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TECHNICAL APPLICATION OF IMAGE PROCESSING IN THE IDENTIFICATION OF FOREIGN OBJECTS IN THE AEROSPACE INDUSTRY

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ABSTRACT

In the aviation industry, foreign objects (FOs) - any items not part of the aerospace product - pose risks of damage if they come into contact with aircraft. This study explores the implementation of both automated and manual image processing techniques for the detection of FOs, aiming to enhance safety by reducing inspection times and improving quality over traditional manual methods. The proposed approach utilizes infrared cameras for image capture in low-light or complex environments, combining automated detection algorithms with manual oversight. Experiments were conducted on the structures and cockpit of the Super Tucano 314, Xavante AT-26, and the F5 (J85 model) engine, employing the Yoosee application for imaging and Python with Anaconda Spider for processing. The results demonstrate the system's ability to identify FOs that are difficult to detect visually, ultimately contributing to a reduction in operational risks within the aerospace sector.

Keywords: Foreign Object. Aerospace Industry. Infrared. Image Processing.

1. INTRODUCTION

In the aerospace sector, addressing the risks posed by foreign objects (FOs) is crucial for ensuring flight safety, especially considering past accidents linked to such hazards. FOs can manifest in various forms, from small debris in jet engine compressors to larger objects, often resulting in damage that is underestimated (Lowe, 2015).

A foreign object refers to any item that is not an integral part of aerospace equipment or products and can potentially cause harm or malfunction upon contact. This may lead to accidents, financial losses, or reputational damage to the aerospace industry. FOs can arise from numerous sources, including human activities, airport infrastructure, environmental factors, and production or maintenance operations. Consequently, substantial efforts are dedicated to maintaining aircraft safety.

Foreign Object Damage (FOD) describes any harm caused by an FO, whether it is physical or economic and may compromise the safety or performance of the product. Therefore, effective prevention and control measures are required by regulatory bodies. The aerospace industry faces significant challenges in ensuring the quality and safety of its products, encompassing the entire supply chain, while meeting diverse customer and regulatory expectations.

While it is nearly impossible to eliminate human errors in production and maintenance, these errors can be minimized through enhanced processes and adherence to aviation regulations. To comply with foreign object prevention standards, it is essential for the industry to establish programs that promote good housekeeping practices, maintaining a tidy work environment to reduce potential FOs. This includes controlling operations at all stages, encompassing tools and personal items that may become FOs.

Detecting foreign objects is a vital component of the inspection process in the aerospace field, as mandated by the AS9100 international standard. Achieving these detection requirements necessitates the use of effective techniques and tools capable of identifying FOs, particularly in hard-to-access or poorly lit areas. However, detection and inspection activities often encounter challenges due to physical constraints and the limitations of manual inspections.

This research presents two models—automated and non-automated—for detecting foreign objects in aircraft products, aiming to enhance FOD prevention. While many studies concentrate on detecting FOs on airport runways, there is a notable lack of research addressing detection in production settings. This study seeks to fill that gap by providing innovative solutions to improve safety and operational efficiency within the aerospace industry.

2. THEORETICAL FOUNDATIONS

2.1 Foreign Object Damage (FOD)

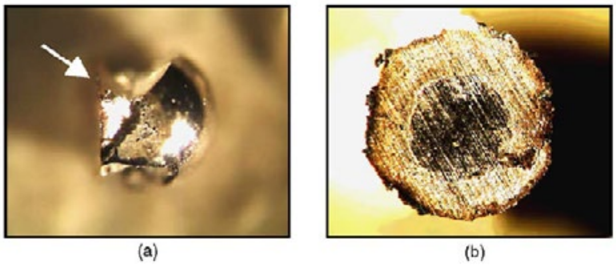
As defined by AS9146 and NAS412, a foreign object (FO) refers to any item or substance that may enter aerospace products and potentially lead to Foreign Object Damage (FOD) if not properly managed. This can include tools, hardware components, consumables, and debris from manufacturing processes. The NAS412 standard applies to a wide range of aerospace products, such as aircraft and satellites, and extends FOD prevention measures to various operational environments, including manufacturing and assembly facilities.

