Problem Chosen	2021 MCM/ICM Summary Sheet	Team Control Number
B		2127045

The dynamic monitoring wildfire models

Abstract

With the global warming, forest fires occur frequently. For prevent forest fire effectively, in this paper, we use integer programming and dynamic programming to establish forest fire monitoring model to monitor the eastern Australian forest. It can improve the efficiency of fire prevention and is great significance to forest fire monitoring.

Based on the coordinates of wildfire points in eastern Australia observed by MODIS C6 satellite, the EOC of the data transmission terminal is determined to be (-26.2370,133.8162). Then use EOC as the center to determine the orbital distribution of repeater drones and SSA drones to ensure that all wildfire areas can transmit signals. The number of UAVs is determined by the central angle of UAVs in orbit. The minimum value of SSA UAV is obtained by integer programming. According to the monthly increment of wildfire radius, the prediction function was fitted. The maximum radius of wildfire in 10 years is 21.9121m.

Finally, we get: According to the calculation, the relay drones need to be placed on 5 tracks. The total number of relay drones is 49; the number of SSA drones is 6. That is, the optimal combination strategy is: 6 SSA drones and 49 repeater drones, which cost a total of 550,000 US dollars. then, the fitted function $f(x) = -0.1263x^4 + 1.601x^3 - 6.743x^2 + 10.66x - 5.032$ to find the maximum increment, the maximum wildfire radius in 10 years is 21.9121m, which is smaller than the monitoring range of question 1, so the cost of the drone combination remains unchanged. Finally, we improve the UAV monitoring model and calculate the relationship between the UAV monitoring range on the hillside and the horizontal monitoring range as $M = 2\mathrm{r}/\cos\beta$. From the angle β between the mountain and the horizontal plane, we get that the number of UAVs placed on the cross section of the mountain is $Q = 2r\tan\beta / \mathrm{H}$.

Keywords: **Integer optimization**; **MATLAB**; **UAV**

Contents

1 Introduction

Wildfires have had a devastating impact on every state in Australia during the 2019-2020 fire season. The impact is particularly severe in the eastern part of New South Wales and Victoria. Wildfires typically occur during severe droughts and persistent heat waves, exacerbated by climate change. 错误!未找到引用源。 shows wildfire hotspots in the region from October 1, 2019 to January 7, 2020, with fire from October 1 to January 6 in yellow and active fire from January 7, 2020 in red.

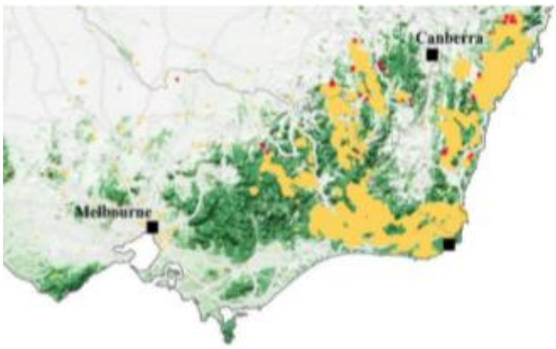

Figure 1

SSA UAV carries high-definition and thermal imaging cameras and telemetry sensors to detect the ever-changing situation on site. The emergency operations center (EOC) can guide the staff more efficiently and safely. The forward team provides the EOC with the status change of the two-way radio communicator, and the EOC gives the command to the forward team.

The range of handheld bidirectional radios carried by deployed personnel operating in the VHF/UHF frequency band is limited by their low transmission power (not affected by weather). A 5-watt radio has a nominal range of 5km on flat, accessible ground, but drops to 2km within borough limits. The repeater is an extended radio range, located between the front line and the EOC, that can provide information to both directions. Its range is provided in distance and terrain, but is much greater than that of a low-power handheld radio.

Problem 1: Create a model and determine the optimal purchase quantity ratio of SSA UAV and radio repeater UAV for Victoria’s Country Fire Authority to purchase. The model should take the scale and frequency of fire events as parameters. Balance capability and security with economy, taking into consideration reconnaissance communications mission requirements and terrain.

