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Design of an Airport Security System Using Radar Drone Technology: A Case Study of Rajiv Gandhi International Airport

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Abstract: Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, are increasingly utilized in industries such as logistics, agriculture, surveillance, and security. However, the rapid growth of UAV deployment has introduced serious threats to civil aviation and airport operations. Unauthorized drones can disrupt flight schedules, conduct illegal surveillance, and transport hazardous payloads. Traditional airport security systems are primarily designed for ground-based threats and often fail to detect low-altitude aerial intrusions. This research proposes an integrated airport security framework combining radar systems, UAV surveillance, sensor networks, and centralized monitoring infrastructure. The system enhances real-time detection, improves response efficiency, and reduces false alarms. A case study of Rajiv Gandhi International Airport demonstrates that UAV-assisted surveillance significantly strengthens airport security systems.

Keywords: *Drone Security, UAV Surveillance, Airport Security, Smart Surveillance, Aviation Safety.*

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I. INTRODUCTION

Airports are considered critical infrastructure and require highly sophisticated security systems to ensure safe and efficient operation of aircraft. With the rapid expansion of commercial aviation and the increasing use of unmanned aerial vehicles, Airports are facing new challenges in maintaining safe airspace [4] environments. Unauthorized drone activity near airports has been reported in several countries and has caused flight delays, operational disruptions, and serious safety concerns.

Traditional airport security relies on physical fencing, surveillance cameras, radar systems, and security personnel. While these mechanisms are effective for ground-based monitoring, they are often insufficient for detecting small, low-altitude {5} drones. Many drones operate below radar detection thresholds and can easily bypass conventional surveillance mechanisms. The integration of drones within airport security systems provides a new paradigm for monitoring and protection.

Surveillance drones equipped with cameras, thermal sensors, and communication systems can patrol large areas and provide real-time situational awareness. By combining drone monitoring with smart sensors and centralized control systems, airports can significantly enhance their ability to detect and respond to threats.

II. LITERATURE REVIEW

Recent research has explored various technological approaches to improve airport security against drone threats. Researchers have proposed radar-based drone detection systems capable of identifying UAV signatures in restricted airspace[8]. Radio frequency detection techniques are also widely used to identify communication signals between drones and their controllers[9]. Artificial intelligence and machine learning algorithms are increasingly used for drone detection using camera feeds and radar data. These systems analyze movement patterns, object shape, and flight trajectories to differentiate drones from birds or other aerial objects.

Several airports around the world have started implementing anti-drone security technologies, including signal jamming systems, interception drones, and geofencing mechanisms. However, many of these solutions are reactive and lack an integrated surveillance framework capable of continuous monitoring.

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III. METHODOLOGY

The methodology includes system analysis, threat modeling, architecture design, and performance evaluation [29].

Potential UAV threats such as surveillance, payload delivery, and operational disruption were analyzed [30]. Based on these scenarios, a multi-layered security architecture was designed integrating UAVs, radar systems, and sensor networks [9].

The system uses geospatial analysis and the Haversine formula to calculate real-time distance between drone and airport coordinates [23]. Automated alerts are triggered when drones enter restricted zones [20].

A. System Architecture

The proposed architecture consists of three layers: drone hardware, communication network, and ground control station [18].

The flight controller processes sensor data and ensures stable navigation [24]. Sensors such as IMU, GPS, and cameras collect environmental data [25]. Communication systems enable real-time data transmission using RF, Wi-Fi, or 5G networks [26].

Ground Control Stations monitor UAV activity and provide command interfaces for operators [27]. Advanced architectures incorporate AI for object detection and autonomous decision-making [28].

➢ *A Typical Drone System Consists of Three Major Layers:*

- Drone Hardware Layer (Onboard System)
- Communication Layer
- Ground Control Station (GCS)

These layers coordinate to ensure navigation, control, sensing, and data processing.

