Research on anti UAV swarm system in prevention of the important place

Q Hao*, W Z Li*, Z K Qiu and J L Zhang
Institute of Army Aviation, Beijing 101123, China
Email: haoqiv@163.com, lichangshuo060226@163.com

Abstract. With the rapid development of artificial intelligence (AI) technology, UAV swarm has become possible. It has become an urgent problem that how to realize the effective counteraction to the UAV swarm in the important target security defence, or in the important place prevention in the war. In this paper, by analysing the development status and combat characteristics of UAV swarm, as well as existing anti-UAV technology, the countermeasures and technologies applicable to UAV swarm is combed. Then the further construction of anti UAV swarm control system is built to realize the effective anti UAV swarm in the key prevention and control.

1. Introduction
In recent years, the UAVs show a significant trend of intelligence with the rapid development of the AI technology. Based on the formation and flock of the micro UAVs, the concept of UAV swarm operation has evolved. As a new kind of unmanned and intelligent combat equipment, UAV swarm has a unique combat mode in battlefield reconnaissance, air penetration, target strike, electronic confrontation and other operations, which also brings a new challenge to the anti-UAV. For example, in January 2018, terrorists used 13 simple UAVs to form a primary UAV swarm. The swarm attacked the Russian military base in Syria, posing a serious threat to the base.

Table 1. The effect of different method in anti UAV swarm.

| Method                | Percentage of successful defense |
|-----------------------|---------------------------------|
| GPS decoy             | 1%                              |
| air defense fire      | 2%                              |
| laser weapons         | 4%                              |
| microwave damage      | 24%                             |
| Data link interference| 0%                              |
| Net gun hunting       | 0%                              |
| Fiber mesh            | 2%                              |

How to resist the terrorist attack, close reconnaissance or penetration attack of the UAV swarm, which is in the important activities or prevention of the important place, will be an important problem UAV counter control and defense in the future. The UAV swarm, which is with large number of
individuals, wide distribution and strong AI, is difficult to achieve effective counteraction against with a single mode anti-UAV method, such as early warning, electronic countermeasures or damage capture.

In a Military exercise in 2019, Russia used GPS decoy, air defense fire, laser weapons, microwave damage and other methods to intercept a UAV swarm, which included 90 Micro UAVs with various configurations. But the effect is very poor, as shown in table 1. It is necessary to establish a perfect Anti UAV Swarm System, shorted by AUSS, to defend UAV swarm in the prevention of the important place.

2. The concept and development of the UAV swarm

2.1. The concept of the UAV swarm

When multiple UAVs are used together, different concepts such as UAV formation, UAV cluster and UAV swarm are distinguished. UAV formation refers to the formation of more than two UAVs in the air according to the specified interval, distance and altitude. UAVs can form mixed formation with manned fixed-wing aircraft, helicopter or other aircraft. UAV cluster refers to the UAV group composed of several UAVs or UAV formations which perform the same task, receive unified command and maintain information contact. The UAV swarm is a kind of UAV cluster which performs the same task and is composed of many UAVs with high autonomy and cooperation ability.

The UAV swarm is based on the combat ability of single UAV, supported by the autonomous cooperation among the UAVs, and based on the open architecture integrated integration. The UAC swarm, which has the characteristics of high intelligent autonomy and function distribution, can carry out specific combat tasks. The UAV swarm, which is composed of micro UAVs, is a high-level form of UAV cluster. The UAV swarm, witch can asymmetrically cancel the capability of traditional large-scale and multi-functional platform with its low cost unit, has attracted the attention of various national militaries or military organizations.

2.2. The development of the UAV swarm

In the early 21st century, the United States first proposed the concept of UAV swarm, and carried out a series of concept improvement and technology accumulation work. In recent years, the research of UAV swarm in the United States has entered a rapid development period with the support of sensors, digitalization, ad hoc network and AI.

