AeroWatch

INFO8665- Spring 2024- Section 1

Projects in Machine Learning

Vinith Shadu Shetty
Rubel Binu Thomas

Introduction

- Traditional surveillance methods often rely on fixed camera systems and human patrols. While effective in some scenarios, these methods have several limitations that can hinder their effectiveness.
    - Limited Field of View
    - Installation and Maintenance Costs
    - Inflexibility
    - Limited Coverage
    - Fatigue and Human Errors
    - Safety Risks

- Drones, with their ability to capture high-resolution imagery and access hard-to-reach areas, have become invaluable tools in various sectors, including environmental monitoring, disaster management, security, and agriculture.
- Why Drones for Surveillance?
    - Mobility
    - Real-Time Monitoring
    - Cost-Effective
    - Advanced technology
    - Versatility

Project Objective

This project aims to harness the power of machine learning to enhance drone surveillance capabilities. By developing sophisticated algorithms that can analyze real-time data from drone cameras, we seek to improve surveillance operations' efficiency, accuracy, and effectiveness. Our approach utilizes state-of-the-art machine learning techniques for object detection, classification, and anomaly detection, enabling drones to autonomously identify and respond to various scenarios.

The primary objectives of this project are to:

1. **Develop Robust Object Detection Models:** Utilize deep learning frameworks to train models capable of accurately detecting and classifying objects of interest in diverse environments and lighting conditions.
2. **Implement Real-Time Processing:** Design algorithms to process drone-captured imagery in real-time, ensuring timely responses to detected anomalies or threats.
3. **Improve Security Measures:** Leverage machine learning to bolster security surveillance by detecting unauthorized activities, intrusions, and other potential security breaches.
4. **Crowd Control**: During significant public events or protests, drones offer a bird's-eye view, helping authorities manage crowds and ensure public safety.
5. **Crime Scene Analysis**: High-resolution drone imagery can help investigators capture detailed views of crime scenes, preserving crucial evidence.

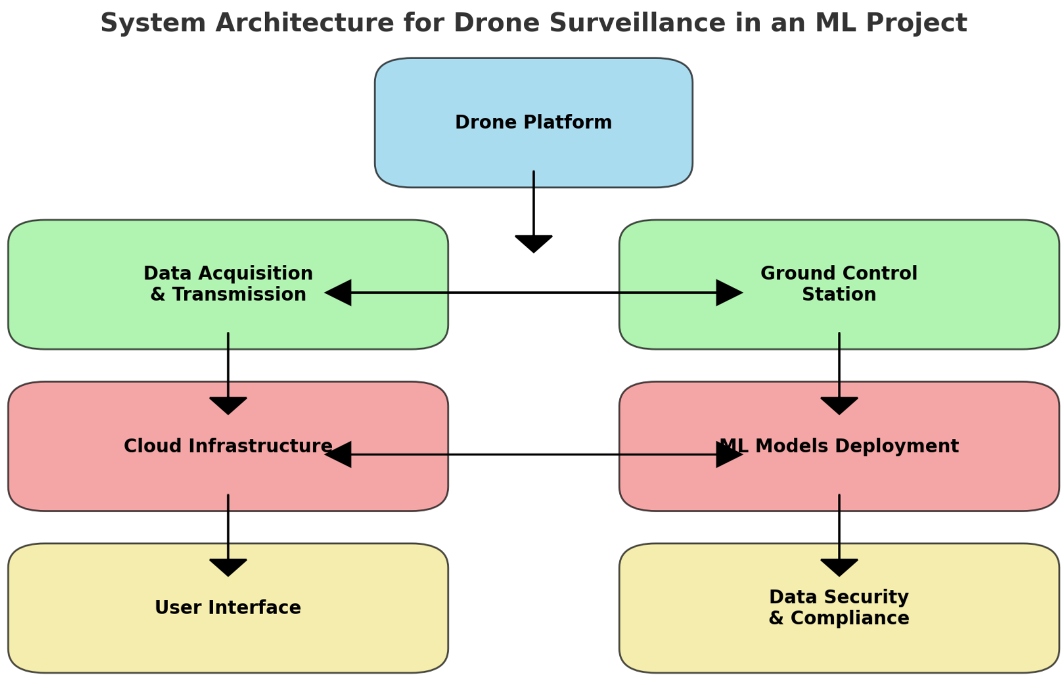
Role Of Machine Learning

Machine learning enhances drone surveillance for law enforcement by enabling advanced analytics, real-time decision-making, and automation.