An effective FOD prevention program must focus on more than just identifying risks; it should also prioritize mitigation strategies, employee training, and ongoing process improvement. The significance of preventing damage from FOs is underscored by their role in compromising equipment integrity and safety. Specifically, FOD in turbine blades is a critical concern for engine operational safety. Moreover, FOs can be expelled from engines, posing injury risks to individuals near runways (Liu et al., 2018; Choi et al., 2004; Xu et al., 2020; O'Donnell, 2009). The substantial relative speed of these collisions can result in significant impacts, creating dents or cracks that can dramatically reduce the lifespan of the blades. This risk is heightened by the cyclic loading that blades experience, which can accelerate crack formation and propagation (MARANDI, RAMANI and TAJDARI, 2014; XU et al., 2020).

With FOD-related expenses in the aviation sector estimated to reach billions annually (Melichar and Skrivanová, 2020), this research aims to improve detection methods, which are recognized as the most vital component of effective FOD management (Özturk and Kuzucuoğlu, 2016).

In a study conducted by Choi et al. (2018), the researchers simulate the collision of a foreign object, a steel ball with a diameter of 1.59 mm, striking a composite sample made of AS800 silicon nitride at a speed of 350 m/s. The results demonstrate severe plastic deformation, heating, and cracking, as illustrated in Figure 1.

Figure 1. a) Lateral view of specimen AS800; (b) Superior view of specimen. (Choi, et al. 2018).



Ceramic materials, due to their fragile nature, are susceptible to breakage and structural failure when exposed to foreign objects, such as combustion particles or small debris, especially in aerospace engine applications.

2.2 Images Processing

Luz et al. (2024) and Tabosa, Oliveira, and Hayama (2024) highlight that image processing is commonly employed in industrial environments for object counting. This technique involves computational methods to manipulate and analyze digital images, generating valuable insights for users. Images are formed by pixels arranged in a two-dimensional matrix, where each pixel's intensity corresponds to a gray level (Luz et al., 2024; Tabosa, Oliveira, and Hayama, 2024; Chicalski, Kleina, et al., 2024).

Digital images can be segmented into regions of interest (ROIs) to focus on specific details. Pre-processing steps, such as resizing, reshaping, and noise reduction, are often necessary before analysis. Key operations in image processing include filtering, segmentation, feature extraction, and pattern recognition (Tabosa, Oliveira, and Hayama, 2024).

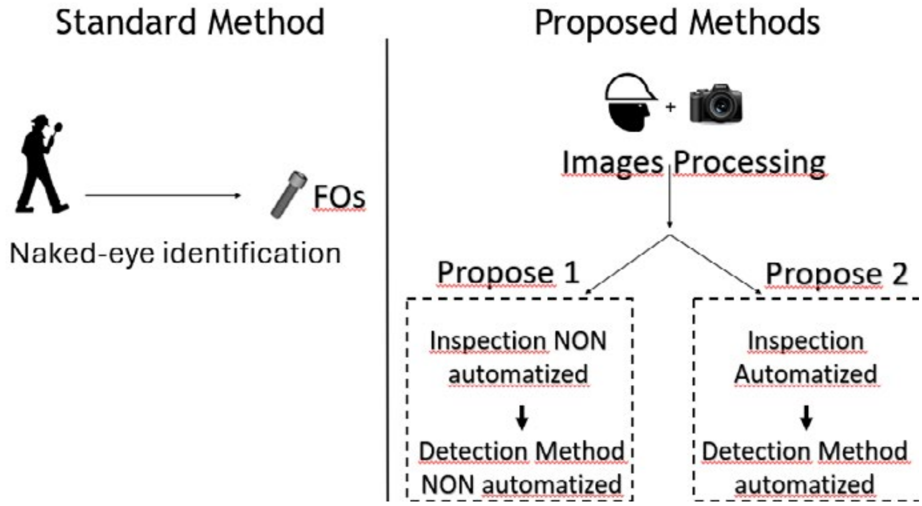
Segmentation involves dividing images based on color and texture, which aids in identifying distinct elements (Tabosa, Oliveira, and Hayama, 2024). Binarization, a widely used technique, distinguishes features using black and white pixels, while grayscale allows classification by pixel intensity, supporting up to 256 shades (Luz et al., 2024; Tabosa, Oliveira, and Hayama, 2024).