Under the unified leadership of Department of Defense (DoD), Defense Advanced Research Projects Agency (DARPA) and the strategic capabilities office (SCO), as well as the military, air force and Navy, have carried out a lot of research and demonstration work, launching a number of projects. These projects are functionally independent, each has its own emphasis, and complement each other and develop in an integrated way.

In September 2015, DARPA released the Gremlins program, which aims to develop a drone swarm system for carrier launch, air recovery. It can be used in reconnaissance, surveillance or electronic attack missions. It can be launched from air platform, which is outside the defense area. The Gremlins, which implement distributed collaborative operations and carry reconnaissance, surveillance or electronic warfare loads, can quickly penetrate into the enemy defense area, suppress the enemy's missile defense system, cut off the enemy's communication, guide the precise fire strike, or invade the enemy's data network to carry out a cyber attack. It can evacuate and be recovered after completing the mission.

In April 2015, the Office of Naval Research (ONR) announced the Low Cost UAV Swarm Technology (LOCUST) project, which aims to rapidly and continuously launch low-cost UAVs by using tubular launchers on platforms such as ships, vehicles, aircraft or UAVs. It can coordinate attack or defense, and suppress the enemy with quantity advantage. The wings and propellers of Coyote UAV, which is used in this project, can be folded. It can be launched in the air or on the ground. It can
carry different mission loads, perform intelligence collection, communication interference, fire attraction and other missions.

In 2014, the U.S. strategic capabilities Office (SCO) led the High Speed Launch Demonstration of Micro UAV project, which aimed to release the micro UAV group to carry out such tasks as situation awareness, intelligence reconnaissance and electronic jamming. The Perdix UAV used in the project, which is assembled by 3D printing and with foldable wings, can be carried and launched by F-16 or F/A-18f fighters, or launched from the ground or sea. It can be independently organized and operated in the air.

In May 2015, the United States Naval Research Laboratory (NRL) declared the Close Combat Invisible Disposable Autonomous UAV (CICADA). It is a kind of low-cost, GPS navigation and one-time micro UAV, with a single unit weight of 65g and a 3D printing body. It can be distributed through P-3 Orion reconnaissance aircraft. It is convenient for large-scale and efficient deployment, and can quickly establish a sensor or communication network within a designated area.

3. The characteristics of the UAV swarm Operation
Due to the characteristics of large number, flexible formation, cooperative operation, low detection, low cost and easy production, the UAV swarm has strong concealment, attack and robustness. It can effectively improve the communication, command, intelligence reconnaissance, situation awareness and attack ability of its own side. And it can block the communication network, suppress the air defense system, damage the important target of the enemy at the same time. The UAV swarm meet the requirements of mobile, flexible and diverse operational in the future war.

3.1. Strong penetration ability with low detectability
The UAV swarm, which is distributed and self-organized, can fly at ultra-low altitude, regroup and intelligently group to avoid obstacles. Some UAV swarm can fly in silence, which increases the detection difficulty of the enemy early warning system. After landing on the ground, the CICADA UAV can even leave the air defense system monitoring. Most of the UAV swarm node platforms are small in size and radar reflection area, which makes it difficult for the enemy to detect the UAV swarm in a long distance. So the reaction time of the enemy can be compressed. For example, Coyote UAV attacks at 250km/h, so the Aegis system radar only has 15 seconds to intercept after exploration.

3.2. Large number and large scale advantage
The UAV swarm can organize large-scale operations. The number of UAVs exceeds the threshold which the enemy early warning system can probe, track or lock at the same time. So the UAV swarm can effectively break through the air defense and implement saturation attack. Such as the Armor S1 air defense system of Russia can track twenty targets at the same time, and attack four of them. However, for more than 20 UAVs, the defense system capability cannot be effectively exerted. In the tactical application, if group coordinated attack at more than one direction, or other long-range precision attack means, the air defense side will be at a disadvantage in the whole process of early warning reconnaissance, tracking identification, interception and resistance.

