Research on Multi-scene Application of Maritime Police Shipborne Drones

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ABSTRACT: In order to provide theoretical support for the use of unmanned equipment by the marine police force, this paper takes the current situation of the use of marine police drones in Asia-Pacific countries as the entry point, the type characteristics of marine police drones is introduced and the use of different materials for the typical task scenarios of the current marine police force drones, the needs of maritime police drones in different scenarios is analyzed and composed, and a variety of operational methods for the maritime use of drones by the marine police force are emphasized.

1. INTRODUCTION

At present, the marine police force of major Asia-pacific countries have installed a series of unmanned reconnaissance equipment based on the existing air platform of the coast guard to upgrade their maritime situation awareness, target monitoring, emergency response and a series of other capabilities and build a multidimensional reconnaissance and rights protection system that they can to meet the needs of offshore law enforcement and offshore rights protection. The US Coast Guard, for example, is now equipped with the Hermes 450, MQ-8B fire Scout and Scan Eagle unmanned aircraft, which have extensive unmanned reconnaissance and strike capabilities. The Indonesian marine police are mainly equipped with CH-4 unmanned reconnaissance aircraft, which are mainly used for routine rights protection and law enforcement missions.

Based on the analysis of existing data, most of the marine police UAVs of major Asia-pacific countries are medium-sized UAVs taking off and landing from shore, while there are few shipborne UAVs, which are only equipped by a few countries. Compared with shore-based unmanned aerial vehicle, carrier-based unmanned aerial vehicle is more restricted by the ship landing environment. Take-off and landing from a general marine carrier-based unmanned aerial vehicle considering its operational use requirements, more for long-endurance fixed-wing unmanned aerial vehicle uses the catapult launch, while the coastguard vessels under thousand tons may find it hard to provide infrastructure, so we should consider vertical take-off and landing fixed-wing unmanned aerial vehicle in the future. However, at present domestic vtol UAV, the mainstream is lithium battery powered navigation in 30-40 minutes or so, and carrying weight is limited; another limitation and coastal issues in the development of unmanned aerial vehicle is dynamic system. If we use lithium electric power battery pack for power supply, it is easy to be eroded by the damp and salt fog environment at sea, which reduces the battery life. If we want to increase service life and long endurance, marine fuel as power is a better choice. The reasons are as follows: first, it is convenient for replenishment at sea. And second, it can improve the problem of shipping time.

In this article, recent medium-range aircraft in situational awareness, target monitoring, emergency treatment of three scenarios corresponding key technologies and marine police unmanned aerial vehicle is a method of operational use key research, and algorithms and tactics affecting search, reconnaissance, cooperative control and other combat effectiveness of marine police UAV are elaborated, in order to provide theoretical support for marine police carrier unmanned aerial vehicle system using, joint three-dimensional patrols over waters under China's jurisdiction will be gradually realized.

2. TYPES OF MARINE POLICE'S UAV

There are three main types of marine police UAV: tethered UAV, rescue UAV and forward reconnaissance UAV.

2.1. Tethered UAV

Tethered multi-rotor UAV is an unmanned aerial vehicle

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with onboard power module and ultra-light photoelectric composite cable attached externally to ordinary multi-rotor UAV [1]. In case of emergencies such as maritime missions, the coast guard can send a tethered UAV equipped with airborne lighting facilities to assist. The UAV solves the problems of darkness at night, potentially dangerous waters, and the need for mobile lighting for large-scale missions.

The UAV is integrated with ground power supply, high-performance power supply cable and automatic retracting and retracting device, which is characterized by the use of tethered power mode to provide continuous power to the UAV. The mooring power supply mode converts the single-phase AC power into dc high voltage, and then transmits it to the airborne power supply through the high-performance nickel alloy power supply cable, so as to achieve the purpose of power supply for the aircraft for a long time, supporting 24 hours hovering in the air.

