

Research on Logic Optimization and Reliable Calculation Model of Satellite Based Wildfire Monitoring for Power Transmission Line

Zhenzhen Zhou¹ and Gang Chen²

¹ Senior Production Editor, Maintenance & Test Center, EHV, China Southern Power Grid, Guangzhou, China

² Production Assistant, Baise Bureau of EHV, China Southern Power Grid, Baise, China

E-mail: joebuuaa@163.com

Abstract. In order to improve the accuracy of wildfire monitoring for transmission line based on satellite sensing data, this paper proposed a new method that can be used to verify different data from synchronous satellite and polar orbiting satellite mutually. Also, this paper optimized the wildfire identification logic by considering surface elements, wide-area meteorology, cultural environment, and history records, and then proposed a corresponding calculating model to evaluate the reliability of wildfire detected. Relied on the improvements above, the accuracy of wildfire monitoring of EHV Power Transmission Company increased almost 30% in April to May 2018.

1. Introduction

At present, the application of meteorological satellites has gone far beyond the traditional meteorological scope. Detecting heat sources for forest fire monitoring is an important aspect of the application of meteorological satellites in non-meteorological fields. With the growth of China's power grid, large-capacity and long-distance transmission lines are increasing year by year. And many transmission lines pass through mountains and dense forest areas. The special topography and climatic conditions of these areas are very likely to initiate wildfires, which threaten the overall security and stability of the large regional power grid [1]. Traditional human or helicopter inspection methods for transmission line cannot meet the requirements of timeliness and accuracy for wildfire monitoring [2]. Therefore, it is necessary to build wildfire warning system which could analyze the heat detecting data acquired from meteorological satellites to find out the real fire that may threaten the stability of power transmission lines or power grids.

However, due to the limitations of satellite remote sensing technology, there are many problems in daily wildfire monitoring, low accuracy, for example [3]. During the long-term application and continuous modification for wildfire monitoring system based on satellite, this paper proposed a new method to optimize the logic of wildfire identification by considering multidimensional data including the data collection cycle from different satellites, surface morphology around fire point, recent meteorological data and so on. This method has significantly increased the accuracy of wildfire monitoring and been applied in the wildfire monitoring system of China Southern Power Grid EHV Power Transmission Company.

2. The principle of fire monitoring based on satellite



2.1. Synchronous satellite and polar orbiting satellite

The synchronous satellites are located 36,000 kilometers above the equator, the orbital plane of which coincides with the equatorial plane, and the orbital velocity and direction are the same as the Earth's. Therefore, the synchronous satellite enables static observation as they are relatively stationary with the Earth. Although synchronous satellites are not as accurate as polar orbiting satellites, they can perform continuous observations on a given area.

The polar orbiting meteorological satellite, also called the sun-synchronous orbiting meteorological satellite, has an orbit of 800 to 1000 km above the Earth. The instantaneous orbital plane in which polar orbiting satellites are located is always in a stable orientation with the sun, so that the local time when the satellite passes the same area is the same [4]. Compared with synchronous satellites, polar orbit satellites have lower orbital heights, and can get better observation results. Also, because they keep in sync with the sun, the illumination in each observation is almost the same, which is conducive to the comparative analysis of the observed data [5]. However, polar orbiting satellites can only carry out observations twice a day for the same area, so it is impossible to achieve the goal of real-time monitoring.

In view of the respective characteristics of the satellites mentioned above, it is recommended to take use of both synchronous satellites and polar-orbiting satellites in practical applications, in order to get more reliable data. Take the wildfire monitoring system of EHV Power Transmission Company as an example, the satellite data of this system acquired from the Guangzhou Meteorological Satellite Ground Station, one of four major satellite ground stations in China, is mainly consisted by synchronous geostationary satellites and polar orbiting satellites as a supplement. The synchronous geostationary satellite, which mainly include Himawari-8 geostationary satellite of Japan, FengYun satellite of China, scans the earth surface every 10 minutes. And the polar orbiting satellites include TERRA, AQUA of US and other meteorological satellite data. All the satellites connected to the system collect a large amount of data including remote sensing data, vegetation index data, and meteorological cloud map, the resolution of which is 1×1 km.

