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Research on Strategy of Wildfire Detection Towards Different Weather Information-Based on ARIMA Model

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Abstract: Wildfires have caused huge economic and ecological damage to Australia in the past few years. This paper studies a man-machine cooperation based response system to help the Victorian Country Fire Authority better monitor and control the wildfire disaster. In order to solve the problem, this paper establishes mathematical model called ARIMA. The Model is a probability prediction model based on climate factors. The occurrence of wildfire is closely related to the climatic conditions. In this paper, the time series auto-regressive model (ARIMA) is established to predict the temperature, precipitation and other meteorological factors in the next ten years. On this basis, the contribution of meteorological factors to the occurrence of wildfire was analyzed, and the future wildfire occurrence was predicted by using Logistic linear regression method.Finally, we discuss the advantages and disadvantages of the model.

1. Introduction

Wildfire is a kind of fire that burns without any plan in the forest or jungle, which is destructive to the ecological environment.[1] Due to the influence of climate factors, wildfires have caused great economic and ecological losses in Victoria.[2] In order to monitor and take control of wildfire disasters, reducing the number of ground firefighters as much as possible and protecting their safety, the national fire bureau introduces a variety of drones to assist ground firefighters to monitor and extinguish the fire.[3] When the wildfire broke out, CFA quickly established an emergency operations center, ground vanguard troops wearing equipment entered the fire area for detection, and the information was transmitted to the EOC through a drone equipped with a repeater.[4] The situation sensing UAV monitors the environment and reports the situation of the vanguard forces at the same time, so as to establish two data transmission chains.[5] In summary, we consulted relevant websites to collect topographic data and wildfire occurrence data for Australia from 2000-2020, and pre-processed the data.[6]

2. Establishment and Solution of Model

The occurrence of wildfires is closely related to climatic conditions. Multiple meteorological factors such as temperature, precipitation, wind speed and wind direction all contribute to the burning of wildfires to a certain extent. In order to predict the extreme fire situation in Victoria in the next ten years, based on the pre-processing of the above data types, we first establish *a time series auto-regressive model (ARIMA)* to predict meteorological factors such as temperature and precipitation in the next ten years. On this basis, by analyzing the contribution of various meteorological factors during wildfire occurrence in the past two decades, using *Logistic linear regression method*, calculating the influence probability of wildfire occurrence factors and determining the influence factors, thereby establishing a probability prediction model based on climate factors.

2.1 Forecast of Climate Factors

Given the data of multiple climate factors such as the Victorian summer in the past 20 years, we want to predict the changes in climate factors in the next ten years. The ARIMA (p, d, q) model is the most common statistical model used for time series forecasting, and it is quite compatible with the problem. Through the processing of historical data, the current data is obtained, and the data for the next 10 years can be obtained through auto-regressive analysis.

Table 1 Summer climate factors

Symbol	Description	Unit
$x_1 / T_{\max}$	maximum temperature	°C
$T_{\min}$	minimum temperature	°C
$x_2 / \Delta T$	temperature difference	°C
x_3 / L	precipitation	mm
x_4 / v_{wind}	wind speed	m/s

We give the curve of wind speed with month in figure 1.

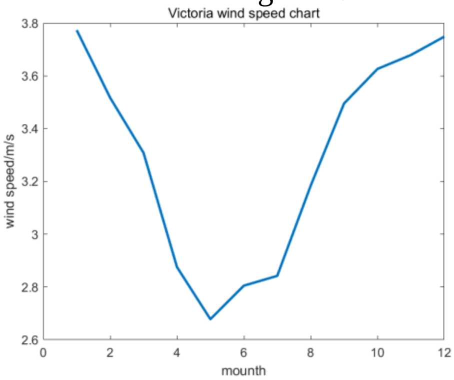


Figure 1: anemobia-graph

2.1.1 Establishment of ARIMA model

y_t is the value of a certain meteorological factor in year t, and p represents the total number of known historical data. According to the auto-regressive model, we get the following relationship:

$$y_t = u + \sum_{i=1}^{p} y_i \, y_{t-i} + \varepsilon_t \tag{1}$$

Among them, u is a constant term, r_t is the auto-correlation coefficient, and ε_t is the error term for the year.

