ACOUSTIC-BASED DRONE DETECTION: IDENTIFYING UAVS THROUGH SOUND SIGNATURES

Capstone Project Proposal

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TABLE OF CONTENTS

Mentor Consent Form

I hereby agree to be the mentor of the following Capstone Project Team

Project Title: Acoustic-Based Drone Detection: Identifying UAVs Through Sound Signatures		
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Problem Statement

The rapid advancement of drone technology has introduced both opportunities and challenges across various sectors. While UAVs are widely used for commercial, industrial, and recreational purposes, their misuse has raised serious security concerns. Traditional drone detection systems, such as radar, optical tracking, and RF signal analysis, often struggle in real-world scenarios. Small drones can evade radar due to their low cross-section, while optical systems depend on clear visibility, making them ineffective in adverse weather conditions. Moreover, RF-based detection is rendered useless against autonomous UAVs that operate without active communication signals.

Adding to these limitations, the high cost of deployment and maintenance makes conventional detection methods impractical for large-scale use. Many organizations, including airports, military bases, and critical infrastructure sites, seek a reliable and cost-effective solution for drone monitoring. This project proposes an acoustic-based detection system that leverages sound signatures to identify drones, offering a passive, affordable, and efficient alternative to existing methods. By combining advanced signal processing with machine learning, the system aims to provide accurate and real-time drone detection in diverse environmental conditions.

Project Overview

This capstone project is aimed at developing an innovative system for detecting unmanned aerial vehicles (UAVs), commonly known as drones, through the analysis of their unique sound signatures. As drones continue to be utilized across various sectors, including commercial, recreational, and security applications, the need for effective monitoring solutions has increased. In this project, sound recording devices and acoustic sensors, primarily microphones, will be utilized to capture drone noises. Subsequently, advanced signal processing techniques and machine learning algorithms will be employed to distinguish drone sounds from background noise. Through this approach, accurate drone identification in diverse environments will be enabled, thereby contributing to enhanced security and airspace management.

Additionally, methods for estimating the distance and direction of detected drones will be incorporated using sound intensity analysis and time-delay localization techniques. This capability will allow critical information regarding drone activity to be provided, facilitating timely responses to potential threats or unauthorized operations. By focusing on a non-intrusive detection method, a practical solution suitable for deployment in various settings, such as urban areas, event venues, and sensitive locations like airports or military installations, will be offered.

Ultimately, a comprehensive acoustic-based drone detection system is intended to be developed, enhancing situational awareness and improving airspace management. The successful implementation of this technology is expected to significantly impact the monitoring and regulation of drone activities in real-world scenarios.

Need Analysis

The escalating use of drones has introduced significant concerns pertaining to security, privacy, and safety across various environments. Traditional drone detection methodologies, including radio frequency (RF) analysis, optical sensors, and radar systems, often encounter limitations related to cost, effectiveness in cluttered environments, and dependency on visual or RF conditions. For example, while RF-based detection is low-cost and doesn't require a license, it can fail for autonomous drones and is less effective in areas with crowded RF signals. Optical sensors, though offering a high price-quality ratio and the ability to record visual evidence, are prone to high false alarm rates and are affected by weather conditions, sometimes confusing drones with birds. Radar systems provide accurate localization independent of visual conditions but can be limited by drone size and difficulty in distinguishing between drones and birds.

Acoustic-based drone detection presents itself as a promising alternative, capitalizing on the unique sound signatures emitted by drones. The analysis of these sound signatures allows for the detection and identification of drones without the need for visual contact, reliance on RF signals, or expensive equipment. Acoustic sensors are portable, low cost, independent of drone size, detect autonomous drones, are independent of light intensity and weather, and are completely passive. This approach holds particular relevance in urban settings where visual surveillance may be hindered by buildings or foliage. Moreover, acoustic detection systems can be deployed covertly, allowing for discreet monitoring of drone activity. However, it's important to acknowledge that acoustic sensors have a short-range and sensitivity to environmental noise.