2.2. The principle of remote sensing recognition

The normal temperature of earth surface is about 300K [6], and the flame temperature of wildfire can reach 1000K. According to Stephen Boltzmann's law and Wien's law of displacement, the total amount of radiation is in a quadratic relationship with temperature. A small change in the temperature of the black body will cause significant radiation changes. Therefore, the high temperature of heat source would cause a drastic change in the radiation, which makes the monitoring of wildfire possible. According to Planck's law of black body radiation [7], the wavelength of the hot spot radiation at normal temperature is close to that of the mid-infrared channel, while the one of the high-temperature heat source is close to that of the far-infrared channel. The feature can be used to make coarse judgments to high temperature heat sources. The radiation growth rates of the mid-infrared and far-infrared channels are quite different, which can be used for the identification of fire points on the ground.

2.2.1. Method for calculating channel brightness temperature. From the Planck black body radiation formula:

$$W_{\lambda} = \frac{2\pi hc^2}{\lambda^5} \cdot \frac{1}{e^{hc/k\lambda T} - 1} \quad (1)$$

The brightness of channel p as T_p can be drawn:

$$T_p = \frac{hc}{\lambda_p k} \ln^{-1} \left(\frac{2\pi hc^2}{\lambda_p^5 W_{\lambda}} + 1 \right) \quad (2)$$

Where: w_{λ} is the corresponding radiance of the channel with wavelength of λ , $W \text{ m}^{-2} \cdot \mu\text{m}^{-1} \text{ Sr}^{-1}$; T is the channel brightness temperature value, K ; T_p is the brightness temperature value of channel p, K ; h is the Planck constant, $h=6.63 \times 10^{-34} \text{ J s}$; c is the speed of light in vacuum,

$c=3.0 \times 10^8 \text{ m s}^{-1}$; λ is the channel data wavelength, μm ; λ_p is the data wavelength of channel p , μm ; k is the Boltzmann constant, $k=1.38 \times 10^{-23} \text{ J K}^{-1}$.

2.2.2. Hot spot discrimination. The identification of fire point is the key of fire monitoring system based on satellite for power transmission line. Set the brightness parameter T_h as the threshold to determine whether the pixel is fire point. After the picture taken by the satellite processed by noise reduction algorithm, the point will be considered to be a fire if the calculated bright temperature value of the corresponding bright spot is greater than the threshold value. That is, the judgment condition is:

$$T_C > T_h \quad (3)$$

As delivered to the wildfire monitoring system, the satellite data will be automatically processed with the threshold fire point identification method [8] to initially determine the existence of fire point.

3. Difficulties in satellite wildfire monitoring and early warning

Using satellite data to monitor wildfire for transmission lines can effectively improve the response speed for wildfires disposal and reduce the risk for power grid. However, the accuracy rate of wildfire monitoring based on satellite is far less than 100% because of interferences from complicated ground factors. After the fire point was found out by the system, the power transmission line operation department should organize personnel to check on site. As the high-voltage transmission lines often cross mountain or jungle, fire point review costs much human labor. Therefore, how to improve the accuracy has become the biggest difficulty in wildfire monitoring based on satellite.

According to the experience of power transmission line operation and maintenance, there are many factors that may affect the accuracy of the wildfire monitoring. It is necessary to analyze all those interferences comprehensively and use the computer to calculate the credibility of fire point.