Problem 2: Based on the model constructed in Question 1, explain how it ADAPTS to the likely changes in extreme fire events over the next decade. Estimate how much the cost of the equipment should increase, assuming the cost of the UAS stays the same.

Problem 3: A model was developed to optimize the location of VHF/UHF radio repeater UAVs for different size files on different terrain. Figure 2: Topographic map of Victoria. The elevation range refers to the 1,986 meters from sea level to East Victoria mountain range.

Problem 4: Prepare an annotated budget form based on the model in this paper and are presented at Victoria State Government.

2 Assumptions

For the dynamic monitoring wildfire models, we made the following assumptions:

(1) The UAV is released by ground forces and does not consider returning to the same base;

(2) UAV with repeater is in fixed hover state;

(3) The altitude from sea level to Bogong mountain increases uniformly;

(4) Assume that the drone is always in normal working condition during flight；

3 The Dynamic monitoring wildfire model

3.1 Definitions

Symbol	Mean	Dimensional
d	Distance from the furthest wildfire point to EOC	m
n	The number of orbital layers the drone operates in	pcs
R	The radius of the most central UAV orbit	m
A	The arc length of the repeater UAV orbit corresponds to half of the central Angle	degree
s	The flying distance of the drone	m
x_n	The number of drones in the NTH orbit	pcs
H	The altitude	m
r	The strafing range of the drone	m
M	The drone is projected onto the covered diameter of the mountain	m
D	The distance from the top to the bottom of the mountain	m

3.2 Range of Victoria wildfires from 2019/8/1 to 2020/1/11

According to the data of MODIS C6 satellite instrument and VIIRS 375m satellite instrument, Map the wildfire range from August 1, 2019 to September 30, 2019 and from October 1, 2019 to January 11, 2020, as follows:

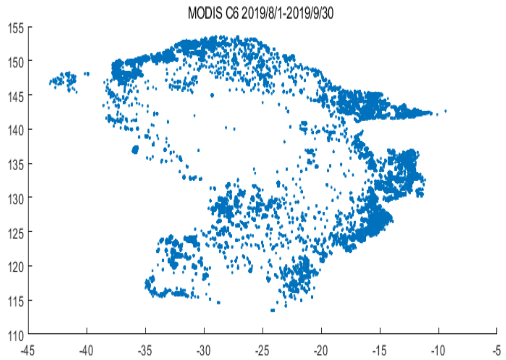

Figure 2

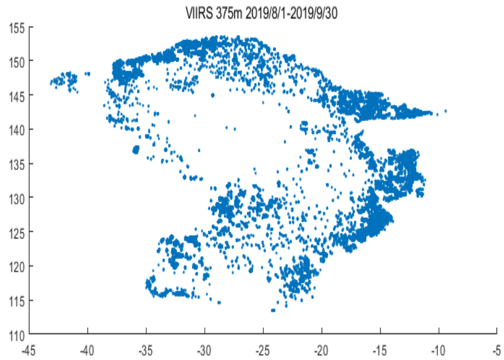

Figure 4

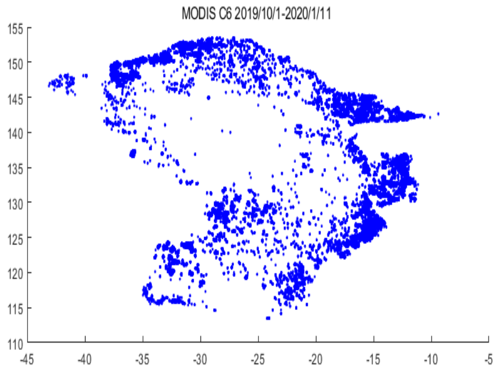

Figure 3

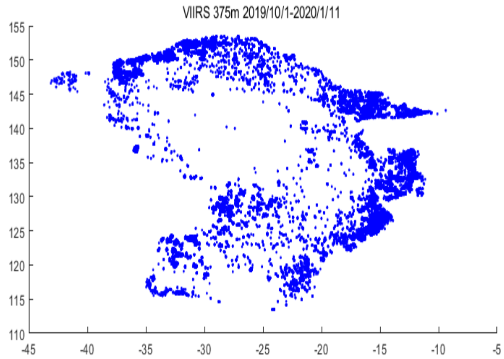

Figure 5

3.3 Radio relay UAV model

In order to ensure SSA unmanned aerial vehicle (UAV) can transmit monitoring data to EOC, the above figure shows the coverage of wildfire points. We need the range of repeater to completely cover the range of wildfire point before SSA unmanned aerial vehicle (UAV) can transmit real-time data to EOC.

