ISSN: 2664-9640

Research on Scheduling Strategy of Fire Monitoring Drone Based on Greedy Algorithm

Tianyu Yu

Northeast Electric Power University, Jilin, 132011, China

Abstract

Frequent fires in Australia have displaced many small animals and residents. In order to effectively control the fire situation and solve the fire problem more quickly, it is of great significance to establish a reasonable drone deployment and cooperation system. In this paper, we used the drone integrated scheduling strategy model. Firstly, we transform the geographic information into two-dimensional coordinates for visualization. Later, under the influence of fire frequency and size, altitude and terrain, we establish a comprehensive income function. Secondly, we discrete the target inspection area, substitute the income function into the greedy algorithm to calculate the best inspection area and the number of SSA drones. And we use the cellular network model to get the optimal allocation strategy of Radio Repeater drones. Finally, it was determined that the best allocation of drones was 375 SSA drones and 125 Radio Repeater drones.

Keywords

Cellular network model, Greedy Algorithm, Drone Scheduling Strategy.

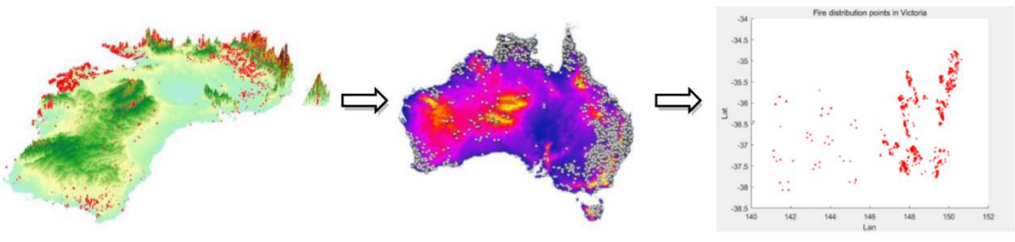
1. Introduction

The 2019-2020 fire season in Australia saw devastating wildfires in every state, with the worst impact in New South Wales and eastern Victoria. The wildfires occurred during a severe drought and persistent heat wave exacerbated by climate-change.[1]

Firefighters have used drones for surveillance and situational awareness (SSA) for several years; SSA drones carry high definition & thermal imaging cameras and telemetry sensors that monitor and report data from wearable devices on front-line personnel. Wearable devices can be used as Personal Locator Beacons or more complex environmental monitors. SSA drones help monitor the evolving situation, letting the Emergency Operations Center (EOC) best direct active crews for optimal effect and maximal safety.[2]

2. Data Preprocessing

When solving complex 3D space problems, we can set some conditions to transform them into simple 2D plane problems. According to the data in hand, we can get the topographic elevation data of Australia and the size and frequency of the fire in the recent period. With the help of MATLAB, we can get the figure about the data of most ignition points in Victoria.



(a)3D date (b)2D date (c) Fire distribution points in Victoria

Figure 1 Visualization of 2D Coordinates

ISSN: 2664-9640

It can be seen from the above part that the Victoria fire inspection area can be simplified as a two-dimensional plane. Therefore, the inspection range of SSA drones can be simplified as the total area swept by the circle with SSA drones as the center and radius. According to the data in the question, because the data of fire target inspection area is huge and difficult to solve, it is necessary to further optimize the fire target inspection area and discretize it into a reasonable number of target points.

Firstly, using the covering method in each target group. Covering method is a greedy algorithm. Its basic idea is to cover as many target points as possible. The coverage radius is set to the inspection radius of drone. In this way, the covered target points can be inspected in the discrete area.

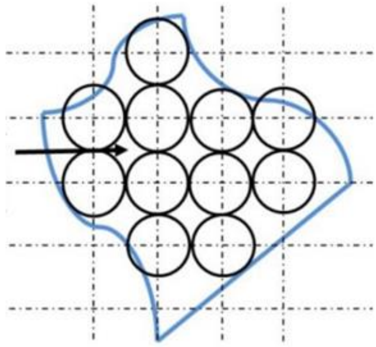


Figure 2 A schematic of area discretization

As shown in the figure, the grid is established, and each target point is taken as the center of the circle to make a diagram of the discretization area. Although there will be blank areas that seem not to be inspected, considering the actual situation, the inspection path of drone from one target point to the next will present a "strip", and these blank areas will also be scanned. Secondly, because the boundary of the inspection area is uneven, some areas at the boundary may not be scanned, but their area is very small compared with the total inspection area, so these areas that can't be scanned can be ignored. To sum up, it is reasonable to discretize the target patrol area in this way, so that 2120 target points can be transformed into the target range after discretization.

