Task Allocation and Traffic Route Optimization in Hybrid Fire-fighting Unmanned Aerial Vehicle Network

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Abstract. With the increase of extreme weather conditions in the world, the probability of forest fires is increasing. How the forest fire management decision-making system can monitor and control the fire quickly and effectively is the key of forest fire fighting work. This paper uses SSA drones carrying high-definition and thermal imaging cameras and telemetry sensors in conjunction, as well as Repeater drones used to greatly expand the frontline low-power radio range, to support fire management decision-making systems. At the same time, explore a drone cooperation plan to deal with different fire terrains and different scales of fire conditions. The aim of this paper is to improve the existing fire management decision system in order to quickly respond to the emergency fire. Research object for the Australian state of Victoria on October 1, 2019 to January 7, 2020 wildfires, explore SSA drones and Repeater drones in the application of the forest fire, ensure that fire management decision-making system to provide the optimal number deployment scheme of fire task quickly and efficiently, and achieve the maximum efficiency and economic optimal compatibility.

Keywords: fire management decision system; SSA drones; Repeater drones; multi-objective planning.

1. Introduction

With the development of the concept of a community with a shared future for mankind, protecting and respecting nature has become the common responsibility of people all over the world, and the construction of ecological civilization is the top priority. In recent years, as climate warming has intensified, the frequency and intensity of global forest fires have also increased, and the potential risks of forest fires around the world will exist for a long time. (Jolly, W., Cochrane, M.&Freeborn, P,2015) Forest fires are one of the most serious ecological disasters in the world today. Due to their suddenness, great destructiveness, and extremely difficult disposal and rescue, they have had a major impact on forest ecological resources. (Xiao Dong et al.,2021) Therefore, how to effectively prevent forest fires has become a major issue worldwide.

With the continuous maturity of UAV technology, UAVs have been used in many fields such as weather detection, disaster monitoring and environmental remote sensing. In terms of forest fire detection, compared with infrared sensors, multi-spectral sensors, hyper-spectral sensors and other thermal imaging, the use of drones equipped with vision cameras for forest fire identification technology research has lots of advantages such as low cost, wide application range and simple operation. Compared with other rescue and fire fighting tools, UAVs have the advantages of being light and dexterous and able to overcome a variety of extreme environments in terms of forest fire rescue.(Chi Yuan, Youmin Zhang, & Zhixiang Liu,2014) In recent years, as the demand for emergency response to disasters continues to grow, the state has carried out a lot of research in the

fields of satellite remote sensing and unmanned aerial vehicles to explore the establishment of an integrated air-space-ground system. However, most of this type of research focuses on the field of UAV remote sensing technology, ignoring the importance of UAV resource allocation. As a result, the deployment location of drones is unreasonable, and it is difficult to obtain data in a large number of fire areas in time, which makes it impossible for the drone group to maximize the benefits during collaborative disaster relief, further causing personal injury and property loss.The multi-UAV dynamic reconnaissance resource allocation model has been established. Compared with the traditional static allocation model, it has the advantages of high reconnaissance efficiency and strong endurance, and it is more suitable for large-scale UAV cluster combat situations.(Zhao Xiaolin et al.2020)UAV is used as a relay, which is an effective technical solution for realizing wireless communication between long-distance terminals. It is the first time to jointly study the placement of UAV nodes and the allocation of communication resources in UAV relay systems.(R. Fan, J. Cui, S. Jin, K. Yang & J. An,2018)Considering user drone base stations with different requirements and transmission rates, a novel perception resource allocation scheme is proposed.(P. Lohan & D. Mishra,2019)There are few researches on the resource allocation of firefighting drones, and most of them are in the theoretical stage and lack practicality.

The problem of UAV resource allocation is inseparable from research on UAV layout and path planning.The problem of drone layout is essentially a problem of facility location planning. The problem of facility planning is mainly divided into three types: coverage problem, median problem and central problem. This research mainly studies the problem of information acquisition and transmission of the area where the fire occurs by the drone. It is a typical coverage problem. Coverage problems include maximum coverage problems and collective coverage problems. Maximum coverage problems mainly studies how to use a given service station to serve more service objects, and collective coverage problems mainly studies how to use the least service station to serve all service points. The research hopes that by planning the layout of drones, based on the minimum number of drones, the maximum firefighting efficiency and economic optimization can be achieved, which is a collective coverage problem.

