A Study of Anti-drone Swarming Strategies

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Abstract

With the rapid development of military intelligence technology, the use of drones in combat is becoming more and more widespread, countries have increased the research on drone combat to varying degrees, especially for the drone swarm has a high consumption ratio, decentralisation, functional diversity, and other advantages, to launch the drone swarm project research. The anti-drone swarm strategy is a strategy that specifically responds to drone swarms. With the continuous development of drone swarm technology and the exploration and application of tactics, the anti-drone swarm strategy will become more important, and it is of great practical significance to carry out the research on anti-swarm strategy to prevent and resist drone swarm combat in the future.

Keywords

Anti-drone; Swarm; Strategy research.

1. INTRODUCTION

Throughout the recent local wars, UAVs have been widely used for reconnaissance and guidance, surveillance and tracking, precision strikes, and transport and security, and a certain number of UAVs are at a loss for ground targets. With the development of UAV swarm formation control, intelligent decision-making and other aspects of technology, the threat of ground targets from UAV swarm will become more and more prominent. UAV swarms have a leading role in the development of modern warfare, and how to prevent and resist UAV swarms has become an urgent research topic.

2. UAV SWARM CONCEPT AND OPERATIONAL CHARACTERISTICS

(1) Concepts

Some organisms in nature will form swarms and show autonomous coordination when searching for food, such as bird flocks, bee swarms, ant colonies, and fish swarms. Inspired by these phenomena, researchers have considered whether combat clusters can collaborate on missions like biological clusters, and this is how the idea of unmanned aircraft swarms (UAV swarms) to join forces, collaborate, and perform different missions individually, and a common mission as a whole was developed. The U.S. Army was the first to propose the concept of UAV swarm combat in the late 1990s: UAV swarm refers to a group of UAVs based on a certain level of intelligence, through simulating the behavioural strategies of biological clusters, implementing management in accordance with decentralisation, and realising highly intelligent and autonomous collaborative combat activities [1].

(2) Operational characteristics

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A drone swarm is an aggregation of a certain number of drones of the same type or different types, which has the characteristics of winning by quantity, decentralisation, performance aggregation, strong survivability, difficulty in countermeasures, and high cost-effectiveness ratio (see Figure 1).

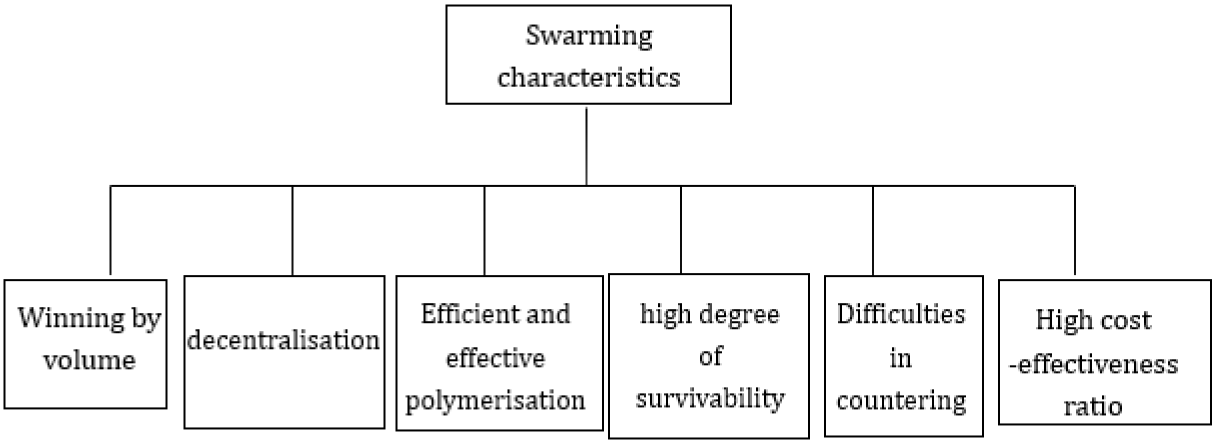

Figure 1. Characteristics of drone swarm warfare

①Winning by volume

Drone swarms have a significant numerical advantage over individual drones. Individual drones in a swarm have a certain degree of autonomous decision-making ability, and also synergise with other platforms through a variety of direct or indirect ways to form a powerful group combat effectiveness. In 2019, the Shia Houthi militant group used 18 drones and seven missiles to coordinate attacks on Saudi oilfields to cause a severe impact on its crude oil production, demonstrating the huge potential of drone swarm combat.