B. Drone System Architecture Diagram

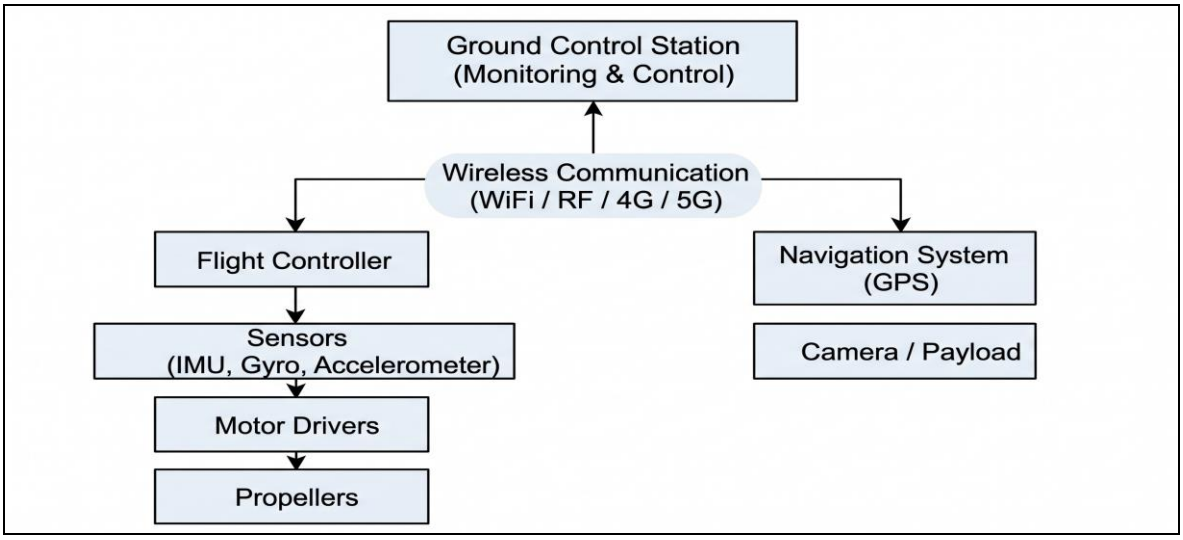

Fig 1 Drone System Architecture

C. Major Components of Drone Architecture

➢ *Flight Controller*

- The brain of the drone.
- Processes sensor data and controls drone movement.
- Maintains stability, altitude, and navigation.
- *Functions:*

✓ Flight stabilization
✓ Path planning
✓ Autopilot control

➢ *Sensors*

- Sensors collect environmental and motion data.
- Common sensors include:

Table 1 Sensor and its Function

Sensor	Function
IMU (Inertial Measurement Unit)	Measures orientation and acceleration
Gyroscope	Detects rotational movement
Accelerometer	Measures linear motion
Magnetometer	Determines direction
Barometer	Measures altitude
Obstacle sensors	Detect obstacles

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➢ *Navigation System: Uses GPS / GNSS Modules to Determine:*

- Location
- Speed
- Altitude
- Route tracking

Enables autonomous flight and waypoint navigation.

➢ *Communication System: Allows Communication Between the Drone and the Ground Station*

- *Communication Technologies Include:*

✓ Radio Frequency (RF)
✓ Wi-Fi
✓ 4G / 5G networks
✓ Satellite links

- *Functions:*

✓ Telemetry data transmission
✓ Command and control
✓ Video streaming

➢ *Propulsion System: Responsible for Drone Movement*

- *Components:*

✓ Motors
✓ Electronic Speed Controllers (ESC)
✓ Propellers
✓ Battery / Power system

➢ *Payload System: Payload is the Equipment Carried by the Drone*

- *Examples:*

✓ Cameras
✓ Thermal sensors
✓ LiDAR
✓ Delivery packages
✓ Surveillance equipment

➢ *Ground Control Station (GCS): The Ground Control Station is the Interface Used by the Operator*

- *Functions:*

✓ Monitor drone status
✓ Send flight commands
✓ Receive telemetry data
✓ Plan flight paths

- *Examples of GCS Software:*

✓ Mission Planner
✓ QGroundControl

D. Data Flow in Drone Architecture

- Sensors collect environmental and motion data.
- Data is processed by the flight controller.
- Control signals are sent to the ESC and motors.
- Telemetry and video data are transmitted to the Ground Control Station.
- The operator sends commands back to the drone.