Key roles include:

1. **Object Detection and Tracking:** CNNs detect and track vehicles, people, and items, improving target monitoring.
2. **Anomaly Detection:** Algorithms analyze video patterns to spot unusual activities, aiding in crime prevention.
3. **Facial Recognition:** ML models identify suspects or missing persons, enhancing suspect apprehension.
4. **Behavioural Analysis:** ML assesses human movements for suspicious behaviour, identifying potential threats.
5. **Scene Understanding:** Models categorize scene elements, improving situational awareness.
6. **Real-Time Data Processing:** Algorithms process sensor data promptly, ensuring timely insights.
7. **Predictive Analytics:** ML predicts crime hotspots, optimizing resource allocation.
8. **Autonomous Navigation:** Reinforcement learning enables obstacle avoidance and efficient flight paths.
9. **Data Integration:** ML fuses data from multiple sources, enhancing surveillance accuracy.
10. **Privacy Considerations:** ML preserves privacy by blurring non-target faces and balancing surveillance with individual rights.

System Architecture for Drone Surveillance



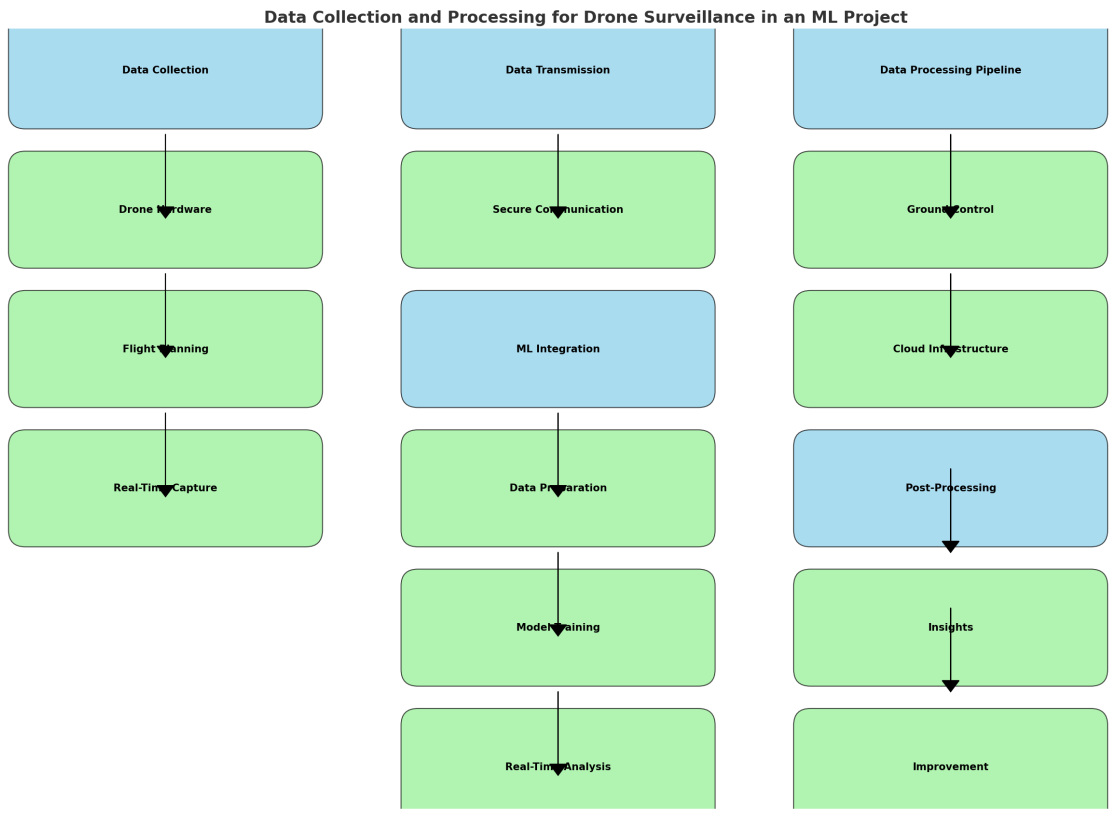
The diagram illustrates the system architecture for a drone surveillance ML project:

1. **Drone Platform:** Captures data through onboard sensors.
2. **Data Acquisition & Transmission:** Transfers collected data to the Ground Control Station.
3. **Ground Control Station:** Manages drone operations and initial data processing.
4. **Cloud Infrastructure:** Receives data from the Ground Control Station for storage and further processing.
5. **ML Models Deployment:** Applies machine learning algorithms to analyze the data.
6. **Data Security & Compliance:** Ensures data privacy and regulatory compliance.

7. **User Interface:** Displays processed information to users, allowing interaction and decision-making.

   This architecture ensures efficient data collection, processing, and analysis, enhancing surveillance capabilities while maintaining security and compliance.

Data Collection and Processing



The diagram illustrates the data collection and processing workflow for a drone surveillance ML project:

1. **Data Collection:**
   - **Drone Hardware:** Equipped for data collection.
   - **Flight Planning:** Prepares routes and tasks.
   - **Real-Time Capture:** Gathers data during flights.

2. **Data Transmission:**
   - **Secure Communication:** Ensures safe data transfer.
   - **ML Integration:** Prepares data for ML processing.
   - **Data Preparation:** Cleans and organizes data for analysis.

3. **Data Processing Pipeline:**
    - **Ground Control:** Manages initial data processing.
    - **Cloud Infrastructure:** Stores and processes large data volumes.
    - **Post-Processing:** Applies ML models for analysis.
    - **Insights:** Extracts actionable information.
    - **Improvement:** Refines models and processes for better accuracy.

This workflow ensures efficient and secure data handling, enabling accurate real-time analysis and continuous improvement in drone surveillance operations.

Case Studies

1. Object Detection from the Video Taken by Drone via Convolutional Neural Networks.

Objective:

This paper aims to implement and evaluate object detection on drone videos using the TensorFlow object detection API. The study compares the performance of different target detection algorithms, specifically SSD and Faster R-CNN, with various feature extractors like MobileNet, GoogleNet/Inception, and ResNet50, to recognize objects such as people, trees, cars, and buildings from real-world video frames taken by drones.

Positive Aspects:

1. **High Detection Accuracy:** The models achieved high detection accuracy for buildings, trees, cars, and people, with an average accuracy of over 85% and a maximum of 99%.
2. **Use of Transfer Learning:** The application of transfer learning significantly improved the efficiency of training models on smaller datasets, reducing computational expenses.
3. **Comparative Analysis:** The study provides a detailed comparison of SSD and Faster R-CNN, highlighting their strengths in terms of speed and accuracy.
4. **Real-World Application:** The research demonstrates practical applications of drone-based object detection in urban management and real-time monitoring.

Negative Aspects:

1. **Performance Trade-offs:** While SSD is faster, it has lower detection accuracy than Faster R-CNN, which is more accurate but slower.
2. **Resource Intensive:** The models, especially Faster R-CNN with ResNet50, require substantial computational resources and memory, making deploying resource-constrained devices challenging.

3. **Fixed Camera Angle Limitation:** The fixed camera angle on drones can affect detection accuracy, as it may not match the angles in the training data.

Results

The study found that:

- **SSD models** are faster, with an average frame processing time of 115ms, but have lower detection rates.
- **Faster R-CNN models** are more accurate, detecting nearly 95% of objects in the images, but are slower, with an average frame processing time of at least 140ms.
- **Memory Usage:** MobileNet requires the least memory (<1GB), while ResNet50 requires the most (~5GB) when used with Faster R-CNN.
- **Image Size Effect:** Higher image resolutions improve detection accuracy but increase processing time.

