Advancing Aerial Swarms: Intelligent Task Allocation, Trajectory Planning, and Hardware Optimization

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The Core Challenge

3D Dynamic Environments

Complex airspace with moving obstacles and changing conditions

Limited Bandwidth

Communication constraints restrict data exchange between agents

Energy-Constrained

Battery limits drive efficiency requirements for extended missions

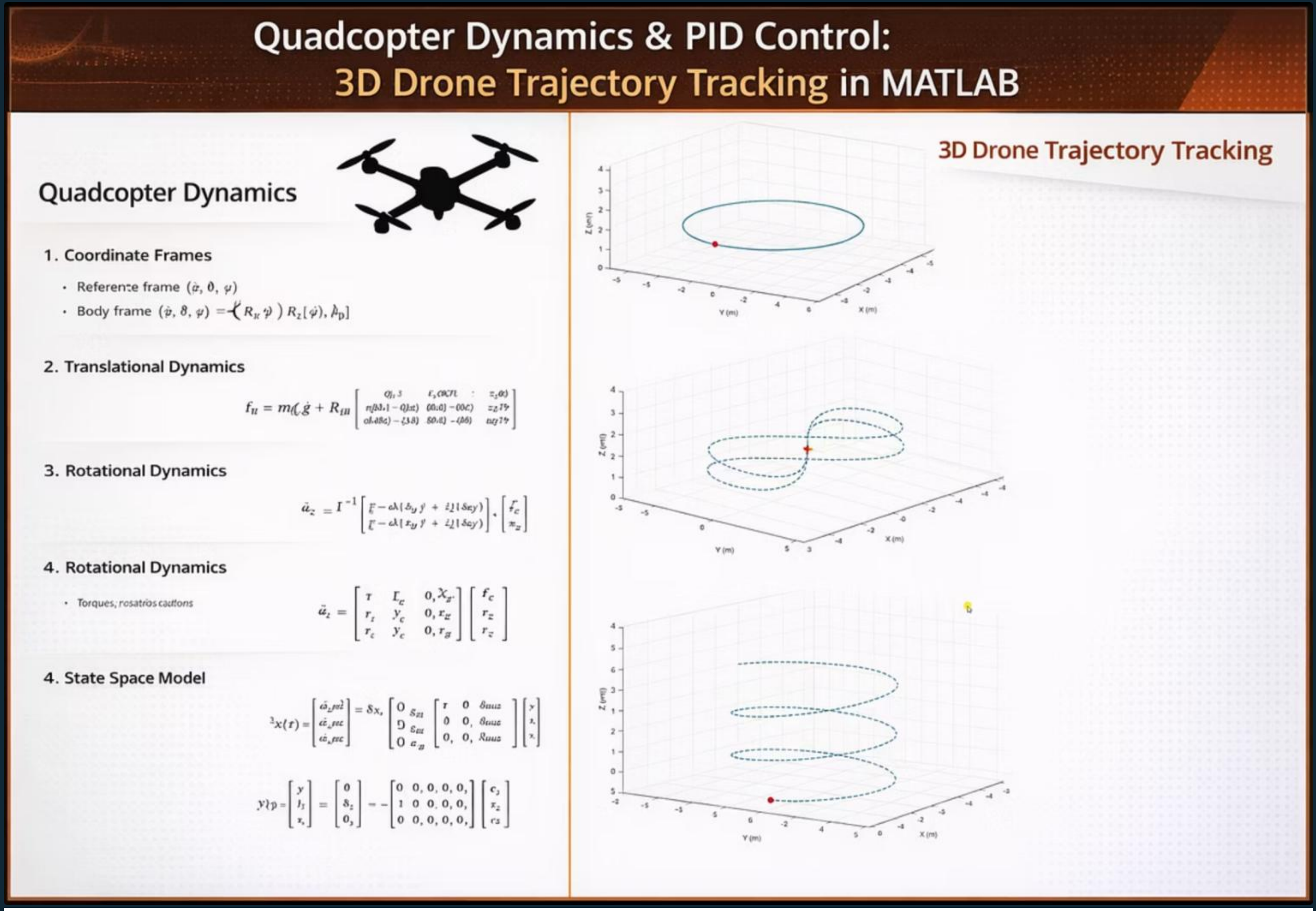
Coordination complexity grows exponentially with swarm size, demanding decentralized intelligence.

