Foreign Object Debris (Fod) Detection System Using Ai Drone

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***Abstract* – The project proposes an innovative approach to runway inspection in airports. By integrating a drone equipped with an optical camera and an ESP32 microcontroller, the system aims to revolutionize the traditional methods of detecting foreign objects on runways. The drone's optical camera captures high-resolution images of the runway surface, enabling precise identification of potential hazards. Upon detecting foreign objects, the ESP32 microcontroller facilitates real-time notifications to the ground station, allowing airport authorities to promptly address safety concerns. The integration of drone technology not only enhances runway safety but also improves operational efficiency by automating the inspection process. With its ability to provide real-time alerts, the system ensures proactive management of runway safety, thereby reducing the risk of accidents and minimizing operational disruptions. Overall, this project contributes to advancing aviation safety standards and underscores the importance of leveraging innovative technologies for enhancing airport operations**

Key words: Runway inspection, Drone technology, Optical camera, ESP32 microcontroller, Real-time notifications, Foreign Object Debris (FOD) detection, Airport safety, Efficiency improvement, Aviation operations, Innovation in aviation security

I INTRODUCTION

Airports are vital nodes in global transportation networks, emphasizing the critical importance of runway safety. This project proposes an innovative solution employing drone technology for runway inspections. Titled "Foreign Object Debris (FOD) Detection System Using AI Drone," the project aims to enhance aviation safety and operational efficiency. By equipping the drone with an optical camera, the system enables accurate detection of foreign objects on runways. Additionally, the integration of an ESP32 microcontroller enables real-time notifications to the ground station, ensuring prompt response to detected anomalies. The utilization of AI algorithms enhances the drone's capability to identify and classify debris, reducing the risk of potential hazards to aircraft during takeoff and landing. This project not only contributes to enhancing airport safety protocols but also showcases the potential of advanced technologies in addressing critical challenges in aviation operations.

Drones offer significant advantages in runway inspections by enhancing efficiency and accuracy. They can swiftly inspect runways for various issues, including cracks, potholes, debris, and foreign object damage. Moreover, drones increase inspection frequency, leading to improved hazard detection and prevention. This technology also provides operators with comprehensive overviews of runway conditions, facilitating better decision-making. By leveraging drones for inspections, airports can optimize safety protocols and ensure efficient runway maintenance, ultimately enhancing aviation safety and operational effectiveness.

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

The project combines Drone, RGB cameras, and Artificial Intelligence (AI) detectors trained using deep learning methods to detect Foreign Object Debris (FOD) on airport runways. The system utilizes locally collected images to train the AI detector on specific FOD classes such as paper, metal, bolts, plastic, and plastic bottles, considering different lighting conditions for image collection. By leveraging data augmentation techniques like resize, rotate, and color augmentation during training, the system aims to improve detection accuracy. The concept involves deploying UAVs equipped with AI detectors to conduct aerial surveillance of runways, enabling quick and efficient FOD detection. This innovative approach has the potential to reduce runway closure times and minimize disruptions caused by FOD incidents, ultimately enhancing runway safety and operational efficiency in the aviation industry.

III RELATED WORK

Your project focuses on utilizing drones for foreign object detection on runways, ensuring safety and efficiency in airport operations. The Proof of Concept (POC) involves the integration of various components, starting with the drone body, which serves as the platform for implementing your solution. Key components include the ESP32 microcontroller and a 4-channel relay along with a buzzer.

The ESP32 serves as the central control unit, communicating wirelessly with a laptop via Wi-Fi using UDP (User Datagram Protocol). This setup facilitates real-time data transmission and control. Additionally, you've incorporated mobile streaming for live video feed transmission to the laptop over a local Wi-Fi network. This enables operators to monitor the runway remotely and respond promptly to any detected foreign objects.

The heart of your solution lies in image processing, where you've employed convolutional neural networks (CNNs) trained on datasets containing images of foreign objects like bolts. Leveraging platforms like Google Colab for training, you've developed a robust model capable of accurately identifying foreign objects within the runway environment.

Once the image processing detects a foreign object, the laptop sends UDP commands to the ESP32 microcontroller. Upon receiving these commands, the microcontroller triggers the buzzer to alert nearby personnel. Additionally, it activates the relay system, allowing the drone to mobilize and navigate towards the detected object autonomously.