②Decentralisation

In the UAV swarm system, individual UAVs can make autonomous decisions and flexible formations based on their own capabilities, acquired local information, and established rules and algorithms, and there is no absolute central control node to direct the actions of all UAVs. Even if some of the drones fail in the course of combat due to malfunction or attack, the other drones can still continue to carry out the mission, with a high mission success rate.

③Efficiency and excellence

UAVs adopt a modular design, which allows UAVs with specific functional equipment to perform corresponding tasks, and also allows UAVs with different functions to be combined according to mission needs, making up for the lack of individual capabilities and improving the group's combat capability and the types of tasks to be attempted. Within the UAV swarm, local information such as terrain and target dynamics reconnaissance by each UAV will be shared in real time with other UAVs in the swarm, resulting in a significant increase in the perception capability of individual UAVs.

④Strong survivability

From the perspective of a single aircraft, UAVs are small in size, flexible in flight, typical "low, slow and small" targets, not easy to be detected by radar, optoelectronic, acoustic and other means of detection, and are highly covert; from the perspective of the swarm as a whole, it adopts a "decentralised" architecture with robust self-healing capability. From the perspective of the swarm as a whole, it adopts a "decentralised" architecture with robust self-healing capability, so even if part of the UAVs are destroyed or incapacitated, other UAVs can still continue to carry out their tasks, which makes their survivability on the battlefield stronger.

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⑤Countermeasures are difficult

As the autonomous capability of drones improves, future combat drone swarms will inevitably have a higher degree of autonomy, and it may be difficult to achieve good results with traditional electronic jamming, navigation deception and "soft kill" means such as blinding by breaking the chain. Hard-kill measures such as the use of anti-aircraft artillery, missiles, rapid-fire artillery and other weapons to destroy drones, although missiles have a high hit rate and are effective in intercepting and striking drones, are also very costly, and there are still many difficulties in achieving large-scale countermeasures against large numbers of multi-directional attacking drone swarms.

⑥High cost-effectiveness

In the drone swarm, the single aircraft design structure is simple, the research and development and manufacturing cost is low, such as the U.S. army "coyote" drone, the cost of a single frame is only 15,000 U.S. dollars, compared with the surface-to-air missiles, air-launched decoys and other anti-drone weapons have an asymmetric cost advantage [2]. In addition, UAV swarms can replace combatants in high-risk missions, which is not only highly efficient, but also reduces the probability of combatant casualties, and has a very high cost-effectiveness ratio.

3. STATUS OF DRONE SWARM DEVELOPMENT

(1) Status of UAV swarm development in the United States

The United States remains the world leader in drone swarm research. Relevant projects have been initiated by important national military departments and service units, and some of the typical projects initiated in the last decade are: Gremlins, OFFSET, Skyborg, etc. (see Table 1). Skyborg" project, etc. (see Table 1).

①Gremlins

A cluster of recovery decoy jamming UAVs that perform reconnaissance and surveillance, electronic attack, and suppression and destruction of air defence missions against enemy air defence systems in an anti-access/area denial environment [4]. Launched in 2015, each UAV can be reused around 20 times, with a maximum range of 556km.The cost is low, with a single UAV not exceeding $1 million. Adopting a decentralised design, the destruction of a single UAV will neither cause large losses nor affect the overall mission accomplishment.

②"Offensive Swarm Project" (OFFSET)

It is an infiltration strike-type UAV cluster with autonomous sensing, intelligence sharing and other functions, which can collaborate with manned equipment to attempt urban combat and improve overall combat effectiveness. The project was launched in 2016, and as of 2025, six field trials have been conducted. The project includes about 250 small drones and a number of ground-based unmanned systems, the autonomy of drones and drones and ground-based unmanned systems coordinated control is an important aspect of the project research, the U.S. Defence Advanced Research Projects Agency (DARPA) hopes to explore new unmanned systems enabling technologies, such as distributed sensing, distributed computing, and other new technologies, from the study of offensive swarming projects.

③"Skyborg" project (Skyborg)

Based on algorithms such as convolutional neural networks, develop AI software suite systems for expendable unmanned aircraft to enable them to act as AI co-pilots or realise autonomous piloting, and improve quality and efficiency for manned/unmanned aircraft to collaborate and cooperate to carry out missions. The project was launched in 2018, and the U.S. Army began operational testing of the SkyBorg software in 2021.In April 2021, a UTAP-22 UAV equipped with the SkyBorg Autonomous Core System underwent basic flight testing at Tyndall Air Force Base, demonstrating aeronautical capabilities such as navigation, flight, and

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coordinated manoeuvres; In October 2021, two MQ-2Q Avenger stealth UAVs with autonomous core systems completed flight tests in California.