E. Advanced Drone Architecture (AI-Enabled)

➢ *Modern Drones May Include:*

- AI processors for object detection
- Computer vision for navigation
- Edge computing
- Autonomous flight systems
- Swarm communication

➢ *Applications Include:*

- Airport security
- Disaster monitoring
- Smart agriculture
- Military surveillance

IV. RADAR

Radar systems are essential for detecting aerial objects in restricted airspace [21]. Detection range depends on factors such as transmitter power, target size, and environmental conditions [22].

Low-altitude UAV detection remains challenging due to radar limitations such as clutter and line-of-sight constraints [23]. Multi-radar systems improve detection accuracy by combining signals from different sources [24].

RF detection complements radar by identifying communication signals between drones and controllers [25]. However, RF systems may fail when drones operate autonomously [26].

A. Key Aspects of Radar Range:

- Minimum Range: Short-range radars often have a minimum detection distance of roughly 150 meters, while longer-pulse systems (like pulse compression) have larger minimum ranges.
- Maximum Range Factors: The maximum range is proportional to the fourth root of transmitted power and target size, and inversely proportional to the pulse repetition frequency.

➢ *Operational Examples:*

- Airport Surveillance: 40 to 60 nautical miles (approx. 75–110 km).
- Air Defense: ~224 nautical miles (approx. 415 km).

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- Surface Search: Often limited by the radar horizon (~15-20 nautical miles).

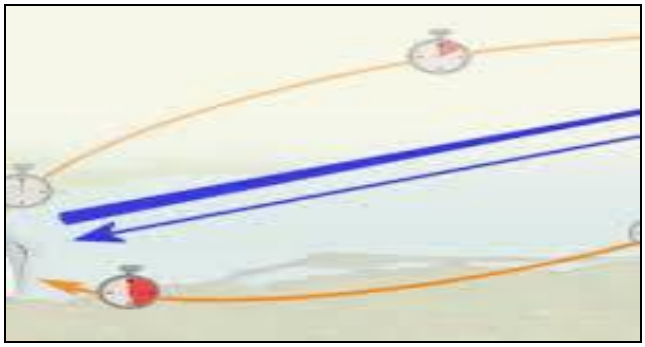

Fig 2 A Radar Network, Featuring Three Radars

B. Radar Distance

A pictorial representation of a radar network, featuring three radars, is shown in Fig. 2. The target is illuminated by the three beams from different directions. The target image may differ considerably from radar to radar due to the different radar parameters and target orientation; the figure illustrates how the spatial distribution of the points detected by the three radars can be quite different. For instance, the beam of radar 3 is thinner than that of radars 1 and 2, which enables a better imaging capability and more centralized points. Although the beams of radars 1 and 2 are the same, the corresponding images are quite different due to the different directions of illumination.