2.2. Rescue UAV

The rescue UAV is an emergency search and rescue UAV integrating image acquisition and analysis and relief materials delivery. It is used by the marine police force to search and rescue the missing or dead people.

The UAV usually adopts the design method of combining rotorcraft and fixed wing UAV, and carries optical, infrared and other search equipment. Its advantage is that it has both the characteristics of vertical takeoff and landing of rotorcraft and the characteristics of long endurance and fast flight speed of fixed wing aircraft. It can better realize the functions of precise self-stability, fixed height and fixed-point hovering. Compared with the traditional human sea tactics, which require large manpower and material resources and have low search efficiency, the rescue UAV has fast search speed, wide search scope and significantly improved search effect [2].

2.3. Forward reconnaissance UAV

Reconnaissance UAV is an unmanned aerial vehicle system that integrates a variety of reconnaissance sensors to provide various data transmission [3]. When faced with sudden, uncertain and concealed maritime illegal and criminal activities, the marine police dispatch highly mobile drones to investigate. The UAV quickly captures the sea surface information and transmits the information in real time, providing the coast Guard with accurate location and tracking information, making it easier for the coast guard vessels to deploy and control accurately.

The UAV makes up for the deficiency of direct control effectiveness and overcomes the obstacles brought by criminal investigation.

This UAV is composed of DSP quadrotor UAV flight control platform and reconnaissance sensor, which has the advantages of modularity, low cost, wide application range and real-time information transmission [4]. During the execution of the mission, the reconnaissance UAV can realize scene acquisition and panorama construction for the reconnaissance area. At the same time, it can carry out target tracking and multi-scene fusion algorithm research, and transmit the tracking results in real time. Further adjusting the route of UAV, it realizes real-time data collection and storage through sensors, and carries out data transmission with GPS as the representative of mobile communication network.

3. ANALYSIS OF TYPICAL USAGE SCENARIOS AND REQUIREMENTS OF MARINE POLICE UAV

The marine police vessels in the new era need to be capable of carrying out diversified military tasks. According to the 6 missions of the marine police, we focused on the analysis of UAV use requirements in various mission scenarios, like marine rights protection law enforcement and anti-terror operations, and clarified the role positioning of UAV in mission scenarios.

3.1. Maritime situational Sensing

The situation sensing system of marine police's UAV is an integrated patrol prevention and control project with UAV assistance and firing control function [5]. The main mode of marine police UAV is ship-borne flight near sea area. Situational awareness missions are characterized by flexibility, intelligence and high speed, which expand intelligence, surveillance, target acquisition and reconnaissance missions. Compared with patrol vessels, patrol UAV of the Coast police has a wider range, which is more conducive to the maritime supervision department to grasp the dynamic information of ships at sea in a timely manner, and can implement remote transmission of image data to the large command center through 5G communication network [6], providing information with more timeliness and decision value for emergency decision-making to efficiently complete maritime patrol. In addition, it can also be widely used in the daily patrol of islands and surrounding waters to prevent piracy and improve the effectiveness of comprehensive monitoring and management of piracy.

3.2. Marine target surveillance

Due to the duty and mission of the marine police, it may be faced with carrying out monitoring and protection of specific targets at sea in the future, which mainly includes two aspects: on the one hand, regional surveillance, demarcating a sea area according to protect the targets of ships passing in the sea area. On the other hand, accompanied surveillance, carrying on the accompanying protection to the vessel that needs to be protected.

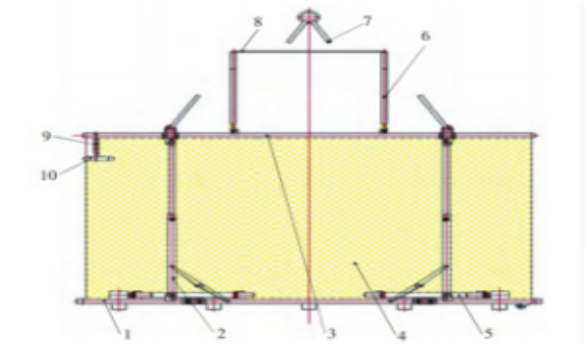
Furthurmore, the marine police is faced with the problem of multiple directions of attack threats and large areas of sea protection. In the traditional model, merchant ships need to set up their own guard points, but for the ordinary ships are not trained in professional guard patrol, they are difficult to provide good reconnaissance effects. Therefore, combined with the characteristics of the action style, the Marine police UAV can be used to give early warning to the maritime area, provide protection in the