Table 1. Some typical projects of U.S. Army UAV swarms [3]

Department in charge	Project Name	Mission Type	Attribute Characteristics	Initiation time
Defence Advanced Research Projects Agency (DARPA)	"Gremlins.	A cluster of retrieval-deluded jamming drones that perform reconnaissance, surveillance, electronic attack, anti-aircraft suppression, and target destruction missions.	A single reusable UAV with a maximum range of 556 km and a cost of less than $1 million. Decentralised design.	2015
	"Offensive Swarm (OFFSET)	Offensive Swarm (OFFSET) is an infiltration strike-type drone cluster with autonomous sensing and intelligence sharing functions, which can work with manned equipment to conduct urban operations and improve overall combat effectiveness.	The project includes about 250 small drones and several ground-based unmanned systems, and the research focuses on the autonomy of drones and cooperative control between drones and ground-based unmanned systems.	2016
Air Force.	"Skyborg" (Skyborg)	AI system developed for UAVs based on algorithms such as convolutional neural networks to enable them to act as AI co-pilots or to achieve autonomy to improve quality and efficiency for manned/unmanned co-operation.	U.S. Army to conduct operational testing of Skyborg software starting in 2021, expected to be completed by July 2026	2018

(2) Current status of domestic research

Domestic research on drone swarm warfare started a little later than the United States, but the speed of drone technology development is relatively fast. in November 2016, China successfully launched a one-time cluster of 67 fixed-wing drones at the Zhuhai Airshow to break the U.S. record. in May 2018, the China Electronics Technology Group Corporation conducted a test and successfully completed the launch of a swarm of 200 fixed-wing drones and coordinated operations, creating a world record. The swarm drones developed by the National University of Defense Technology with anti-jamming computing ability can still rely on their own anti-jamming computing to restore communication even when the drones are subjected to electromagnetic interference and lose contact with the ground station.2024 In September, the

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"Swarm 1 Land Combat Vehicle" unveiled at the Zhuhai Airshow can carry 48 fixed-wing drones on a single vehicle, all of which can be launched in less than 3 minutes. All the launch time is less than 3 minutes, multi-vehicle launch up to dozens of hundreds of vehicles, can effectively improve the diversified combat capabilities. However, in general, the transformation of advanced UAV swarming technology into the military field is not enough, especially in the flight formation, intelligent control, autonomous decision-making and other aspects of the development of space.

4. ANTI-DRONE SWARM STRATEGY

UAV swarm attack has a process of approaching to the target from far and near, combining the combat characteristics of UAV swarm and the current development situation at home and abroad, the first thing that should be done to counteract UAVs is to detect and warn, followed by the use of lower-cost technical control means, and finally, the choice of fire strikes or swarms against swarms. Therefore, the author summarises the anti-UAV swarm strategy from four aspects: multi-means detection and identification, soft-kill technology control, hard-kill attack and destruction, as well as swarm against swarm (see Figure 2).