3. Drone Scheduling Strategy Based on Greedy Algorithm

Drone scheduling results can be evaluated from multiple perspectives. This paper evaluates the benefits and costs of SSA drone from two aspects: the benefits and the costs of SSA drone. Therefore, the goal of SSA drone scheduling solution is to plan the task sequence for SSA drone after completing the task, so as to maximize the objective function corresponding to the scheduling result, and the objective function J can be expressed as

$$J = \omega_1 R + \omega_1 C_1 \tag{1}$$

In the formula, ω_1 and ω_2 represent the profit weight and risk cost weight respectively; R represents the profit efficiency of SSA drone completing task scheduling; C_1 represents the risk cost of SSA UAV completing task scheduling.

The benefit obtained from task scheduling of SSA drone is defined as priority benefit of task × timeliness of completion × whether to execute drone task. The priority benefit of task here represents the benefit evaluation of the frequency and size of fire. Then the benefit efficiency can be calculated by the following formula:

$$R = \sum_{j=1}^{n} \sum_{i=1}^{N} \frac{\sum_{k=1}^{1} z_{\text{reatht}\,[k]} \cdot f_{[\lambda]}}{l \cdot z_{\text{teral}} \cdot f_{\text{mex}}} \cdot P_j \cdot x_{ij} \tag{2}$$

ISSN: 2664-9640

P_j refers to the timeliness of task completion when task j is assigned to execute, and f refers to the fire radiation intensity at the corresponding point.

$$P = \frac{e_j}{e_i + e_{re}} \tag{3}$$

According to Eq.3, the earlier the task is completed in the time window, the higher the timeliness of task completion; where e_j refers to the actual time required to execute the task, e_t refers to the maximum endurance time of SSA drone, and e_{re} refers to the battery charging time of SSA drone, C_1 represents the risk cost in SSA drone scheduling problem, and its calculation method is shown in Eq.4.

$$C_1 = \sum_{i=1}^{N} \sum_{i=1}^{n} \sum_{k=1}^{\prime} x_{ij} \cdot \delta_{jk} \tag{4}$$

Among them, x_{ij} is the decision factor, δ_{jk} is the risk assessment value of each task j by the threat source k, e_k is the threat range of the threat source, d_{jk} is the distance between task j and k threat source.

This involves the charging problem of SSA drones. After consulting the data, we decided to set up a charging station in the mission point to solve the charging problem of SSA drones. The setting position of the charging station is on the best flight path of SSA drones calculated by ant colony algorithm. [3]

The risk parameters of SSA drone mission point can be expressed as the risk assessment parameters of whether to execute the mission. The high-altitude mountain area is marked as hazard area, and then the radiation range is set as parameter e_k, and the distance between mission point and hazard area center is d_{jk}, then when $d_{ij} > e_k$, the risk assessment parameter is 0, and then the hazard assessment parameter value of drone mission point can be expressed as

$$1 - \frac{\sum_{k=1}^{l} d_{jk} \frac{1}{l}}{e_k} \tag{5}$$

$$\delta_{jk} = \begin{cases} 1 - \frac{\sum_{k=1}^{l} d_{jk} \frac{1}{l}}{e_k} & , d_{jk} < e_k \\ 0 & , d_{jk} > e_k \end{cases} \tag{6}$$

The objective function considers the frequency and size of fire events, terrain safety and the ability of coverage to evaluate whether it is appropriate to establish drone mission point, so as to establish the drone mission point with the widest coverage under the premise of maximum interests. Through the greedy algorithm, j value parameter, longitude parameter and latitude parameter are used to determine the coverage mode of drone mission circle. The number of drones equipped in Victoria can be calculated as 375 by the number of discrete points of comprehensive income function and greedy algorithm.[4]

In order to let more firefighters carry out radio communication within the range of repeater, we divide the area into many small areas, and a relay station is built in the center of each small area. The communication of firefighters is in charge of the repeater in the small area.