Your project addresses critical safety concerns at airports by providing a proactive approach to foreign object detection. By combining drone technology, wireless communication, and advanced image processing, you've created a comprehensive solution that enhances runway safety and operational efficiency. This report content highlights the innovative integration of hardware and software components to achieve your project's objectives effectively.

IV COMPONENTS OF FOD Detection System Using AI Drone

Foreign Object Debris (FOD) Detection System Using AI Drone using components are 1) ESP32, 2) Electromagnet, 3) GPS, 4) Relay, 5) Buzzer, 6) Motor, 7) Battery, 8) Arduino ide, 9) python IDLE.

1.ESP32

ESP32 microcontroller is a versatile and powerful system-on-chip (SoC) developed by Espressif Systems. It combines Wi-Fi and Bluetooth connectivity in a single chip, making it ideal for a wide range of IoT (Internet of Things) applications. The ESP32 is designed with TSMC low-power 40nm technology, emphasizing power efficiency and robust RF performance.

Key features of the ESP32 microcontroller include:

Dual-core Xtensa LX6 microprocessors with clock frequencies up to 240 MHz

Integrated Wi-Fi (2.4 GHz) and Bluetooth connectivity for seamless wireless communication

Support for various interfaces such as SPI, I2C, I2S, SDIO, UART, and more

Rich set of peripherals including GPIOs, PWM controllers, LED controllers, and infrared remote-control support

Advanced features like cryptographic hardware acceleration and low-power management for energy-efficient operation

The ESP32 series offers different chip revisions catering to specific requirements and applications. With its combination of connectivity options, processing power, and low-power capabilities, the ESP32 microcontroller is a popular choice for IoT projects, smart devices, wearables, and other wireless applications.

Versatility: The ESP32 is highly versatile, capable of performing various functions such as wireless communication and IoT applications.

Cost-Effectiveness: Using ESP32 reduces hardware costs due to its affordability. Ready-to-use ESP32 development boards are available in the market at a low cost, around $6USD.

Integrated Features: ESP32 integrates Wi-Fi and dual-mode Bluetooth functionalities, making it suitable for wireless communication applications.

IoT Applications: The ESP32 is commonly used in IoT applications due to its capabilities and features. It enables connectivity for IoT devices, making it suitable for smart home, industrial automation, and other IoT projects.

Infrared Communication: ESP32 supports transmission and reception of signals using various infrared protocols, expanding its application possibilities.

Specifications:

Processor: Dual-core Xtensa LX6 microprocessors with clock frequencies up to 240 MHz.

Connectivity: Integrated Wi-Fi (2.4 GHz) supporting 802.11b/g/n standards and Bluetooth v4.2 BR/EDR and Bluetooth LE specifications.

Memory: Includes 448 KB of ROM, 520 KB of on-chip SRAM, and additional SRAM in RTC for data storage.

Security: Features like secure boot, flash encryption, and cryptographic hardware acceleration for AES, Hash (SHA-2), RSA, ECC, and Random Number Generation.

Power Management: Offers fine-resolution power control with multiple power modes for efficient energy consumption.

Peripherals: Supports various interfaces such as SPI, I2C, I2S, SDIO, UART, PWM, and more for versatile connectivity options.

Applications: Suitable for IoT devices in smart home, industrial automation, healthcare, consumer electronics, smart agriculture, and more.

Working Process:

Initialization: The ESP32 microcontroller boots up and initializes its hardware components, including the processor, memory, and peripherals.

Connectivity Setup: It establishes connections over Wi-Fi or Bluetooth networks based on the application requirements.

Data Processing: The microcontroller processes data received from sensors, user inputs, or external devices using its processing capabilities.

Communication: It communicates with other devices

or servers over the network to exchange data or receive commands.
Power Management: The microcontroller manages power consumption by switching between different power modes based on the operational requirements.
Security: Ensures data security through features like secure boot, encryption, and cryptographic hardware acceleration.
Application Execution: Runs the application logic, performs tasks based on the programmed instructions, and interacts with the connected devices or services.
Error Handling: Monitors for errors or exceptions, handles them appropriately, and ensures the system operates smoothly.

