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Strategy for Fighting Wildfires Using Mean-Shift Algorithm

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Abstract: To deal with the wildfires in Victoria, we need to arrange the drones reasonably. Taking into account capability, safety, economy and topography, we use Mean-Shift algorithm to determinate the optimal numbers and mix of drones and predict the situation of extreme wildfires in the future. Finally, we determine the optimal number and combination of drones after optimization. According to the size, frequency and locations of wildfires in Victoria in 2019, we use logistic model to estimate the general location of the wildfires. And we use Mean Shift algorithm to find the Optimal number, mix and locations of drones. The result is we need 95 SSA drones, 122 repeater drones and 122 drones with two functions, and the total cost is $3,390,000.

1. Background

Wildfires occur almost every year in Australia during a severe drought and persistent heat wave exacerbated by climate-change.Therefore, firefighters have used drones for surveillance and situational awareness (SSA), to carry high definition & thermal imaging cameras and telemetry sensors that monitor and report data from wearable devices on front-line personnel.In addition, two-way radio communication with hovering drones carrying repeaters to dramatically extend the range of low power radios on the front lines allows“boots-on-the-ground”forward teams to give status reports to the EOC (Emergency Operations Center) and allows the EOC to give orders directly to forward teams. Therefore, it is necessary to arrange drones properly to deal with all kinds of wildfire situations.

2. Model Establishment

2.1 Wildfire Location Estimation

According to Victoria's geographical location and boundary lines, to make it easier to quantify the frequency of wildfires, we divide its land to 21 parts (Figure 1), and then by collecting the wildfires data in Victoria in 2019 we can get the frequency of wildfires by dividing the number of wildfires in that area by the total number of wildfires. (Table 1).

So, we set up matrix BR , $BR=\left[br_1 1, br_2, br_3, \ldots, br_{17099}\right]^T$, which represents the brightness of wildfire and is used to characterize the size of wildfire, $PR=[pr_A, pr_B, pr_C, \ldots, pr_U]^T$, which represents the frequency of wildfires occurring at any point in each region, and we set up matrix $XR = [BR, PR]$.

Here, we use the Logistic model to evaluate the average location of wildfires.And we use the known data to predict the data of wildfires in the future, so as to evaluate the approximate location data of wildfires.

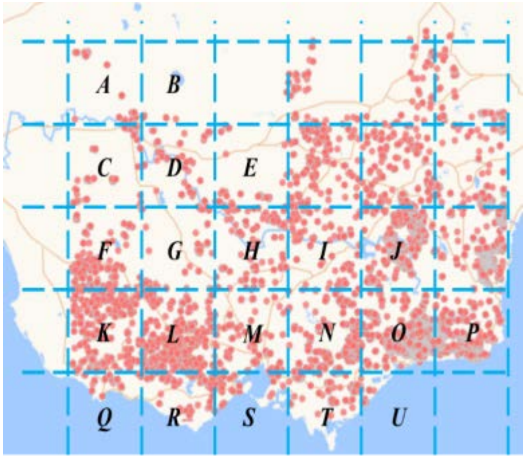

Figure 1: Result of Division

Table 1: Frequency of Each Area

Area	Wildfire Times	Frequency
A	167	0.0098
B	50	0.0029
C	90	0.0053
……	……	……
T	361	0.0211
U	70	0.0041

There are two possibilities for predicted wildfire locations, one for wildfire, which we set to 1, and one for no wildfire, which we set to 0, that is, if $YY = 1$, wildfires will occur,and if $YY = 0$,wildfires will not occur. Thus, we can get the expression:

$$\pi = P(YY = 1 | x_1, x_2) \qquad 0 < \pi < 1 \tag{1.}$$

$$Logic(\pi) = \ln(\pi/1 - \pi) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \tag{2.}$$

We can get the solution:

$$\pi = \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2)/(1 + \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2)) \tag{3.}$$

With Matlab for multiple linear regression, we can obtain the value of β_0, β_1 and β_2 .After the value of π is solved, we ought to determine threshold. If π is greater than the threshold, the point can be used as the estimated wildfire location.If π is less than this threshold, the point will not be used as the estimated wildfire location.

According to the reference [1], we can know the threshold value: $YY_0 = 0.1793$.

$$YY = \begin{cases} 1 & \pi > 0.1793 \\ 0 & \pi \le 0.1793 \end{cases} \tag{4.}$$

In the known data, we select 300 points were randomly, among which 54(0.1793×300) points were regarded as locations without wildfires, and the rest were regarded as locations with wildfires. According to equation5, we given value of π, and then solve the value of β_0, β_1 and β_2 ,and finally get π of each region. Using Matlab for the next screening solution, we can get the approximate wildfire location.

$$\pi = \begin{cases} \frac{0.1793+1}{2} = 0.58965 & YY = 1 \\ \frac{0+0.1793}{2} = 0.08965 & YY = 0 \end{cases} \tag{5.}$$

Through MATLAB and multiple linear regression, we obtain the values of β_0, β_1, β_2 are 0.4562366, 0.0001406, -0.0341949 respectively.Because the p is less than 0.05,the coefficients are valid. In order to avoid the influence of heteroscedasticity,we use OLS+ robust standard error regression to eliminate the variates with heteroscedasticity and make the remained independent variates more significant.Using White test, we obtain test result of null hypothesis that there is no heteroscedasticity.The test result was P =0.4407>0.05,so we accept the null hypothesis and there was no heteroscedasticity.In addition, we test the existence of multicollinearity,and the vif is all less than 10,suggesting that the regression equation does not have serious multicollinearity.

