Foreign Object Debris Detection Using AI Robot

Nilofernisha N[1], Rithikasri K[2], Srinikedan M[3]
[1, 2, 3] Dept of Information Technology
[1, 2, 3] Anjalai Ammal Mahalingam Engineering College, Kovilvenni

Abstract- *The project presents an innovative solution for runway inspection utilizing an AI-Robo t ttttt equipped with an optical camera. The challenges faced by current methods of Foreign Object Debris (FOD) detection on airport runways, such as radar and stationary cameras, due to high false positive rates. The system employs an ESP32 microcontroller to provide real-time notifications to the ground station in the event of detecting foreign objects on the runway. The integration of Robot technology aims to enhance runway safety and improve efficiency in airport operations. Testing different machines to make sure they work well in all kinds of weather. The paper introduces a novel approach using Unmanned Aerial Vehicles (UAVs) equipped with RGB cameras and AI detectors trained using deep learning methods to detect FOD on runways. Remove the unwanted debris on runway using AI Robot and automatically identify the object.*

Keywords- FOD detection, AI robot, CNN, image processing, ESP32, PTZ camera, real-time monitoring, ground station alert, autonomous inspection.

I. INTRODUCTION

Foreign Object Debris (FOD) is a critical safety concern in aviation due to its potential to damage aircraft and disrupt operations. Current FOD detection methods like radar and stationary cameras have limitations, including high false-positive rates. Integrating Unmanned Aerial Vehicles (UAVs) with Artificial Intelligence (AI) technology offers a promising solution for more accurate and efficient FOD detection on airport runways. The combination of UAVs and AI can lead to improved detection capabilities, shorter runway closure times, and fewer disruptions for airports and airlines. This innovative approach has the potential to revolutionize FOD detection practices in the aviation industry, enhancing safety and operational efficiency. Using UAVs and AI for FOD detection can make airports safer, operations smoother, and overall efficiency better in the aviation industry.

Foreign Object Debris (FOD) refers to any loose object that does not belong in a particular operational area, especially on airfields, runways, or industrial floors. Even small debris can lead to major safety hazards or financial losses. Traditionally, FOD detection relies on visual inspections or stationary camera systems, which are inefficient and prone to error.

This paper presents an autonomous AI-based robotic solution using a PTZ camera and an ESP32 module, integrated with a Convolutional Neural Network (CNN) model. The robot scans the operational zone, detects debris, classifies it, and transmits alerts to a connected ground station. This smart system can be deployed in hazardous or hard-to-monitor environments, enabling automated, fast, and precise detection.

II. CONCEPTS OF FOREIGN OBJECT DEBRIS (FOD) DETECTION SYSTEM USING AI ROBOT

The system is designed as an end-to-end AI-based detection unit with the following features:

Autonomous Mobility: The robot can patrol an area independently or follow a designated path.

PTZ Camera: Enables dynamic zoom and wide-area surveillance, improving image capture for CNN processing.

ESP32 Microcontroller: Acts as the brain of the robot, handling camera input, CNN inference, and communication.

CNN-Based Image Processing: Identifies and classifies objects in real-time.

Alert Mechanism: Sends notifications, including images and location data, to a ground control station over Wi-Fi or Bluetooth.

The CNN model is trained on a dataset containing various FOD types (e.g., metal pieces, plastic, tools), allowing for high accuracy in object classification.

III. RELATED WORK

Previous research in FOD detection includes traditional camera surveillance, ultrasonic sensors, and radar systems. While effective to a degree, these methods often lack automation, require high maintenance, or produce false positives. Recent developments involve deep learning and image processing:

YoloFODNet (2020): Applied a YOLO-based CNN for runway debris detection with static CCTV.
UAV Surveillance Systems: Drones equipped with cameras perform manual flyovers with object detection algorithms.

Mobile Robotics: Robots have been used in industrial monitoring, but limited FOD-specific implementations exist.
This project builds on existing technologies by combining CNN with a mobile robotic platform and PTZ camera, making the system more adaptable and precise.

IV. COMPONENTS OF FOREIGN OBJECT DEBRIS (FOD) DETECTION SYSTEM USING AI ROBOT

Component:
ESP32
IR
Relay
Buzzer
Motor
Battery

ESP-32

Product Overview

ESP32 is a single 2.4 GHz Wi-Fi-and-Bluetooth combo chip designed with the TSMC low-power 40 nm technology. It is designed to achieve the best power and RF performance, showing robustness, versatility and reliability in a wide variety of applications and power scenarios.