UAV path planning refers to the design of a path that meets the optimal performance of the UAV based on the energy consumption, speed, and size of the UAV, taking into account factors such as terrain and environment.In recent years, UAV path planning is an open research topic that has attracted widespread attention from the academic community, and UAV path planning is a complex network optimization problem.However, from a functional point of view, a single UAV itself has only partial combat capabilities and is unable to undertake comprehensive tasks; from a safety point of view, a single UAV has weak anti-interference ability, flight range and scenarios Restricted, and once a failure or damage occurs, it means the failure of the mission.Therefore, path planning under the cooperative operation of multiple drones has gradually attracted attention.UAV path planning refers to the design of a path that meets the optimal performance of the UAV based on the energy consumption, speed, and size of the UAV, taking into account factors such as terrain and environment. In recent years, UAV path planning is a complex network optimization problem, which has attracted widespread attention from the academic community.However, from a functional point of view, a single UAV itself has only partial combat capabilities and is unable to undertake comprehensive tasks; from a safety point of view, a single UAV has weak anti-interference ability, flight range and scenarios Restricted, and once a failure or damage occurs, it means the failure of the mission.Therefore, path planning under the cooperative operation of multiple drones has gradually attracted attention.Based on a complete hardware and software architecture, creating coverage area track points and optimizing the track list can achieve autonomous and efficient area coverage by multiple drones(Hong, Y., Jung, S., Kim, S., & Cha, J.2021).The energy-constrained multi-UAV coverage path planning of aerial image missions generated by columns solves the limitations of traditional methods(Younghoon Choi et al.2020).Distributed multi-UAV task allocation and path planning iteration strategies are applied, which can achieve better planning result performance and consume less computing resources(Weiran Yao et al.2019).

When a forest fire occurs, the fire decision-making department must take remedial measures extremely quickly. Whether the fire fighting is timely and whether the decision is appropriate depends on whether the fire detection and response are fast. Therefore, the establishment of a decision-making plan for the resource allocation of firefighting drones is helpful to make fire-fighting task arrangements and control forest fires at the first time when a fire occurs, and is of great significance to forest fire prevention and treatment.

2. Literautre Review

With the increase of extreme weather in the world, the probability of forest fires has increased. Forest fires are one of the most serious public emergencies in the world. How to monitor and control forest fire insurance has attracted more and more attention. However, drones are gradually applied to the field of forest fires,due to their small size, fast moving speed, and high survey accuracy.

In recent years, with the development of unmanned aerial vehicle technology, since 2004, the application of unmanned aerial vehicle technology in the field of forest fire monitoring has begun to rise. UAVs can overcome the shortcomings of high cost, low credibility and poor real-time performance of forestry aerospace remote sensing, and the limited scope of traditional field detection and patrol. Based on the "early detection, early response" forest fire response guidelines, they have obtained extensive and fruitful results.The research and application can be roughly divided into two categories:

The first category is a single drone operation. A small fixed-wing UAV system that integrates location recognition, fire source detection and navigation control is designed to be used in forest fire monitoring(Alfredo Martins et al.,2007).A new type of forest fire detection visual system using color and motion features, which effectively extracts and tracks fire pixels in aerial video sequences, improves the accuracy of fire detection and reduces the false alarm rate(C.Yuan, Z. Liu&Y. Zhang,2016).The UAV system for forest fire automatic monitoring can rely on the information acquisition module carried by the UAV to achieve real-time control of the fire situation, and the system has passed the field reliability test(Luis Merino et al,2012).UAVs are combined with frequency continuous wave (FMCW) radar sensors to form a spatial distribution network, which can achieve full coverage of the monitoring area as well as improve the ability of forest fire safety prevention and the automation and digital level of forest fire warning(Coluccia, A., Parisi, G., & Fascista, A.2020).Based on the actual monitoring scenario, the machine learning application is applied to the drone wildfire detection process.The fire and smoke detection are compared, which proves the effectiveness of the detection (C.Alexandrov et al.,2019).

The second category is the cooperative operation of multiple drones. Compared with the single drone operation, this category better solves the problems of data quality and operation efficiency, and the stability of the operation in the forest area has been improved.Liu Yuxuan et al. (2020) proposed a multi-drone double-layer distributed control architecture for continuous forest fire reconnaissance. In the action layer, an artificial neural network (ANN) based on reinforcement learning training can be realized under windy conditions. The autonomous fire field surround and terrain following functions of the UAV have achieved the uniformity and immediacy of the time-domain distribution of the continuous forest fire detection by multiple UAVs; Martinez-de-Dios et al. (2007) are used in existing UAVs. GPS, conventional navigation and visual sensors were added to the platform to successfully verify the technical feasibility of multi-UAV forest fire reconnaissance through field measurements;Alexis et al. (2009) used fire field information sharing and re-calculation at the rendezvous point. Based on the hypothesis that the drones merge and turn back, the dynamic distribution of multiple drones in the forest field expansion line;.The use of artificial potential field multi-UAV collision avoidance method and intrusion detection system method improves the safety of the drone fleet and the accuracy of task assignment(Z.Fu, Y. Mao, D. He, J. Yu & G. Xie,2019).