2.2 Determination of Drone Locations

Because the headquarters of Victoria's CFA is located in Melbourne with convenient transportation, we chose Melbourne [2], Australia (longitude: 144.9630576 latitude:-37.8136276) as the location of the Emergency Operations Center (EOC). And we assume that in a small square region with side length *r*, the number of wildfire locations is *n*, the number of drones is *k*, and the position of drone *i* is $X_i(x, y)$ $(i = 1, 2, \ldots, n)$, and the position of wildfire *i* is $Q_i(x, y)$.

The basic form of Mean-shift vector of any point X_i in space is:

$$M_h = \frac{1}{K} \sum_{x_i \in S_k} (X_i - x) \tag{6.}$$

And the drift vector is:

$$S_h(x) = \{ y : (y - X_i)^T (y - X_i) < h^2 \} \tag{7.}$$

Where, S_h represents the set of wildfires whose distance from drone *i* ($i = 1, 2, \ldots, n$) is less than the radius of drones.By calculating the drift vector, we update the position of the drones, and the update formula is:

$$x = x + M_{\&} \tag{8.}$$

In theory, we also need to consider the distance between the drone and the EOC [3]. However, considering that EOC is a fixed point and the distance can be regarded as fixed value, so we do not take it into account in the drift update.

After we add Gaussian weight to drift vector, the formula of drift vector is

$$m(x) = \left[\frac{\sum_{i=1}^{n} x_i g\left(\left\| \frac{x - x_i}{h} \right\|^2 \right)}{\sum_{i=1}^{n} g\left(\left\| \frac{x - x_i}{h} \right\|^2 \right)} - x \right] \quad (9.)$$

The coordinate of the center of the circle for each update is

$$x = \frac{\sum_{i=1}^{n} x_i g\left(\left\| \frac{x - x_i}{h} \right\|^2 \right)}{\sum_{i=1}^{n} g\left(\left\| \frac{x - x_i}{h} \right\|^2 \right)} \quad (10.)$$

3. Model Result

According to the situation of the Victoria wildfires in 2019, we calculate the number, combination and location distribution of SSA drones, repeater drones and drones with two abilities. In Figure 2, red represents the repeater drones, yellow represents the SSA drones, and green represents the drones with two abilities. We can see from figure NN that the location distribution of drones is uniform and the distribution of drones is dense in the area of severe wildfires.To reduce the cost, when the distance between the SSA drones and the repeater drones is less than 4km, we replace their position with a drone that contains both abilities.

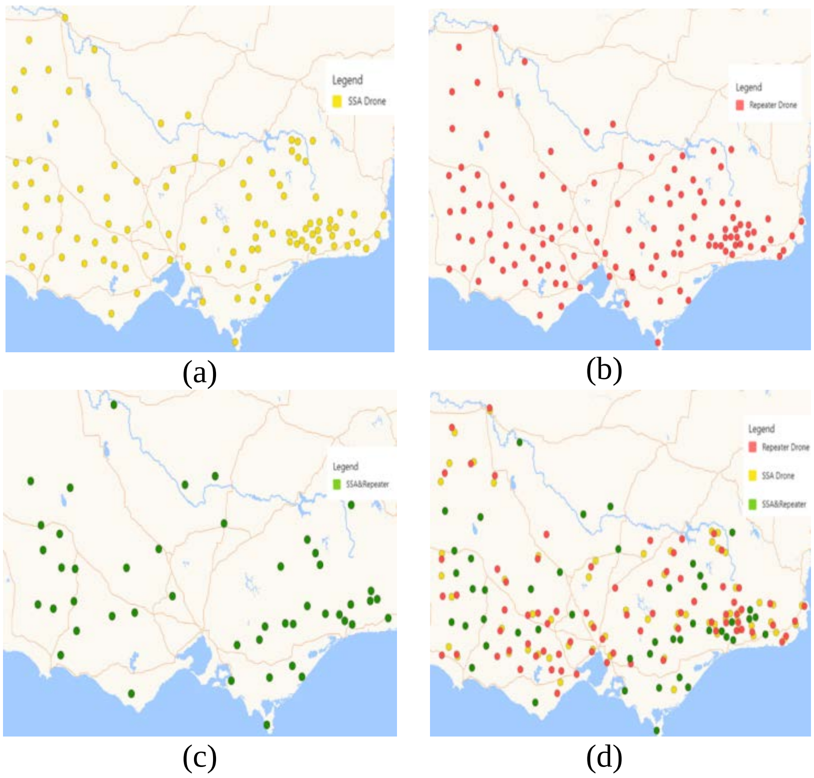

Figure 2: Distribution of Drones for Problem 1

Where the total number of drones is 339, the number of SSA drones is 95, the number of repeater drones is 122, and the number of drones with both abilities is 122. Without considering the change of drone cost and depletion of drones, the cost is $3,390,000.

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