Developing algorithms for image processing presents challenges, as precise adjustments are crucial, and errors can significantly affect results (Luz et al., 2024; Chicalski et al., 2024). This study presents two alternative approaches for detecting foreign objects that are not visible to the naked eye of the operator. Both methods involve using image processing techniques on images captured by an infrared camera mounted on the operator (on the wrist, helmet, or uniform, depending on the area being inspected). The key distinction between the two proposals lies in their specific detection methods for identifying foreign objects through image processing.

3. PROCEDURE FOR DEVELOPMENT

Regarding the proposals presented in this study, Proposal 1 (Non automatized architecture) uses a non-automated detection module, while Proposal 2 (Automatized architecture) employs an automated detection module.

Figure 2 | Presentation of the standard method versus the proposed methods.



3.1. Non-Automatized Architecture

The first proposal involves using an infrared camera attached to the operator to capture images during their tasks. It considers the images to be processed and sent via Bluetooth or Wi-Fi to a computer for subsequent analysis and identification of foreign objects by a company employee. The surveillance camera utilized in this paper is a generic imported model that provides 360° rotation, connects to a mobile device via Wi-Fi, and can operate in both well-lit and dark environments. It is equipped with 10 infrared LEDs capable of detecting objects up to 10 meters away, offers a resolution of 1920*1080P, and has an automatic filter to block infrared light. Throughout the experiment, the camera continuously recorded images, while its monitoring and movements were managed in real-time through the Yoosee application.

3.1.1. Module of Detection Non automatized

In this module, after processing the images as per item 3.1, the user conducted a manual analysis, highlighting by himself the positions of identified foreign objects using an image editing tool, with no use of software nor algorithm.

3.2 Architecture Automatized

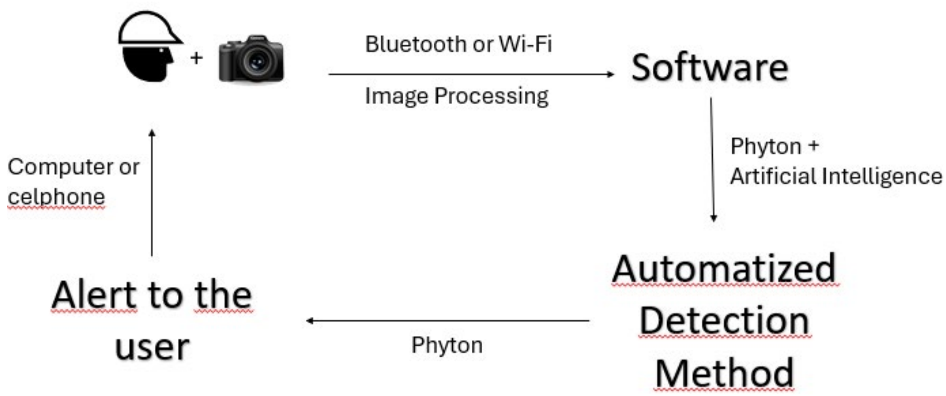
In the second proposal of this study, the same camera and application (Yoosee), referenced in section 3.1. were employed. This approach assumes that the images captured by the operator's attached camera will be sent via Bluetooth or Wi-Fi from Yoosee to the Anaconda Spider software. By utilizing image processing techniques, along with Python programming and artificial intelligence, this method seeks to enhance the subsequent phase of automated detection.

3.2.1 Module of Detection Automatized

In this module, the detection of foreign objects is conducted automatically using the Anaconda Spider software. By employing artificial intelligence, the software compares images of the workspace taken before and after the introduction of foreign objects and establishes a baseline for the normal state of the workspace at the start of operations.

At the end of the tasks, it automatically analyzes the resulting scenario against this baseline to identify any discrepancies. When such discrepancies are detected, the software is designed to generate an alert system for the operator, indicating the presence of foreign objects in the workspace.

Figure 3 | Flow of Module of detection automatized.