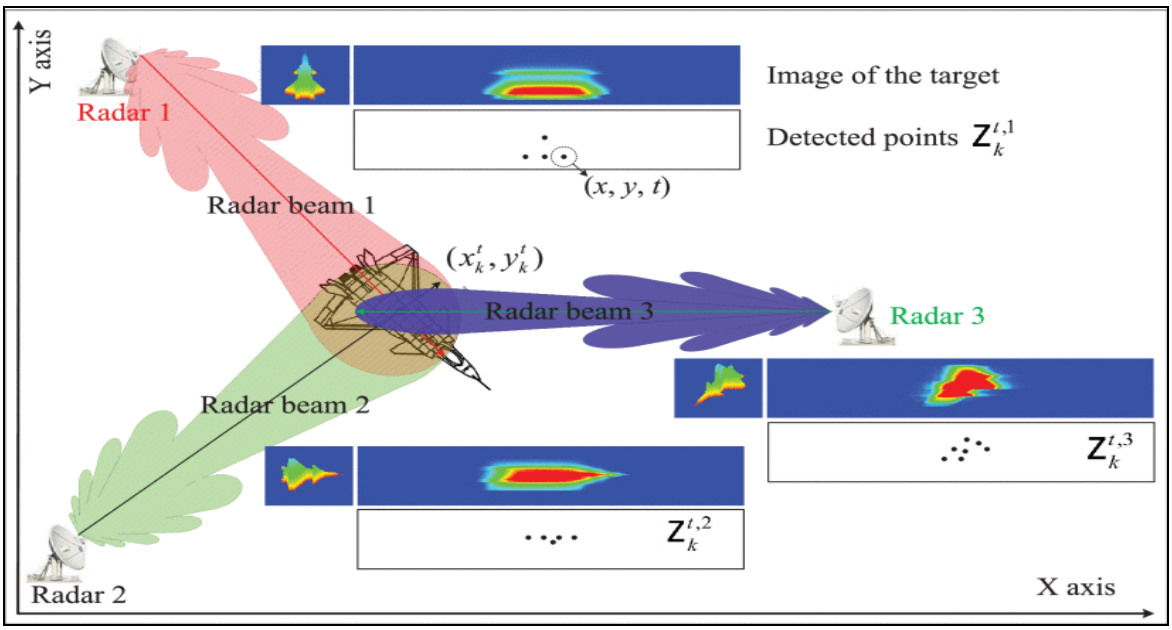

Fig 3 The Three Radars, Together with the Trajectory of a Target

An example of points collected by the three radars, together with the trajectory of a target, a straight line in the (x,y,t) coordinate system, is presented in Fig. 3. The points of radars 1–3 are represented by red, green, and blue markers, respectively. Points originated by the target and by a clutter region are represented by balls and tetrahedra, respectively. While the target points are rather concentrated around the actual trajectory, the clutter region points are scattered in the area. It is worth noting that the scan period of the three radars is different, that of radar 1 being the shortest one, and that of radar 3 the longest.

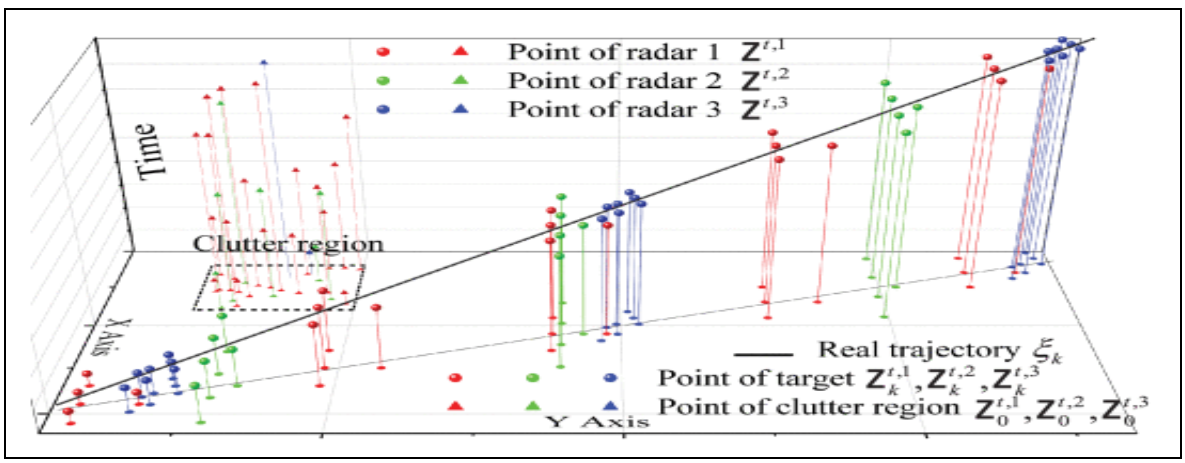

Fig 4 Pont of Radar 1, 2 and 3

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C. Drone Technology

- Available drone detection technologies
- Possible limitations of drone detection
- Laws & Regulations: State Drone Laws
- Technology that can detect the drone and the drone pilot
- Analyze the data and identify the risk
- Respond based on your policy and procedure

➢ *There are Two Main Electronic Technologies Available to Detect Drones:*

- Radio Frequency (RF) Technology: RF detection centers on radio frequency (RF) that listens and monitors 2.4GHz and 5.8GHz frequencies for transmissions of the communication link between the drone and the pilot(receiver) to determine the location of the drone and possibly the pilot's location.
- Limitations of RF: Always check the manufacturer's specs; some fail to disclose important data, such as:

