The drones configuration system based on linear programming with A-star intelligent algorithm

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Abstract. In this paper, We according to Australia on October 1, 2019 to January 7, 2020, took place during the fire, put forward a kind of drones configuration system, mainly used for the different terrain, different fire, under the premise of guarantee the safety and economy, determine the number of SSA drones and relay radio, so that the firefighters can better cooperate with EOC (Emergency Operations Center). Based on the satellite map, this paper classified the fire areas in Australia into four types, according to the performance and possible function of the drone, and determined the number of SSA drone and relay radio drone in the four areas with the largest fire area in Australia based on the different types of fire areas that have been classified, combined with drone performance, and using the idea of linear programming. Then, the A-star intelligent algorithm is introduced to the urban terrain where the hand-held bidirectional radio is limited, and the shortest path from the entrance point to the end point of the fire area is found out. According to the shortest path and the performance of the drone, the number of SSA drone and relay radio drone in this area is determined, and then the fires in Australia in recent 170 years are rated, then get a record of extreme fires in Australia over the last 170 years, and use the Poisson distribution function and Monte Carlo algorithm to predict the extreme fire scenarios in Australia in the next decade to determine the increase in the number and equipment budget of SSA and relay radio drones. Finally, this paper use ArcGIS software to eastern Victoria terrain simulation, after get the specific data, using drone configuration system determines the position of trunking radio drones, and use genetic algorithm to improve model, to get the position of trunking radio drone, the results said than before improvement, relay radio drone to reduce the number of location is more reasonable.

1. Introduction

1.1. Background
The 2019-2020 fire season in Australia[1] 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.[2]

So Australian firefighters use drones for surveillance and situational awareness(SSA) to monitor and report data from wearable devices used by front-line personnel. Enables the Emergency Operations Center (EOC) to best direct the active aircrew for best results and maximum safety. Minimize the danger and damage of forest fires as much as possible. However, two-way radio
communication allows firemen forward teams to give status report to the EOC and allows the EOC to give orders directly to forward teams. The range of hand-held radios is depends on the terrain, up to 5km in flat, accessible areas and down to 2km in urban areas. But a 10-watt repeater, weighing 1.3 kg carried by a drone hovering well above ground level, can achieve a range of 20 km. In this paper, firstly, according to the largest fire area in the satellite image as the representative, the SSA drones and relay radio drones in this area are calculated by using the idea of linear programming [3], and then the remaining large-scale fire areas are brought into the model, and the number of SSA drones and relay radio drones required in the area with large fire coverage area is obtained. Considering the terrain, due to the particularity of urban terrain, a city map is simulated by using MATLAB, Poisson distribution algorithm and network method, and then A-star intelligent algorithm[4] [5] [6] is introduced to find the shortest path. Combined with the idea of linear programming, a model of finding the shortest path based on terrain is designed. Compared with some traditional algorithms for finding the shortest path, it considers more factors and improves the reliability of path selection.; Then, according to the extreme fire data of the past 170 years, the possibilities of extreme fires in the next ten years are predicted by Poisson distribution function[7] and Monte algorithm [8], and a prediction model of extreme fires in Australia in the next ten years is established based on weather change. On the premise of realizing economy (the number of drones reflects economic) and safety. Effectively solve the problem of equipping the drone[9] [10] [11], so it is called "Drones Configuration System". The drones configuration system can deal with all kinds of terrain and fire size flexibly, etc.

1.2. Notations Description

| Table 1. symbol illustration |
|-------------------------------|
| N | Total number of drones |
| K1 | The number of SSA drones |
| K2 | The number of relay radio drones |
| x | A parameter that describes the size of a fire event |
| y | A parameter that describes the frequency of fire events |
| r | Drones range radius |
| S’ | Fire area coverage |
| W | Fire area cross wide |
| L | Fire area in depth |

2. General assumption

● Drones enter the scene of a fire after it starts, rather than being deployed before it stars.
● Drones can change position by following the movement of front-line personnel.
● After a fire is extinguished in one area, the EOC determines that it is safe to move to the area and direct the front-line personnel to move to the next area, so the fire is put out in a cycle.
● The number of drones is proportional to the size of fire incidents and the frequency of fire incidents.
● The probability of extreme fire occurrence in the next decade conforms to the same parameter Poisson distribution as the previous extreme fire occurrence.

