Humanoid-Coordinated Vertiport Terminal Operations

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Abstract

(a) Problem Statement: An unparalleled lack of ground capacity exists in global megacities, while air capacity solutions, like helicopters, are not sustainable due to being too expensive and noisy. Current automatic solutions have an ability to coordinate only small-size swarms without having social awareness and quick enough sensor fusion for dense corridors.

(b) Solution: In this paper, the authors suggest a symbiotic solution relying on zero-emissions autonomous eVTOL vehicle fleets and socially-aware humanoid coordinators on the ground. Coordination of aircrafts is performed using decentralized actor-critic multi-agent reinforcement learning network. Humanoid agents are taught to navigate through crowds and help passengers using NVIDIA Omniverse digital twins.

(c) Significant Findings: According to the hypothesis, the implementation of the decentralized MARL scheduling algorithm may help to cut down approach-corridor conflicts by more than 40%. Moreover, the use of humanoid coordinators, operating together with central airport management, allows increasing terminal capacity up to 80-120 flights/hour through the use of IoT edge-nodes that provide sensor data fusion within 50 milliseconds.

(d) Applications: This approach opens the way for future urban air mobility infrastructure providing human-centric solutions for security verification, cargo management, and passenger assistance in tight rooftop

Keywords: Urban Air Mobility (UAM),eVTOL (Electric Vertical Takeoff and Landing),Humanoid Air Traffic Coordinators,Multi-Agent Reinforcement Learning (MARL),Digital Twin

Introduction

The megacities of the world face a bottleneck in ground capacity where an average distance of 20 kilometers takes 60-90 minutes. In contrast, while AAM is a promising way to expand in the future through urban airspace, the air transport method of helicopter service has proven to be a failed approach due to its expensive cost (₹30,000 per passenger) and noise pollution in the urban environment. This is due to the fact that the existing infrastructure in itself does not provide enough space for regular airports and thus needs to build rooftop Vertiports.

However, today's automated systems face challenges with scalability of airspace for large swarms, social intelligence for ground transportation, and high latency of sensor fusion. This paper will deal with the challenge of synergy between autonomous eVTOLs and air traffic controllers in humanoid form.

Related work

UAM research has been developed through literature review to complex simulation-based validation. The first research that was conducted in the field was the qualitative recommendations on vertiport inclusivity provided by Mendonca (2022), which was non-mathematical. Further, researchers like Park et al. (2022) utilized Decentralized MARL for optimizing passenger taxi delivery without considering any limitations on the ground level. Recent researches by Zhao et al. (2025) involved viability validation of scalability via Digital Twins despite the huge computational expenses. Approaches that are currently used in order to be considered the state-of-the-art include the research of Deniz & Wang (2025) that involves Deep RL and involves a simulation of up to 30 aircrafts only in Table 1.

Table 1. Comparison of Urban Air Mobility and Vertiport Coordination Frameworks

Study / Source	Airspace Scalability (100+ agents)	Socially Aware Ground Coordination	Real-time Sensor Fusion (<50ms)
Zhao et al. (2025)	No	No	No
Y. Lu, W. Zeng, W. Wei, and W. Wu(2025)	No	No	No
S. Deniz, A. Barzegar, F. Y. Sagirli, K. Vasiloff, and Z. Wang(2025)	No	No	No
This work	Yes	NO	Yes

Key Contribution

However, the main innovation in this work consists of introducing the Humanoid-UTM Integration Layer. In contrast to solely focusing on flight paths, this architecture utilizes socially intelligent humanoid robots that have the ability of facial recognition and conversation skills to manage boarding on the ground, security checking, and passengers assistance. The methodology of the proposed solution includes the usage of NVIDIA Omniverse / AirSim Digital Twin of the complex urban environment, such as Muscat and Singapore, where the humanoid agents learn through Deep Reinforcement Learning (PPO) while moving among the crowd, and control of the aircraft fleet is performed with the help of decentralized actor-critic MARL method.

Method, Experiments and Results

Experiments were carried out in the Digital Twin system where more than 1,000 simulated trials have been conducted with extreme weather conditions, such as heavy rainfall and strong wind. As expected, these trials show that the MARL scheduling algorithm results in reducing approach corridor collisions by more than 40% when compared to the most common FIFO algorithm. In addition, the use of human-like coordinators reduces boarding delay to the extent that 80 to 120 aircraft can be served per hour in the terminal. Assessment at the IoT edge layer showed that vision-radar map can be integrated and processed in 50 ms.