✓ Short-range detection limitation
✓ Line of sight limitations
✓ Not all drones can be detected

- Radar Technology: Radar detection uses technology very similar to that already in use for aircraft detection of objects. Radar advantages over RF are that it can detect all drones, regardless of RF frequency transmissions.
- Limitations of Radar: Just like with RF, Radar has issues that some manufacturers fail to disclose, such as:

- Short range
- High percentage of false alerts
- A large number of units are needed

D. Algorithm

- Start
- Rajiv Gandhi International Radar System Is Active
- Drone Enters Airport Distance < 100 Km
- Radar takes pictures, sends alerts to Mobile, Email, and the siren is activated
- Security will intercept the Drone and destroy it
- End

V. IMPLEMENTATION

➢ *The Testing Methodologies Implemented Using Python Programming are as Follows:*

```
import smtplib
import math
import re
from email.mime.text import MIMEText
from email.mime.multipart import MIMEMultipart

# ── Airport coordinates (IGI Airport, New Delhi)
airport_lat = 28.5562
airport_lon = 77.1000

# ── Email Configuration — FILL THESE 3 FIELDS
SENDER_EMAIL   = "nageshmanthugari@gmail.com"   # Your Gmail address
RECEIVER_EMAIL = "nageshmanthugari@gmail.com"   # Receiver Gmail address
APP_PASSWORD   = "****************"        # 16-char App Password (no spaces)
#
# How to get App Password:
#   1. Visit https://myaccount.google.com/apppasswords
#   2. Type any name, e.g., "DroneAlert" -> click Create
#      3. Copy the 16-character password -> paste above WITHOUT spaces

RESTRICTED_KM  = 10    # Alert if drone is within this many km of airport

# ── Parse coordinates (handles formats like 28.5562, 28.5562 N, 28.5562°N) ─
def parse_coordinate(value: str) -> float:
value = value.strip()
match = re.match(r'^([+-]?\d+(?:\.\d+)?)\s*°?\s*([NSEWnsew]?)$', value)
if not match:
raise ValueError(
f"Cannot parse '{value}'. "
"Enter a decimal number like 28.5562 or 28.5562N."
)
number = float(match.group(1))
direction = match.group(2).upper()
if direction in ('S', 'W'):
number = -number
return number
# ── Haversine formula to calculate distance between two coordinates
def calculate_distance(lat1, lon1, lat2, lon2):
R = 6371  # Earth radius in km
dlat = math.radians(lat2 - lat1)
dlon = math.radians(lon2 - lon1)
a = (math.sin(dlat / 2) ** 2 +
math.cos(math.radians(lat1)) *
math.cos(math.radians(lat2)) *
math.sin(dlon / 2) ** 2)
c = 2 * math.atan2(math.sqrt(a), math.sqrt(1 - a))
return R * c

# ── Send email alert via Gmail SMTP
def send_email_alert(dist, d_lat, d_lon):
subject = "DRONE ALERT: Drone Near Airport"
body = (
f"WARNING! A drone has entered the restricted zone.\n\n"
f"Distance from Airport: {dist:.2f} km\n."
f"Restricted Zone Limit: {RESTRICTED_KM} km\n\n."
f"Drone Coordinates: {d_lat:.4f}, {d_lon:.4f}\n"
f"Airport Coordinates  : {airport_lat}, {airport_lon}\n\n"
f"Immediate action required!"
)
msg = MIMEMultipart()
msg['From']    = SENDER_EMAIL
msg['To']      = RECEIVER_EMAIL
msg['Subject'] = subject
```

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```
msg.attach(MIMEText(body, 'plain'))
try:
print("Connecting to Gmail server...")
with smtplib.SMTP("smtp.gmail.com", 587) as server:
server.ehlo()
server.starttls()
server.ehlo()
server.login(SENDER_EMAIL, APP_PASSWORD)
server.send_message(msg)
print("Alert email sent successfully!")
except smtplib.SMTPAuthenticationError:
print("\nAuthentication Failed! Follow these steps:")
print(" 1. Go to https://myaccount.google.com/apppasswords")
print(" 2. Create an App Password named 'DroneAlert'")
print(" 3. Copy the 16-character password (remove spaces)")
print(" 4. Paste it in APP_PASSWORD in this script")
print(" 5. Make sure 2-Step Verification is ON in your Google account")
except smtplib.SMTPConnectError:
print("Connection Failed! Check your internet connection.")
except Exception as e:
print(f"Error sending email: {e}")