Aiming at the research of UAV path planning, Wei Yongchao et al.(2021) proposed a UAV trajectory planning structure based on an improved bacterial foraging optimization algorithm, which

can effectively solve the current UAV trajectory planning method with slow convergence speed, low efficiency, and easy Fall into problems such as local optimality. Regarding the research of drones in the field of fire, the low-latency 5G network and fire disaster theory are applied to model and calculate the data obtained by drones,which provides dynamic disaster relief decision-making solutions(Yan Su et al.，2020).Sun Chunling et al. (2018) proposed an improved grid search algorithm based on the ant colony algorithm, so as to obtain a regional disaster inspection plan with a small number of drones, a short inspection time, and an excellent inspection route.A collaborative task planning method for heterogeneous multi-UAVs in complex three-dimensional mountain environments has been established to improve the effectiveness of UAVs in actual combat environments (H.Liu et al.,2020).The multi-drone forest fire-fighting system automatically replaces the battery and supplements the fire extinguishing fluid to ensure the continuity of rescue and provide a breakthrough means for extinguishing wildfires(Ausonio, E., Bagnerini, P., & Ghio, M.2021).A fire monitoring system based on perception algorithms is used to perform monitoring tasks and monitor specific areas, providing complete information about the fire and the drone itself(Al-Kaff et al.,2020).The set coverage problem is an NP problem, which mainly solves the problem of the optimal layout of service points through linear programming, and covers all service points with the least number of service stations.Fire station positioning and facility configuration models under different periods and emergencies (wars and natural disasters) are designed. The design of the model takes into account the needs and coverage radius of the facility, and the area is based on the dynamics of traffic and type(Vahid Hajipour et al.,2021).

However, most of the existing research still focuses on the monitoring and detection of forest fires, and there is very little research on multi-UAV operations that cooperate with staff to rescue and transmit information after a fire occurs. At the same time, there are very few researches on using two types of UAVs with different functions for collaborative task scheduling and deployment of the best combination of UAVs. This article pioneered the use of SSA drones carrying high-definition and thermal imaging cameras and telemetry sensors in conjunction with repeater drones used to greatly expand the frontline low-power radio range, in order to find a way to deal with different forest terrains and With the large-scale fire drone coordination model, under the premise of optimizing the full coverage of the radio repeater drone area and maximizing the benefit of the SSA drone area detection, determine the radio repeater drone and the SSA drone. Optimal quantity combination. The purpose is to provide the fire control decision-making department with the optimal number of drones deployment plan, so that the fire department can effectively and quickly complete the forest fire task, but also realize the maximum use of drones, and ultimately ensure the efficiency and economic optimization.This research takes the forest wildfires in Victoria, Australia from October 1, 2019 to January 7, 2020, as the research object, and discusses in detail the application and coordination of SSA drones and radio repeater drones in forest fires. It is hoped that the discussion on the application of hybrid drones in Australia's forest fires will help the global forest fire fighting and rescue work.

3. Problem Description

A large-scale forest fire occurred in a certain area, and the fire area covered a large area.In order to effectively and quickly fight fires and reduce unnecessary losses, and strictly control the fire area, the fire department takes into account many factors such as safety, observation and command, and establishes several emergency centers within a safe distance from the edge of the fire.The emergency center completes the frontier fire-fighting task, and the internal fire area is not taken care of by other emergency centers. The emergency center that has extinguished the fire will move forward and continue to perform the fire-fighting task until the fire is completely extinguished.

In order to control the disaster, the emergency center uses hybrid drones to assist in the fire fighting. There are currently two drones with different functions, namely the SSA drone and the radio repeater drone with high-definition, thermal imaging cameras and telemetry sensors.The former is responsible for monitoring and reporting frontline personnel’ s wearable device data, and the latter is responsible

for cooperating with the substantial expansion of the frontline low-power radio range, ensuring that personnel carrying handheld radio deployments maintain smooth communication with the corresponding emergency center.The reasonable resource allocation of the two hybrid drones helps frontline rescuers to quickly complete the firefighting mission.At the same time, considering that the power of the drone is limited and it needs to be charged back home, when constructing the hybrid drone task allocation plan, it is necessary to reasonably plan the alternate work plan between the hybrid drones according to the time of the drone charging and flying, so as to make the benefits. maximize.

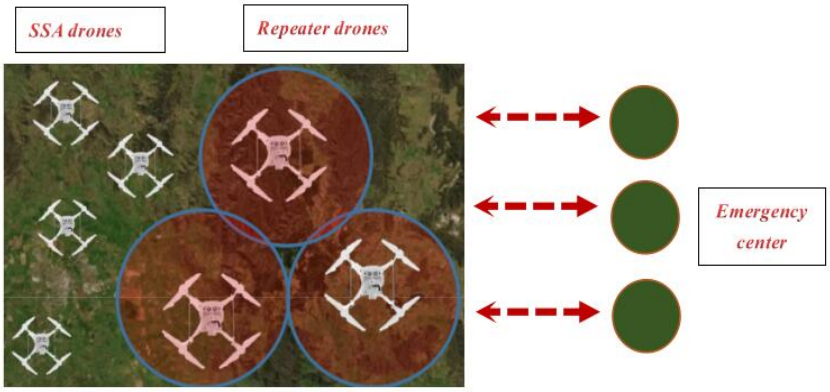


Figure 1. Emergency center and hybrid drone fire fighting scene

The range that the drone can cover is a circle with EOC as the center and R as the radius. The radius calculation formula is:

$$R = \frac{1}{2}d + \min\{\alpha \cdot r_1, \beta \cdot r_2\} \tag{1}$$

Further roughly calculate the number of EOC as:

$$m = \frac{c}{\sqrt{R^2 - d'^2}} \tag{2}$$

The working time sequence of drones: Due to the uncertainty of the duration of the fire, the life time of a drone is limited, so when a drone returns to the EOC for charging and leaves its target track point, there must be a new drone will take its place. Take the maximum flight time of the drone $t_{max} = 1.25h$ and the charging time of the built-in battery $t_c = 1.75h$ as an example:

