Research on Mountain Fire Detection method of UAV based on Mathematical Modeling method

Hongchao Jiang¹*, Di Wu², Yating Tan³

¹School of Modern Post (School of Automation), Beijing University of Post and Telecommunication, Beijing, 100876
²School of Cyberspace Security, Beijing University of Post and Telecommunication, Beijing, 100876
³School of Electronic Engineering, Beijing University of Post and Telecommunication, Beijing, 100876

*Corresponding author e-mail: hcj2020@bupt.edu.cn

Abstract. For the first question, we establish two main models for SSA drones and repeater drones respectively. For repeater drones, we establish a grid search model, aiming at terrain, repeater range limits and other restrictions, by gradually removing the grid points, work out the optimal position and quantity of the repeater drones. For SSA drones, we also use the grid search model, considering the flight parameters of SAA drones, to find the position of the charging station (EOC) and fully meet the charging needs of SSA drones. Considering the impact of the size of fire, we divide the size of the fire into three levels, which correspond to different SSA drones demand quantities, and referred to the VRPTW algorithm to solve the TSP problem with different node requirements. Finally, we use genetic algorithm to optimize.

Keywords: Fire; drone, VRPTW algorithm, SSA, TSP.

1. Introduction

Frequent Bushfires in Australia are widespread occurrences continue to pose a natural hazard to life on earth. The most catastrophic bushfire season during summer 2019-20 ever experienced in Australia's history caused immeasurable loss of lives and property. So much was lost, and the impacts will be felt by years to come. And it is estimated that the 2019-2020 bushfires led to the deaths of at least 33 people and over 3 billion animals.

The most destructive fires are usually preceded by extreme high temperatures, low relative humidity and strong winds, which combine to create ideal conditions for the rapid spread of fire. As the fires raged well and destroyed even more habitat, emergency support is urgently needed by Emergency Operations Center (EOC). Luckily, with the progress of technology, in the searching part, drones are widely used to detect the fire behavior, and to carry repeaters for extending communication range.

We are required to formulate the purchase plan of the drones with SSA or Radio Repeater for the disaster relief response system named “Rapid Bushfire Response”, of Victoria’s Country Fire Authority (CFA). We defined our problem as:
• Arrange the drones.
determine the optimal numbers and mix of SSA drones and Radio Repeater drones.
• Forecast the changing likelihood of extreme fire events over the next decade.
• Set a budget.
Balance capability and safety with economics
In our paper, we develop three models to solving problems.
In our paper, we establish three models to solve the problem. At first, we develop simple models of DR and SSA. To make models close to reality, we take several factors into account, such as terrain and size of the fire, and optimize our model. In order to evaluate its ability to adapts to the possibility of extreme fire events change, we also develop a model of forecast.
At last, we make a budget chart for the CFA according to our models so that they can apply for funds from the government.

2. Notations
The primary notations used in this paper are listed in Table 1.

| Symbol | Descriptions | Range of value |
|--------|--------------|----------------|
| f_j    | Wildfire hot spots | n_f \in \mathbb{Z}, n_f \geq 0 |
| n_f    | The number of f_j | -39.0^\circ \leq x_j \leq -33.5^\circ, y_j \geq 141.0^\circ, 0 \leq j \leq n_f |
| (x_j, y_j) | The coordinate of f_j | |
| DR     | Drones equipped with radio repeater | |
| a_i    | The location of the DR | n_a \in \mathbb{Z}, n_a \geq 0 |
| n_a    | The number of the DR | -39.0^\circ \leq m_i \leq -33.5^\circ, n_i \geq 141.0^\circ, 0 \leq i \leq a_i |
| (m_i, n_i) | The coordinate of a_i | d = 20 km |
| d      | The range of radio repeaters | |

3. Model Preparation

3.1. Data preprocessing
Above all, in terms of the complexity and confidence of the wildfire hot spots data, we preprocess the data for accuracy: Since data illustrates major differences and varies into two phases. We cut out the time period of more research value to limit the scope of research.
Due to the complex process of fire detection through MODIS, even cloud, water, and metalclad factories on the ground can impact the process without a hitch. Hence, detecting data is utmost tough, and the reliability of fire-related data varies dramatically. Therefore, we classify the confidence of fire-related data, which involves Victoria from October 1st, 2019 to January 5th, 2020.