3. Design scheme of drones configuration system

Because of different terrain, hand-held two-way radio range can have 2 km, 5 km, the difference between the corresponding relay radio drones number will be different, so this paper to hand-held two-way radio range as the main factors, the difference between the regional size and frequency of fires
secondary factors to determine the number of SSA drones and relay radio drones. The main scheme is considered by regions, as shown in Figure 1 (The green transparent area is the fire area).

![Figure 1. Map of fire coverage](image)

4. Model design

4.1. Terrain classification

Step 1: According to the satellite images, this paper divided the main land-forms of Australian bushfires into the following four types according to the possible use of unmanned aerial vehicles, forests, wilderness, cities, and mountains.

The wilderness is vast. The fire is small and difficult to spread. The range of the hand-held two-way radio is 5km, the drones flying height is low; In the forest terrain, the fire is large, the range of the hand-held two-way radio is 5km, and the flying altitude of the drones is medium; In urban terrain, the fire is medium, the range of the hand-held two-way radio is 2km, and the altitude of the drones is medium; In the mountainous terrain, the fire is large, the range of the hand-held two-way radio is 2km, and the drones flies at a high altitude.

4.2. Data extraction

Step 2: This paper according to Carlos Paradis provided from NASA's MODIS satellite instrument C6 and VIIRS 375 m Australian fire data, including data on October 1, 2019 to January 11, 2020 during the fire details, because too much data is difficult to say, this paper selected 2019 representative on the day October 1, 7 sets of data to display, as shown in Table 2:

| latitude | longitude | brightness | scan | track | acq_date | acq_time | satellite instrument | confidence | version | bright _T31 | frp | daylight |
|----------|-----------|------------|------|-------|----------|----------|----------------------|------------|---------|------------|-----|----------|
| -14.281  | 143.636   | 323.9      | 1.7  | 1.3   | 2019/10/1| 25       | Terra MODIS          | 70         | 6.0NRT  | 302.3      | 26.8| D        |
| -14.284  | 143.532   | 343.5      | 1.7  | 1.3   | 2019/10/1| 25       | Terra MODIS          | 90         | 6.0NRT  | 306.3      | 84.3| D        |
| -14.302  | 143.706   | 320.2      | 1.7  | 1.3   | 2019/10/1| 25       | Terra MODIS          | 30         | 6.0NRT  | 305       | 14.1| D        |
| -14.283  | 143.652   | 320.4      | 1.7  | 1.3   | 2019/10/1| 25       | Terra MODIS          | 57         | 6.0NRT  | 303.3      | 18.4| D        |
| -17.092  | 143.387   | 308.8      | 2.2  | 1.4   | 2019/10/1| 1235     | Terra MODIS          | 19         | 6.0NRT  | 294.6      | 19.2| N        |
| -17.094  | 143.381   | 306.2      | 2.2  | 1.4   | 2019/10/1| 1235     | Terra MODIS          | 12         | 6.0NRT  | 294       | 14.1| N        |
| -18.25   | 142.513   | 303        | 2.7  | 1.6   | 2019/10/1| 1235     | Terra MODIS          | 28         | 6.0NRT  | 292.2      | 14.2| N        |
| -27.558  | 147.194   | 301        | 1.7  | 1.3   | 2019/10/1| 1235     | Terra MODIS          | 36         | 6.0NRT  | 288.5      | 11  | N        |
| ...      | ...       | ...        | ...  | ...   | ...      | ...      | ...                  | ...        | ...     | ...        | ... | ...      |
According to the data, first, the width is used as the parameter to measure the size of the fire and ACQ_TIME as the parameter to measure the frequency of the fire event. After calculation based on the weighted average, get $x=0.62$, $y=0.83$. (The parameter value is set to be between 0 and 1, conversion method: for example, the maximum width of fire in the field is 495, then approximately 500 is set as the upper limit 1)

4.3. Linear programming

Step 3: Select the area with the largest fire area as the representative, and determine the number of SSA drones and radio relay drones in this area. Consider security first and economics second.