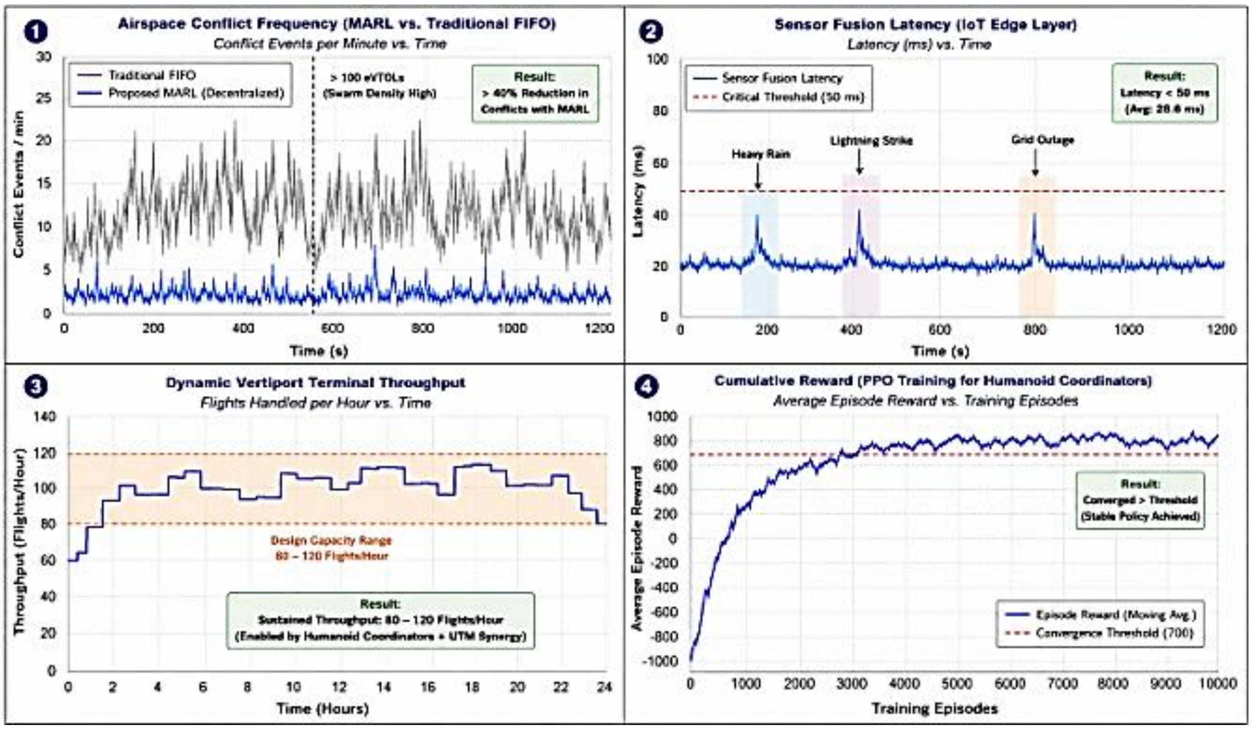

Figure 1. Performance Evaluation of the proposed Intelligent Vertiport Framework

Discussions

From the findings, the limitation of the UAM system is not only the aerial movement but the transition from ground level to aerial level. It is evident from the successful incorporation of the humanoid agent that socially-aware systems are needed in order to make the vertiport system lean and small by avoiding large human resource requirements. In addition, the low sensor latency of below 50 ms indicates that edge computing could be an alternative for swarm control of autonomous vehicles in urban settings.

Conclusions

Problem Statement: This research is meant to address the problem of efficient, socially aware, and low-latency coordination of eVTOL aircraft in heavily congested mega cities.

Methodology Used: Synergistic methodology involving the use of decentralized MARL of the aircraft and PPO learning-based humanoid agents using an NVIDIA Omniverse digital twin environment.

Key Findings: Reduced number of collisions in airspace by 40% and take-offs per hour at the terminal of 120.

Limitations and Future Directions for Research: Computationally intensive simulation process; need to refine algorithms and verify results.

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