area or around the formation, and carry certain equipment to fire away when necessary. In addition, the target surveillance function of marine police UAV promotes the establishment of a marine law enforcement system with clear rights and responsibilities by the China Marine Police Bureau. The traditional marine police vessels are basically in the state of horizontal rights protection when performing the tasks of marine rights protection and law enforcement. They often use surface ships and their formations to monitor and drive away enemy targets, especially in law enforcement operations in gray areas at sea. Marine police ships and other ships participating in daily rights protection often use ramming, jumping and other tactics. These methods can easily lead to equipment damage, which may endanger human life. Marine reconnaissance means mainly based on coast police UAV can provide efficient and reliable decision support for relevant law enforcement work through UAV multi-frequency, high-time-phase aerial photography, image processing and analysis, and establishment of database and management platform [7].

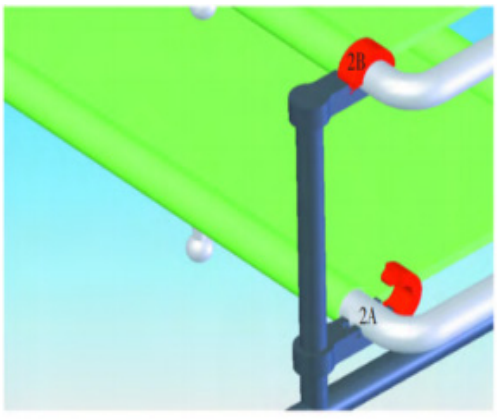
3.3. Marine Emergency Response

Through a series of maritime emergency responses such as reconnaissance and surveillance, target judgment and threat assessment, marine police UAV realizes maritime anti-terror operations, expanding China's marine anti-terror operations area by several orders of magnitude.

Photoelectric reconnaissance UAV by assembling, can intercept the enemy targets of photoelectric information and real time back to the base station on the ground, at the same time, the UAV can be equipped with electronic reconnaissance equipment, access to the enemy electronic signals and the accumulation of radiation source parameters of basic information database [8] compare analysis, grasp the other communications equipment deployment situation, provide information support for the fight against terrorism. Relying on the real-time link system, the marine police UAV shares the target parameter information with the shipborne shooting unit, conducts target analysis, and realizes the precision guidance of shipborne weapons. Carrier-borne UAVs can be equipped with non-lethal weapons and automatic shooting guns. Through the target information obtained from early reconnaissance, the target can be captured and tracked, and the shooting elements can be calculated to complete the rapid shooting or blocking shooting of small moving targets at sea. In marine emergency rescue and disposal, the marine police UAV has the additional capacity of carrying and launching, which can carry out emergency transport of medical supplies within a limited time and is also suitable for long-distance delivery. In addition, the UAV can also transfer blood samples of people in disaster areas, helping medical teams to carry out treatment work at the fastest speed. Marine police UAV can also transport the injured at sea. Evacuation of the wounded is an important link in the rescue process, but also often difficult. Emergency medical UAV [9] will carry out the transport of the wounded in different environments. The traditional wayside method has high requirements on transportation equipment and transportation environment, while the wayside basket transfer assisted by the marine police UAV [10] reduces the resource demand, improves the safety, efficiency and stability in the process of transporting the wounded, and greatly reduces the casualty rate. The disadvantage is that each time can only carry out a small number of wounded transfer, high cost. The basic structure design of the hanging basket is shown in Figure 1.