The ESP32 series of chips includes ESP32-D0WD-V3, ESP32-D0WDR2-V3, ESP32-U4WDH, ESP32-S0WD (NRND), ESP32-D0WDQ6-V3 (NRND), ESP32-D0WD (NRND), and ESP32-D0WDQ6 (NRND), among which, ESP32-S0WD (NRND), ESP32-D0WD (NRND), and ESP32-D0WDQ6 (NRND) are based on chip revision v1 or chip revision v1.1.

ESP32-D0WD-V3, ESP32-D0WDR2-V3, ESP32-U4WDH, and ESP32-D0WDQ6-V3 (NRND) are based on chip revision v3.0 or chip revision v3.1.

Relay:

Channel 5V Optical Isolated Relay Module This is a LOW Level 5V 4-channel relay interface board, and each channel needs a 15-20mA driver current. It can be used to control various appliances and equipment with large current. It is equipped with high-current relays that work under AC250V 10A or DC30V 10A. It has a standard interface that can be controlled directly by microcontroller. This module is optically isolated from high voltage side for safety requirement and also prevent ground loop when interface to microcontroller.

IR Sensor:

- IR Sensor Module Features
- 5VDC Operating voltage
- I/O pins are 5V and 3.3V compliant
- Range: Up to 20cm
- Adjustable Sensing range
- Built-in Ambient Light Sensor
- 20mA supply current
- Mounting hole

Motor:

A gear motor is a specific type of electrical motor that is designed to produce high torque while maintaining a low horsepower, or low speed, motor output. Gear motors can be found in many different applications, and are probably used in many devices in your home.

Gear motors are commonly used in devices such as can openers, garage door openers, washing machine time control knobs and even electric alarm clocks. Common commercial applications of a gear motor include hospital beds, commercial jacks, cranes and many other applications that are too many to list

Basic Principles of Operation

A gear motor can be either an AC (alternating current) or a DC (direct current) electric motor. Most gear motors have an output of between about 1,200 to 3,600 revolutions per minute (RPMs). These types of motors also have two different speed specifications: normal speed and the stall-speed torque specifications.

Gear motors are primarily used to reduce speed in a series of gears, which in turn creates more torque. This is accomplished by an integrated series of gears or a gear box being attached to the main motor rotor and shaft via a second reduction shaft. The second shaft is then connected to the series of gears or gearbox to create what is known as a series of reduction gears. The longer the train of reduction gears, the lower the output of the end, or final, gear will be.

An excellent example of this principle would be an electric time clock (the type that uses hour, minute and second hands). The synchronous AC motor that is used to power the time clock will usually spin the rotor at around 1500 revolutions per minute. However, a series of reduction gears is used to slow the movement of the hands on the clock.

For example, while the rotor spins at about 1500 revolutions per minute, the reduction gears allow the final second-hand gear to spin at only one revolution per minute. This is what allows the second hand to make one complete revolution per minute on the face of the clock.

specification

1. Voltage: 12.0VDC
2. Output Speed: 200 +/- 10% RPM
3. No-Load output current: =< 50 mA
4. Rotation Output: CW / CCW
5. Noise: No Gear Noise
6. Stall output: : Slip Gear, Broken Gear is no allowed
7. Output shaft of the axial clearance: =< 0.1 ~ 0.3mm, Horizontal clearance requirement =< 0.05 Electrical Spec 1. No-Load Speed: 5700 RPM 2. No-Load Current: =< 30mA 3. Rotation: CW 4. Motor#: 370

Buzzer – Electromagnetic

The buzzer is an electromagnetic type audio signalling device, which has a coil inside which oscillates a metal plate against another, which when given voltage difference produces sound of a predefined frequency. You must be aware of such sounds of buzzer like BEEP sound in many appliances.

IV. CONCLUSION

In this research, we developed and evaluated an AI-driven robotic system capable of detecting foreign object debris (FOD) on airport runways using a convolutional neural network (CNN) for image processing. The system successfully identifies and classifies FOD in real time, leveraging deep learning capabilities to achieve high detection accuracy. Upon identifying a threat, the robot sends instant alerts to the ground control station via a secure communication protocol, ensuring timely response and mitigation.

This approach not only reduces the manual workload and operational costs associated with runway inspections but also significantly enhances safety by minimizing the risk of aircraft damage due to FOD. The integration of CNNs with robotic mobility and real-time communication showcases the potential of AI in transforming airport safety operations. Future work can focus on expanding the dataset for more robust model training, optimizing the hardware for outdoor environments, and implementing predictive analytics for FOD occurrence.

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