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Study on visualization of forest fire spread based on ArcGIS

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***Abstract*—The unique geographical features and changeable climatic of Yunnan Province make the forest fire prone and frequent. Aiming at the problem of forest fire that may be suffered by overhead transmission lines and power grid equipment in Yunnan Province, the research on forest fire spread was carried out, and the method of combining Rothermel model and Huygens principle was mainly used to simulate forest fire spread. On this basis, the powerful graphic processing capabilities and spatial analysis capabilities of ArcGIS are used to graphically display the spread process to improve usability and visibility.**

Key words-forest fire spread; Rothermel model; Huygens principle; ArcGIS

I. INTRODUCTION

Forest fires (hereinafter referred to as forest fires) are listed by the United Nations as one of the eight natural disasters due to their suddenness, wide coverage, great destructiveness, and difficulty in fighting them. It is not only easy to destroy a large number of forest resources, severely damage the ecosystem, but also seriously threaten the lives and property of the country and people. Therefore, effectively preventing and predicting the occurrence and development of forest fires has become a general concern of all countries in the world.

Forest fire is a very complex process. There are many natural factors that affect its spread, such as terrain (slope and aspect), vegetation (type of combustibles), and meteorology (wind direction, wind speed, temperature, and humidity). To describe forest fire behavior well, people usually simulate the process of forest fire spread by establishing data models, that is, to derive the quantitative relationship between forest fire behavior and various natural factors. At present, there are many mathematical models of forest fire spread, representative examples include the Rothermel model of the United States, the national forest fire spread model of Canada, the McArthur model of Australia, the Wang Zhengfei model of China, and the modified model based on these models [1]. However, the mathematical model of forest fire spread is static, which cannot reflect the dynamic change process of forest fire spread. With the continuous development of geographic information technology and remote sensing technology, it has become an inevitable trend to use the computer to simulate the dynamic process of forest fire spread in real time based on the selection of a suitable mathematical model of forest fire spread, combined with the current advanced GIS technology and research methods.

This article mainly studies the spread of forest fires in the area of transmission lines. The method of combining Rothermel model and Huygens principle is used to simulate the spread of forest fires in real time and realized by ArcGIS. Visualization of the spreading process.

II. FOREST FIRE SPREAD MODEL

A. *Rothermel model*

The Rothermel model is a semi-theoretical and semi-empirical forest fire spread mathematical model based on combustion physics and forest fire experiments [2]. Its abstract degree is high, covering almost all factors that can affect combustion. According to the analysis of various factors such

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as the geographical location, climate environment and topography of Yunnan Province, this paper adopts the Rothermel model.

According to the law of conservation of energy, the Rothermel model believes that the spread speed of forest fires under the condition of no wind and flat ground is [3]:

$$R = \frac{I_R \zeta}{\rho_b \varepsilon Q_{ig}} \tag{1}$$

In the formula, R is the spreading speed of forest fire, and the unit is m/min ; I_R is the reaction intensity of the flame zone, the unit is $(kJ^2/m) \cdot min$; ζ is the forest fire spread rate, Dimensionless. ρ_b is the combustible bed density, $the\ unit\ is\ kg/m^3$; "ε" is the effective thermal coefficient, dimensionless; Q_{ig} is the pre-combustion heat, that is, the heat required to ignite a unit mass of combustible material, the unit is kj/kg.

In an actual fire scene, due to the combined effects of wind and slope, the spread of forest fires will increase dramatically. Therefore, the Rothermel model believes that the change in the spread of forest fires under wind and slope conditions can be measured by the wind speed correction coefficient ϕ_w and the slope correction coefficient ϕ_s. The forest fire spread speed is:

$$R = \frac{I_R \zeta}{\rho_b \varepsilon Q_{ig}} \left(1 + \overrightarrow{\phi_w} + \overrightarrow{\phi_s}\right) \tag{2}$$

Among them, ϕ_w and ϕ_s are empirical formulas fitted from experimental data:

$$\phi_w = C(3.284U)^B \left(\frac{\beta}{\beta_{OP}}\right)^{-E} \tag{3}$$

$$\phi_s = C\beta^{-B}(\tan\phi)^2 \tag{4}$$

In the formula, β is the compactness of combustibles, dimensionless; β_{OP} is the optimal compactness of combustibles, dimensionless; ϕ is the slope; B, C and E are all coefficients. As shown in Figure 1, the vector superposition direction of wind direction and slope is the direction of the fire head, which spreads the fastest. The fire tail is opposite to the fire head, and its spread speed is the slowest. The fire wing is the spreading part perpendicular to the fire head. Between the fire head and the fire tail.