To enhance the accuracy of the research, we select data with confidence between 80% and 100%.

- **choose the time period.**
  After summing the number of fire hazards in Victoria from October 1st, 2019 to January 5th, 2020 (with the confidence between 80% and 100%), we draw a bar chart and a line chart as below (for the convenience of charting, we numbered the dates):

  Observing the diagrams, we find that there is a turning point at the end of November. The number of fires differs significantly around the point.

  As for few fires the point before, we discard the data before the point. And we take the data after the point for research.

  In addition, we consider that the number of fires from the point to January 5th, 2020 illustrates a trend of periodic increase. We take the changing rate of fire numbers per day as a measurement standard and calculate the cycle as 12 days. Thus, we regard November 21st as the point to research the data containing three fluctuation cycles since then to January 5th, 2020.

- **Remove extreme data and perform interpolation fitting**
  We discover that December 30th, 2019 and January 4th, 2020 turn out to be abnormal, as their daily number of fires is utmost large. And the abnormal data is highly possible to lead a inaccurate conclusion.

  Therefore, we eliminate the data of the two and make use of the data left for spline linear interpolation and polynomial fitting. The distribution histogram, line diagram and fitting curve of data after interpolation are displayed in the figure 2.

  As the fitting curve reveals, the results fit quite well. We can say that removing extreme data and performing interpolation fitting owns remarkable efficiency, which advances the accuracy and rationality of the following models and data prediction.

### Table 2. The confidence value (C) classes of Fire-pixel from NASA

| Notation | Confidence Class |
|----------|------------------|
| 0% ≤ C ≤ 30% | Low |
| 30% ≤ C ≤ 80% | Nominal |
| 80% ≤ C ≤ 100% | High |
4. Models

4.1. Model of Solution to DR
In this part, we concentrate on working out how many drones equipped with radio repeater are needed.

4.1.1. Model of Solution to DR. The problem requires us to work out how many drones equipped with radio repeater are needed. Evidently, the locations of Radio Repeater drones occupy a essential position. Then, we apply search algorithm to obtain the solution to the problem.

4.1.2. Model Design. Procedure 1 Based on Monte Carlo method, we grid the Australia map to get the DR’s location.

Figure 2. Daily total number of fires

Figure 3. Interpolation fitting
Table 3. DR Notations

| Symbol | Descriptions |
|--------|--------------|
| \( t \) | The grid’s length |
| \( A \) | The coordinate set of all grid points |
| \( p_{mn} \) | \( p_{mn} \in A, 1 \leq m \leq t, 1 \leq n \leq t \) |
| \( B \) | The DR’s optimal hovering coordinate, \( B \subset A \) |
| \( d_{min} \) | \( d_{min} = 22\text{km} \) |
| \( d_{max} \) | \( d_{max} = 25\text{km} \) |

And we introduce new parameters to this section which are displayed below:

First, we make a grid of \( t \times t \), which can cover all the hot spots \( f_j \) in Victoria. And denote the coordinate set of all grid points as set \( A \). On account of subtle grid, the number of the grid points is in a large scale. Thus, \( B \subseteq A \). Our model is working on to searching for all the grid points, making \( A \) shrink to \( B \), then we can apply the least drones to cover all the hot spots.

**Procedure 2 Eliminate the points roughly and reduce the scope of \( A \).**

Affected by terrain, the communication range of handheld radios is divided into two categories: one is 5 km over flat, unobstructed ground, the other is 2 km in an urban area. As a result, in the coverage area of the radio repeater, communication range can reach to \( d_{max} \) as 25 km over flat, unobstructed ground or \( d_{min} \) as 22 km in areas blocked by obstacles.

The schematic is Figure 3:

![Figure 3](image3.png)

**Figure 4. The name of figure**

For improving the efficiency of solving problem, we reduce the scope of \( A \) initially, by the condition:

If \( d_{mn} > d_{max} \), then \( p_{mn} \in A \) and \( p_{mn} \in \neg B \)

Where,

\( d_{mn} \) is the distance from \( p_{mn} \) to \( f_j \)

We set \( m \) and \( n \) as constant, if the distance \( d_{mn} \) from a grid point \( p_{mn} \) to any hot
spots fj surpass the dmax, then this grid point dmn is definitely not the optimal position. Consider the above conditions, we decrease a lot of points, the grid points left are denoted as pmn0.