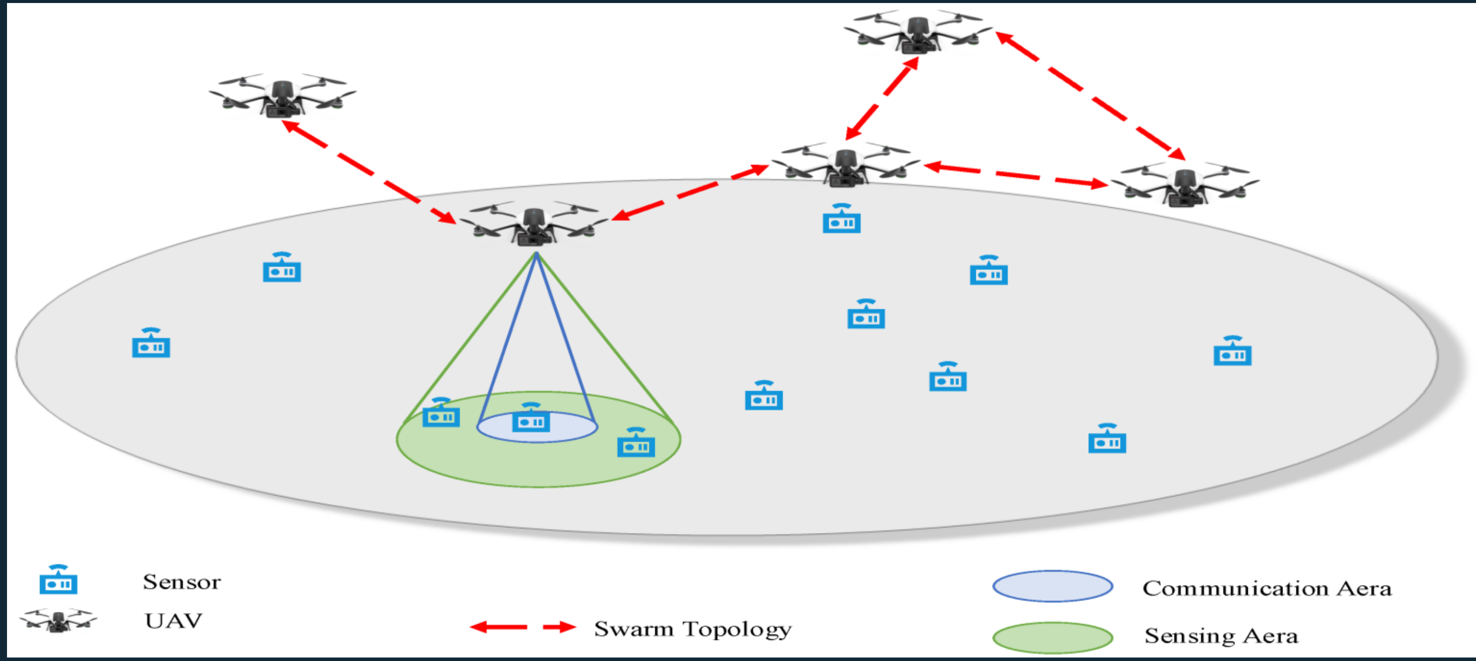
Intelligent Task Allocation

Decentralized Intelligence

Bio-inspired frameworks combining market-based auction algorithms with reinforcement learning enable local decision-making without central control.