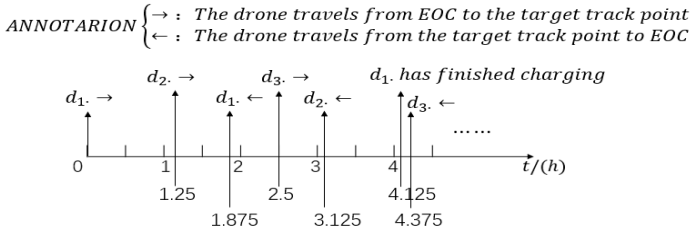


Figure 2. Schematic diagram of the alternate working time sequence of drones

The research content of this paper: Under the premise of optimizing the full coverage of the radio repeater drones area and maximizing the benefit of the SSA drones area detection, determine the optimal combination of radio repeater drones and SSA drones. The purpose is to provide the optimal number of drones for the fire department's decision-making system, so that the fire department can not only complete forest fire tasks effectively and quickly, but also maximize the use of drones, and ultimately ensure efficiency and economic optimization.

The research question hypotheses are as follows:

(1) All drones are charged at their own EOC;

(2) The range of the hovering radio repeater drone is a cylinder with itself as the center of the circle;
(3) The severe fire situation in each area has been determined by advance reconnaissance;
(4) All UAV flight paths are approximately straight lines;
(5) Considering safety factors, each EOC is distributed near the periphery of the fire area;
(6) All drones start from the EOC to perform tasks;
(7) All drones work alternately and must not terminate the mission.

4. Model Building

Table 1 listed the notations that will be used in the models.

Table 1 Notations

Notations	Description
r_1	Monitoring radius of SSA drone (km)
r_2	Range radius of relay drone (km)
d	Maximum flight distance of drone (km)
c	Perimeter of fire region (km)
$t_{\max}$	Maximum flight endurance of drone (hour)
t_c	Charging time of drone built-in battery (hour)
α_i	Influence factors of different terrain on detection radius of SSA drone
β_i	Influence factors of different terrain on range radius of Radio Repeater drones
P_i	The i-th grid region in EOC
Q_j	The j-th SSA drone sent by EOC
M	The number of grids in EOC partition region
N	Number of SSA drones in EOC region
i	Batch number of Radio Repeater droness
m	The number of small squares marked 1
n	Number of relay drones in EOC region
d_{ij}	Denotes the j-th Radio Repeater droness of the i-th batch

4.1 Environmental Map Model

During the UAV's fire fighting mission, different terrains interfere with the UAV to different degrees. To facilitate research, first construct a three-dimensional environment map model, and then project the three-dimensional environment map onto a two-dimensional plane to determine the degree of interference of different terrains to the UAV to determine the effective range of the UAV.

Use function expressions to characterize and describe different environmental factors and constraints, such as formulas:

$$z(x,y) = \sin(y+a) + b\sin(x) + c\cos(d\cdot\sqrt{x^2+y^2}) + e\cos(y) + f\sin(f\cdot\sqrt{x^2+y^2}) + g\cos(y) \quad (3)$$

In this formula: a, b, c, d, e, and f are all constant term coefficients, and different map models can adjust various parameters for representation; x, y are the horizontal and vertical coordinates of a specific point in the airspace of the map model; z is the height value of the point.

Since the drone's flying terrain is mountainous, its range and flight route will be affected by the terrain, so the above formula changes are adjusted to a formula suitable for mountainous terrain:

$$z(x,y)=\sum_{i=1}^{k}(h_i \exp\frac{(x-a_i)^2}{m_i}-\frac{(y-b_i)^2}{n_i}) \tag{4}$$

In this formula: hi is the limit value of the height of the mountain; ai, bi are the coordinates of the center of the mountain; mi ni is the slope information of a specific point in the mountain terrain. By adjusting the above parameters, digital models of different types of mountains can be constructed.

In order to show the covered area more intuitively, project the three-dimensional map model to the two-dimensional plane to get mountain topography map.The two-dimensional position of the drone can be expressed in coordinates (x,y), and the three-dimensional position can be expressed as(x,y,z) , where z is the contour value at the point(x,y).

Regarding the area between every two contour lines as the same type of terrain, at the same time, to protect the drone from serious damage, if the heat generated by a fire in a certain area exceeds Q, this area will be set as a no-entry area. The drones will not hover or pass through the area. As shown in the figure 3, the red area indicates the no-entry area.