In order to effectively eliminate the random fluctuations in the prediction model, we need to accumulate the error terms in the above self-review model, and the accumulation of the q-order auto-regressive process follows the following formula:

$$y_t = u + \varepsilon_t + \sum_{i=1}^{q} \theta_t \varepsilon_{t-i} \tag{2}$$

From the above formula, the auto-regressive moving average model for a certain meteorological factor is as follows:

$$y_t = u + \sum_{i=1}^{p} r_i\, y_{t-i} + \varepsilon_t + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i} \tag{3}$$

On the basis of these formulas, combined with the idea of difference, construct an ARIMA *(p, q, d)* model, where d is the order of difference of the data.

We take the pre-processed data from 2000 to 2019 as known time series data, and perform first-order and second-order differences on these data respectively, and compare the differences to determine the order of difference.

First order difference is performed on the data:

$$\Delta \mathrm{y(x)} = \mathrm{y_{i+1}} - \mathrm{y_i} \tag{4}$$

Second order difference is performed on the data:

$$\Delta\big(\Delta \mathrm{y(x)}\big) = \Delta\big(\mathrm{y(x+1)} - \mathrm{y(x)}\big) = \mathrm{y(x+2)} - 2\mathrm{y(x+1)} + \mathrm{y(x)} \tag{5}$$

As the result of difference is the most direct embodiment of data stationarity, we visually express the difference result of the used data, observe the stationarity of the image, and determine the order of difference, that is, the value of *d*.

In order to further determine the specific values of *p* and *q*, we will introduce two new functions to facilitate the solution of the problem,

Describe the linear correlation between predicted data and known historical data. Auto-correlation function ACF:

$$ACF(k) = \rho_k = \frac{cov(y_t, y_{t-k})}{var(y_t)} = \sum_{t=1}^{n-k} \frac{(y_t-\mu)(y_{t-k}-\mu)}{\sum (y_t-\mu)^2} \tag{6}$$

For the data series with stable change from 2000 to 2019, the interference degree function AKFC on the model are as follows:

$$PACK(k) = \rho_{x_t - x_{t-k} | x_{t-1}, \dots, x_{t-k+1}} = \frac{E[(X_t - EX)(X_{t-k} - EX_{t-k})]}{E[(X_{t-k} - EX_{t-k})^2]} \tag{7}$$

Using the above formula to solve the auto-correlation coefficient ACF and partial auto-correlation coefficient PACF, draw the auto-correlation graph and partial auto-correlation graph of the observation data sequence, you can determine the best order *p* and *q*, finally, we can be obtained ARIMA *(p,q,d)*.For example, the maximum temperature auto-correlation plot and partial auto-correlation plot of the observed series are shown.