Application:

The ESP32 microcontroller is widely used in a variety of applications due to its versatile features, connectivity options, and low-power capabilities. Here are some common applications where the ESP32 excels:

Smart Home Devices: ESP32 is used in smart home automation systems to control lighting, HVAC systems, security cameras, and other connected devices.
Industrial Automation: In industrial settings, the ESP32 is employed for monitoring and controlling machinery, collecting sensor data, and enabling communication between different components.
Healthcare: ESP32 is utilized in healthcare applications for remote patient monitoring, medical device connectivity, and health data collection.
Consumer Electronics: The microcontroller is integrated into various consumer electronics products such as smartwatches, fitness trackers, and home entertainment systems.
Smart Agriculture: ESP32 is used in agricultural applications for monitoring soil moisture, controlling irrigation systems, and collecting environmental data for precision farming.
POS Machines: Point-of-sale (POS) terminals and payment systems often incorporate ESP32 for wireless connectivity and secure data transmission.
Service Robots: ESP32 powers the communication and control systems of service robots used in hospitality, healthcare, and retail environments.
Audio Devices: The microcontroller is utilized in audio streaming devices, wireless speakers, and voice-controlled assistants.
IoT Sensor Hubs: ESP32 serves as the core of IoT sensor hubs that collect data from various sensors and transmit it to the cloud for analysis.
Data Loggers: ESP32 is used in data logging applications to record and store sensor data for analysis and monitoring purposes.
Networking Cards: The microcontroller is integrated into SDIO Wi-Fi + Bluetooth networking cards for wireless connectivity in various devices.
Touch and Proximity Sensing: ESP32 is employed in touch-sensitive interfaces and proximity sensors for user interaction in devices like touchscreens and gesture-controlled systems.
These applications showcase the versatility and adaptability of the ESP32 microcontroller in diverse fields, making it a popular choice for IoT projects, smart devices, and wireless communication systems.

2)Electromagnet

An electromagnet is a type of magnet that generates a magnetic field through the flow of electric current. It typically consists of a coil of wire wound around a core material, such as iron, which enhances the magnetic field's strength.

Working:
Electromagnets function by passing an electric current through a coil of wire, creating a magnetic field around the coil. The strength of the magnetic field can be controlled by varying the amount of current flowing through the wire.

Specification:
In technical terms, a specification refers to documented requirements that must be fulfilled by a particular material, design, product, or service.

Feature:
Electromagnets can be designed with various features, including adjustable magnetic strength, compact size, and compatibility with different power sources. Additionally, some electromagnets may incorporate features for heat dissipation or insulation to enhance performance.

Application:

- Electromagnets find applications in numerous fields, including:
- Magnetic resonance imaging (MRI) machines in medicine.
- Magnetic separation in mining and recycling.
- Magnetic levitation trains in transportation.
- Electric motors and generators in engineering.
- Loudspeakers and headphones in audio technology.

3)GPS (Global Positioning System)

GPS is a satellite-based navigation system that provides location and time information anywhere on Earth where there is an unobstructed line of sight to four or more GPS satellites. It comprises satellites, ground stations, and receivers.

Working:
GPS works by triangulating signals from multiple satellites to determine a receiver's precise location, velocity, and time. Each satellite transmits signals containing its own position and time. The GPS receiver uses the differences in time between when the

signals were transmitted and received to calculate its own position on Earth.

Specification:
GPS specifications include accuracy, update rate, sensitivity, and power consumption. For example, high-precision GPS receivers may have sub-meter or centimeter-level accuracy, while consumer-grade devices typically offer meter-level accuracy.

Feature:
Features of GPS systems can include:

- Real-time tracking of vehicles or assets.
- Geofencing capabilities to define virtual boundaries.
- Integration with other technologies like cellular networks or inertial navigation systems.
- Waterproof and rugged designs for outdoor use.

Application:
GPS finds applications in various fields such as:

- Navigation for automobiles, ships, and aircraft.
- Location-based services like mapping, geocaching, and fitness tracking.
- Fleet management and asset tracking.
- Surveying, agriculture, and outdoor recreation.

4)Relay

A relay is an electromechanical device used to control the flow of electricity in a circuit by allowing a low-power signal to switch a higher-power circuit on or off. It typically consists of a coil of wire, an armature, and one or more sets of contacts.