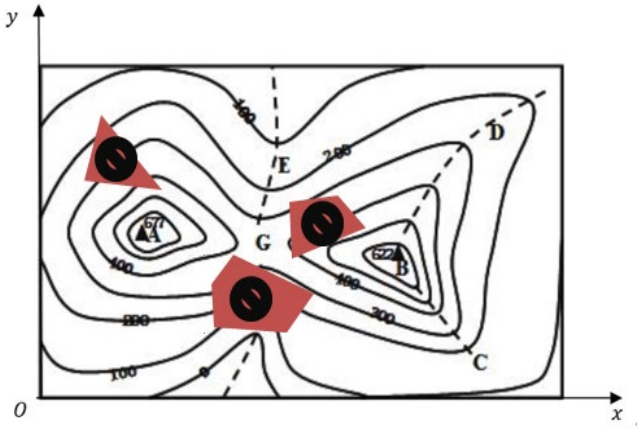
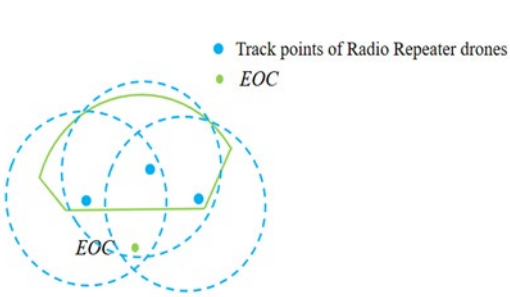


Figure 3. Environmental map model(Labelling prohibited areas)

4.2 Radio repeater drones full coverage optimization model

Since radio repeater drones are used to establish communication between EOC and frontline personnel, in order to ensure all-round real-time communication between them, the range of all radio repeater drones should completely cover the EOC responsible area. In the case of achieving full coverage, it is the most economical to ensure that the number of drones is the least.

First, study the hovering situation of a batch of radio repeater drones: n indicates the number of drones that can achieve full coverage of the area, and βr_2 indicates the coverage radius of the radio repeater drone , then the problem can be transformed into finding n circles with a radius of βr_2 to cover the entire area, and the center of the circle is the target track point. The UAV flies in an approximate straight line from the EOC to the target track point, and starts hovering after reaching the target track point.



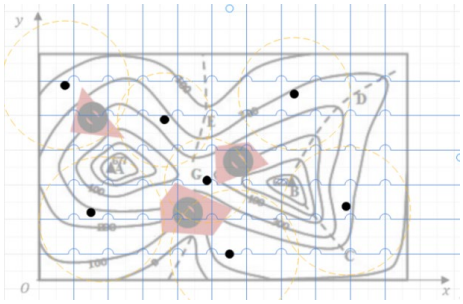


Figure4. Schematic diagram of wireless repeater drone covering fire area Figure5. Grid environment map

The original environment map is gridded, the black dots represent the location of the drone, and the yellow dotted circle represents the range of the drone at that point. When the area of the small square covered by the circle is greater than 50%, it can be approximately considered that the small square is completely covered. Initially, each small square in the grid environment map is marked as 0. Take the particle as the center and the radius βr_2 as the circle to simulate the target trajectory point of each UAV. Finally, use the fewest particles to mark all the small squares in the area as 1.

4.3 SSA drones region coverage detection model

Still only studying the detection situation of a batch of SSA drones: The mission of SSA drones is to continuously monitor and perceive the area of interest, that is, area coverage detection. In the grid environment map, each grid is assigned a different detection value according to the fire situation.

The model of region coverage and detection target allocation

In the drone region coverage detection target allocation model, the evaluation indicators that determine the object of the drones to perform coordinated detection tasks mainly include mission profit and mission cost. The goal is to use the least number of SSA drones to detect the maximum mission revenue value from an economic point of view.The SSA drones detection task allocation model is obtained as

$$\min \sum_{i=1}^{M}\sum_{j=1}^{N} x_{ij}(\omega_2 Z_{ij}^2 + \omega_3 Z^3 - \omega_1 Z_{ij}^1)$$

$$s.t.\begin{cases} \sum_{j}^{N} x_{ij} = 1, \forall i = 1,2,...,M \\ \sum_{i,l\in L_j} S_{il} + S_{in} + S_{out} \le d \\ \sum_{j=1}^{N}\sum_{i=1}^{M} x_{ij} = M \end{cases} \tag{5}$$

In this formula, $\omega_1, \omega_2, \omega_3$ are the weight of different goal respectively and satisfy

$$\sum_{i=1}^{3} \omega_i = 1$$

Maximize mission profit

Mission profit refers to the amount of fire information obtained by SSA drones after detecting the grid area Pi. The greater the detection value of the grid area Pi, the more fire information SSA drones can obtain. Therefore, the detection value of the grid area can be used to define the mission profit of SSA drones, which can be normalized by the linear scaling method as:

$$Z_{ij}^1 = \frac{\gamma_{ij} V_{P_i}}{\max_{i\in M} V_{P_i}} \tag{6}$$

In this formula, symbol Z_{ij}^1 indicates mission profits of drone detection grid area;symbol γ_{ij} indicates probability of drone to detect grid area;symbol V_{P_i} indicates the detection

value of the i-th grid area in the area divided into EOC (that is, the irregular region covered);M indicates the number of grids in the EOC division region.