**Procedure 3: classify pmn0**

**Step 1: delineation the communication range.**

Primarily, because the communication range varies by terrain, we divide it into two categories: dmax and dmin. Draw circles with radius dmax with pmn0 as the center, which located in the area of E142°-143°, S35°-36°; E143°-144°, S37°-38°; E148°-150°, S37°-38° and draw circles with radius dmin with pmn0 as the center, which located in Victoria but outside the area above.

**Step 2: Get the number n* of hot spots in the envelop, and mark each hot spot with unique number.**

**Step 3: Go through the location of target point pmn0, get the information matrix, which involves coordinate and mark number of hot spots within each target point’s range.**

**Procedure 4: According to the information matrix select the optimal DR hovering location.** Starting with the maximum of n*, we record the mark number of hot spots within the range. Go through all the n*, the model finishes to calculate.

Thus, we obtain the optimal solution to the number of DR and DR's hovering location.

4.2. Optimize the model

**Procedure 1 Based on Monte Carlo method, we grid the Australia map to get the DR’s location.**

We make a grid of t × t, which can cover all the hot spots fj in Victoria. And denote the coordinate set of all grid points as set A. On account of subtle grid, the number of the grid points is in a large scale. Thus, B ⊆ A. Our model is working on to searching for all the grid points, making A shrink to B, then we can apply the least drones to cover all the hot spots.

**Procedure 2 Eliminate the points roughly and reduce the scope of A.**

We optimize our model based on the model of solution to DR. On the basis of disparate terrains and fire areas, we add three situations when deleting target points.

- the altitude of the target point is excessively that the drone has trouble in flying, such as the yellow cross in the picture.
- the target point is in the fire area, such as the purple cross in the picture.
- there are mountain areas between the target point and the fire area. That is to say one of the two points is in mountain areas while the other is not, such as the green line in the picture.

![Figure 5. The grid map](image-url)
Procedure 3: classify pmn

Step 1: delineation the communication range.

Primarily, because the communication range varies by terrain, we divide it into two categories: \( d_{\text{max}} \) and \( d_{\text{min}} \). Draw circles with radius \( d_{\text{max}} \) with \( \text{pmn}_0 \) as the center, which located in the area of E142°-143°, S35°-36°; E143°-144°, S37°-38°; E148°-150°, S37°-38° and draw circles with radius \( d_{\text{min}} \) with \( \text{pmn}_0 \) as the center, which located in Victoria but outside the area above.

Step 2: Get the number \( n^* \) of hot spots in the envelop, and mark each hot spot with unique number.

Step 3: Go through the location of target point \( \text{pmn}_0 \), get the information matrix, which involves coordinate and mark number of hot spots within each target point’s range.

Procedure 4: According to the information matrix select the optimal DR hovering location.

Starting with the maximum of \( n^* \), we record the mark number of hot spots within the range.

Go through all the \( n^* \), the model finishes to calculate.

5. Sensitivity Analysis

We initially work out the total number, rate and size of daily fires’ expected number during 21st, November 2019 to 5th, January, 2020. They are respectively 289.9, 0.073, 539.23. then, we cluster the coordinates of hot spots, and the clustered categories are 290. The coordinates of each type of center point are taken as the coordinates of the expected fire point.

We mainly use data above to analyze the sensitivity, and respectively consider the rate and size of fire conditions, then get the form below

| SSA drones   | -10% | -5%  | 0      | 5%    | 10%   |
|--------------|------|------|--------|-------|-------|
| the rate of fires | 1996.7 | 2094.7 | 2193.6 | 2293.7 | 2395.1 |
| the size of fires   | 823.29 | 854.40 | 885.22 | 915.75 | 946.00 |

Figure 6. Number of repeater drones
Analyze the above data, regardless of SSA drones or repeater drones, ±5% change in fire rate resulted in change of demand of drones is slightly lower than ±10% change in fire rate’s. Nevertheless, the demand of drones affected more evenly by the size of the fire. Then we can conclude that the sensitivity of fire rate is greater.

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