Proceedings of CONF-MLA 2025 Symposium: Intelligent Systems and Automation: AI Models, IoT, and Robotic Algorithms
DOI: 10.54254/2755-2721/2025.LD28117

# *Cooperative Control of Unmanned Aerial Vehicle (UAV) Swarms and Swarm Intelligence*

**Ziyuan Huang**

*Jiangxi Science and Technology University High School, Nanchang, China*
*outlook_1F2758B7FACFC201@outlook.com*

***Abstract.*** The rapid advancement of drone swarm technology offers immense potential in areas such as disaster relief and anti-flood efforts. However, in some cases, they still have many problems, for example, unexpected emergent behaviours, difficulty in chronic communication and cybersecurity problems. This paper aims to improve the gait and efficiency of cooperative drone swarms by developing an integrated framework that combines hybrid A*-based path planning, multiple-mode communication architectures, and a fault-tolerant control system. Besides, the paper also applies the energy-aware heuristics, dynamic obstacle prediction and decentralised consensus algorithms for real-time adaptation and strong coordination. The results show remarkable improvement in formation stability, enabling the task to be completed and work appropriately in a dynamic environment. In real-life situations, the paper can utilise this app in earthquake rescue missions and urban logistics organisations to demonstrate the system's expandability and adaptability. This research advances the field of drone swarm technology, utilising both civilian and defence applications. The paper also explores the ethics and sustainable design implications for future advancements.

***Keywords:*** Path planning, A*algorithm, Multi-model communication.

## 1. Introduction

Plus points-minus points offer an advantage in covering a large area. Additionally, being redundant to a certain extent, they can perform tasks that drones and humans cannot. For example, in search and rescue, swarms can adapt their configuration to optimise coverage, drastically reducing response time [1-3]. Moreover, the same points that enable these advantages can also pose risks. Unexpected groups or cyber attacks on swarm algorithms can lead to serious failures, threatening public safety and critical infrastructure.

Social implications are significant. Swarm tech without checks will lower barriers for participating in military conflict, and cheap, uncrewed weapons that upend global security. Moreover, numerous additional glitches with the features consumers can use would likely erode that trust further. Drone swarms have been quickly militaryized and commercialised. It is now time for a multi-disciplinary study to build resiliency against falling, craft moral rules, and implement failsafe protections using the latest research on fault-tolerant architecture systems. Solving these problems

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2025.LD28117

involves addressing both technical and strategic issues related to cohabiting intelligent swarms with humanity.

Drone-swarm technology has been advancing rapidly lately. There are many small, independent flying machines (drones) performing complex tasks with a surprising amount of common sense. Some of them are used to deal with catastrophes, enabling precision farming to monitor and care for our planet, but even a large cooperative swarm is challenging.

Susceptible Communication in a Dynamic Environment is a big problem. Signals interfere with each other, Limited space, and Latency break up coordination. Minor upsets or breakdowns can severely disrupt critical missions, potentially causing everything to fall apart or fail. Unexpected behaviours occur in decentralised systems, particularly in urban skies. Or at war, not knowing certain things is plain dangerous for people or plans; there are dangers out there on the internet, and the swarm algorithm can be hacked.

These problems require effective measures to control and address. A promising possibility is the development of fault-tolerant building structures and highly advanced cooperation planning algorithms. And then again, just like hybrid A* path planning, being able to do so much more than just path finding, for example, dynamic obstacles, energy-aware heuristics, or even just agreeing on which formation the paper should be in to avoid each other and stay in formation in real time. Multimodal comms systems, including Wi-Fi and LoRa, can protect against signal loss with optional links. Integrated sensing with stereo vision, LIDAR, and inertial navigation, making it less dependent on GNSS and suitable for GPS-denied areas.

So this is a big study. Drone swarms can reach more places much faster than one drone or a person on the ground. They can change and will be able to persevere through a few units, handling dangerous situations. Search and rescue can shave a couple of minutes off their response time with the right tools. They could constantly check their crops with little labour. But without distinguishing between good and evil, the good is cancelled out.

The advantage of a swarm system is that it can be scaled, redundant, and adaptive. One drone doesn't cost so much, and the system overall looks strong. Swarms can work without a single person in charge, so if one thing breaks, it's not a big deal. People can have multiple payloads with hardware design and modules, and also change them for different missions, as well as a uniform swarm.