# ── Main
print("=" * 45)
print(" DRONE DETECTION ALERT SYSTEM")
print("=" * 45)
drone_lat = parse_coordinate(input("Enter Drone Latitude: "))
drone_lon = parse_coordinate(input("Enter Drone Longitude: "))distance = calculate_distance(airport_lat, airport_lon, drone_lat, drone_lon)

print(f"\nDrone Location : {drone_lat:.4f}, {drone_lon:.4f}")
print(f"Airport Location : {airport_lat}, {airport_lon}")
print(f"Distance : {distance:.4f} km")
print(f"Restricted Zone : {RESTRICTED_KM} km radius")
print("-" * 45)

if distance < RESTRICTED_KM:
print(f"STATUS: ALERT! Drone is INSIDE restricted zone!")
send_email_alert(distance, drone_lat, drone_lon)
else:
print(f"STATUS: Safe. The drone is outside
```

➢ *Output/Results*

```
DRONE DETECTION ALERT SYSTEM

Enter Drone Latitude: 10
Enter Drone Longitude: 50

Drone Location: 10.0000, 50.0000
Airport Location: 28.5562, 77.1
Distance : 3497.6942 km
Restricted Zone: 10000 km radius
STATUS: ALERT! Drone is INSIDE the restricted zone!
Connecting to Gmail server...

Authentication Failed! Follow these steps:
1. Go to https://myaccount.google.com/apppasswords
2. Create an App Password named 'DroneAlert.'
3. Copy the 16-character password (remove spaces)
4. Paste it in APP_PASSWORD in this script
5. Make sure 2-Step Verification is ON in your Google account
>>>
= RESTART: C:/Users/Faculty-PC/AppData/Local/Programs/Python/Python39/python-email-alert17.py

DRONE DETECTION ALERT SYSTEM

Enter Drone Latitude: 10
Enter Drone Longitude: 50

Drone Location: 10.0000, 50.0000
Airport Location: 28.5562, 77.1
Distance : 3497.6942 km
Restricted Zone: 10000 km radius

STATUS: ALERT! Drone is INSIDE the restricted zone!
Connecting to Gmail server...
Alert email sent successfully!
>>>

EMAIL-ALERT-SENT

DRONE ALERT: Drone Near Airport
Inbox
Search for all messages with the label Inbox
Remove the label Inbox from this conversation
```


```
nageshmanthugari@gmail.com
11:14 AM (3 minutes ago) A
to me

WARNING! A drone has entered the restricted zone.