- Multi-Objective Constrained Policy Optimization (MOCPO)
- Coordination fields guided by LLM interpretation
- Dynamic workload balancing
- Distributed consensus mechanisms for robust state estimation
- Local sensing and communication to enable swarm self-organization
- Adaptive learning for emergent behavior in dynamic environments





Optimized Trajectory Planning

1

Collision Avoidance

Potential fields and optimization-based planning for dense formations

2

Real-Time Updates

PE-PSO with B-spline curves enables smooth path generation

3

Formation Control

Dubins trajectories respecting kinematic constraints

Hardware-Algorithm Co-Design

Battery Limits

Energy density and power management trade-offs for extended flight

Weight vs Capability

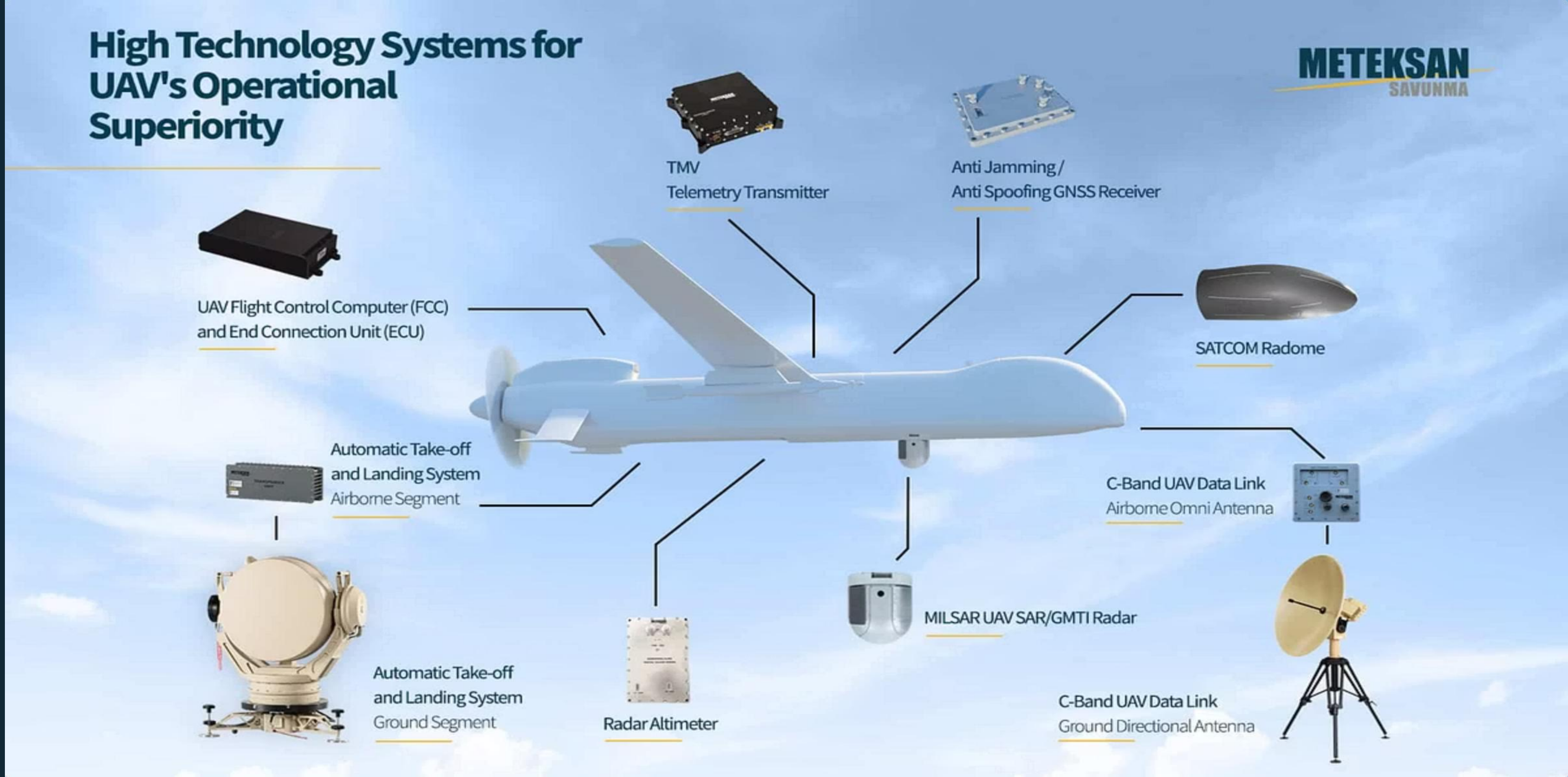
Miniaturization challenges balancing sensors, processors, and payload