4. Wildfire monitoring logic optimization

4.1. Monitoring frequency analysis

If a hot spot is considered to be fire (suspected fire spot) by calculating channel brightness temperature, the wildfire monitoring system will load this spot into a task queue, and then carry out periodic comparison with different logic according to the data acquisition satellites. The logic map is as shown in Figure 1:

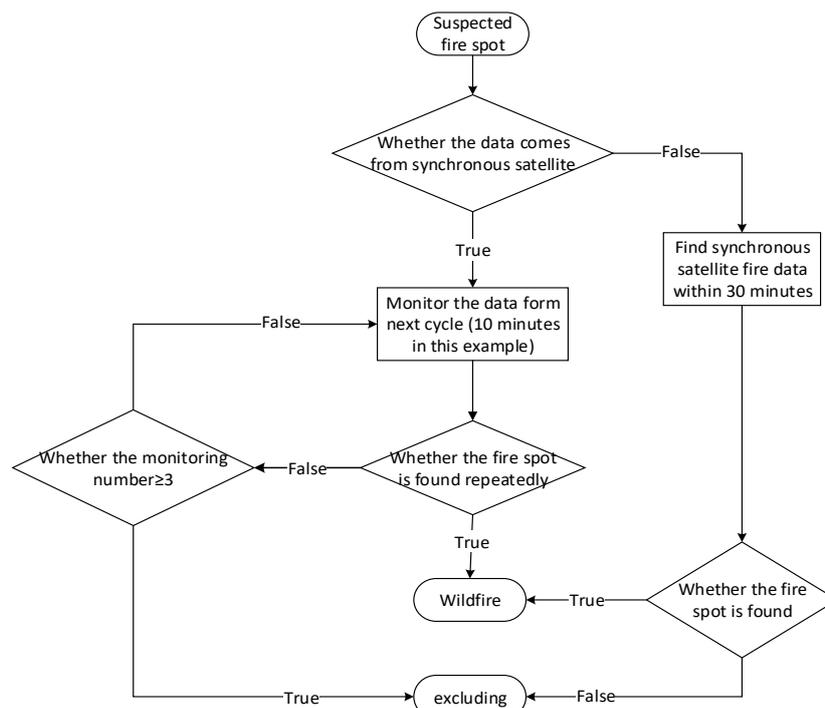


Figure 1. Multiple satellite monitoring data comparison logic

If this suspected fire spot is confirmed as a wildfire at the end of the procedure above, the system will take more influence factors as below into consider in order to make a more accurate judgement.

4.2. Earth surface element analysis

Check the earth surface around the fire based on the hot spot coordinates provided by the satellite data. There are usually two ways to acquire information about the surface: geographic image data, and lidar scan data especially for transmission line corridors. In real application, geographic image data can be viewed on GIS platform such as Google Earth (also, image data can be purchased separately and superimposed on GIS platform in monitoring system), and the resolution can satisfy the requirement for surface elements discrimination. Lidar scan data is much more precise, and can be also used to check the vegetation information around the hot spot. However, due to the high cost of lidar scanning, image data is more often used for element recognition in fire monitoring. The common earth surface elements [9] and their application in wildfire discrimination are shown in Tab 1 :

Table 1. Surface elements and their discriminating methods

Earth surface elements	Discriminant method
Natural vegetation	If the natural vegetation between the fire point and the nearby line corridor is dominated by low-lying plants, the fire will not have a large impact on the high-voltage transmission line. If natural vegetation is dominated by densely growing trees, the fire point should be focused on.
Bare rocks	If a rock is exposed to strong light for a long time, its surface temperature would rise and show a significant temperature difference from periphery. Therefore, if the hot spot is located in a large area filled with exposed rock, it is less likely to be a real fire.
Lakes and rivers	The water surface can reflect sunlight, and it may be identified as fire by satellite sometimes. Therefore, if located in lake or river, the hot spot is should be defined as a false alarm and recorded into database storing ignore areas. If there is a large river between the hot spot and transmission line corridor, the fire point would not affect the transmission line.
Farmlands	If the fire point is located in a large area of farmland, it is more likely transient fire caused by farmers burning straw and will not last long time. It would not have a major impact on the transmission line [10].
Industrial plants	If the fire point is located near the industrial plant area, it is more likely to be an industrial fire (such as chimneys). After several times detected as fire by satellite, this area can be moved into ignore areas of the system.