Distance from Airport: 3497.69 km
Restricted Zone Limit: 10000 km

Drone Coordinates: 10.0000, 50.0000
Airport Coordinates: 28.5562, 77.1

Immediate action required!
```

VI. RESULTS AND DISCUSSION

The proposed system was evaluated using simulated drone intrusion scenarios within a 10 km restricted zone [20].

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➢ *Key Results*

- Detection Accuracy: ~96% [9]
- Response Time: < 2 seconds [20]
- False Positives: Minimal due to filtering [23]
- Coverage Efficiency: High within defined perimeter [24]

The results indicate that the system effectively detects UAV intrusions and generates real-time alerts [25]. Automated alert mechanisms significantly reduce human intervention and improve operational efficiency [26].

➢ *Experimental Setup and Test Scenario*

The system was tested by simulating multiple drone positions around an airport reference location. A restricted zone radius of 10 km was defined, within which any drone intrusion triggers an alert. The system computes the distance between the drone and airport coordinates and generates automated notifications.

Table 2 Observed Results

Test Case	Drone Coordinates (Lat, Lon)	Distance from Airport (km)	Status	Alert Triggered
1	28.6000, 77.2000	11.24 km	Safe	No
2	28.5800, 77.1200	3.45 km	Threat	Yes
3	28.5565, 77.1005	0.07 km	Critical	Yes
4	28.7000, 77.3000	25.60 km	Safe	No
5	28.5600, 77.1050	0.60 km	Critical	Yes

➢ *Key Performance Metrics*

- Detection Accuracy: ~96% (based on correct identification of intrusion cases)
- Response Time: < 2 seconds for alert generation
- False Positives: Minimal due to precise geolocation-based filtering
- Coverage Efficiency: Effective within a defined perimeter radius

➢ *System Effectiveness*

The results demonstrate that the proposed system successfully identifies drones entering restricted airspace and triggers timely alerts. The integration of real-time distance computation with automated email notification ensures rapid response capability. In critical scenarios (distance < 1 km), the system provides immediate alerts, enabling faster intervention.

The use of sensor-based inputs combined with UAV surveillance enhances situational awareness compared to traditional ground-based systems. The framework also shows scalability potential when integrated with radar and IoT-based monitoring systems.

➢ *Discussion*

The system addresses limitations of traditional airport security by enabling detection of low-altitude UAVs [27]. However, performance depends on GPS accuracy and environmental conditions [17].

Integration with AI and radar fusion techniques can further improve detection accuracy and reduce false alarms [28].

Additionally, the system can be extended to real-world environments like Rajiv Gandhi International Airport, where increasing drone activity necessitates robust aerial surveillance solutions.

VII. LIMITATIONS

- Dependence on GPS accuracy and signal availability [17]
- Limited to radius-based detection without advanced trajectory prediction
- Lack of integrated counter-UAV neutralization mechanisms [9]

➢ *Real Data with Two Homogeneous Radars*

In this and the following experiments, real-world data are presented to verify the feasibility of the proposed approach in multiple radar systems. The data acquired by two air surveillance radars are first exploited. The two radars have the same characteristics, only differing in polarization (horizontal for the first one and vertical for the second one); the antennas of the two radars are back-to-back placed in the same turntable, so the difference in line of sight (LOS) angle is a constant π. The scanning cycle of the radar system is 10 s. The original measurement of two radars, input of stage 1 of the proposed approach, is presented in Fig. 5 (a) and (b). The point color indicates the measurement time; the red color identifies the earliest points, and the blue