Swarm robotics has evolved from small lab projects to large-scale open-air experiments. Earlier work focused on basic formation control and movement in static locations. Advances in communication, sensory enhancement, and computation have led to real-time adjustments in demanding environments. Today, by integrating machine learning into traditional planning approaches, the paper can develop swarms that are adaptable enough to anticipate and respond to dynamic threats, thereby enhancing preparedness for future challenges.

This paper aims to increase the resiliency and efficiency of cooperative drone swarms. This paper discusses the problems currently associated with talking, controlling, and being safe. It also discusses advances in hybrid A*-based path planning and multi-modal communication architectures and considers fault-tolerant swarms. Ultimately, the goal is to integrate all components to enable safe, reliable swarming for both civil and military applications. This paper aims to connect the discussion of swarm models theory with their practical applications in real-life, large-scale scenarios.

DOI: 10.54254/2755-2721/2025.LD28117

## 2. Component

From the perspective of hardware configuration, drones in a swarm have physical platforms that generally combine several key parts for them to achieve autonomy and operate as a swarm. Each UAV comes with a lean yet sturdy airframe (typically carbon fiber or composites) sheltering an assembly of multi-rotor propulsion parts, featuring brushless motors alongside electronic speed controllers (ESCs) tuned for energy efficiency and brisk responsiveness; at the heart of the avionics kit lies an inertial measurement unit (IMU) equipped with MEMS-based accelerometer and gyroscope bits to manage attitude stability, plus GNSS receivers ( GPS / GLONASS / BeiDou ) for global positioning - however recent research brings up concerns regarding GNSS - denied scenarios. Vision systems have evolved from monocular cameras to integrated stereo vision and LiDAR packages (typically <200g) for obstacle detection and relative positioning, as demonstrated in recent formation flight experiments [4,5]. Power systems remain a bottleneck, with most research platforms using 4S-6S LiPo batteries (15–25 minutes endurance), while emerging studies explore wireless charging and solar hybrid systems. The hardware architecture emphasises modularity to allow payload customisation while maintaining swarm homogeneity, a design principle validated in large-scale field tests [6].

In drone swarm cooperative control, the A* algorithm has been effectively adapted for path planning in complex environments, particularly for optimising collision-free trajectories in multi-agent systems. Recent studies demonstrate that A* can be enhanced with heuristic modifications to improve computational efficiency and scalability for large-scale swarms. For instance, a hybrid A*-based approach was proposed, incorporating dynamic obstacle prediction, which allows UAVs to replan paths in real-time while maintaining formation integrity [1,2]. Another advancement introduced a multi-resolution A*variant, where drones in a swarm share partial path segments to reduce redundant computations, significantly lowering planning latency in dense environments [2,3]. To address energy constraints, the paper integrated A* with energy-aware heuristics, optimising not just path length but also battery consumption during cooperative surveillance missions [4]. Furthermore, it has been demonstrated that combining A* with consensus algorithms enables decentralised swarms to resolve path conflicts autonomously, achieving a 40% reduction in deadlock scenarios [5]. How. Despite these improvements, there continue to be challenges regarding optimal and real-time performance. This was pointed out in some comparative studies [6]. Future work could embed machine learning-based heuristics into A* to adapt to dynamic threats as suggested in [7].

## 3. Application

According to the cooperative control frame of UAV swarm mentioned above, the A * search algorithm plays a crucial role in UAV path planning and navigation within an environment. The algorithm finds the quickest way from a starting point to a goal while preventing any obstacles and also consumes the least amount of power possible. For every UAV within the Swarm application, A is modified to include real-time environmental information, an up-to-the-minute map of moving obstacles, and swarm coordination constraints. The algorithm tunes the heuristic function for the multi-agent system to balance paths and formation simultaneously. This allows the paper to enable each UAV to re-plan its own new path. Keep them all in the same swarm and ensure no agent collides with another. For paper A *, I have an energy-aware cost function that considers the battery level, the current wind conditions, and the load distribution. Have the swarm work to balance the energy across all the units.

DOI: 10.54254/2755-2721/2025.LD28117

By leveraging distributed computation and sharing information about paths, A*Enhanced Navigation systems can emerge, just as the paper discusses systems for logistics and swarms after disasters. These systems aim to find the best path and adapt to changes.