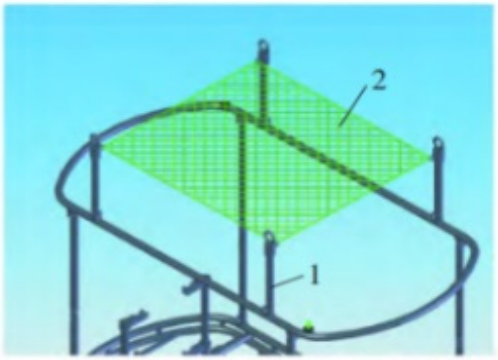
Frame



Note: 2A indicates open state and 2B indicates locked state

Stretcher fixing device

Glowing lightning bolt



Safety agencies

Figure 1 Basic structure of the gondola interchange [10]

4. OPERATION AND APPLICATION OF MARINE POLICE UAV

Intelligent war is coming, in the unmanned combat technology and equipment development, under the impetus of the marine police unmanned aerial vehicle with someone intelligent decision-making system of high efficiency in support of close air support, air cover aspects such as operations, air operations technology significance, can greatly improve the air forces in air defense to suppress the role of efficiency and meet the needs of the many scenes of operational application.

4.1. Working together &Conducting Divisional Search

In terms of maritime situational awareness, surface ships have the advantages of long endurance and comprehensive equipment loading when conducting marine search, but they cannot operate continuously and efficiently because of their small load and poor endurance. Therefore, the ship-to-aircraft cooperative search mode fully combines the advantages of ships and UAVs. Through information sharing and fusion, behavior interaction and cooperation, and task cooperation, functions are complementary, energy efficiency is doubled, and search capability in complex environment is improved.

UAV search model has two types: transverse line search [11] and spiral line search [12]. Under the transverse-line model, the search area of ship and marine police UAV synergistic action is as follows:

$$2V_A d_1\left(t-\frac{a}{V_{A\max}}\right)+2V_B d_2 t=a^2 \qquad (1)$$

Including:

Speed of the marine police UAV along route A

$V_{A\max}$: Maximum speed of the marine police UAV along route A

d_1 : The width of the unilateral visual search area of the marine police UAV

V_B : The speed of the ship along route B

d_2 : The coverage width of a ship's unilateral visual force

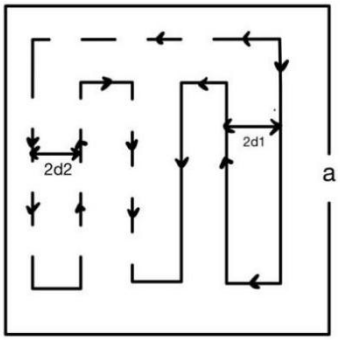


Figure 2 Traverse line search schematic diagram

Based on the horizontal line model, the spiral model takes into account the influence of wind and other factors on the speed of the marine police UAV during the turning process, so the search speed of the marine police UAV is controlled at 80% of the original flight speed to ensure the effectiveness and rationality of the search process. Under this model, the search area under the cooperative action of ship and marine police UAV is as follows:

$$\frac{8}{5}V_A d_1\left(t-\frac{\sqrt{(a-d_1)^2+a^2}}{V_A}\right)+\frac{8}{5}V_B d_2 t=a^2 \qquad (2)$$