3.3. Active in operation with multiple types of loads
The UAV swarm mission load is modularized, which can be flexibly configured according to the needs. The launch mode is diverse, such as manually launch, and launch from vehicle, ship, aircraft, UAV. The function can cover reconnaissance, surveillance, detection, attack and other aspects, and the combat space covers urban, air, sea, electromagnetic, network and other fields. The combat coordination ability is strong too, such as the coordination in UAV swarm and the internal coordination between the UAV warm and the plane, ship, ground forces and other nodes in the combat system, to improve the combat effectiveness of the system. The tactical application has a great space for innovation with a variety of mission loads, which can realize some new combat modes.
3.4. Strong supplement ability with low production cost
Compared with traditional aircraft and weapons, the cost of micro UAVs platform of life cycle is low, and some of them can be recycled and reused. For example, eighty coyote UAVs can be purchased cost 1.2 million US dollars, which is the same as a harpoon missile. The Coyote, Partridge, COCADA UAVs’ components can be made by 3D printing. So the UAV swarm can meet the requirements of high loss and high consumption in the battlefield. It can quickly consume the enemy’s air defense missiles, efficiently destroy enemy radar and other high-value weapons. Because of the advantage of asymmetric combat cost, the ability and cost of the supplement system must be further improved.

4. Anti UAV swarm defense system
Different from anti single UAV, in order to realize the effective anti and defence of UAV swarm in prevention of the important place, it is necessary to construct the anti UAV swarm defense system with complex structure, perfect function and full range coverage. It can realize a comprehensive area protection system with multi-directional and multi means. It can comprehensively use the detection, early warning, prediction, tracking, decoy, interference, capture, damage and other technical means.

4.1. UAV swarm detection and early warning
At present, in the aspect of UAV detection and early warning, the optical, radar, radio detection and early warning methods, as well as the corresponding UAV route prediction and other technical means are mainly used. It can realize long-distance detection, high-precision positioning, target property identification and flight route prediction of the incoming single UAV. However, unlike the traditional single UAV operation, the UAV swarm is smaller, with the characteristics of small size, small radar cross-section, low flight height, slow flight speed and so on. It is difficult to achieve accurate detection by using a single traditional detection or early warning mean.

Therefore, it is necessary to carry out special research on the basis of traditional detection and early warning methods, aiming at the characteristics of small target characteristics and scattered flight distribution of UAV swarm. Efficient composite means for UAV swarm detection and early warning can be developed by this way. For example, sensor fusion technologies such as visible light, infrared, laser and low light are used to realize the detection and tracking of optical targets in complex background; clutter modeling, simulation and suppression technology in complex background and low-speed target detection technology based on signal energy accumulation are used to improve the detection ability of radar equipment for UAV swarm; multi-source target information fusion and feature recognition technology are used to realize the combination detection under the condition of large field of view and long distance; the high-efficiency antenna array technology of ultra wide band target detection, as well as the telemetry signal identification, demodulation, analysis and direction finding technology are used to improve the detection and discovery ability of UAV swarm’s data link or internal data link.

4.2. UAV swarm electronic countermeasure
UAV electronic countermeasure is to achieve the non physical damage or takeover control of all kinds of UAVs in the designated area by means of data link suppression, navigation system interference and other technical means. So UAVs cannot complete the combat task. The UAV electronic countermeasure mainly includes UAV remote control information analysis and alternative control, telemetry information detection and UAV positioning, navigation information interference and deception, etc. For UAV swarm, the traditional electronic countermeasure technology is still applicable, but it puts forward higher requirements for the function and performance of electronic countermeasure.

In the aspect of jamming and deception of navigation system, the satellite navigation system (including GPS and Beidou system, etc.) is still the main orientation of anti UAV swarm technology, so the suppression and deception of satellite navigation system is still the main direction of anti UAV swarm technology. However, considering the highly intelligent and autonomous characteristics of
UAV swarm, it also has the ability of intelligent prediction and location, inter machine measurement and location in denied environment. In the aspect of UAV remote control signal interception, remote control information analysis and suppression, the universal means still have certain effect. But due to the characteristics of UAV swarm autonomous operation, the communication frequency between UAV and ground control station is not high, and even zero transmission can be achieved. Then the means of remote control signal interception and remote control information analysis need to improve. Therefore, in order to effectively suppress the UAV swarm, we should pay more attention to the inter aircraft positioning, inter aircraft link suppression and cracking.