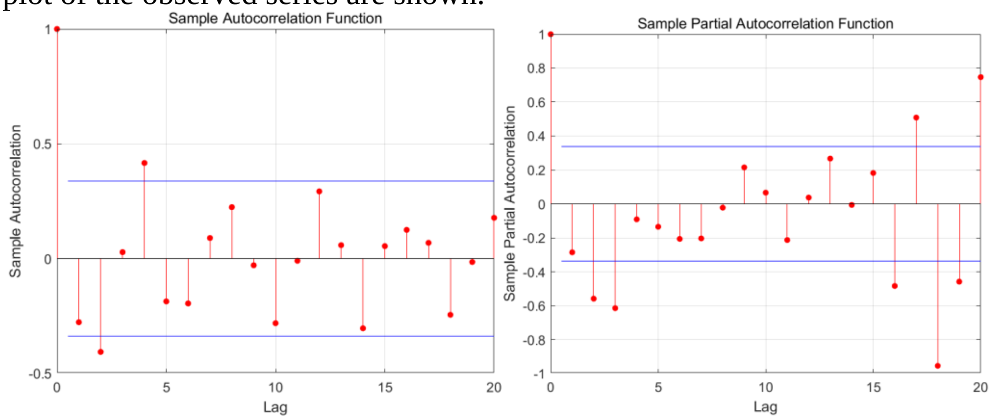
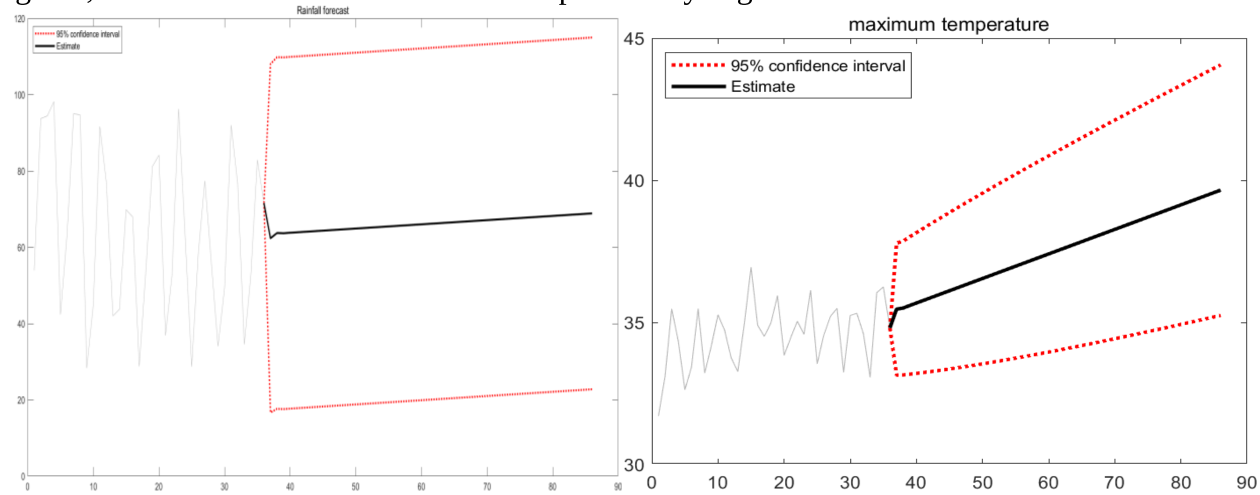


Figure 2: ACF and PACF testing

2.1.2 Application of ARIMA model

Substituting the maximum temperature, temperature difference, average precipitation and wind speed in the above ARIMA *(p,q,d)* prediction model in turn in each summer, simplifying the solution process, we can get their corresponding models, and then getting the meteorological factors in the next ten years predictive value.

From the figure 10,we know *p*=1,*q*=1 in the maximum temperature's ARIMA,accords with the ARIMA(1,1,1) model and the ARIMA model prediction image of rainfall and maximum temperature is given, and the confidence interval of 95% probability is given.



(a) (b)

Figure 3: ARIMA model predicts rainfall (a) and maximum temperature (b)

2.2 Wildfire Prediction Model Based on Climate Factors

Through the statistical analysis of the data, we found that there is a certain law of climate factors when wildfires occur frequently. When continuous drought, high temperature and little rain, fires are more likely to occur.

2.2.1 Single factor prediction

If 0-1 variable is used to describe whether wildfire occurs, then

$$Y = \begin{cases} 1.\text{occur} \\ 0,\text{else} \end{cases} \tag{8}$$

The probability of wildfire occurrence is represented by *p*, and *p* is regarded as a linear function of x_i , so

$$p = \alpha_0 + \sum \alpha_i x_i + \varepsilon \tag{9}$$

If *y* is used to represent the predictive value of wildfire risk, the regression model is established according to the logistic algorithm

$$y = \ln\left(\frac{p}{1-p}\right) = \alpha_0 + \sum \alpha_i x_i + \varepsilon \tag{10}$$

$$p = \frac{e^y}{1+e^y} \tag{11}$$

We can calculate the probability of each factor's influence on wildfire by logistic regression, that is, the value of α_i corresponding to each x_i.