The parameter Settings are the same as in the traverse line model

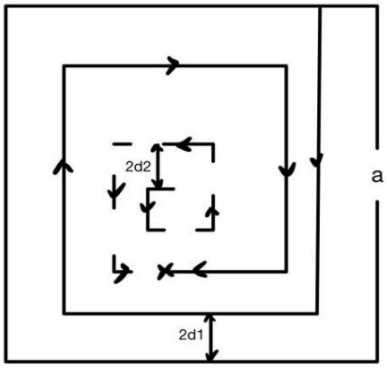


Figure 3 Schematic diagram of helix search

4.2. Stereo Reconnaissance & Fast Forensics

Shipborne UAV can reduce the influence of earth curvature and enlarge the field of view of reconnaissance. It can use the photoelectric equipment carried by the carrier-borne UAV to provide correction basis for rear carrier-borne artillery, improve the accuracy of observation, and fulfill the function of marine target monitoring. In the forensics link of maritime arrest, because the involved scene is often wide in scope, complicated in terrain, the illegal point is large in size and irregular in shape, and the criminals are mostly hidden. The marine police is often faced with the problem of destroying evidence at sea. Therefore, the marine police need to use the marine police UAV to quickly obtain evidence by using photoelectric reconnaissance equipment before destroying the target at sea. Through aerial photography and remote sensing technology, law enforcement officers can quickly and timely obtain information of the crime scene, and develop appropriate strategies through aerial photography of the surrounding environment. With the help of the scientific and technological guarantee of UAV, the advantages of its ultra-high definition video, high altitude shooting, wide range of terrain, dynamic tracking can help to improve the efficiency of forensic work and improve the quality of case handling.

The sensor used in the detection range of UAV is a fixed digital camera, without the panyard and other systems. Its basic model is shown in the figure below.

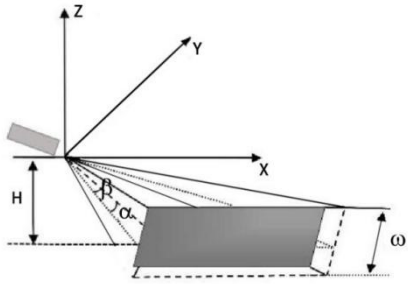


Figure 4 Sensor detection model

Thus, we can define the detection range of the UAV sensor at a certain flight altitude

$$r = 2H\tan(\gamma)\left[\cos\alpha + \sin\alpha\tan\left(\frac{\pi}{2} - \alpha - \beta\right)\right] \tag{3}$$

Among them, H represents the flight altitude of the UAV, α represents the included Angle between the sensor and the ground, and β represents the field of view Angle of the sensor.

UAV reconnaissance accuracy is based on digital camera sensors, which are generally limited by their pixel density. Regardless of the impact of natural environmental factors such as light, rain and fog, its detection accuracy is directly determined by the flight altitude of the UAV. The target detection probability can be expressed as:

$$p = \frac{k}{d^3} \tag{4}$$

Detection probability P_d : describes the presence of a target in the area and the detection of the target by the UAV. This performance is mainly related to sensor performance and image algorithms.

False alarm probability P_f : describes the presence of a target in the area incorrectly detected by the UAV. It can be seen from the sensor detection model that in a certain range, the sensor accuracy mainly depends on the accuracy of the image algorithm, and the detection accuracy will decrease with the increase of the distance. The sensor detection model can be simplified.

$$p(d_k) = \begin{cases} P_d & (d_k < d_{\min}) \\ P_d - \dfrac{(P_d - P_f)(d_k - d_{\min})}{d_{\max} - d_{\min}} & (d_{\min} \le d_k \le d_{\max}) \\ P_f & (d_k > d_{\max}) \end{cases} \tag{5}$$

$p(d_k)$ is the detection probability at the KTH moment of action, $d_{\min}$ is the upper limit of the optimal detection distance of the sensor, and $d_{\max}$ is the maximum effective detection distance of the sensor.

After the unmanned aerial vehicle performs the reconnaissance task, it turns into the attack state, and A* algorithm is planned to be used to solve the problem in the course planning of the attack section. Based on the heuristic search structure, the traditional algorithm comprehensively evaluates the generation value of each extension node and compares its size to make a selection, so as to find a path with the lowest cost between the starting point and the ending point. The essential difference or improvement between algorithm and algorithm is the use of evaluation function:

$$f(n) = g(n) + h(n) \tag{6}$$

f(*n*) represents the evaluation function of the current node n; g(n) represents the generation value from the initial track point to the current track node n. h(n) represents the estimated generation value from node N to target track node, which is the most important heuristic information in the algorithm. It can be seen that the algorithm not only introduces global information when checking each possible node, but also makes scientific calculation of the generation value of the current node from the target node for and to guide the forward direction of the node.

