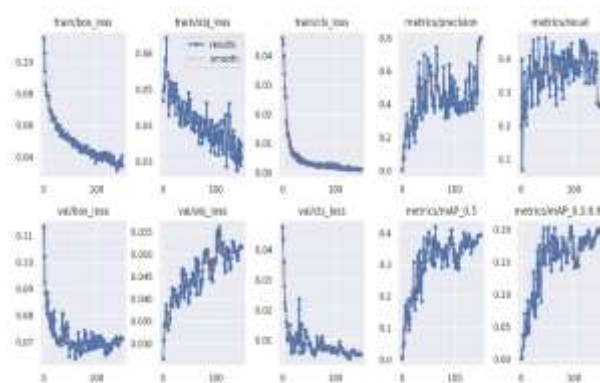


Fig. 5. Result of Accuracy Test.

Total loss is the combined value of box loss, objectness loss, and classification loss obtained from the training process using the pre-trained YOLOv5 model. The graph shows that the total loss value during the training process exhibits a decreasing trend, reaching 0.06343 (6.34%). This result indicates that the system using the pre-trained YOLOv5 model has a relatively low error rate in detecting objects.

The Precision result, based on 150 iterations, shows an increasing trend. The Precision value is 79.82%, with all three classes demonstrating good Precision results. However, the Precision with 150 iterations experiences sharp fluctuations due to dataset factors. The overall Precision obtained is 88.76%, indicating that this model is sufficiently good for practical use. The average Precision value in repeated readings is utilized to measure object accuracy in other models. The mean

Average Precision (mAP) values close to 1 or 100% indicate that the system performs well. The detection model has two mAP values: mAP 0.5 and mAP 0.95. The average mAP 0.5 is higher than the average mAP 0.95 because mAP 0.5 considers 10 IoU (Intersection over Union) threshold values, while mAP 0.95 has an IoU threshold of 0.95, which results in higher accuracy in dataset readings. The results from the pre-trained YOLOv5 model show that the mAP 0.5 value reaches 0.4198 (41.98%), while the mAP 0.95 value reaches 0.2042 (20.42%).

3.7.2 Testing Dataset Results

After completing the training process, the system's test results ranged between 0.6 and 0.8, indicating that the system is fairly accurate. The main factor contributing to the lower detection accuracy is the inadequacy of the available data and the use of sample images rather than real images from the field.



Fig. 6. Result of Dataset Testing.

3.7.3 Detection Range Test of the Device

This test was conducted to determine the detection range of the FOD (Foreign Object Debris) detection system and to measure the effectiveness of the device in detecting various types of foreign objects in a designated area. The trial was conducted at the General Workshop of Palembang Aviation Polytechnic under clear weather conditions, with the device placed on a vehicle at a height of approximately 75 cm from the ground.



Fig. 7. Device Testing.

The results of the detection range test of the device are presented in the table below:

Table 2. Result of Detection Range Test

Space	Bird Carcasses	Paper	Metal	Aggregates
1 Meter	Detected	Detected	Detected	Detected
2 Meter	Detected	Detected	Detected	Detected
3 Meter	Detected	Detected	Not Detected	Not Detected
4 Meter	Detected	Not Detected	Not Detected	Not Detected
5 Meter	Detected	Not Detected	Not Detected	Not Detected

3.7.4 Device Usage Trial

The data for this usage evaluation phase comes from personnel of the Airside Maintenance Infrastructure & Accessibility (AMIF) at Sultan Mahmud Badaruddin II Airport in Palembang. The user experience data was collected from 4 personnel in the AMIF unit, and the information was obtained through a questionnaire.

Based on the data from the usage trial, the total score obtained was 71. The ideal score for comparison is 80. Using the following formula, the satisfaction score can be calculated:

$$\text{Ideal Score} = (\text{Total Score}) / (\text{Ideal Score}) \times 100\% \quad (1)$$

$$\text{Ideal Score} = 71 / 80 \times 100\%$$

$$\text{Ideal Score} = 88.75\%$$

The results from the questionnaire indicate that the satisfaction level for the use of this FOD detection device reached an average score of 88.75%, which falls into the "Very Satisfied" category. Feedback and suggestions regarding the device's usage provide valuable insights for the development and improvement of this application.

Based on the critiques and suggestions received, it can be concluded that the webcam-based FOD detection device needs to emphasize the importance of user input, prioritize security and privacy, design a good user interface, optimize performance and stability, provide useful features, offer strong support, and continuously update the device to meet user needs.

4. Conclusion

The development of a webcam-based Foreign Object Debris (FOD) detection system using image processing has proven to be both effective and reliable. The system successfully detected four types of FOD—bird carcasses, paper, metal, and aggregate fragments—with high accuracy. Leveraging real-time image processing algorithms, it achieved a precision rate of 79.82% and a recall rate of 89.72%, demonstrating its capability to quickly and accurately identify FOD. The system's range performance also showed reliable detection at different distances, with bird carcasses detectable up to 5 meters, paper up to 3 meters, and both metal and aggregate fragments up to 2 meters.

User feedback from trials conducted at Sultan Mahmud Badaruddin II Airport in Palembang was overwhelmingly positive, with an average satisfaction score of 88.75%, indicating that the system is user-friendly and suitable for practical airside inspections. This level of satisfaction demonstrates the tool's operational readiness and its ability to improve the efficiency and effectiveness of FOD management in a real-world airport environment. The system's ability to provide real-time alerts makes it a valuable asset for enhancing airside safety.

However, despite its overall success, the system does have some limitations. It showed sensitivity to changes in lighting conditions and struggled to detect small or transparent objects, which could pose challenges in certain operational environments. Addressing these issues will be crucial for further improving the system's performance and adaptability. Nevertheless, the system shows great promise as an innovative solution for airport safety and FOD management, with room for continued enhancement and broader implementation.

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Declarations

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Conflict of interest. The authors declare no conflict of interest.

Additional information. No additional information is available for this paper

Data and Software Availability Statements

Data and Software availability statements provide a statement about where data and software supporting the results reported in a published article can be found, including hyperlinks to publicly archived datasets and software analyzed and generated during the study/experiments.

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