Working:
When a current passes through the coil of a relay, it creates a magnetic field that attracts the armature, causing the contacts to close or open, depending on the relay type. This action allows the relay to control the flow of current in another part of the circuit.

Specification:
Relay specifications may include parameters such as contact ratings (voltage and current), coil voltage, contact configuration (normally open, normally closed), switching time, insulation resistance, and mechanical endurance.

Feature:
Common features of relays include:

- Compact size for easy integration into circuits.
- Low power consumption.
- High switching speed for rapid response.
- Wide range of contact configurations to suit different applications.
- Durability and reliability for long-term operation.

Application:
Relays are utilized in various applications across industries, such as:

- Automotive: for controlling headlights, motors, and ignition systems.
- Industrial automation: for controlling machinery, motors, and production processes.
- HVAC (heating, ventilation, and air conditioning): for controlling fans, compressors, and heating elements.
- Power distribution: for circuit protection, load shedding, and remote switching [4].

5)BUZZER

A buzzer typically refers to a small electrical device that produces a buzzing sound when activated. It's commonly used in various applications such as alarms, timers, games, and notification systems. Buzzer circuits typically consist of an electromagnet that causes a metal disk or other component to vibrate rapidly, creating the buzzing noise. Buzzers come in different shapes and sizes, ranging from simple standalone units to integrated components in electronic devices. They are widely used in everyday electronics for their simplicity, reliability, and effectiveness in alerting users to certain events or conditions.

Working:

A buzzer typically operates on the principle of electromagnetism

Electromagnetic Coil: The main component of a buzzer is an electromagnet coil. When an electric current passes through this coil, it generates a magnetic field around it. The coil is usually made of copper wire wound around a core, often made of iron or a ferromagnetic material.

Armature: Inside the coil, there's typically an armature, which is a movable component made of a ferromagnetic material like iron. When the coil is energized and generates a magnetic field, it attracts the armature towards it due to magnetic attraction.

Spring: There's usually a spring attached to the armature, pulling it back when the current is not flowing through the coil. This creates a mechanical oscillation system.

Contact Points: As the armature is attracted towards the coil, it comes into contact with a stationary contact point. This completes an electrical circuit, allowing current to flow through the coil.

Vibration: When the current flows through the coil, the armature is pulled towards it, making contact with the stationary contact point. This action interrupts the flow of current, causing the magnetic field to collapse. As a result, the armature is released and pulled back by the spring. The cycle repeats rapidly, causing the armature to vibrate back and forth.

Sound Generation: The rapid oscillation of the armature creates vibrations in the surrounding air, producing a buzzing sound. The frequency of the buzzing sound depends on the rate of the armature's oscillation, which is determined by factors such as the design of the coil, the strength of the magnetic field, and the tension of the spring.

In summary, a buzzer works by converting electrical energy into mechanical motion and then into sound through the rapid vibration of an armature in an electromagnetic field.

Buzzer Features and Specifications

- Rated Voltage: 6V DC
- Operating Voltage: 4-8V DC
- Rated current: <30mA
- Sound Type: Continuous Beep
- Resonant Frequency: ~2300 Hz
- Small and neat sealed package
- Breadboard and Perf board friendly

6)Motor

A motor is a device that converts electrical energy into mechanical energy, leading to the rotation of a shaft. It operates based on the principle of electromagnetic induction, where the interaction between magnetic fields and electric currents generates rotational motion.

Working:

Motors work by applying electrical current to conductors within a magnetic field, causing the conductors to experience a force, resulting in rotational motion. The direction and speed of rotation can be controlled by adjusting the electrical input or the configuration of the motor.

Specification:

Motor specifications typically include parameters such as power rating, voltage, current, speed, torque, efficiency, and physical dimensions. These specifications define the motor's performance characteristics and compatibility with specific applications.

Feature:

Motors may feature various characteristics such as:

- Variable speed control for precise operation.
- High torque output for heavy-duty applications.
- Compact design for space-constrained installations.
- Energy efficiency to minimize power consumption.
- Overload protection mechanisms to prevent damage.

Application:

Motors are utilized in a wide range of applications across industries, including:

- Industrial machinery and automation.
- Electric vehicles and transportation systems.
- HVAC (heating, ventilation, and air conditioning) systems.
- Household appliances like washing machines and refrigerators.
- Robotics and motion control systems.