Accord to that program designed by the data in annex I, the cent coordinates of the area covered by wildfire points can be found out that is, you can determine the coordinates of EOC, the center point in the plane figure in Figure 2 above: $(x, y) = (-26.2370, 133.8162)$. Then the wildfire point farthest from EOC is screened as follows $(x_0, y_0) = (-43.0799, 153.5211)$, the distance between two points as the radius of the repeater coverage.

According to

$$d = \sqrt{(x - x_0)^2 + (y - y_0)^2}$$

Then find out: d= 21.3878.

The range of UAV by radio repeater is 20 kilometers. We can design a circular orbit to place the radio repeater UAV according to the distance from the center EOC to the farthest point. With the scale of 1:5km in the figure 6, the range of the radio repeater UAV in the figure is 4. Upper formula d= 21.3878, it can be calculated that a total of 6 tracks need to be set up (in which the number of tracks is an integer and needs to be rounded up). Draw the calculated placement track of repeater UAV in the figure, as shown in Figure 6 below:

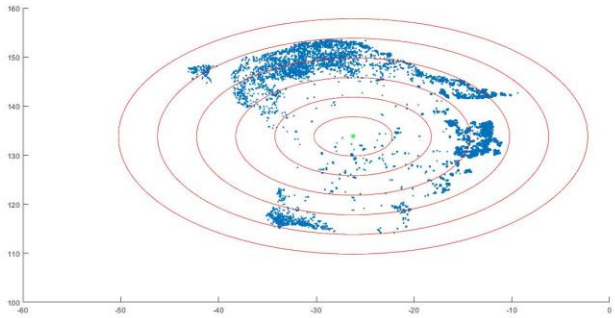

Figure 6

The relationship between the arc length and the track perimeter of the UAV scanning range and each track is transformed into the relationship between the central angle corresponding to the arc length and the central angle of the whole circular track, so as to determine the number of UAVs:

$$\cos A = \frac{2(nR)^2 - R^2}{2(nR)^2} = \frac{2n^2 - 1}{2n^2}$$

It can be concluded that the angle of an unmanned aerial vehicle in the center of the circle on the nth track is:

$$2\arccos A$$

That is, the number on the nth track is:

$$\frac{360}{2\arccos A}$$

Then the total number of repeater drones required is:

$$m=\sum_{n=1}^{5}\frac{360}{2\arccos A}(In\ which:\cos A=\frac{2n^2-1}{2n^2})$$

3.4 UAV model for monitoring and situation awareness

Based on the repeater model, we establish the number model of SSA detecting UAVs:

The flight range of SSA UAV is known to be 30 kilometers. We can design a circular orbit to place SSA detection UAV according to the distance from the central point EOC to the farthest point. With the scale of 1:5km in the figure, the range of SSA monitoring UAV in the figure is 6. According to the above formula, d= 21. 3878.

It can be calculated that a total of 4 tracks need to be set (where the number of tracks is an integer and needs to be rounded up), and the calculated SSA UAV placement track is drawn in the figure, as shown in Figure 7 below:

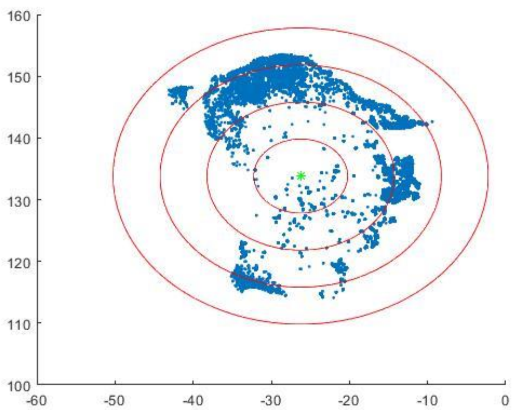

Figure 7

According to the characteristics and functions of SSA monitoring UAV, SSA monitoring UAV can fly around the orbit shown in the above figure to dynamically monitor wildfire points. The flight distance of the unmanned aerial vehicle is set as s km, and the known data can be used to calculate that the unmanned aerial vehicle needs to be placed on the first and third tracks. The perimeter of the first layer is 37.68 and that of the third layer is 113.04. Then assume that the number of SSA UAV inspections is X1 and X3, and carry out integer programming for them:

$$\min x = x1 + x3$$

There are constraints:

$$\begin{cases} sx_1 \geq 37.68 \\ sx_3 \geq 113.04 \\ x_1, x_3 is\ an\ integer \end{cases},$$

That is, there are at least 6 SSA drones

4 The Experimental Results

4.1 Conclusion of wildfire monitoring model

We combine repeater UAV model with SSA UAV model to determine the best combination of them. As shown in the figure below：

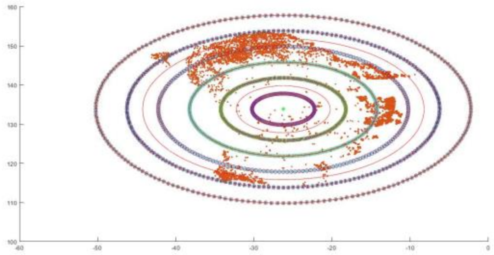

Figure 8

According to the range of each repeater UAV, we intercept the arc length of the orbit, determine the center angle occupied by the UAV, and determine the number of repeater UAVs, as shown in the table below:

Table 1

Drone laps Parameter (n)	1	2	3	4	5
J	60.00	28.96	19.19	14.36	11.48
2*J	120.00	57.91	38.38	28.72	22.96
Number of UAVs	3	7	10	13	16

$$m = \sum_{n=1}^{5} \frac{360}{2\arccos A} (In\ which: \cos A = \frac{2n^2 - 1}{2n^2}) = 49$$

We determine the number of SSA UAVs in each orbit according to the flight distance of SSA UAVs:

$$\min x = x1 + x3$$

There are constraints:

$$\begin{cases} 30x_1 \geq 37.68 \\ 30x_3 \geq 113.04 \\ x_1, x_3 \textit{ is an integer} \end{cases}$$

Use MATLAB to solve:

$$\begin{cases} x_1 = 2 \\ x_3 = 4 \end{cases}$$

To sum up: in order to monitor wildfires in NSW and eastern Victoria more safely, we need six SSA UAVs and forty-nine repeater UAVs.

4.2 Prediction of extreme wildfire radius

We find out the farthest wildfire point from EOC in each month between August 2019 and January 2020, and determine the maximum wildfire radius in each month as follows:

Table 2

month	2019/8	2019/9	2019/10	2019/11	2019/12	2019/1
Wildfire radius	21.0316	21.3879	21.4818	20.7183	20.5255	21.3224

Then find out the increment of wildfire radius every month, as shown in the table below:

Table 3

sequence	1	2	3	4	5
Increment of wildfire radius	0.3563	0.0939	-0.7635	-0.1928	0.7969

According to the increment of wildfire radius in each month, we use matlab toolbox cftool to fit the prediction function $f(x)$。The fitting results are shown in the figure below：