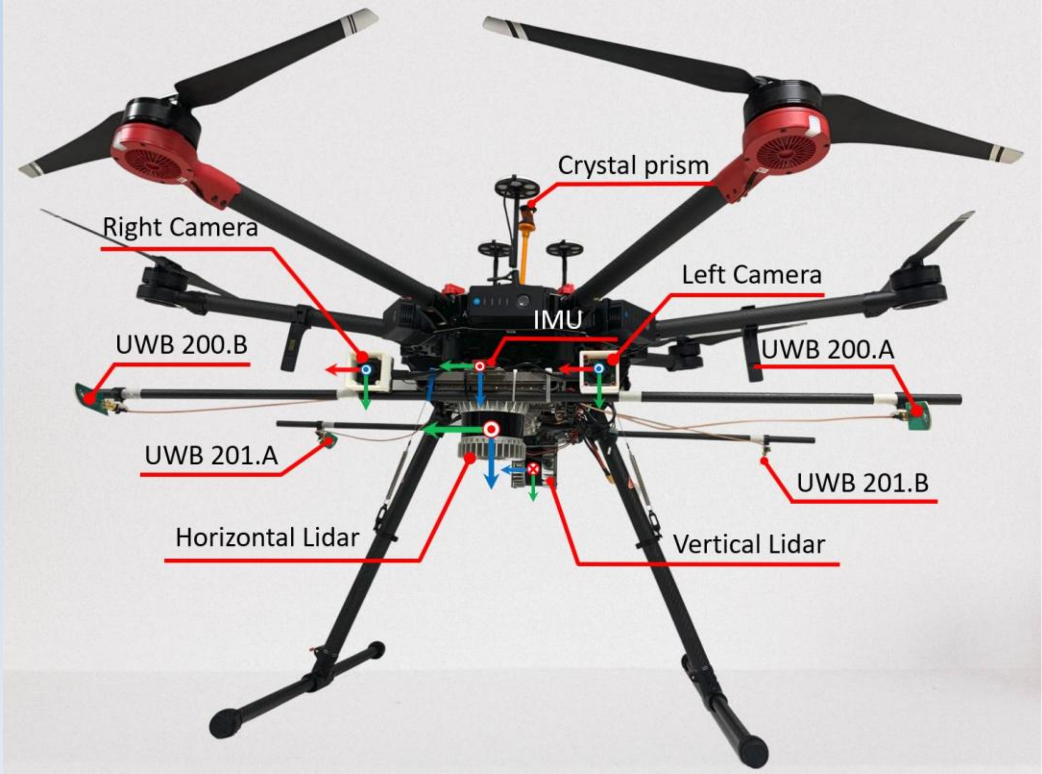
Communication Modules

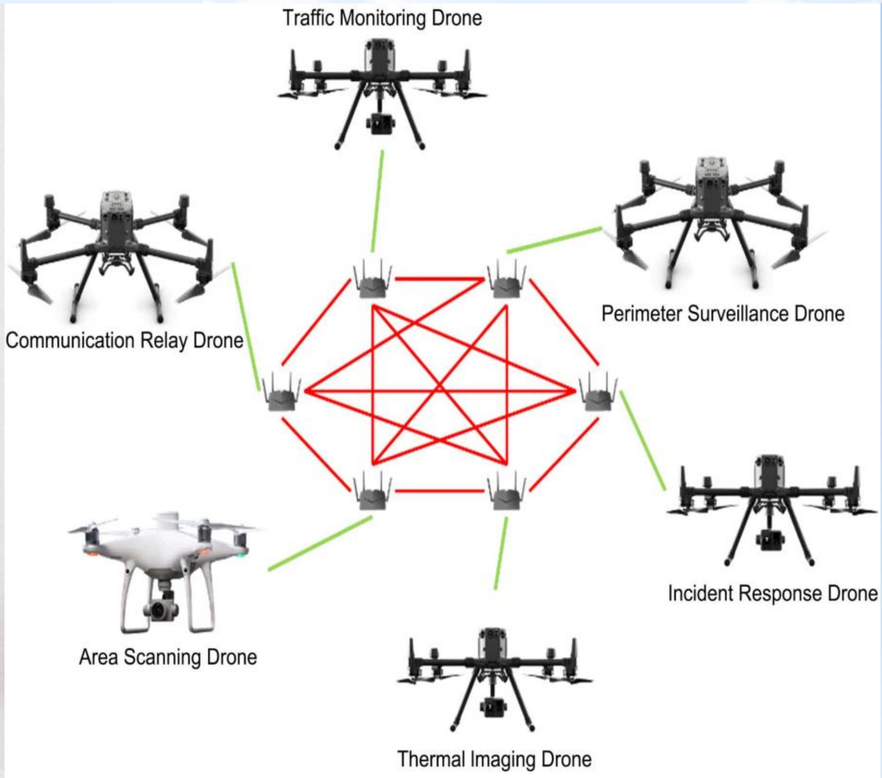
Wi-Fi, RF, and mesh networking for robust swarm coordination

Edge Computing

Onboard processing reduces latency and bandwidth requirements