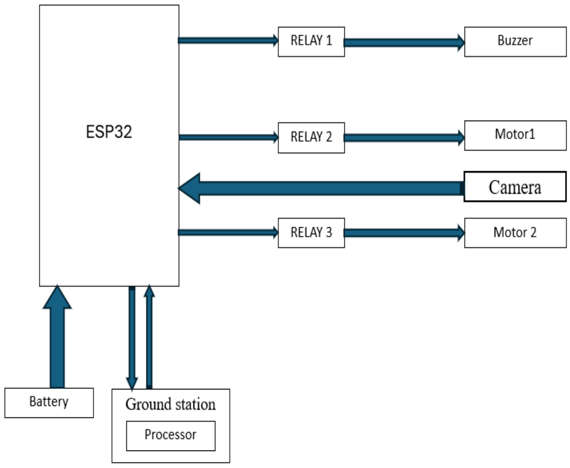

Fig (1): Drone FOD Block diagram

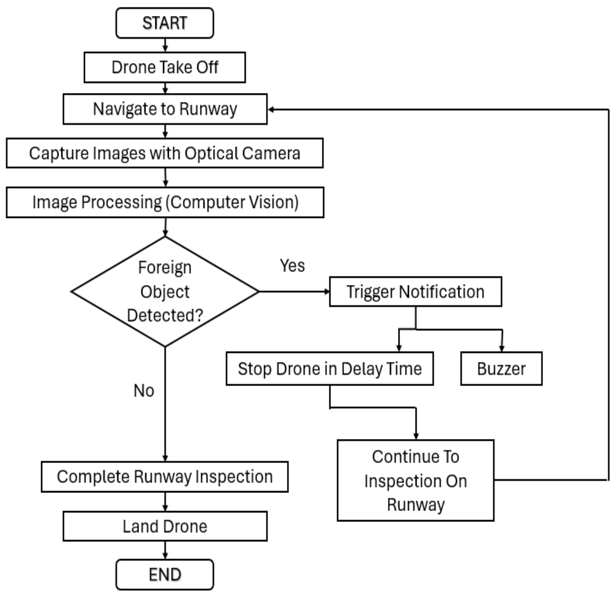

Fig (2): Drone FOD flow chart

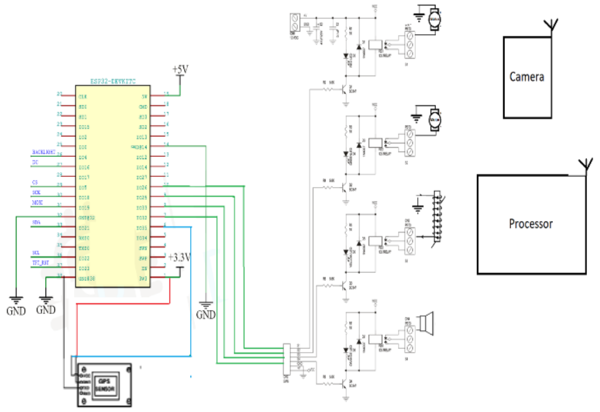

Fig (3): Circuit Diagram of FOD Drone

EXECUTION

Drone Navigation: The drone is programmed to follow a predefined path for systematic coverage of the entire runway.
Image Capture: The optical camera captures images of the runway surface during the drone's flight.
Image Processing: Computer vision algorithms analyze the captured images to identify foreign objects based on predefined criteria.
ESP32 Notification: Upon detection, the ESP32 microcontroller sends a real-time notification to the ground station.

RESULTS & DISCUSSIONS

The system demonstrated efficient detection of foreign objects, improving runway safety. The drone's ability to cover the entire runway quickly enhances the inspection process compared to traditional methods. However, challenges such as varying weather conditions and object recognition accuracy need further consideration. Continuous refinement of the algorithm and sensor calibration is essential for optimizing performance.

INFERENCE

The successful execution of the proposed method indicates the potential for drone-based runway inspections to revolutionize airport safety protocols. Real-time notifications enable swift responses to foreign object detection, minimizing the risk of operational disruptions and enhancing overall runway safety.

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