2.2.2 Multi factor comprehensive prediction

By substituting the experimental results of n times into the formula(15), a system of multivariate linear equations can be obtained.

Among them, α is the regression coefficient, and the least squares estimated value a of α corresponding to the minimum square sum of the difference between the observed value of y and the regression value is solved according to the principle of least squares, denoted as a_i.

So,

$$y_i = \mu + \alpha_1(x_{i1} - \overline{x_1}) + \Lambda + \varepsilon \tag{12}$$

$$\hat{y} = a_0 + a_1x_1 + \Lambda + a_4x_4 + \varepsilon \tag{13}$$

$$\overline{x_i} = \frac{1}{n}\sum x_{ki} \tag{14}$$

y_i represents the wildfire risk level. Using the matrix to solve the problem, the relationship between the wildfire risk level and the four meteorological factors can be finally obtained. We will take 2020, 2025 and 2030 into the model to solve the corresponding year wildfire probability distribution.

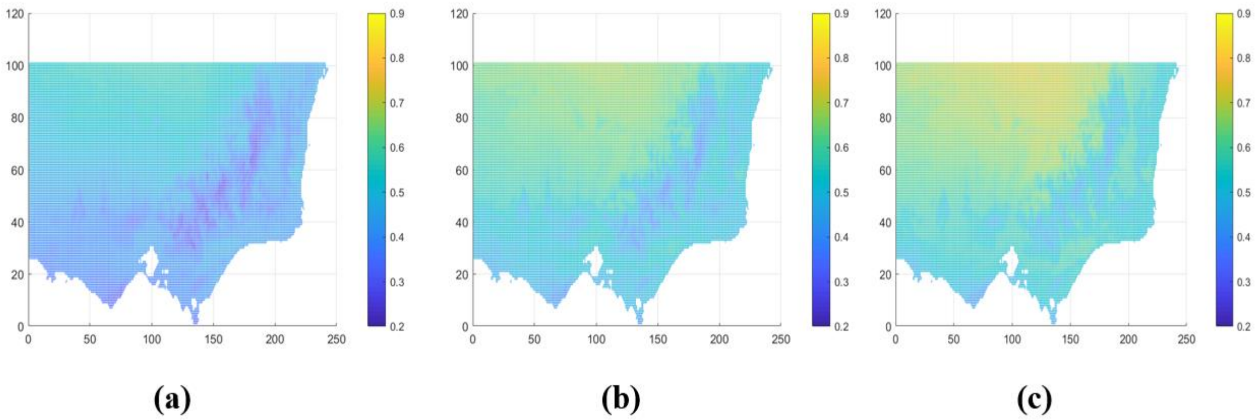


Figure 4: Wildfire probability distribution map in 2020(a), 2025(b) and 2030(c)

2.3 Results of problem

The number of two drones that need to be purchased are: SSA UAV α frame, UAV equipped with repeater β frame, and its purchase cost ω.

Table 2 The optimal combination of different fire situations

Forest fire severity	Fire coverage/hectare	Assumed fire radius/km	Number of ass dispatched	Distance from EOC to fire center/km
High	1<	0	0	0
Very High	[1.100]	5.5	1	30
Severe	[100,1000]	18	2	40
Extreme	>1000	25	3	50

topography	Forest fire severity	Weighted communication distance	Number of repeaters
Mountainous terrain	Very High	163.02	8
	Severe	195.627	10
	Extreme	229.6211	12
Plain topography	Very High	28.0857	2
	Severe	32.6342	2
	Extreme	33.9322	2

According to the quantity, we can obtain the optimal combination and cost price of wildfire in different range and degree.We give a roadmap for signal transmission of one of the results, as shown in Figure 5.