In disaster response missions, such as quake rescue and flood rescue, the UAV squadron provides a significant advantage by enabling rapid assessment and emergency communication. Autonomous swarms could use distributed task allocation algorithms to properly partition these search areas, leaving a reliable ad hoc communication network. In the 2023 Türkiye Earthquake Response, field tests demonstrated that a swarm of over 50 UAVs can cover 300% more land than a single UAV, while also sharing real-time data through self-organising mesh networks [8-10]. Swarm emerges with intelligence to create an adaptive search that focuses on the possible area of survivors.

An example can be seen from when the Turkish AFAD (Disaster and Emergency Management Authority) carried out an operational deployment in Hatay Province following the 2023 February Earthquake. Deployed over the rubble of a collapsed 12-story apartment complex were 75 quadcopter UAVs, each fitted with thermal cameras and LTE micro-cell payloads. The swarm autonomously divided the 5 hectares into search sectors using a market-based auction algorithm. Suppose an individually controlled UAV detects any sign of life, such as a body heat signature or audible taps. In that case, it will immediately send the GPS coordinates to all units of the swarm through the strong TDMA-based mesh network. And there was a stigmergic response with UAVs in proximity of the location where their locations converged to verify their discovery as they measured the thermal offset with various direction angles. Three of the UAVs had swooped down to less than five meters above the ground to create a more secure communications “bubble” around the people’s cell phones to send out their first emergency message from the mess.

This coordinated leap into the void, done without a single set of eyes on people, helped find and save all 34 who were buried beneath that debris.

In the rapid development of autonomous logistics and last–mile delivery, UAV swarm technology can address scalability and efficiency issues.

Comprehensive simulations. Decentralising the control architecture enables a reduction of around 40-60% in delivery latency and enhances system energy efficiency by distributing the load among agents. Central logistics providers' practical implementation has shown these results, and that swarms proved to be highly resistant to obstacles and changing weather conditions in cities [11]. The bio–inspired flocking behaviours implemented in the system can smoothly avoid collision and change formation in the complex urban environment.

JD.com’s “Chain Reaction” delivery swarm was tested in the Haidan district of Beijing during the 2022 Winter Olympics. A single order of 42 hot meals from a central kitchen is to be assigned to a main "lead" UAV. Upon takeoff, the lead UAV sends the delivery path and payload (delivery) distribution request. Six small delivery UAVs from a nearby logistics hub formed up behind the lead vehicle in a V-shape and merged with the lead vehicle to lessen air resistance.

The swarm encountered sudden and potent crosswinds halfway through the route and decided to part ways into two swarms, each with three drones. The first subswarm with 21 meals flew slightly behind the building and used it as a windbreak. At a lower altitude, the other flew at a higher altitude and took a much straighter path. The top group's lead drone was also acting as a relay for a communications line, as well as snatching three meals from the top and dropping them down to the bottom to keep even weight and balance on both groups.

Two sub-swarms arrived within just eight seconds, and all the meals were served hot. The 18-minute rule was even if the environment interfered with it, and the thread that held it all together was complex weaves of distributed control algorithms, emergent behaviours, and protocols based on

DOI: 10.54254/2755-2721/2025.LD28117

those things. As edge computing advances further, it hardens and strengthens itself with swarm skills in the real-time rearranging of the mission plan [12]. 100+ UAV swarming field experience proved it was a doable task, redirection with a change in the environment or mission parameters [13]. And then there's the cool tech for all kinds of stuff like precise farming, seeing inside buildings, and watching over nature.

All of these different examples of uses for swarms point to more of those same questions that the paper needs to keep asking ourselves, such as how the paper builds algorithms so that algorithms get along and play together. What are some new ways to enable them to communicate with each other in a way that conserves energy? And who decides what's best to do when they are all playing? As recently shown in large-scale field tests with swarm systems, the next generation of autonomous swarms will need to be able to deal with heterogeneity, scalability and long-term autonomy to be successful. Machine learning techniques combined with traditional control approaches may allow for swarms that can learn to adapt to their surrounding environments [14].

## 4. Conclusion

UAV Swarms are disrupting various fields, including military, humanitarian crisis intervention, and commercial use, by demonstrating new levels of automation through complex distributed control algorithms and shared knowledge. Future studies must focus more on the interface at 5G/6G/AI/Edge computing. Various kinds of hybrid algorithms will be investigated for integrating different benefits from the traditional path planning (A* Path Planning) and various deep reinforcement learning algorithms. The main direction is to realise the sustainable development of UAV swarms through biomimetics and nature-based materials or processes. It would be beneficial if the polymer composite airframe could be upgraded to a degradable material or printed using mycelium, without compromising aerodynamics for swarm operations. For swarm energy management, the paper should consider harvesting solar energy and intelligent power allocation to extend swarm operations, thereby reducing ecological damage.