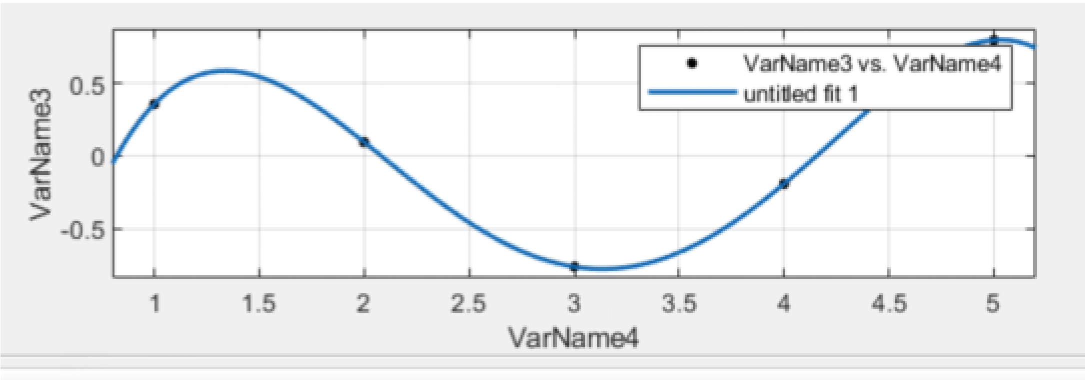

Figure 9

$$f(x) = -0.1263x^4 + 1.601x^3 - 6.743x^2 + 10.66x - 5.032$$

According to the function $f(x)$, we predict the extreme wildfire events in the next 10 years, that is to say, the maximum value of F (x) is 0.8805m, and the maximum increment of wildfire radius is 0.8805m. It is predicted that the radius of wildfire from EOC will be 21.9121m in the next ten years. According to question 1, the detection range of wildfire is 24m. Therefore, the cost of UAV in the next 10 years will remain the same as the first question.

4.3 Monitoring mountain terrain wildfire

The altitude is added to the model, where the altitude range refers to VHF between the sea level of the coast and the 1986 meters of Bogong Mountain in Victoria for fires of different sizes on different terrains /UHF radio repeater position of UAV.

First of all, we can think of the mountain as a cone, and half of the front view of the cone is shown in Figure 10.

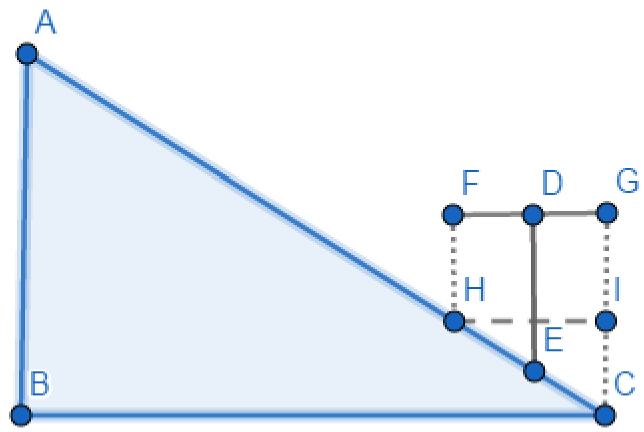

Figure 10

According to the figure, the altitude H=AB=1986 m; place the UAV at point D in the figure. It is known that the shooting range of UAV is R, and the length from FG to HC when its coverage is projected onto the mountains is recorded as M. The angle between the mountains and the horizontal ground is $\angle ACB = \beta$, and the quantitative relationship can be constructed as follows:

$$M = \frac{2r}{\cos\beta}$$

From the altitude h, we can know that the total length d from the top of the mountain to the foot of the mountain is:

$$D = \frac{H}{\sin\beta}$$

$$Q = \frac{M}{D} = \frac{2r}{H}\tan\beta$$

Q UAVs can be placed from the top of the mountain to the foot of the mountain to cover the whole range.

4.4 Budget Application

Dear Government of Victoria：

In order to effectively address the wildfire problem in Victoria, enabling the government to take steps to rescue quickly, accurately, economically, and safely, minimize the damage caused by wildfires.

In the above paper, we established a specific model to solve the position placement problem of SSA monitoring UAV and radio repeater UAV, as well as how to place the UAV so that the number of UAVs can be used to reach the lowest cost while ensuring safety.

All budgets below are based on the block design of the map of Victoria.