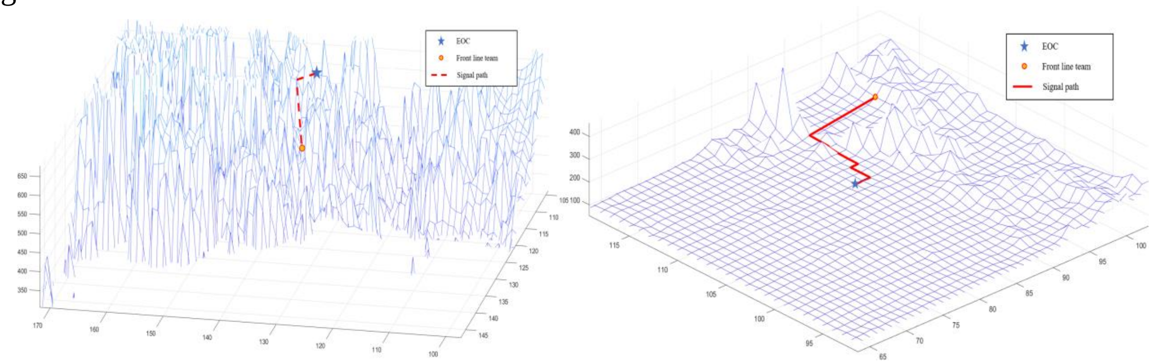


Figure 5: The shortest path to a situation

3. Evaluation of the model

3.1 Strength

- The data signal transmission model is based on the mechanism of electromagnetic wave propagation, which is scientific and reasonable.
- The sensitivity analysis of the model shows that the forecast model can well adapt to the combination of different parameters, which proves the robustness of the model.
- The wildfire prediction model is based on a large number of data analysis, considering the probability of the impact of various climate factors on wildfire, and is not limited by time interval such as time regression series. The model is scientific and reasonable, and has passed the test of the model.

3.2 Weakness

In order to process the data more conveniently, we discretize a large amount of data every year, and use some data to represent the whole data of the year.

3.3 Generalization of the model

Our model is universal and transferable:

- The propagation of data transmission model radio can be extended to any kind of wave passing through obstacles, such as solving the diffraction effect of light in the presence of obstacles.
- The wildfire prediction model is based on the analysis of a large number of data to obtain the probability model of wildfire occurrence in the future. We can also establish the prediction model

of wildfire or forest fire around the world according to this method.

- The UAV hovering optimization position optimization model, especially the wildfire spread model, can effectively predict the trend of wildfire spread, so as to better realize the rescue.

4. Conclusion

Country Fire Authority is a statutory body in Victoria. Since the establishment of Country Fire Authority in 1958, we have been adhering to the mission of “to protect lives and property”, making unremitting efforts for the fire prevention and fighting work in Victoria, and persisting in supporting all regions to do a good job in fire fighting preparation and emergency services. We hereby apply to the state government for 1800,000 $ funds to ensure the progress of the project. The specific uses of the funds are as follows:

Table 3 The usage of funds

			($ thousand)
Project	unit-price	amount	Total
Drone for surveillance and situational awareness	10	6	60
Drone carrying repeater	10	24	240
Two-way radio communication	0.1	100	10
Mobile EOC	350	3	1050
Total commitments		133	1360

The main expenditure of our budget is the purchase of drones and mobile EOC. In addition, due to the high incidence of wildfire, the need for personnel to carry out ground auxiliary work caused by the cost of hiring personnel and purchasing radio equipment. The specific uses are briefly described:

- The mobile emergency EOC is placed near the wildfire burning area and is responsible for on-site command and dispatching.
- Drone for surveillance and situational awareness is mainly used to monitor and report the situation of ground workers and their surroundings.
- Drone carrying repeater and Two-way radio communication is used as the communication tool and auxiliary communication tool at the disaster relief site to ensure the real-time contact and data transmission between people and EOC.

The budget cost is reasonable. If the wildfire fails to respond quickly and the best extinguishing period is missed, the economic loss and ecological loss will be huge, and it even takes a long time to restore people's production, life and ecological environment.

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