4.3. UAV swarm damage and capture

UAV damage and capture, which is aimed at all kinds of UAVs with security threat, is with the support of detection and early warning system, to make the UAVs lose its combat ability through direct physical damage or capture. It mainly includes ground/air fire strike, high-energy laser/electromagnetic damage, and all kinds of interception and capture technologies. It is the most important and effective means in UAV countermeasures. For the UAV swarm’s large number of individuals, sparse flight formation and scattered attack angle, the traditional methods of damage and capture still have a certain defence effect, but it is difficult to achieve effective countermeasures for the whole UAV swarm.

Especially for the prevention of important places, the direct physical damage will often lead to greater collateral damage. Therefore, on the basis of strengthening the original damage technology, the drone colony interception ability without collateral damage should be further strengthened. In terms of capture technology, the research on intercepting technology of intercepting net based on early warning information should be strengthened. For example, large-scale intercepting net, which is mounted by UAV or balloon, can realize the mass capture of UAV swarm. In terms of intercepting technology, the research on intercepting Technology of degradable flexible fiber cloth should be strengthened. For example, large area fiber through air/base foundation can be quickly distributed at the edge of the defence zone. In the aspect of damage technology, the research and development of high-power laser or electromagnetic, and other directional energy weapons should be strengthened. Such as high-power wide cross-section electromagnetic directional weapons which can achieve rapid damage to the UAV swarm in the specified direction.

4.4. UAV swarm defence command and control system

The UAV swarm has a series of characteristics, such as large number of individuals, large scale of application, low detectability, strong penetration ability, high intelligence, and operational activity, which makes it very difficult to counter. In order to realize the effective defense of UAV swarm, the UAV swarm reaction system need to make full use of all kinds of countermeasures, and integrate the target feature analysis, route prediction, threat assessment, disposal decision-making and other technologies, as shown in figure 1.

When constructing the command and control system of UAV swarm defence, the ability of multi-source target fusion and trajectory prediction, target threat assessment, and disposal action assistant decision-making is improved through the construction of command and control network. Multiple optical detection equipment or wide area radar detection equipment will be arranged within 5-10km of the periphery of the important prevention area, to realize the pre detection and early warning of the drone colony. The mobile reconnaissance and early warning equipment will be mobilized around the prevention area according to the local target situation, to realize the multi-dimensional and multi-source detection of the UAV swarm. The equipment will be selected around the prevention area according to the actual situation of the battlefield to carry out fire strike, laser electromagnetic damage. For the UAV entering the prevention area, it is necessary to take the interception means without collateral damage, such as net catching, decoy and other ways. For key target areas in the prevention area, the balloons will be used to build a large area interception network, the UAVs are used to spread a large area of fiber screen to strengthen the protection.
In addition to the above-mentioned anti means of UAV swarm, we should also strengthen the research on anti reconnaissance target camouflage technology, aiming at the potential threats of enemy UAV swarm reconnaissance and attack. The optical camouflage, electromagnetic camouflage and target decoy of high-value targets will be improved through research on visible camouflage, infrared radiation suppression, electromagnetic radiation suppression, photoelectric signal decoy and other technologies.

5. Conclusions
In this paper, the main purpose is to construct the anti UAV swarm system in prevention of the important place. By combing the concept, development and operational characteristics of the UAV swarm, the applicability of different UAV countermeasures to the UAV swarm is analyzed. Then the anti UAV swarm defense system with complex structure, perfect function and full coverage is further constructed. The detection system is comprehensively applied with early warning, prediction and tracking, decoy and jamming, capture and damage, anti reconnaissance and camouflage, and other technical means, to realize the efficient counter control of UAV swarm.

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