Minimal mission cost

The mission cost refers to the cost that the drone may be hit by unexpected conditions such as fire during the execution of the mission. It is mainly affected by the probability of fire threats to drone strikes. This probability is approximately considered to be affected by the size and frequency of the fire event, so it can be used that the detection value of the grid approximates the threat probability. The mission cost is normalized as

$$Z_{ij}^{2} = \frac{\left(1 - \prod_{i=1}^{N}(1 - x_{ij}d_{ij})\right)V_{Q_j}}{max\, V_{Q_j}} \tag{7}$$

In this formula, symbol d_{ij} indicates threated probability of the grid area P_i to the drone Q_j;symbol x_{ij} indicates decision variable. If j-th SSA drone detects the grid area P_i,symbol x_{ij} is 1.Otherwise it is 0.Symbol V_{Q_j} indicates the value of the drone itself.

Minimal the number of SSA drones

Considering economic issues, use as few SSA drones as possible to meet the detection requirements. According to the drones deployment analysis, it can be known that an EOC which has 10 drones can meet the conditions. It is hoped that the number N of SSA drones is as small as possible to avoid the impact of this goal being greater than the first two goals, so let

$$Z^{3} = \frac{N}{10} \tag{8}$$

In this formula, N divided by 10 is to ensure that the range of Z^3 is from 0 to 1.

Constraint on completion of detection mission

Each grid area is detected by one SSA drones, that is

$$\sum_{j}^{N} x_{ij} = 1, \forall i = 1,2,\ldots,M \tag{9}$$

In this formula, symbol x_{ij} is Boolean variable to express decision. If the detection grid area of the first SSA UAV is 1, it is 0 otherwise. Each area of interest coverage detection mission is completed by one and only one drone.

Constraint on flight distance of SSA drones

The total distance of each SSA drone can not exceed the flight distance $d = 30km$, that is

$$\sum_{i,l \in L_j} S_{il} + S_{in} + S_{out} \leq d \tag{10}$$

In this formula, symbol S_{in} indicates the distance from EOC to the center of the first grid area by the SSA drone. S_{out} indicates the distance from the last grid area detected to the EOC by the drone and the distance of flight path by the j-th SSA drone. The total distance is not greater than the maximum distance that the SSA drone can fly.

Constraint on the number of tasks

The number of grid areas detected by the drone is equal to the number of grids in the EOC divided area, that is

$$\sum_{j=1}^{N}\sum_{i=1}^{M} x_{ij} = M \tag{11}$$

In this formula, symbol x_{ij} is decision variable.M is the number of grids in this EOC division area.

Region coverage detection time allocation model

The detection time allocation of area coverage determines the time required for UAV to perform tasks, and the detection revenue is mainly affected by the working performance and detection duration of UAV airborne sensors.The detection revenue of UAV is proportional to the detection time

$$R_i(t) = 1-(1-R_0)e^{-\delta_i t_i} \tag{12}$$

Among them, R_0 is the initial information of UAV to the grid region P_i; δ_i is the detection performance index of airborne detection sensor to the region of interest;

The detection performance index of airborne sensor is mainly affected by the detection range of sensor per unit time and the coverage region of grid region. The expression is

$$\delta_i = \frac{2vs_1}{S_i} \tag{13}$$

In this formula, v is the flight speed of UAV; s_1 is the scanning width of airborne sensor detection coverage; S_i is the region of interest coverage. From the previous formula

$$R_i(t) = 1-(1-R_0)\exp(-\frac{2vs_1}{S_i}t_i) \tag{14}$$

It is assumed that the initial information of each grid region is 0 before the start of the SSA drone detection task. To ensure that the UAV can obtain effective information every time, there should be a minimum information revenue constraint $R_{i\min}$ for different regions of interest, and the total flight time of the UAV to perform the task should not exceed the maximum flight duration. The time allocation of region coverage detection can be expressed as the problem of maximizing the revenue function. The objective function and constraints are as follows:

$$\max \sum_{i=1}^{M} c_i[1-\exp(-\frac{2vs_1}{S_i}t_i)]$$
$$s.t.\begin{cases} c_i[1-(1-R_0)\exp(-\frac{2vs_1}{S_i}t_i)] \geq R_{i\min} \\ \sum_{i=1}^{N} t_i \leq t_{\max} \end{cases} \tag{15}$$

5. GA-PSO particle swarm optimization algorithm

The cooperative task assignment problem of UAV is a typical MTSP problem. Since the MTSP problem is an NP problem, if an accurate method is used to solve it, the amount of calculation will increase exponentially as the number of grids increases. Therefore, modern heuristic algorithms are usually used to solve the problem. The traditional global particle swarm algorithm is to reproduce all individuals and the best individuals of the group to produce the next generation, which is easy to cause problems such as premature convergence and falling into local optimal values. For the standard genetic algorithm, although the diversity of solutions can be ensured by crossover mutation, it has problems such as huge time-consuming and weak global search ability. Therefore, this paper adopts the GA-PSO algorithm which combines the advantages of standard particle swarm algorithm and genetic algorithm. In the GA-PSO algorithm, the individual update is crossed with the individual optimum and the group optimum.In the reproduction process, the crossover and mutation operations similar to those in the genetic algorithm are added, so it can avoid converging to the local optimum.