3.3 Experimental Data

The experimental portion of this paper was conducted at the JUTA campus of the mechanical engineering department at the University of Taubaté (UNITAU). The research utilized sections from the cockpit and tail of a Supertucano EMB314, provided by the Aerospace Science and Technology Department (DCTA) to UNITAU. Additionally, an AT-26 Xavante (also donated by the DCTA) and an F5 engine (model J85, donated by the Brazilian Air Force - FAB) were used in the experiment.

The engine was given to the University of Taubaté because it can no longer be operated, having suffered damage to its blades from foreign objects of unknown origin during flight.

4. RESULTS

The inspections were conducted in hard-to-reach areas of the Supertucano 314's tail and cockpit, as well as the tail cone of an AT-26 Xavante and an F5 engine. The following figures display images captured by the infrared camera during the experiment.

To activate the infrared feature, the ambient lighting was slightly reduced. Monitoring was facilitated by the "Yoosee" app, allowing real-time control of the camera's rotation and automatic logging of date and time. In addition to the strategically placed objects for identification, various debris, including dirt and weather-related particles, were discovered.

The main challenge in positioning the camera and objects occurred in the engine compartment due to its uneven surfaces and size. The engine had previously suffered blade damage from foreign objects while in service with the Brazilian Air Force (FAB). Despite this, the identification of the placed objects was successful.

While the Supertucano and Xavante presented some stability issues for the camera, these were less pronounced than with the engine. The structural ribs affected stability, but the camera's 360-degree rotation ensured a clear view of the experimental area.

4.1 Non-Automatized Inspection Method

The images in Figures 4-7 depict some results captured by the infrared camera, along with objects that were manually identified. These identified objects are marked with circular shapes in the images, in accordance with Proposal 1, "Non-Automated Detection Module."

Figure 4 | Region of the Supertucano stabilizer.

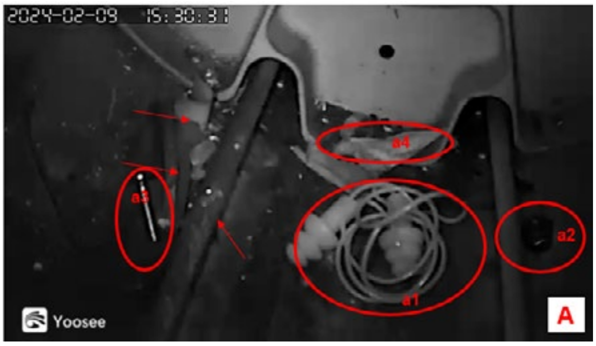


Figure 5 | Region of the Supertucano stabilizer.

Figure 6 | F5 engine region.

Figure 7 – F5 engine region.

These images illustrate the items that were intentionally arranged:

- Figure 4:
    - a1; a headset frequently used in the aerospace industry;
    - a2: a nut;
    - a3: a bolt;
    - a4: a section of a glove;
- Figure 5:
    - b1: pliers;
    - b2: rivet;
- Figure 6:
    - a1: hearing protection headset;
    - a2: section of a small metal;
- Figure 7:
    - b1: fragment of a broken engine blade.

4.2 Automatized Inspection Method

The infrared camera provided the following images (Figures 8-10). These images were analyzed using a model developed in Python to automatically identify foreign objects within the Anaconda Spider software. Figure 12 shows the experimental site (Xavante tail) in its original condition, before any objects were added. The software identified this as the 'baseline pattern,' which corresponds to the environment operators work in prior to starting their tasks.

Figure 8 | Xavant Tail free of objects - the baseline pattern.

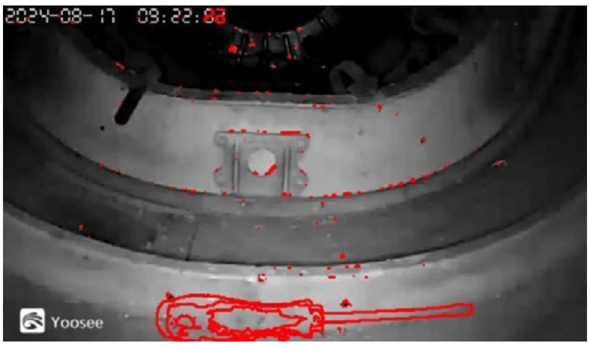
Figure 9 – Xavante tail with some objects introduced (screws and ears protectors).