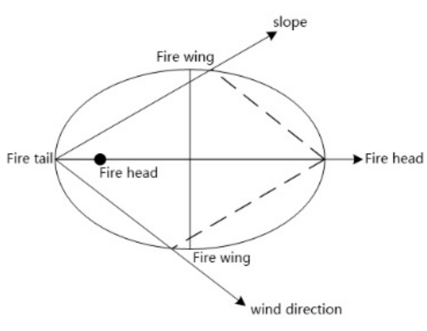

Figure 1. Schematic diagram of wind direction and slope vector superposition

B. Huygens principle

The Huygens principle is an extension of the Anderson ellipse model, which regards the forest fire spread area as a continuously expanding polygonal representation that changes over time [4]. As shown in Figure 2, it is the result of the spread of two steps based on Huygens principle. The inner polygon is the range of the fire point spreading in the first step, that is, the shape of the initial fire field. The step length is short, generally an ellipse, the fire point is a focal point of the ellipse, the long axis direction represents the direction of the fire head, which is the vector superposition direction of the wind direction and the slope. Select several points on the ellipse as the control points for the next time step, use it as a new starting point to get the small ellipse that expands in the second time step, and use the outer polygon of the small ellipse as the second time step. The scope of the spread [5].

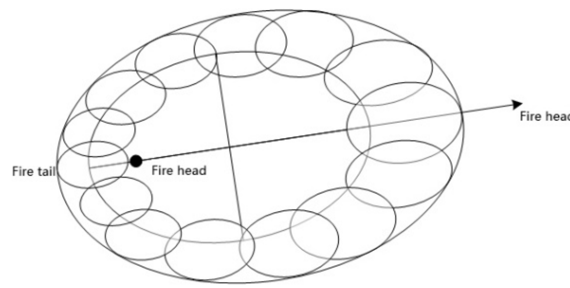

Figure 2. Spreading results based on Huygens principle

Assuming that the ratio of the major axis to the minor axis of the ellipse is LB, and the ratio of the distance from the focus to the fire head to the distance from the focus to the fire tail is HB, LB and HB are calculated according to the basic equation and experimental data as [4]:

$$LB = 0.936\exp(0.2566U) + 0.461\exp(-0.1548U) - 0.397 \tag{5}$$

$$HB = 0.5 \cdot \left[LB + \frac{LB^2-1}{LB} - (LB^2 - 1)\right] \tag{6}$$

From the above two formulas, the major axis a, b and focal length c of the ellipse can be obtained, and the units are all m/min:

$$a = 0.5 \cdot \left(R + \frac{R}{HB}\right) \tag{7}$$

$$b = 0.5 \cdot \frac{R + \frac{R}{HB}}{LB} \tag{8}$$

$$c = b - \frac{R}{HB} \tag{9}$$

C. Forest fire spread simulation process

This paper adopts the method of combining Rothermel model and Huygens principle to simulate forest fire spread in real time. The basic flow of the simulation is shown in Figure 3. The core part is the spreading process based on Huygens principle.