Step 1:Individual code

The individual particle coding adopts an integer coding method. The length of the chromosome is n+m-1, and the first n digits of the chromosome are random integers arranged in random order. After sorting by size, it is the order of the drone to each detection area. The last m-1 bit is the label of the

position of the breakpoint, and the breakpoint is used to indicate the allocation of UAVs in each detection area.

Step 2:Population initialization

Set the number of individuals, the probability of crossover and mutation.

Step 3:Fitness calculation and selection strategy

The fitness function is the objective function, and the individual with the highest fitness function is used as the parent for reproduction, and other individuals are deleted.

Step 4:Crossover operation and mutation operation

The particle update formula is as follows:

$$\mathrm{v}[\,] = \omega \mathrm{v}[\,] + \mathrm{c}_1 \times \mathrm{rand}^1(\,) \times (\mathrm{pbest}[\,] - \mathrm{present}[\,]) + \mathrm{c}_2 \times \mathrm{rand}^2(\,) \times (\mathrm{gbest}[\,] - \mathrm{present}[\,])$$
$$\mathrm{present}[\,] = \mathrm{present}[\,] + \mathrm{v}[\,] \tag{16}$$

In this formula :$\omega v[\,]$represents the mutation operation in genetic algorithm;$c_1 \times rand^1(\,) \times (pbest[\,] - present[\,])$represents that the current individual extreme value and the individual historical optimal value are cross-operated; $c_2 \times rand^2(\,) \times (gbest[\,] - present[\,])$represents the cross operation between the current individual and the historical optimal value of the population.

Judge whether the fitness value of the new individual obtained after the cross mutation operation is better than the original individual, if it is better, select the new individual, otherwise it will be eliminated.

Step 5 : Algorithm termination criteria

When the number of iterations reaches the maximum number of iterations or the fitness value after updating the individual is less than the accuracy requirement, the difference between the fitness value of the original individual and the fitness value of the original individual.

6. Case analysis

This article selects the wildfire point data source in southeastern Australia provided by NASA (time: October 1, 2019 to January 7, 2020) for visual analysis, and preliminarily determines that the location of frequent fires in Victoria is east of 146° east longitude. Take the realistic fire-fighting mission scenario simulated in the previous article as an example, the fire-fighting drones and frontline firefighters in fire-prone areas cooperate to rescue.The range of handheld radios and drones is mainly affected by distance and various terrains. Assuming that a 10-watt handheld radio has a standard range of 10 kilometers in a flat and barrier-free area, it drops to 4 kilometers in urban areas; A 20-watt repeater can reach a range of 40 kilometers.

Table 2 Functional parameters of Akme's prototype hybrid drone

Flight range:35km	Maximum speed:30m/s	Maxinum flight time:3 hour
2 hour recharge time for the built-in battery		

6.1 Choose a specific study area

Since the radio signal is determined by the topography of the building, this study divided the study area into four types-rural flat type, rural high type, urban flat type, and urban high type. After investigation, it is found that the average radius of a city is about 15 kilometers. To simplify the model, all urban areas are regarded as circles with a radius of about 15 kilometers, and the rest are rural areas.

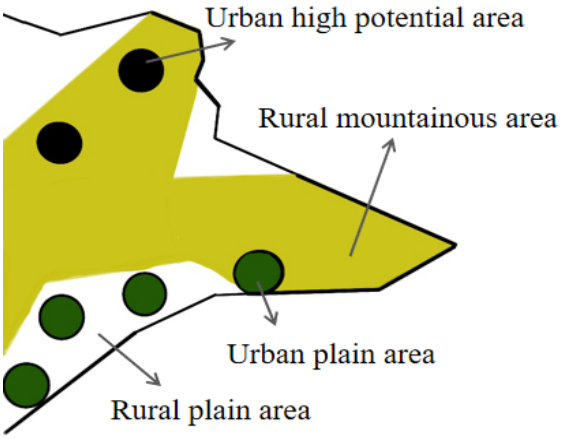


Figure 6. Simplified topographic map of southeastern Victoria

Table3. Interference factors of different terrain on detection radius and range

	Rural flat land	Urban flat land	Rural mountainous area	Urban mountainous area
α	1	0.9	0.8	0.7
β	1	0.8	0.6	0.4

6.2 Meshing the region of interest

Use Excel to process the information (including latitude, longitude, date, etc.) about fires in the eastern part of Victoria from August 2020 to January 2021, and visualize it on the map as follows. The darker the color, the higher the frequency of fires.