4.3. Efficient Coordination & Distributed Control

In cases of marine emergency response, the survival ability of a single UAV is challenged more and more in air combat due to the limitation of its task execution [13]. In the face of complex operations, rescue and other tasks, the decentralized UAV cluster has the advantages of higher autonomy, robustness and resistance to destruction. In addition, UAVs and ships form a common cluster network to fully share data and video information flow in the network and achieve efficient command coordination. This mode has a low requirement for communication resources and is conducive to the effective development of systematic operations in the marine police. Clustering to the optimal point is the basis of realizing multi-aircraft cooperative combat, and its collaborative work flow chart is shown in Figure 5.

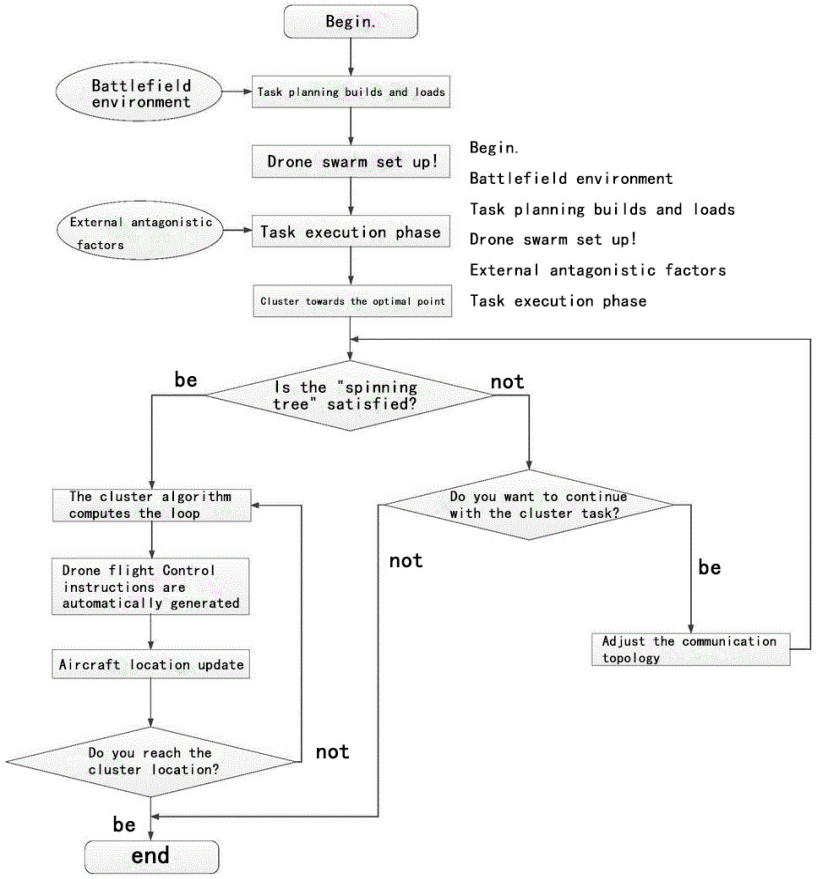


Figure 5 Cooperation diagram of Marine police UAV

In addition, with the increase of the number and density of space UAVs, how to efficiently use distribution control distribution principle has become an urgent problem to be solved. At present, the model of distributed formation of marine police UAVs means that all marine police UAVs can be controlled through the command and decision center and coordinate efficiently through data link and intelligent decision system. At the same time, information can be exchanged between adjacent UAVs through mutual negotiation. Compared with the traditional saturated centralized control, this model is more flexible and efficient, and finally realizes the integrated control of UAV formation. The functionality of distributed control is shown in Figure 6.