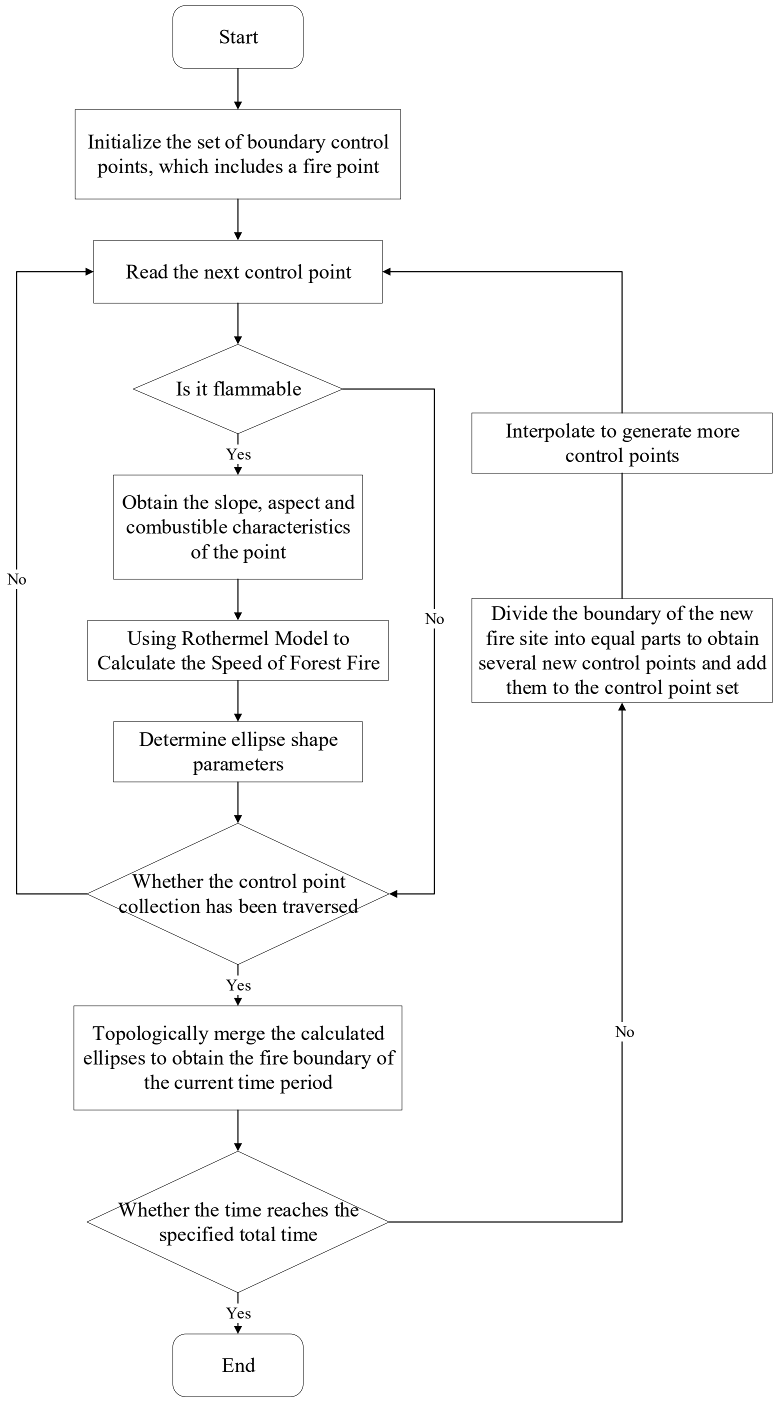

Figure 3. Flow chart of forest fire spread simulation

III. VISUALIZATION OF FOREST FIRE SPREAD

This article chooses Visual C# programming language and GIS secondary development component library ArcGIS Engine to realize the visualization of forest fire spread simulation [6,7]. The main interface of the visualization system is shown in Figure 4.