1. "Security" requires a sufficient number of drones to cover the area in order to monitor the safety of front-line personnel and the fire situation. Therefore, according to the performance of drones and the fact that this region is mostly mountainous and a small amount of forest, the area, perimeter, depth and transverse width of this region measured by satellites are shown in Figure 4.5. It is known that drones can reach a range of 20km, so the signal coverage area of a single drone is:

$$S = \pi \cdot r^2$$ (1)

According to the assumption 3, set the EOC and front-line staff to choose fire cross wide value small covering area, deep values of one party for the entry point, namely the present things in figure 2 direction (white arrows indicate the direction, the blue line distance on both ends), because through the data, the horizontal value maximum 122.459 km wide, and the depth value maximum 227.692 km, fire fighters will adopt the way of the direction is more efficient than using the north-south direction, reduce duplication of path. In order to ensure adequate safety, the distance between the EOC and the front-line personnel was kept as far as possible. Therefore, the range of the hand-held two-way radio was extended by the radio relay drones between the two. In the area, the range of the hand-held two-way radio was 5km.

2. Considering "economy", the fewer drones, the better, so that they can be recycled by charging.

3. Formulate equations using the idea of linear programming:

$$\begin{align*}
    K_1 &\leq K_2 \\
    N \times S &\geq S' \\
    2N \times r &\geq W \\
    K_1 + K_2 &= N \\
    1.75K_1 &\leq 2.5K_2 \\
    2(A + B) \times K_1 \times r &\leq L \\
    2(A + B) \times K_2 \times r &\leq L
\end{align*}$$ (2)

Using the LINGO software, the required SSA drones in this area are 7. The number of radio relay drones are 5.
Step 4: According to the preliminary model established above, several areas with large fire areas in the fire coverage map were brought into the model for solving, as shown in Fig 3 to Fig 6:

![Figure 3. Area 1st](image1)
![Figure 4. Area 2nd](image2)
![Figure 5. Area 3rd](image3)
![Figure 6. Area 4th](image4)

It is concluded that there are 4 SSA drones and 2 radio relay drones in area 1st. Area 2nd requires 4 SSA drones and 3 radio relay drones; Area 3rd requires 4 SSA drones and 3 radio relay drones; Area 4th requires 2 SSA drones and 2 radio relay drones.

4.4. A-star algorithm

Step 5: In the case of mountain and forest terrain, the urban terrain is discussed separately. Because urban terrain, the terrain is not broad enough, the front line staff need to bypass many buildings, so we before using the linear programming method, grid method is used to simulate the city map, first using the * algorithm to find the firefighters needed through the shortest path, based on the shortest path obtained by combining linear programming SSA unmanned aerial vehicle (uav) combined with the number of relay radio unmanned aerial vehicle (uav). In the area, the hand-held bidirectional electric range is 2km. Matlab was used to write the program, and Poisson distribution method was used to randomly generate urban buildings (i.e. obstacles), as shown in the black square in Figure 7. On the way, the green circle represents the starting point, the blue circle represents the end point, the red square area represents the nodes searched by A-star algorithm, and the blue line represents the final path. Among them, the length of each grid is set as a unit distance, which can be 20m or 20km. The specific value is determined by combining the model with the actual urban area of fire on the satellite map.
After 100 times of experimental tests, found that A* algorithm could find the shortest path well under the randomly generated map. Therefore, combined it with linear programming. Considering the combination mode of UAV required under this terrain, programmed the program with MATLAB as follows:

```matlab
l = input("please your distance"); %l is the shortest path distance
if l<20000
    N = 2 ; %consider the issue of charging the drones
    K1 = 2 ; % the number of SSA drones
    K2 = 0 ; % the number of relay radio drones
else
    N = fix(l/20000) + 2 ; %consider the issue of charging the drones
    K1 = fix((N/(2.5/1.75+1)))+1; % the number of SSA
    K2 = N-K1; % the number of relay radio drones
end
```

It can be concluded that when the path distance in the urban area is below 20km, considering that the power of the drones is used up, it can configure two SSA drone. When the distance is beyond 20km, the number of SSA drone and relay radio drone will be increased according to the program.

All fire areas were entered into the model according to different situations, and 58 SSA drones and 26 relay radio drones were finally obtained.

4.5. The fire prediction
One of the main driving factors of fire intensity, fire spread rate and fire area is temperature. In order to analyze the nature of fires in Australia, this paper have made a statistical analysis of fires over the years and collected the data.

