Strategic Drone Mission Deconfliction System

1. Introduction

This project focuses on designing and implementing a strategic deconfliction system to ensure the safety of drone waypoint missions in a shared airspace environment. The system acts as the final authority to verify whether a drone's planned mission is free from spatial and temporal conflicts with multiple other drones' simulated flight paths.

The primary drone mission consists of a series of waypoints to be completed within an overall time window. The system evaluates potential conflicts in both space and time dimensions before mission execution.

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2. System Overview

The deconfliction system receives as input the planned waypoint trajectories of multiple drones, including the primary mission under evaluation. It simulates drone positions over time and applies spatial and temporal checks to detect possible collisions or unsafe proximities.

The output is a conflict detection report indicating whether the mission is safe to execute or specifying the times and locations of detected conflicts.

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3. Design Decisions and Architecture

3.1. Modular Python Implementation

- The system is implemented in Python for rapid development and ease of integration.
- Code is modularized into components: mission loading, conflict checking, and visualization.
- Clear interfaces separate the loading of drone trajectories, conflict logic, and output generation.

3.2. Data Structures

- Drone trajectories are represented as ordered lists or arrays of 3D coordinates with associated timestamps.

- Conflict reports use structured dictionaries or objects for readability and extensibility.

3.3. Conflict Checking Pipeline

- Input trajectories are interpolated or sampled uniformly over the mission time window.
- For each timestep, pairwise distance calculations determine spatial proximity.
- Temporal overlap is evaluated by matching timestamps to ensure conflicts only count if drones are near each other in space *and* time.

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4. Spatial and Temporal Checks Implementation

4.1. Spatial Check

- Euclidean distance between drone positions at each timestep is computed.
- A conflict is flagged if the distance falls below a defined safety threshold (e.g., 2 meters).

4.2. Temporal Check

- Conflict checks are performed at synchronized timestamps or interpolated points.
- Only pairs of drone positions at the same or near time intervals are compared.

4.3. Combined Conflict Logic

- Both spatial and temporal proximity conditions must be met to declare a conflict.
- Conflicts are logged with details: time, 3D location, involved drones, and exact distance.

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5. AI Integration (Optional)

- Currently, the system uses deterministic geometric checks.
- AI/ML models could be integrated for predictive conflict resolution or adaptive thresholding based on environment or drone dynamics.
- Future work could explore reinforcement learning to optimize conflict avoidance manoeuvres dynamically.

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6. Testing Strategy and Edge Cases

6.1. Testing Strategy

- Unit tests validate individual modules (e.g., distance calculations, interpolation).
- Integration tests simulate multiple drone missions with known conflict scenarios.
- Visualization confirms the spatial correctness of trajectories and conflict points.

6.2. Edge Cases

- Missions with overlapping waypoints but differing time windows.
- Drones moving at drastically different speeds or with pauses.
- Cases with dense traffic and multiple simultaneous conflicts.
- Boundary conditions at the start or end of mission time windows.

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7. Scaling the System

7.1. Challenges

- Real-world applications require handling thousands of drones simultaneously.
- Computational complexity grows with the number of drones and time resolution.

7.2. Potential Solutions

- Spatial partitioning (e.g., 3D grids, k-d trees) to limit pairwise checks to nearby drones.
- Temporal bucketing to reduce unnecessary comparisons.
- Parallel and distributed computation frameworks to process large datasets in real-time.
- Integration with real-world telemetry data streams and secure communication protocols.

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8. Conclusion

This project demonstrates a modular, well-documented system for verifying drone mission safety in shared airspace through spatial-temporal conflict detection. The foundation allows future expansion into AI integration and scaling for practical deployment with thousands of drones.