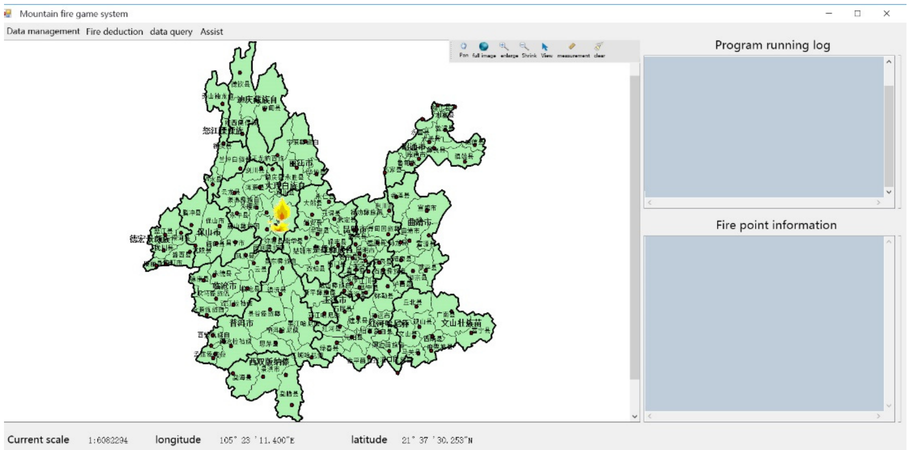

Figure 4. The main interface of the visualization system

A. Parameter input

The parameters that need to be input include topographic data, weather data, combustible data, and operational data. Topographic data is static data, including the slope, aspect, altitude, and vegetation of the grid points, which can be simulated by the digital elevation of the area the model (DEM) is extracted and stored on the raster layer. Meteorological data is dynamic data, including wind direction and wind speed, etc.; combustible data is Rothermel model parameter data input based on the actual situation of the simulated area, including combustible load, combustible heat content, dried particle density and surface area to volume ratio. The operating data includes the simulation time step, the total simulation time, and the latitude and longitude of the fire point.

B. Simulation results

This article is based on the location of the fire in the Yantang forest area of Qinghuadong Forestry Farm in Xiangyun County, Dali Prefecture, Yunnan Province on May 20, 2019 (north latitude $25^{\circ}33'5''$ and east longitude $100^{\circ}35'1''$) is the initial fire point, and its terrain data, weather data, combustible data and operation data are set as input parameters for forest fire spread simulation. The terrain data is Yunnan Province DEM with 30m spatial resolution, and the weather data is fire occurrence Local weather information for the time period, the combustible data is the forest resource second-class survey data [8-11], the operation data is the time step of 10 minutes, the total time is 180 minutes, and the 180-minute spread result can be obtained, as shown in Figure 5.

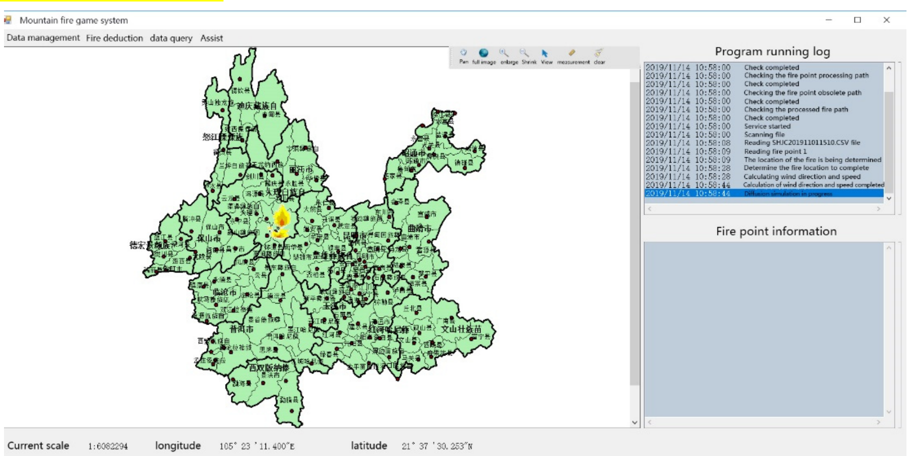

Figure 5 180-minute simulation results

At the same time, on-site data collection obtains three fire point information, respectively 60 minutes (north latitude $25^{\circ}33'24''$ and east longitude $100^{\circ}36'0''$) and 120 minutes (North latitude $25^{\circ}33'24''$ and east longitude $100^{\circ}36'32''$) and 180 minutes (north latitude $25^{\circ}33'53''$ and east longitude $100^{\circ}37'1''$) the latitude and longitude of the fire point, the system operation calculation can get the time to spread to these three fire points are 71 minutes, 103 minutes and 150 minutes, and Compared with the actual collection time, the deviation rates are 18.3%, 14.2% and 16.7% respectively.

IV. CONCLUSION

The spread of forest fires is complex and changeable. It is greatly affected by environmental factors and vegetation. Small changes will cause changes in the direction and speed of spread. This paper simulates real forest fires based on the Rothermel model and Huygens principle, and uses ArcGIS to achieve Visualization of forest fire spreading process.

Due to the special geographical location of Yunnan, the complex and changeable terrain, and the rich and diverse vegetation types, the acquisition of fuel data is more complicated. If you want to further improve the accuracy of the forest fire spread visualization system in actual production, it is necessary to establish an effective region-based the combustibles database of the company contributes to the further production and use of the system.

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