Then this paper rated the fires as table 3.

| Grade            | norm             |
|------------------|------------------|
| Catastrophic/Red Alert | Forest 100+, Lawn 150+ |
| Extreme danger   | Forest 75-100, Lawn 100-150 |
| Higher risk      | Forest 50-75, Lawn 50-100 |
| High risk        | 25-50            |
| Danger           | 12-25            |
| Low to moderate risk | 0-12     |
Table 4. Extreme fire events over the past 170 years were measured using a rating scale.

| Number of times | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|----------------|---|---|---|---|---|---|---|
| The total number of years | 140 | 23 | 2 | 2 | 1 | 1 | 1 |

According to the analysis, it is assumed that the occurrence of extreme fires obey the Poisson distribution. Based on the data in the table, we estimate the parameters of its distribution:

\[
\lambda = \mathbb{E}(x) = \sum p_i \times x_i \quad (3)
\]

Get: \(\lambda = 3.5\);

Using Matlab code to test the goodness of fit of the data, the number of fires was found: \(X \sim \text{P}(3.5)\);

Using the parameters of Poisson distribution, Monte Carlo algorithm was used in MATLAB to generate the random number of Poisson distribution, as shown in Fig 8, and the number of extreme fires in the next ten years was solved: \(S = 6.5180\) (approximately 7).

In combination with the situation of active fires in Australia on January 7, 2020, we divided the area of active fires in the map into 22 areas, and measured that their area size was smaller than the monitoring range of a single drone, as shown in Figure 9.

In the end, this paper calculated that adding 154 SSA drones and 51 relay radio drones. To date, 58 SSA drones and 26 Relay Radio drones are required for a total of 84 at a cost of $840,000, based on safety and economy. But after predict, Australia without human intervention, in the next decade the number of extreme fires may occur for seven times, and extreme fires more dangerous because it is over, we consider the backup device, therefore in 84 based on the demand of the drone should be added to 154 SSA drones and 51 frame relay radio, so a total of 289 drones.

5. Model optimization

5.1. ArcGIS mapping

On the basis of the original model, use ArcGIS software to simulate the topographic map of eastern Victoria. As figure 10. shown.
5.2. Drones deployment
After the simulation of the eastern terrain of Victoria is graded in height, it is substituted into the original established model, and the position distribution diagram of the relay radio drones is shown as follows (the green dots represent relay radio drones):

5.3. Add genetic algorithm
After getting the distribution of the relay radio drone in different terrains in the original model, we add genetic algorithm to the program to optimize the model so that the complex area which is searched repeatedly in the program will be blacklisted after one search, that is, this area will be only searched
once, so as to reduce the probability that the adjacent distance is small or even repeated when the relay radio drone is arranged, so as to achieve the purpose of reducing the number of relay radio drone. The improved distribution diagram is shown below:

The improved distribution diagram is shown below:

![Figure 14. Low level distribution (below 600m)](image)

![Figure 15. Medium level distribution (600m~1200m)](image)

![Figure 16. High level distribution (600m~1200m)](image)

After improvement, five relay radio drones were reduced in the ground floor distribution. Four relay radio drones were reduced in the middle and high distribution maps.

6. Model analysis

(1) From the perspective of the ability of the model to find the shortest path, before the improvement, the number of iterations is relatively large, generally around 500 times. After improvement, the number of iterations tends to be stable after 450 times, so the ability to find the shortest path is good.

(2) According to the prediction of the future fire situation of the model, due to the sufficient data and the Monte Carlo algorithm, the number of extreme fire will be about 7 in the next ten years if there is no human interference, which is also relatively reliable from the human judgment.

(3) From the number determination of SSA drone and relay radio drone, the model can reflect the flexibility of planning, and can well determine the number of two kinds of drone under different terrains, different fire situations and other situations.

(4) From the model of relay radio unmanned aerial vehicle (uav) deployment in Victoria, in the eastern Victoria terrain to make use of the ArcGIS software simulation, can quickly get the location of the trunking radio unmanned aerial vehicle (uav), in the use of the improved genetic algorithm, reduce the iteration times and at the same time, reduced the number of relay radio uavs, shows the feasibility of a well.

7. Conclusion

According to Australia in October 1, 2019 to January 9, 2020 wildfires, the specific fire data are obtained through the NASA website, using satellite map, according to the usage of unmanned aerial vehicle (uav) may be in a first division terrain, classification to determine the regional fire in different
terrain, under the background of different fire, based on the idea of linear programming, Monte Carlo algorithm, ArcGIS terrain rendering, and finally using the genetic algorithm was improved, set up a unmanned aerial vehicle (uav) configuration system, and forecasts the Australia in the next decade the number of extreme fires may occur, through model test, analysis, In a certain extent, the model has achieved good results. The system can be used in real-time or early-stage fire prevention, which can effectively reduce the casualties and economic losses caused by extreme fire, and has a very broad development prospect.

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