The relevance of this project transcends mere detection, addressing a growing societal need for effective airspace management solutions. As drones become more integrated into everyday life—utilized for deliveries, aerial photography, and recreational purposes—the ability to monitor their activity becomes crucial for ensuring public safety and compliance with regulations. Consequently, the proposed acoustic-based drone detection system is not only timely but essential for addressing the challenges presented by the evolving landscape of UAV usage.

Literature Survey

Research on acoustic-based drone detection has proven effective in identifying drones that evade traditional radar and RF-based detection methods. The paper "Acoustic Based Drone Detection Via Machine Learning" proposes a cost-effective and reliable system that leverages machine learning to recognize drones based on their unique acoustic signatures. The study utilizes a dataset comprising drone sounds from GitHub and environmental noise from the BBC sound database and YouTube. By extracting 26 Mel Frequency Cepstral Coefficients (MFCCs) as features, the system employs Random Forest and Multilayer Perceptron (MLP) classifiers, achieving a high F-score of 0.92 on training data. The findings demonstrate that acoustic-based detection is a viable approach for drone monitoring, making it suitable for deployment in diverse real-world environments.[1]

Another research on sound-based drone detection has demonstrated its potential as an effective, low-cost alternative to traditional detection methods. The paper "An Automated Accurate Sound-Based Amateur Drone Detection Method Based on Skinny Pattern" introduces a novel classification approach using a combination of the skinny pattern and iterative neighborhood component analysis (INCA). The study employs tunable Q-factor wavelet transform (TQWT) for multilevel feature extraction and applies 16 machine learning classifiers, achieving a remarkable accuracy of 99.72% using the Fine kNN classifier. By leveraging acoustic data from diverse environmental conditions, this model enhances detection reliability, making it a promising solution for real-world drone monitoring and smart city security applications.[2]

In another study, "Audio Features-Based ADS-CNN Method for Flight Attitude Recognition of Quadrotor UAV," the authors propose a lightweight convolutional neural network (ADS-CNN) for identifying drone flight attitudes based on acoustic signals. The model integrates depthwise separable convolution and an attention mechanism to improve efficiency and accuracy. Using a self-recorded UAV Attitude Audio (UAVAA) dataset, the system extracts Mel-Frequency Cepstral Coefficients (MFCC) and Short-Time Fourier Transform (STFT) features to enhance classification performance. The proposed approach achieves a high accuracy of 98.81%, surpassing conventional models like VGG16 while maintaining a significantly lower computational cost. These findings highlight the potential of audio-based methods for UAV recognition and tracking in various operational environments.[3]

The study *"Acoustic-Based Drone Detection Using Neural Networks – A Comprehensive Analysis"* explores the effectiveness of using acoustic signals for detecting drones in urban environments. The authors employ a neural network model to analyze spectrograms of drone sounds recorded in both anechoic chambers and outdoor settings. The study highlights the advantages of microphone arrays for improved detection accuracy and localization through beamforming techniques. Experimental results show a high detection probability of 99.5% for drones within 600 meters. By leveraging deep learning for sound classification, the research demonstrates the viability of acoustic-based drone detection as a reliable method, even in noisy environments.[5]

The study *"Machine Learning Inspired Efficient Audio Drone Detection Using Acoustic Features"* presents an advanced method for drone detection based on their unique acoustic signatures. The authors analyze five different audio features, including Mel-Frequency Cepstral Coefficients (MFCC), Gammatone Cepstral Coefficients (GTCC), Linear Prediction Coefficients (LPC), spectral roll-off, and zero-crossing rate, to determine the most effective descriptor for drone identification. Using various support vector machine (SVM) classifiers, the study finds that the Medium Gaussian SVM trained on all features achieves a classification accuracy of 99.9%, with 99.8% recall and 100% precision. These results highlight the effectiveness of acoustic-based methods for real-time drone detection in diverse environments.[6]