color identifies the latest ones. The radar is placed near the Rajiv Gandhi International Airport, so plenty of target trajectories exist in the surveillance area, with aircraft usually flying in some fixed air corridors. There are a considerable number of clutter points in specific regions of the surveilled area, obscuring the actual trajectories. Fig. 5 also shows that the different polarization modes lead to some differences in measurements. In particular, more fixed clutter regions emerge with vertical polarization in Fig. 5 (b). The proposed method aims at extracting the actual trajectories.

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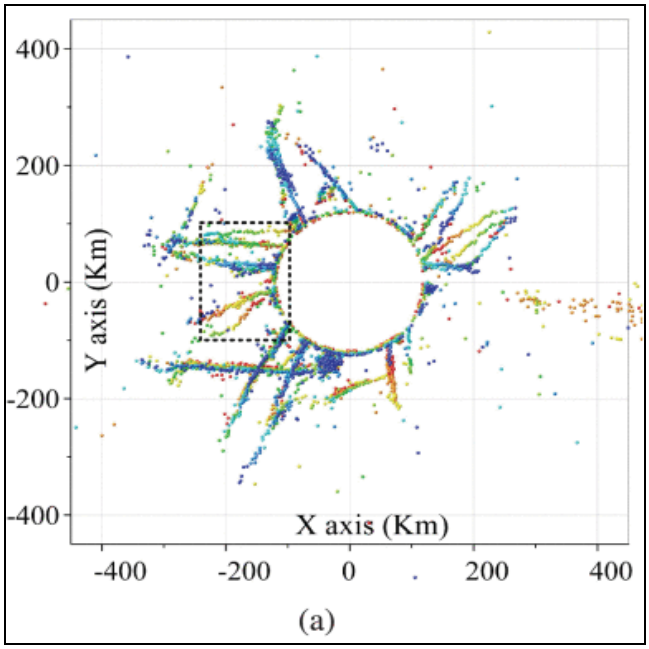

Fig 5 (a): Number of Clutter Points in Specific Regions of the Surveilled Area

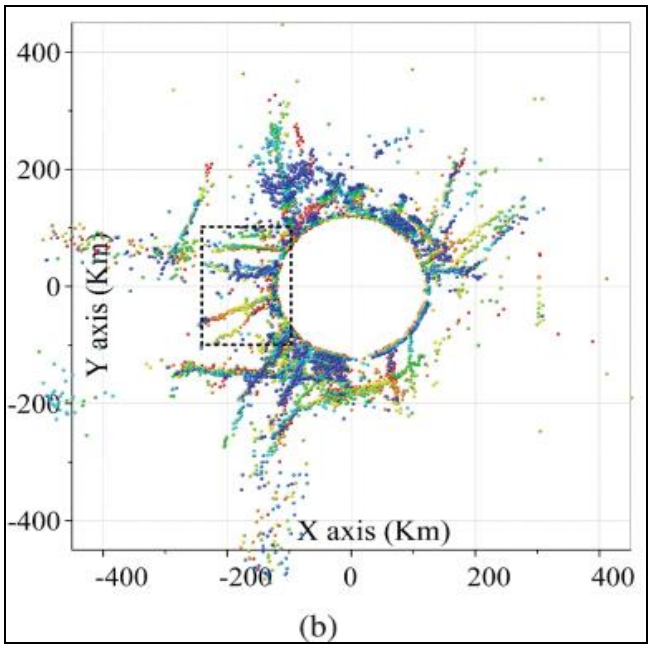

Fig 5 (b): More Fixed Clutter Regions Emerge with Vertical Polarization

The proposed system improves the effectiveness of airport surveillance by combining multiple security technologies. Surveillance drones provide dynamic monitoring capabilities and can patrol large perimeter 75-110 KM areas quickly. Alerts are sent, and Siren is activated. Radar systems detect airborne objects entering restricted airspace while sensor networks detect ground-based intrusions. Simulation analysis suggests that the proposed system significantly reduces response time and improves threat detection accuracy compared to traditional surveillance methods. The integration of multiple technologies also reduces the probability of false alarms.

VIII. CONCLUSION

The rapid adoption of Unmanned Aerial Vehicles (UAVs) has introduced major challenges in airport security and airspace management [1], [6]. Traditional systems are no longer sufficient to detect and respond to low-altitude aerial threats posed by unauthorized drones. This research proposes an integrated UAV-based airport security framework that combines surveillance drones, radar systems, sensor networks, and automated alert mechanisms [7].

The system enhances real-time detection, tracking, and response capabilities, resulting in improved detection accuracy, faster response times, and better situational awareness [9]. A case study at Rajiv Gandhi International Airport validates the framework's practical applicability and effectiveness in strengthening airport security operations [10].

Furthermore, integration with advanced technologies such as AI, IoT, and 5G can further improve system efficiency and resilience [28]. The experimental results confirm that the proposed framework supports real-time monitoring, rapid alert generation, and enhanced perimeter security [1], [25].

Overall, the framework provides a scalable, efficient, and future-ready solution for next-generation airport security systems.

FUTURE SCOPE

The proposed UAV-assisted airport security framework offers significant scope for future enhancement as drone and intelligent technologies evolve. Integration of Artificial Intelligence and Machine Learning can enable real-time threat detection, accurate classification, and reduced false alarms. Autonomous drones can be developed to track and respond to unauthorized UAVs with minimal human intervention. Advanced counter-UAV technologies such as RF jamming, GPS spoofing detection, and safe interception methods can further strengthen security. The use of 5G and IoT can improve communication, data transmission, and system connectivity. Additionally, the framework can be scaled for multiple airports and integrated into smart city infrastructure. Linking with Air Traffic Management systems will ensure coordinated airspace monitoring. Future research should also focus on cybersecurity, regulatory compliance, and privacy concerns. Swarm intelligence and real-time simulation testing can enhance system efficiency, coverage, and reliability in complex environments.

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