2. A review on object detection in unmanned aerial vehicle surveillance

Objective:

The paper's primary objective is to review the state-of-the-art methods and applications of object detection in unmanned aerial vehicle (UAV) surveillance, with a particular focus on deep learning techniques. It aims to identify research gaps and propose a secure onboard processing system for robust object detection in precision agriculture.

Positive Aspects:

1. **Comprehensive Review**: The paper thoroughly reviews existing research on object detection using UAVs, categorizing methods and applications effectively.
2. **Deep Learning Focus**: Highlights the superiority of deep learning algorithms over traditional image processing methods for object detection in drone images, offering insights into their application across various domains.

3. **Proposed Framework**: Introduces a secure onboard processing framework using blockchain-based encryption, addressing significant security concerns in UAV applications.
4. **Future Work Directions**: Identifies key research gaps and suggests areas for future research, particularly in developing efficient deep learning algorithms for onboard processing and improving security measures.

Negative Aspects:

1. **Limited Practical Implementation**: While the paper proposes a robust framework, it lacks practical implementation and experimental validation, which are crucial for assessing its effectiveness.
2. **Challenges with Real-Time Applications**: Acknowledges the difficulties in applying object detection algorithms in real-time due to UAVs' limitations in power, size, and processing capabilities but offers limited solutions to these challenges.
3. **Security Risks**: Although security is a major focus, the proposed solutions need detailed testing to ensure they can effectively mitigate cyber-attacks in real-world scenarios.

Results:

The paper concludes that deep learning methods outperform traditional image processing techniques in object detection tasks for UAVs. It emphasizes the need for more efficient and secure deep learning architectures to handle the unique challenges posed by UAV surveillance, such as viewpoint variations, small object detection, and real-time processing requirements. The proposed secure onboard processing framework aims to enhance the robustness and security of UAV operations in precision agriculture, but its practical application is reserved for future work.

3. VisDrone-DET2018: The Vision Meets Drone Object Detection in Image Challenge Results

Objective

The primary objective of the VisDrone-DET2018 paper is to establish a community-based common platform for discussion and evaluation of detection performance on drones. This includes releasing a large-scale object detection dataset and organizing a challenge to benchmark and track progress in object detection on drone platforms.

Positive Aspects:

1. **Large-scale Dataset:** The paper introduces a comprehensive dataset with rich annotations, enhancing research opportunities and algorithm development.
2. **Community Engagement:** The paper fosters a collaborative environment for researchers to share and compare their methodologies by organizing a challenge.
3. **Performance Benchmarking:** It provides a structured framework for evaluating object detection algorithms, which helps in identifying the strengths and weaknesses of various approaches.
4. **Focus on Real-world Scenarios:** The dataset and challenge are designed to reflect real-world conditions, making the research more applicable and practical.

Negative Aspects:

1. **Class Imbalance:** The dataset suffers from class imbalance, where certain categories like awning-tricycle, tricycle, and bus have significantly fewer instances compared to cars and pedestrians, which affects detection performance for these underrepresented classes.
2. **Scalability Issues:** Handling the large-scale variations in object sizes within the dataset poses a significant challenge for detection algorithms.
3. **Real-world Application Gap:** Despite the dataset's comprehensiveness, the highest achieving detectors still perform below satisfactory levels for real-world applications.

Results:

The challenge evaluated 38 detectors on the released dataset. The top three detectors were HAL-Retina-Net, DPNet, and DE-FPN, achieving 31.8%, 30.92%, and 27.10% average precision (AP), respectively. However, the best detector's performance is still considered inadequate for real-world applications, indicating significant room for improvement in drone-based object detection.

Benefits, Challenges and Solutions

Benefits:

1. **Enhanced Monitoring:**
    - **Benefit:** Drones cover large areas quickly, providing real-time data.
    - **ML Role:** Detect and accurately track targets (vehicles, people).