First, we consider the simple geometric covering problem. As few repeaters as possible to achieve seamless coverage within the region. The repeater has a range of 20 km, and a 5-watt radio has a nominal range of 5 km on flat, barrier free ground. At this time, we can understand that the area that can be effectively transmitted by radio is a circle with a radius of 25 km and a repeater as the center. If we include the fire location in the whole Victoria area in a big circle, the problem can be simplified as: using a small circle with a radius of 25 km to cover the big circle of the area, and finding the minimum number of small circles to use. In this case, the most possible geometric shapes of polygons that can cover a certain area completely (without overlapping) are: square, equilateral triangle and regular hexagon.[5]

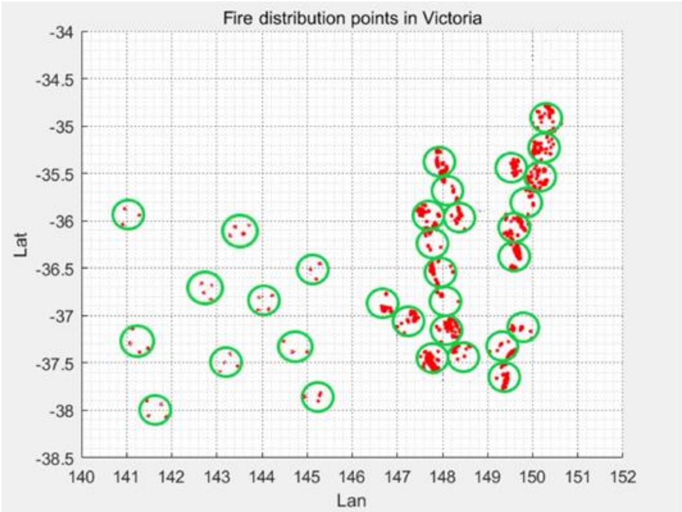


Figure 3 Fire distribution points in Victoria

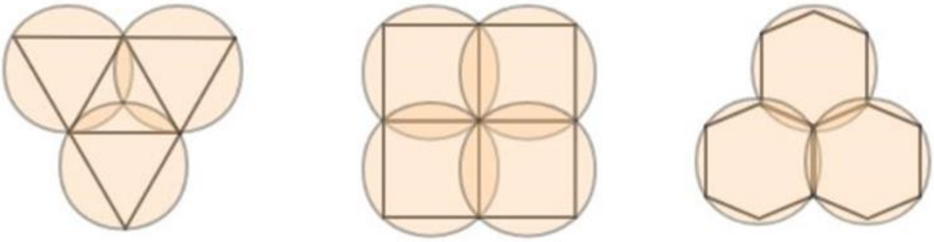


Figure 4 Several graphics that can be ceamlessly covered

Among square, equilateral triangle and regular hexagon, regular hexagon has the largest area. The coverage (cellular network) of inscribed regular hexagon can minimize the sum of overlapping areas of all small circles, that is, the number of circles is the least. The percentage of overlap λ can be obtained from Eq.7.

$$\lambda = 2 \cdot \frac{\frac{1}{2\left(\frac{2\pi}{n}\right)r^2} - \frac{1}{2\sin\left(\frac{2\pi}{n}\right)r^2}}{\pi r^2} = 2 \cdot \frac{\frac{\pi}{n} - \frac{\sin\left(\frac{2\pi}{n}\right)}{2}}{\pi} \tag{7}$$

Table 1. Overlapping comparison of different permutations

Shape	Positive triangle	Square	Positive hex
Overlapping parts	$1.2284r^2$	$0.5078r^2$	$0.1812r^2$
The area of the unit	πr^2	πr^2	πr^2
100% overlap	39.10%	18.17%	5.77%

According to relevant information, modern relay stations usually satisfy the relationship between signal coverage and relay. Therefore, we only need to consider the seamless coverage of repeater radiation radius. The following diagram of maximum coverage area is obtained by MATLAB simulation.