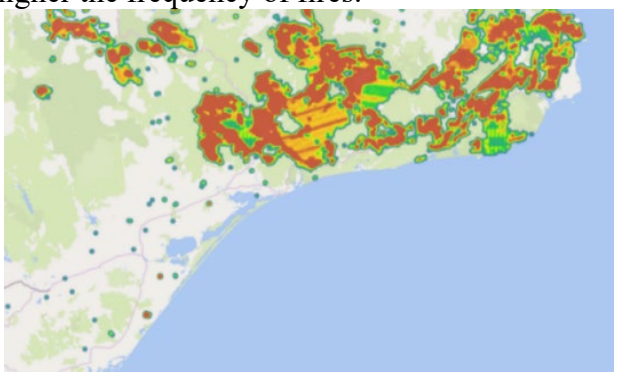
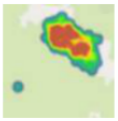


Figure7. Distribution of fires in eastern Victoria

This study divided the eastern part of Victoria in the figure 6 with a grid. The diagonal length of the grid is 2r1. The area represented by each grid has a different frequency and degree of fire occurrence. To measure the frequency and degree of fire occurrence in the grid, this study divided the detection value of fire areas based on the coverage of colored areas. The area ratio of the colored area defines the detection value of the grid area, which can be roughly divided into 5 levels. The specific conditions are as follows:

Table 3. Detection value of different grid areas

Detection value	Color coverage	Schematic diagram of grid area with different detection values
1	80%~100%	
0.8	60%~80%	
0.6	40%~60%	
0.4	20%~40%	
0.2	0~20%	

6.3 The optimal combination of SSA drones and Radio repeater drones and the number of drones deployed in Australia

According to the results obtained by MATLAB: For the fire area studied, the EOC needs to send 3 radio repeater drones and 2 SSA drones to cooperate with rescuers to complete forest fire fighting missions.

Based on the known area ratio of rural plains, urban plains, rural mountainous areas, and urban mountainous areas of 4:2:15:1, the average weakening factor $\overline{\alpha}$ of the SSA drone detection radius can be calculated by the terrain in the eastern part of Victoria, namely：

$$\overline{\alpha} = \frac{4}{22} \times 1 + \frac{2}{22} \times 0.9 + \frac{15}{22} \times 0.8 + \frac{1}{22} \times 0.7 \approx 0.84$$

In order to estimate the number of EOCs, the area responsible for an EOC is approximated as the slash area in the figure 7.

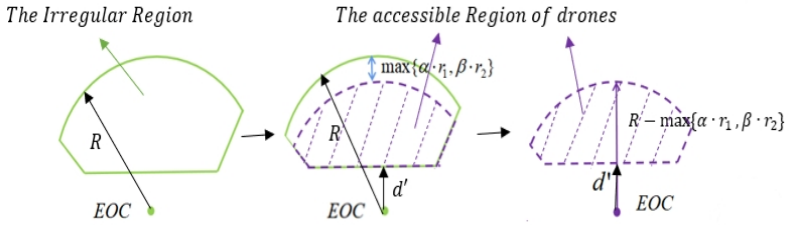


Figure 8. Schematic diagram of drone monitoring area

Assuming that the monitoring radius of the SSA UAV is 7 kilometers, $d' = 1km$, the average coverage circle size of the EOC in the eastern part of Victoria is obtained as：

$$S_{EOC} = \frac{\cos^{-1}\left(\frac{d'}{\frac{1}{2}d + \alpha r_1}\right)}{360}\pi \cdot \left(\frac{1}{2}d + \alpha r_1\right)^2 - \frac{1}{2}\cdot d' \cdot 2\sqrt{\left(\frac{1}{2}d + \alpha r_1\right)^2 - d'^2}$$
$$= \frac{\cos^{-1}\left(\frac{1}{\frac{1}{2}\times 15 + 0.84 \times 7}\right)}{360}\pi \cdot \left(\frac{1}{2}\times 15 + 0.84 \times 7\right)^2 - \frac{1}{2}\cdot 1 \cdot 2\sqrt{\left(\frac{1}{2}\times 15 + 0.84 \times 7\right)^2 - 1^2} \quad (17)$$
$$\approx 120.5 km^2$$

It is found that the average area of fires in the eastern part of Victoria in recent years is the number of EOCs established by dividing this area by the average coverage area of the EOC, which is about 1,660. It requires 3320 SSA drones and no relays. 4980 man-machines.

7. Conclusion

This article simulates the actual fire scene, makes reasonable assumptions that are consistent with reality, and proposes a new hybrid drone firefighting concept to quickly and effectively help frontline personnel to coordinate rescue; in the process of establishing the model, comprehensive consideration of different terrain and The impact of the scale of the fire on the drone, taking into account the dynamic changes of the fire, the introduction of multiple emergency center concepts to improve the adaptability of the model and the stability of solving practical problems; at the same time, on the basis of emphasizing the importance of the technology of the firefighting drone , More emphasis is placed on the importance of the rational allocation of resources for firefighting drones, and information management and calculations are essential for the construction of digital firefighting.

In addition to the above advantages, the research scope of this article also has certain limitations. The actual fire fighting scene is complex and changeable, and the probability of emergencies is high. There may be some errors in the models and theories involved. This research is more applicable to the work of static fire-fighting drones, and there are some constraints on the work of dynamic fire-fighting drones. In the future, we will strengthen the research on the work of dynamic firefighting drones, and also integrate dynamic and static models, incorporate more influencing factors, get closer to the actual firefighting scene, and land in actual combat.

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