Swarm Intelligence Stack

Task Allocation

Distribute goals and assign swarm roles.

Trajectory Planning

Compute paths and collision-free maneuvers.

Hardware Execution

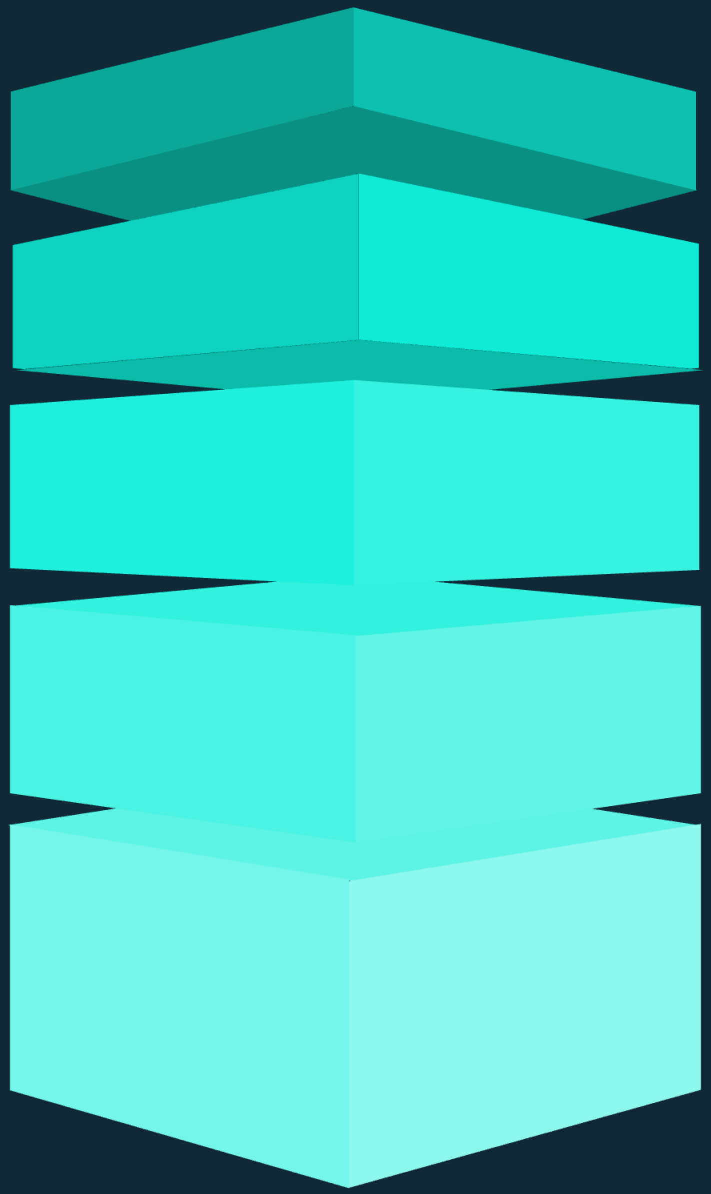
Drive actuators and sensors to follow plans.