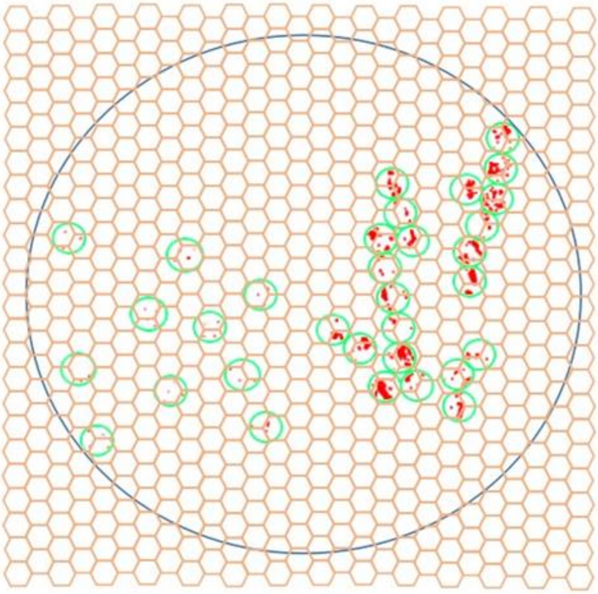


Figure 5 Matlab sumlated cellular coverage

In this way, we can get the maximum coverage area of repeater with a radiation range of 25 km under the assumption that Victoria is a flat area. However, Victoria is not a flat area, there are some urban areas and high-altitude mountainous areas where people live. According to Victoria's satellite map and topographic map, we calculated that there are four urban areas in the map. We surrounded these four areas with a big circle to represent the urban area. In the urban area, the range of radio is 2km. We set up a circle with the center of repeater and the radiation radius of 22km. This part can be simplified as: using a small circle with a radius of 22 km to cover the big circle in the urban area, and finding the minimum number of small circles to use. After MATLAB simulation, the following diagram of maximum coverage of urban area is obtained.

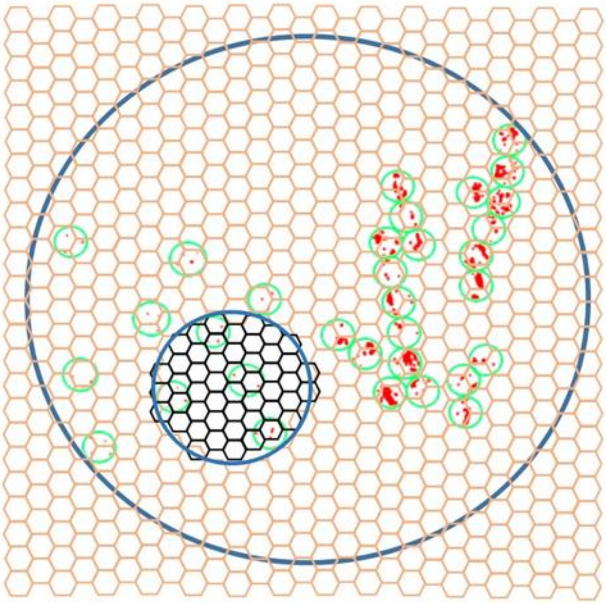


Figure 6 Contains cellular coverage of city

The above figure is the simple relay station coverage problem. However, there are no fire points in many areas in the figure. Considering the actual situation, when Radio Repeater drones can work in coordination with each other, we delete these redundant positions. In this way, we can get the distribution map of unattended Radio Repeater drones which can not only meet the actual needs, but also work effectively. Finally, under the optimal coverage condition, the number of Radio Repeater drones in relay station is 125.

4. Conclusion

In order to make the target patrol area patrol as much as possible within 2.5 hours from the EOC, we need to find the best number of drones through reasonable arrangement to maximize the benefits.

First, we transform terrain data into 2D coordinates for visualization. Then, we discrete coverage of target inspection area. The amount of data in the target inspection area is huge, and the fire size and frequency are uncertain. This has caused great difficulties in solving the problem to some extent. At this time, we regard the size and frequency of the fire as one of the factors affecting the discretization of the target inspection area, and the inspection area is discretized into a representative circle. Through the above analysis, seek SSA drones optimal patrol area. We transformed it into the problem of the largest area coverage rate of SSA drones in the number of drones we need. By comparing the size of the final revenue function J under different conditions, the location of the inspected area is determined to maximize the search coverage. Under the condition of ensuring coverage, the optimal solution of SSA drone mission point can be obtained. This allows for effective control of fire emergencies and timely monitoring of the status of firefighters. Finally, based on the distribution of SSA drones search area, the Radio Repeater drones optimal allocation strategy is established.

References

[1] Shu Yumian, Dan Falk. What fuels today's extreme fire events? - Geophysicists decipher the factors that cause wildfires [J]. World Science, 2021(10):45-48.

[2] Yu Bin. Analysis of the role of drones in the process of fire fighting and rescue [J]. China Science and Technology Information, 2022(05):76-77.

[3] Chen Xia, Zhao Miaoyan. Research on dynamic trajectory planning of UAV under sudden threat [J]. Firepower and Command and Control, 2020,45(07):43-50+55.

[4] Wang Yifei. Analysis of Smart Tourism Route Planning Scheme Based on Ant Colony Algorithm [J]. Hubei Agricultural Science, 2021, 60(09): 127-130.

[5] Ding Jian, Fu Hanning, Tang Jinfei, Cheng Hongbin. Design of power inspection data transmission scheme based on UAV relay [J]. Journal of Air Force Early Warning Academy, 2016, 30(06): 426-430.