2. **Improved Situational Awareness:**
    - **Benefit:** Drones offer a comprehensive bird's-eye view.
    - **ML Role:** Interpret complex environments, aiding decision-making.

3. **Resource Efficiency:**
    - **Benefit:** Reduces the need for ground patrols and human monitoring.
    - **ML Role:** Autonomous navigation and real-time processing optimize resource use.

4. **Proactive Crime Prevention:**
    - **Benefit:** Early detection prevents crimes.
    - **ML Role:** Identify suspicious behaviours or patterns to alert authorities.

Challenges and Solutions:

1. **Data Privacy and Security:**
    - **Challenge:** Privacy concerns with data collection.
    - **Solution:** Use blurring techniques and encrypt data.

2. **Real-Time Processing:**
    - **Challenge:** High computational requirements.
    - **Solution:** Use edge computing and efficient ML algorithms.

3. **Environmental Variability:**
    - **Challenge:** Diverse conditions affect data quality.
    - **Solution:** Train models on diverse datasets.

4. **Scalability and Maintenance:**
    - **Challenge:** Managing drone fleets is complex.
    - **Solution:** Centralized control systems with automated diagnostics.

5. **Regulatory Issues:**
    - **Challenge:** Legal restrictions on drone use.
    - **Solution:** Develop compliant protocols with regulatory bodies.

By addressing these challenges with advanced ML techniques, hybrid processing, robust training data, and transparent policies, drone surveillance can enhance public safety effectively.

Conclusions:

1. **Enhanced Efficiency and Coverage:**
    - Drones improve surveillance efficiency and coverage, offering real-time monitoring over large areas, surpassing traditional ground patrols.
2. **Improved Situational Awareness:**
    - Providing a bird's-eye view, drones enhance situational awareness, aiding better-informed decisions during operations.
3. **Proactive Crime Prevention:**
    - Machine learning algorithms enable drones to detect anomalies and alert authorities to suspicious activities, preventing crimes.
4. **Resource Optimization:**
    - Autonomous navigation and real-time processing reduce human intervention, optimizing resource allocation and cutting costs.
5. **Technological and Ethical Challenges:**
    - Addressing data privacy, real-time processing, scalability, maintenance, and regulatory compliance is crucial for successful deployment.
6. **Advanced Applications:**
    - Advanced machine learning models can enhance drone object detection, tracking, and scene understanding capabilities.
7. **Robust Frameworks:**
    - Developing frameworks for data security, ethical use, and legal compliance is essential to gain public trust and ensure responsible use.

Addressing these challenges and leveraging benefits, drone surveillance can enhance public safety and security in law enforcement.

Dataset

Cars and Vehicles from Low Quality Drone

Low-quality vehicle object detection, as seen by a drone flying around the area. Vehicles include:

- Private cars
- Pickup trucks
- Tractors
- Tanks

Reference

Dataset: Cars and Vehicles from Low-Quality Drone

Papers:

- Ramachandran, A., & Sangaiah, A. K. (2021). **A review on object detection in unmanned aerial vehicle surveillance.** *International Journal of Cognitive Computing in Engineering, 2*, 215-228. https://doi.org/10.1016/j.ijcce.2021.11.005

- Sun, C., Zhan, W., She, J., & Zhang, Y. (2020). **Object detection from the video taken by drone via convolutional neural networks.** Mathematical Problems in Engineering. https://doi.org/10.1155/2020/4013647

- Zhu, P., Wen, L., Du, D., Bian, X., Ling, H., Hu, Q., ... & Song, Z. (2018). **VisDrone-DET2018: The Vision Meets Drone Object Detection in Image Challenge Results.** In Proceedings of the European Conference on Computer Vision (ECCV) Workshops. https://openaccess.thecvf.com/content_eccv_2018_workshops/w27/html/Zhu_VisDrone-DET2018_The_Vision_Meets_Drone_Object_Detection_in_Image_Challenge_ECCVW_2018_paper.html