Another study, *"Machine Learning Algorithms Applied for Drone Detection and Classification: Benefits and Challenges,"* provides a detailed review of ML-based drone detection methods using various sensing modalities such as radar, acoustic, visual, and radio-frequency (RF) systems. The research explores the strengths and limitations of these technologies, highlighting that while radar offers long-range detection, it struggles with low-speed UAVs, and acoustic methods, though cost-effective, are limited in range. The study examines supervised and unsupervised ML approaches for drone classification, addressing challenges like dataset availability, environmental noise, and real-time processing efficiency. By critically evaluating existing ML applications, this study contributes to improving UAV classification and threat mitigation strategies, guiding future research in enhancing detection accuracy and system adaptability.[4]

Another study, *"Aerial Vehicle Detection and Classification Through Fusion of Multi-Domain Features of Acoustic Signals,"* introduces a novel machine learning-based approach for detecting and classifying aerial vehicles using acoustic signals. The researchers extract cepstral, spectral, and time-domain features from publicly available drone sound datasets and evaluate multiple classifiers. Their experiments achieve 98.6% accuracy for a binary classification task (Drone vs. No-Drone) and 98.3% accuracy for a multi-class classification task, distinguishing between background noise, drones, helicopters, and different drone types. The study highlights the effectiveness of the Ensemble Bagged Trees classifier, which outperforms other models. By leveraging multi-domain feature fusion, this research demonstrates the potential of acoustic-based detection in enhancing UAV monitoring and security applications.[8]

In another study, "Drone Detection and Tracking System Based on Fused Acoustical and Optical Approaches," the authors propose a hybrid detection method that combines acoustic and optical data to improve drone monitoring accuracy. The system integrates microphone arrays for sound-based detection and optical sensors for visual tracking, enhancing robustness in diverse environmental conditions. By leveraging machine learning algorithms, the study demonstrates improved detection performance, especially in low-visibility scenarios where conventional optical methods struggle. The fusion of acoustical and optical data results in higher reliability, making this approach suitable for security-sensitive applications such as airport surveillance and border monitoring.[7]

Objectives

The following objectives have been established for this capstone project:

1. To develop an acoustic-based system capable of accurately detecting and identifying UAVs through sound signature analysis.
2. To implement advanced signal processing techniques and machine learning algorithms that differentiate drone sounds from background noise effectively.
3. To estimate the direction of detected drones using sound intensity analysis and time-delay localization techniques.
4. To estimate the distance of detected drones using sound intensity analysis and time-delay localization techniques.
5. To evaluate the performance of the developed system across different environments to assess its effectiveness in real-world applications.

Methodology

Phase	Timeline	Activities
Research & Planning	February	- Conduct literature survey on acoustic drone detection methods. - Identify suitable hardware (microphones, sensors). - Define project scope and technical requirements.
Data Collection	March	- Set up hardware for drone sound recording. - Collect drone audio samples in various environments. - Preprocess data to remove noise and irrelevant signals.
Data Preprocessing & Feature Extraction	April	- Extract spectral, cepstral, and time-domain features. - Implement signal processing techniques (FFT, MFCC). - Normalize and augment dataset for model training.
Machine Learning Model Development	June	- Train and evaluate ML models for drone sound classification. - Compare performance of classifiers (CNN, SVM, Ensemble methods). - Optimize hyperparameters for better accuracy.

Phase	Timeline	Activities
Model Refinement & Optimization	July	- Fine-tune ML models for real-time drone detection. - Implement noise reduction and adaptive filtering techniques. - Improve model efficiency for deployment on edge devices.
Implementation of Distance & Direction Estimation	August	- Apply time-delay localization techniques. - Use sound intensity for distance estimation. - Validate estimation methods using test cases.
Model Evaluation & Testing	September	- Test model performance on real-world audio samples. - Assess detection accuracy in different environments. - Improve false positive and false negative rates.
System Integration & UI Development	October	- Develop a real-time processing interface for detection. - Integrate ML model with frontend visualization. - Ensure smooth user interaction and system response.
Performance Testing in Real-Time Environment	November	- Deploy system in real-world conditions. - Evaluate efficiency in detecting unauthorized drones. - Gather feedback for future improvements.