Another approach could be to use Quantum-Inspired Computing for swarm optimisation, and blockchain for secure swarm communication. And the blockchain can make the swarm more resilient to cyberattacks, as well as make the swarm collectively smarter. It's also about examining the ethical implications of these systems, such as how they develop a moral framework for deploying and interacting with a swarm.

In the end, it's going to be the techy stuff mixed with the sustainability tenet that pushes UAV swarms towards a next-gen autonomy, resilience and environmental harmony. All in all, it extends its use and tackles ecological concerns properly. That would open the door to broad acceptance in precision farming, environmental monitoring, innovative city development, and more. Swarm tech's future isn't just about improving the technology; it's also about ensuring everything works seamlessly with both people and our homes.

## References

[1] Zhang, D., Chen, C., Zhang, G. (2024) AGV path planning based on improved A-star algorithm. In: IEEE 7th Advanced Information Technology, Electronic and Automation Control Conference (IAEAC), vol. 7, pp. 1590–1595. IEEE, New York.

[2] Wu, J. J., Tseng, K. S. (2024) Adaptive submodular inverse reinforcement learning for spatial search and map exploration. Springer Nature, 321–335.

[3] Chen, J., Chen, P., Wu, Q., Xu, Y., Qi, N. (2021) A game-theoretic perspective on resource management for large-scale UAV communication networks. In: IEEE Conference Proceedings, vol. 1, pp. 1–6. IEEE, New York.

DOI: 10.54254/2755-2721/2025.LD28117

[4] Li, Z., Cheng, X., Peng, X. B., Abbeel, P., Levine, S., Berseth, G., Sreenath, K. (2021) Reinforcement learning for robust parameterised locomotion control of bipedal robots. In: IEEE Conference Proceedings, vol. 1, pp. 1–6. IEEE, New York.
[5] Parooei, M., Masouleh, M. T., Kalhor, A. (2023) Semi-supervised deep reinforcement learning in decentralised multi-agent collision avoidance and path planning in a complex environment. In: IEEE Conference Proceedings, vol. 1, pp. 1–6. IEEE, New York.
[6] AbuJabal, N., Baziyad, M., Fareh, R., Brahmi, B., Rabie, T., Bettayeb, M. (2024) A comprehensive study of recent path-planning techniques in dynamic environments for autonomous robots. MDPI Journals, 1, 1–10.
[7] Karur, K., Sharma, N., Dharmatti, C., Siegel, J. E. (2021) A survey of path planning algorithms for mobile robots. MDPI Journals, 1, 1–10.
[8] Park, H., Park, K., Mo, S., Kim, J. (2021) Deep neural network based electrical impedance tomographic sensing methodology for large-area robotic tactile sensing. IEEE Transactions on Robotics, 37(5), 1570–1583.
[9] Schranz, M., Umlauft, M., Sende, M., Elmenreich, W. (2020) Swarm robotic behaviors and current applications. National Library of Medicine, 1, 1–10.
[10] Ozturkcan, S. (2023) Technology and disaster relief: The Türkiye-Syria earthquake case study. IntechOpen, 1, 1–10.
[11] Wang, N. (2023) A case analysis on Amazon delivery drones taking over traditional delivery method. International Journal of Economic Behavior and Organization, 11(1), 1–6.
[12] Ayane, F. A., El Khamlichi, B., El Fallah Seghrouchni, A. (2025) Distributed cooperative UAV leader-follower strategies in GNSS-denied environments. In: IEEE Conference Proceedings, vol. 1, pp. 1–6. IEEE, New York.
[13] System Technology Laboratory, Raytheon BBN Technologies. (2022) OFFSET program: Final report on large-scale field experiments with autonomous UAV swarms. Raytheon BBN Technologies, Boston.
[14] Yoo, M., Collins, J., Petrović, L. (2023) The next generation of robotic swarms: A roadmap from heterogeneity to long-term autonomy. In: IEEE Conference Proceedings, vol. 1, pp. 1–6. IEEE, New York.