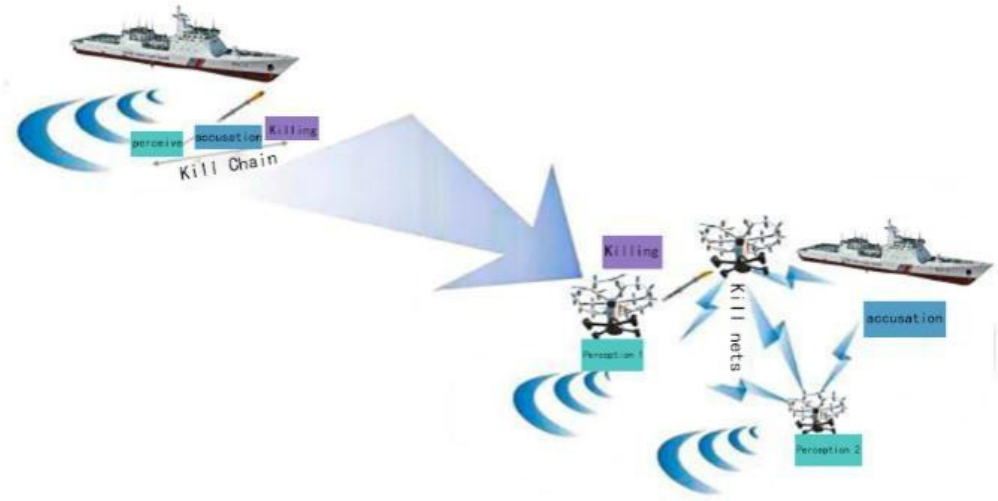


Figure 6 Function decomposition from single platform tomulti-platform based on distributed control

In the emergency processing process of marine police UAV under the principle of efficient coordination and distributed control, the UAV will receive map information from other surrounding UAVs in every action and perform weighted fusion. Its expression can be expressed as:

$$P_{uav_i\_new} = \sum_{\substack{j=1 \\ j\neq i}}^{n} \frac{1}{d_{ij}} P_{uav_i} + \left(1 - \sum_{\substack{j=1 \\ j\neq i}}^{n} \frac{1}{d_{ij}}\right) P_{uav_i} \quad (7)$$

P_{uav_i} represents the target probability map of the ith UAV, $P_{uav_i\_new}$ represents the target probability map of the ith UAV after fusion and update, and d_{ij} represents the distance between the ith UAV and the j UAV.

In order to quantitatively prove the impact of UAV cluster collaboration on search performance, the target map was divided into 30*30 grids and 100 targets were randomly generated. The maximum endurance of UAV is limited to 200 grid steps, and the field of vision of UAV sensor is 3*3 grid with UAV as the center. Different numbers of UAVs are simulated respectively.

It can be seen that increasing the number of UAVs can significantly improve the efficiency of target search. However, the improvement is not linear because multiple UAVs search repeatedly and the path is generally not the optimal path in the process of dynamic search. The four UAVs and five UAVs in the picture prove that blindly increasing the number of UAVs in the search process does not guarantee the improvement of search results. With the increase of UAVs, the redundant information will increase in the process of target probability map fusion, and the target search effect will also be affected.

Figure 7 The relationship diagram between the number of UAVs and the number of search and rescue targets

5. CONCLUSION

This paper introduces the types and functions of the marine police UAV, studies the operational application methods of the marine police UAV corresponding to the scenarios from the requirements of the three scenarios of marine situation awareness, target monitoring and emergency disposal, and expounds the algorithms and operational methods that affect the operational effectiveness of the marine police UAV. The application of marine police UAV has improved the ability of the national marine police to control the sea area under its jurisdiction, and gradually realized the joint three-dimensional patrol of the sea area under its jurisdiction. However, it also promoted the proposal of anti-UAV strategy and the rapid development of anti-UAV technology and equipment [14]. In the next step, the applicability of the algorithm and the maturity of key technologies will be considered, and the continuous innovation and development of the marine police theory will be promoted based on the application requirements of the marine police UAV and the changing situation of the application scenarios of the marine police UAV.

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