Figure 10 | Xavante tail with screwdriver inside.

Figures 9 and 10 show the scenario represented by Figure 8 after the objects were placed in the experimental area. In contrast, Figures 11 and 12 illustrate the outcome of the software's automated detection of foreign objects, following the deliberate placement of these items in the experiment. This phase is similar to the point when an operator finishes their tasks, and any foreign objects left behind in the aircraft are automatically detected by the software, removing the need for manual checks.

Figure 11 | Automated detection performed by the software of the following objects: screws and ear protection, making reference to the Figure 9.

Figure 12 | Automated detection performed by the software of the screwdriver, referring to the Figure 10.



The identification was made possible by the software's ability to compare the baseline pattern to the experimental location where some objects were present.

5. Discussions

Regarding Proposal 1, the images presented show that there was no significant difference in the quality when comparing the intentionally placed objects for the experiment. Additionally, no notable discrepancies were observed concerning the various materials used.

The goal of the experiment was to simulate a real aircraft production environment as closely as possible, utilizing objects typically found in such settings (like washers, rivets, gloves, nuts, screws, pliers, mini saws, screwdrivers, etc.), as well as real aircraft structures and nearby photoluminescent factors.

In all the captured images, the inserted materials and other impurities were clearly identifiable. Issues related to the unevenness of the structural surfaces could be resolved using the proposed foot structure designed in this work.

The 360º camera played a critical role in capturing angles of the experimental area that would otherwise be impossible to see with the naked eye. The detection of all foreign objects (FOs) placed and remaining was notably quicker than manual inspection with a flashlight in a production environment, as the camera allowed for a full, precise scan.

The size of the camera and its placement on the operator should consider the variations in the access points and internal dimensions of the structures. As soon as lighting conditions dropped, the infrared function automatically activated, which helped improve the image quality.

In relation to Proposal 2, the software's programming allowed for the immediate identification of foreign objects, displaying their shape and outline in the image without requiring any manual mapping or user input. This second approach, as anticipated, proved faster in detecting objects than the first proposal.

The programming was straightforward, as Python is an accessible language. This programming approach proved effective because it could establish a baseline scenario (without objects) to be compared with the experimental scenario (with objects).

6. CONCLUSIONS

In this study, to simulate a more realistic environment for the aerospace industry, both aircraft structures and materials typically used in aviation were incorporated into the experiment.

Research on the potential risks posed by foreign objects (FOs) in aerospace components was reviewed to underscore the importance of addressing this issue and to emphasize the need for preventive measures to minimize FO-related hazards.

For the experimental setup, a surveillance camera with built-in infrared light, along with Anaconda software, Python programming, and various aviation-related objects, were utilized.

The study focused on two key phases: image processing (with the support of the camera, infrared light, and camera app) and object detection. Detection was performed both manually (as part of the non-automated architecture) and automatically, with alert notifications (using the software and programming to assist in this process).

The results from all the simulations were favorable, even with the challenges presented by restricted access, varying levels in the internal structures, and low lighting conditions. The images captured were clear, well-defined, and easily recognizable, which aligned with the expected outcomes.

When comparing the two approaches, automated architecture is recommended for industrial applications. This is since the software is straightforward to use and provides object detection faster compared to the manual approach.

From a cost perspective, both approaches are similar, with no significant difference in expenses. The cost would mainly depend on the camera quality chosen, but neither method requires high investment.

Since the camera used in the experiment was of low to medium quality, advanced technological equipment is not necessary for implementation.

Considering the experimental results and the theoretical analysis conducted, it can be concluded that the proposed systems could serve as viable alternatives to manual inspections for detecting FOs, ultimately helping to reduce the risks associated with aviation operations.

Both methods would contribute to improving the efficiency, accuracy, and overall safety of FO detection inspections in aircraft, ensuring the protection of both crew and passengers.

Finally, it is recommended to explore the development of a remote-controlled robot for capturing footage of work areas, which could replace the camera mounted on operators. This would offer better coverage of the workspace and access to more restricted areas.

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