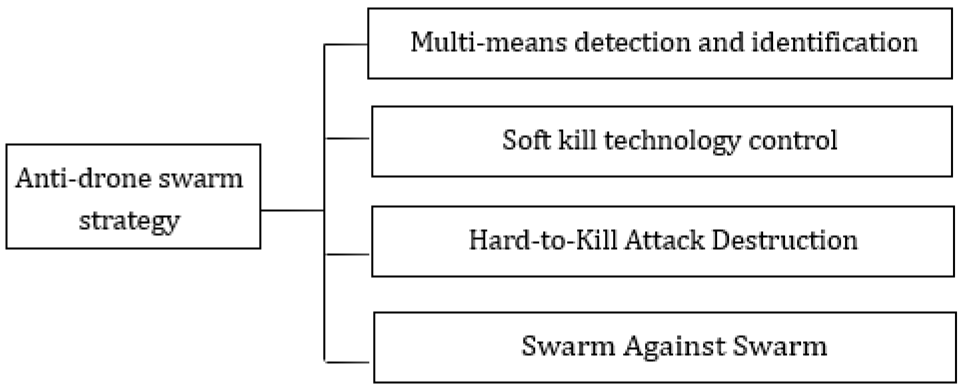

Figure 2. Anti-drone swarm strategy

(i) Multi-means detection and identification. The closer a drone swarm flies to its target, the greater the threat it poses. It is therefore important to detect drone swarms when they are still at a distance. One is the use of radar detection. When the electromagnetic wave emitted by radar encounters the drone swarm, part of the energy will be reflected, forming a signal wave containing information about the drone swarm, which is received and analysed to obtain information about the location, number and speed of the drone swarm. Second, the use of photoelectric detection. UAV swarms will emit infrared and visible light radiation signals in flight, photoelectric detection equipment through the full airspace scanning, access to the infrared or visible light of the UAV swarms, and convert the light signals into electrical signals, so as to achieve the purpose of analysing and processing the light signals and extracting the target's attributes. Third, the use of acoustic wave detection. UAV swarms have acoustic characteristics when flying, such as engine speed sound, propeller rotation sound, etc. Acoustic wave detection is to use sensors to capture the sound from UAV swarms, and complete the detection and identification of UAV swarms through signal feature extraction, model matching recognition and other techniques.

(ii) Soft means technology control. A drone receives commands from a ground control station or a remote controller and, through internal decoding, converts them into flight control signals, thus enabling it to fly in accordance with the commands. Therefore, technical control of the UAV

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can be achieved by cutting the command transmission link or changing the commands received by the UAV. The techniques for cutting the command transmission link include link jamming and link seizure control techniques, and the techniques for changing the commands received by the UAV include acoustic wave jamming, navigation spoofing, and navigation jamming. Cutting off the communication link will cause the swarm drone to lose flight control and intelligence transmission; changing the receiving instructions will disrupt the normal smooth flight of the swarm drone or seize control of the drone. 5 December 2011, a U.S. RQ-170 Sentinel unmanned reconnaissance drone landed in Afghanistan after Iran reconfigured the drone's GPS coordinates. Afghanistan.

(iii) Destruction by hard-kill attack. Once a drone component or control circuit is damaged, the drone can no longer fly normally. Hard-kill is a way of countering drone swarms using microwaves, lasers and anti-personnel weapons. Hard kill means include microwave destruction technology, laser destruction technology, and fire killing technology. Microwave destruction technology is used to launch high-energy microwaves at swarming drones, and the components of the drones irradiated by the high-energy microwaves are heated to high temperatures, causing damage to electronic components; microwave destruction technology can kill multiple targets at the same time. Laser damage technology uses high-energy laser beams to carry out directional strikes on individual drones, and achieves the effect of strikes by burning the control circuits of the drones, and a single piece of equipment emitting high-energy laser beams can only carry out directional strikes on one drone at a time. Fire kill is the use of dense array guns, multi-barrelled rapid-fire guns and other air-launched weapons to fire munitions to combat drones, fire kill and anti-drone swarming compared to the soft means of high cost, while the striking accuracy of artillery weapons, the firing speed of the high requirements [5].

(iv) Countering swarms with swarm defence. UAV swarm defence against incoming UAV swarms is one of the more promising technical routes for future anti-UAV swarm technology. The drones in an anti-drone swarm can be distinguished from suicide, impact and non-suicide drones. Suicide UAVs use their battle parts to carry out suicide strikes against enemy UAVs, such as the US Coyote BLOCK2 UAV; impact UAVs use their manoeuvrability, structural robustness and control robustness to destroy enemy UAVs by direct impact, such as the US Drone Bullet multi-rotor UAV; non-suicide UAVs can be divided into two categories: suicide UAVs and non-suicide UAVs, which are suicide UAVs and non-suicide UAVs, and non-suicide UAVs. Non-suicide UAVs strike enemy UAVs by mounting jamming equipment, kinetic fire or directional energy devices on the UAV, such as the U.S. Coyote BLOCK3 UAV.

5. CONCLUDING REMARKS

This paper analyses the characteristics and development status of UAV swarm combat, and summarizes the four strategies of anti-UAV swarm. At present, all countries have increased their anti-drone swarm research efforts, but the existing anti-drone swarm soft kill means have limited range of action, hard kill means munitions hit rate still needs to be improved, and the means of interception network and vehicle wake disruption are not mature enough. We should explore the technical and tactical perspectives to solve the thorny problems of the current and future anti-drone and swarm, focus on improving the distance of soft-kill means, enhancing the hit rate and attack range of hard-kill means, and developing advanced technologies such as dense interception and vehicle wake disruption, so as to continuously improve the combat capability of anti-drone swarm.

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