Communication Layer

Span all levels for shared state and commands.

Adaptive Feedback

Closed-loop updates for real-time coordination.

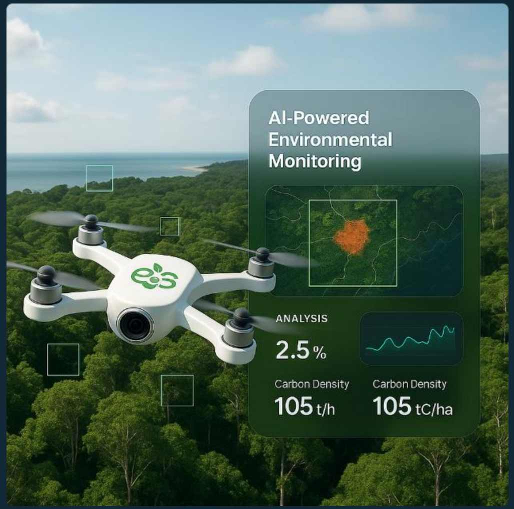


Integrated framework with critical communication layer and adaptive feedback loops enables real-time coordination.

What This Advances

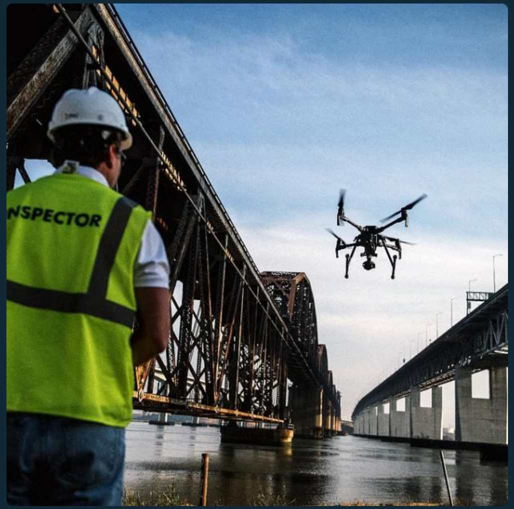
Search & Rescue

Heterogeneous UAV swarms reduce response times by 23.7% with temporal task chains



Environmental Monitoring

Dynamic task allocation enables superior coverage and adaptability in diverse terrains



Infrastructure Inspection

Sequential task planning with Dubins trajectories optimizes path efficiency

Real-World Impact

Coordinated Operations

Military strike missions achieve effective task allocation with communication coordination.

Urban Surveillance

Coordination fields enable adaptive task coverage in complex environments.