The summary is as follows:

In problem one, we used the SSA UAV and the repeater UAV to monitor all ranges simultaneously. In the case of the Victorian terrain affecting data transmission to a lesser extent, the neglect point to the use of manpower in terms of funds. Using the program in the appendix to calculate the number of required SSA is 6, the number of Repeaters is 49. According to the team's market research evaluation, the provisional SSA price is $10,000, and the repeater price is $10,000. The calculation shows that the optimal purchase ratio between the SSA UAV and the radio repeater UAV will cost $550,000.

In the second problem, the distance between the farthest wildfire point and the center point at different times is fitted by the difference value. Predict the specific scope of fire in the next ten years, and calculate that the number of SSA needed is 6 and the number of repeater drones is 49, so the cost is the same as that of Question 1, and the prediction does not increase the equipment cost. We hope that our suggestions will help your government in solving the wildfire problem.

5 Robustness and Sensitivity Analysis

In the dynamic distribution model of SSA and repeaters, we consider the real situation of the actual geographical location, and fit the data scatter diagram by using the real wildfire distribution points in Victoria to better reflect the distribution characteristics of forest wildfires.

In the distribution model proposed by us, the distribution between SSA and EOC can be dynamically established according to the actual wildfire occurrence location and severity, so that forest wildfires can be saved in time, and the best fighting plan can be achieved to the greatest extent.

By fitting the wildfire parameters of Victoria in the past two years, our model can be adaptively applied to predict the impact of various complex terrain on forest wildfires, and can work out the police route of forest firefighters more quickly, thus achieving rapid and effective forest rescue.

6 Limitations

First of all, in the process of building the model in question one, we did not investigate the terrain in Victoria. In practice, the position may be deviated when the UAV is launched, which will cause certain errors in the observation range. Secondly, the unmanned aerial vehicle (UAV) is always regarded as a normal working state during the flight, and no remedial plan is made for its failure, and no charging plan for UAV is made. Finally, due to the lack of monthly wildfire frequency data, there will be a big error in predicting the possible changes of extreme fire events in the next ten years, which will change the budget cost.

7 Conclusions

The UAV annular orbit established in the model can make the UAV more omni-directional in monitoring, and at the same time, multiple charging points can be established on the annular orbit. When the number of UAVs is increased during the high fire incidence period, the monitoring frequency can be improved. According to the established model, we can effectively solve the comprehensive monitoring of wildfire occurrence range by unmanned aerial vehicles, and provide an effective rescue plan for the local government to quickly, accurately, economically and safely solve the problem of forest wildfire propagation.

References

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Appendix

The following codes are written in MATLAB.

```
clc
scatter(latitude,longitude,'.')
a1=max(latitude) ;
a2=min(latitude)
b1=find(a2==latitude);
a3=max(longitude)
a4=min(longitude);
x1=(a1+a2)/2
y1=(a3+a4)/2
a=[x1,y1];
hold on
scatter((a1+a2)/2,(a3+a4)/2,'*','g')
d=sqrt((x1+9.3941)^2+(y1-146.9979)^2)
r=4;
for i=1:6
theta=0:pi/100:2*pi;
x=x1+r*cos(theta);
y=y1+r*sin(theta);
hold on
plot(x,y,'o');
r=r+4;
end
R=6;
hold on
for i=1:4
theta=0:pi/100:2*pi;
x=x1+R*cos(theta);
y=y1+R*sin(theta);
hold on
plot(x,y,'r');
```

```
R=R+6;
end
for i=1:5
   A=((i*4)^2*2-4^2)/(2*(i*4)^2);
   J=(acos(A)/pi)*180
end
R=6;
for i=1:3
      c=2*3.14*(i*R)
end
%title(['MODIS C6 2019/8/1-2019/9/30 '])
%title(['MODIS C6 2019/10/1-2020/1/11 ']);
%title(['VIIRS 375m 2019/8/1-2019/9/30 ']);
%title(['VIIRS 375m 2019/10/1-2020/1/11 ']);
```

Question 2:

```
p1=-0.1263;
p2=1.601;
p3=-6.743;
p4=10.66;
p5=-5.032;
syms x y
x=1:1:124;
y=p1*x.^4+p2*x.^3+p3*x.^2+p4*x+p5;
s=max(y)
```