Work Plan

Sr. No.	Activity	Month	February		March				April				May				June				July				August				September				October				November			
		Week No.	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Researching Hardware / Planning	Plan																																								
		Actual																																								
2	Testing Hardware / Data Collection	Plan																																								
		Actual																																								
3	Data Preprocessing & Feature Extraction	Plan																																								
		Actual																																								
4	Machine Learning Model Development	Plan																																								
		Actual																																								
5	Implementation of distance & direction estimation techniques	Plan																																								
		Actual																																								
6	Model Evaluation / Testing	Plan																																								
		Actual																																								
7	System Integration / UI Development	Plan																																								
		Actual																																								
8	Performance Testing in Real Time Enviornment	Plan																																								
		Actual																																								

Project Outcomes & Individual Roles

Final Deliverables:

1. **Accurate Drone Detection:** The system effectively identifies drone sounds amidst background noise using advanced signal processing and machine learning techniques.
2. **Real-Time Monitoring & Alerts:** Continuous tracking enables instant notifications for unauthorized drone activity, enhancing situational awareness and response.
3. **Distance & Direction Estimation:** Time-delay localization and sound intensity analysis allow precise determination of drone position, aiding in effective monitoring.
4. **User-Friendly Interface:** A dashboard provides real-time detection logs, location tracking, and visualization, ensuring ease of use for operators.
5. **Reliable in Various Environments:** The system is tested in diverse settings, including urban, suburban, and restricted airspaces, with adaptive noise filtering for accuracy.
6. **Enhanced Security & Airspace Management:** By strengthening drone regulation and integrating with existing monitoring systems, the project contributes to improved airspace security and control.

Individual Team Member Roles:

- **Miet Pamecha:** Handles feature extraction, noise reduction, model training, and optimization for accurate drone classification.
- **Gautam Dhawan:** Develops distance and direction estimation algorithms using sound localization and refines ML models for accuracy.
- **Iipsita Devgan:** Develops backend logic, manages databases, and ensures smooth system communication.

- **Tamanna Bajaj:** Integrates ML models with the UI, manages cloud deployment, automates CI/CD pipelines and builds the frontend dashboard for visualization.
- **Devansh Dhir:** Develops ML models for drone sound detection, integrates IoT-based acoustic sensors, and ensures real-time data acquisition and processing.

Course Subjects

1. **Machine Learning (UML501)** – Understanding ML/DL techniques for sound classification, model training, and optimization.
2. **Artificial Intelligence (UCS521)** – Applying AI-based techniques for sound recognition and drone identification.
3. **Data Science (UCS548, UCS654, UCS672 - Elective)** – Handling large acoustic datasets, data cleaning, and preprocessing.
4. **Software Engineering (UCS503)** – Systematic design, development, testing, and maintenance of the drone detection software.
5. **Computer Networks (UCS520)** – Ensuring real-time data transmission and integration with cloud-based monitoring.
6. **Database Management Systems (UCS310)** – Storing and managing collected audio data efficiently.
7. **Data Structures (UCS301)** – Optimizing data processing and feature extraction algorithms.
8. **Design and Analysis of Algorithms (UCS415)** – Developing efficient detection algorithms for drone sounds.
9. **Full-Stack Development (Elective: UCS661, UCS662)** – Developing the front-end and back-end of the drone detection system dashboard.
10. **DevOps and Continuous Delivery (Elective: UCS537, UCS659, UCS660)** – Deploying and maintaining the system in a scalable manner.

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