Key Takeaways

01

Integrated Framework

Simultaneous task allocation and trajectory planning (SAPP) achieves optimal performance

02

AI-Powered Coordination

Reinforcement learning and LLMs enable adaptive, decentralized decision-making

03

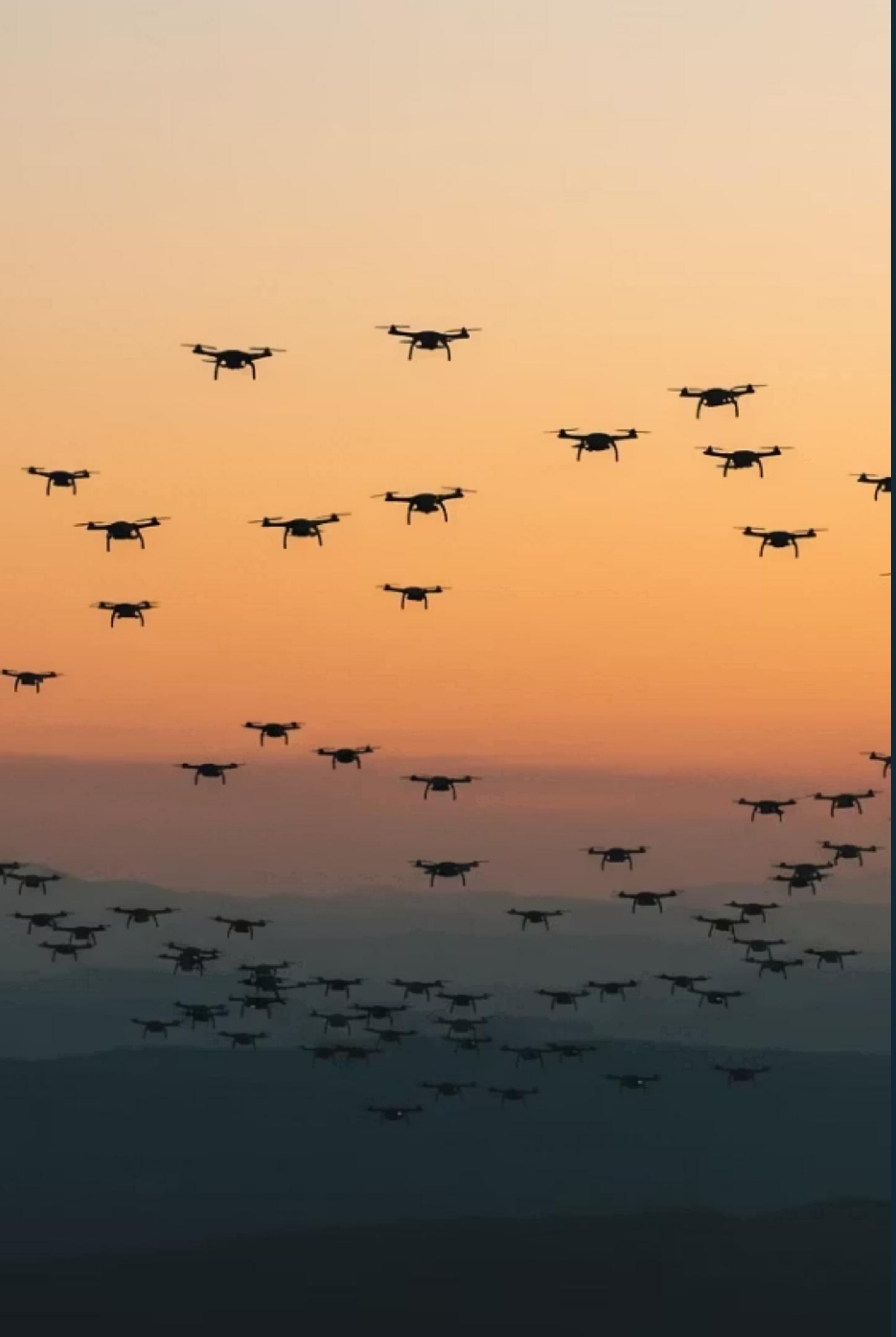
Hardware Foundation

Modular, scalable platforms with edge computing unlock swarm capabilities

04

IEEE Alignment

Contributions inform robotics and AI standardization through IEEE P1872.3 and P1955



Towards Autonomous, Scalable Aerial Intelligence

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