4.3. Wide-area meteorological analysis

The meteorological information of the area where the corridor is located is an important reference for judging the authenticity of the satellite fire. It can be acquired from the public network or the provincial meteorological department by information system connected to the internet. Among meteorological information, temperature, humidity, rainfall should be focused on:

- If there is strong precipitation before or at the same time the hot spot detected, the hot spot is made by the water ripple probably, which should be ignored.
- If the air humidity in the wildfire located area is relatively high, in which large-scale wildfires would not happen, the credibility of the fire point should be reduced.

- If the weather in the wildfire located area is hot and dry, which is conducive to make fire, the credibility of the fire point should be increased.

4.4. Cultural environment analysis

After above screening, if the fire point is not excluded, it still needs further analysis combined with cultural environment. The cultural environment includes two categories: residents' habits and seasons. Among them, residents' habits include burning habits, open fire worship, and other habits or customs that may cause wildfires. Generally, this information is entered into system by line operation and maintenance department or line guards based on experience. The season mainly contains the period before and after the Qingming, the harvest period of crops, the high temperature and dry season [11]. If the above-mentioned facts exist around suspected fire point, the probability of real fire is high.

4.5. Historical data analysis

Some areas are prone to wildfire due to complicated factors such as geographical environment and humanistic environment. The historical data of real wildfire has a high reference value for the current wildfire determination. After the wildfire is discovered by the satellite, the system will search historical wildfire records about the surrounding area of this fire point. If there is a real confirmed historical wildfire record, the credibility of the fire point should be increased.

4.6. Fire point distribution analysis

If the satellite monitoring data shows that there are multiple fire points in a area around the corridor, the probability that these are real fires is high, and also maybe it is a big fire that affects large areas, which needs to be focused on. When counting fire points, the ones within 5 km can be combined as a single point.

According to experience, the 6 steps mentioned above can intercept most of false wildfire alarms. However, some fire points are still confirmed as false alarms by the line guards. Therefore, it is necessary to introduce a kind of confidence algorithm for wildfire monitoring based on satellite, which could assist the wildfire monitoring personnel to carry out disposal measures according to the credibility and scale of wildfire.

5. Credibility calculation model for wildfire monitoring

The identification of wildfire monitoring based on satellite involves complex factors such as earth surface, meteorology and culture. It is useful to establish a reasonable credibility calculation model to minimize the false alarm rate and improve the practicability of the fire monitoring system. Generally, the same as influence factors, different ones plays different roles in the identification of wildfires. The traditional full probability model can not meet the requirement of calculating credibility for wildfire monitoring. Therefore, the concept of dynamic weighting factors will be introduced next. The weights of influence factors are assigned by event priority.

The wildfire credibility calculation model is established for the five aspects mentioned in (3.2-3.6) in wildfire identification logic, as follows :

$$P = \begin{bmatrix} P_A = P_{\max} \{P_{A1}, P_{A2} \dots P_{An}\} \\ P_B = P_{\max} \{P_{B1}, P_{B2} \dots P_{Bn}\} \\ P_C = P_{\max} (P_{C1} + P_{C2} + \dots + P_{Cn}) \\ P_D = P_{D1} \\ P_E = P_{E1} \end{bmatrix} \times \begin{bmatrix} H_A \times Q_A \\ H_B \times Q_B \\ H_C \times Q_C \\ H_D \times Q_D \end{bmatrix} \quad (4)$$

Among them, PA is the credible probability of the wildfire corresponding to the surface element, taking the maximum value of the sub-item, HA as the corresponding weight of the surface element, QA as the corresponding dynamic adjustment factor of HA; PB is the credible probability of the wildfire corresponding to the wide-area meteorology, taking the maximum value of the sub-item, HB is the weight of the wide-area meteorology, QB is the corresponding dynamic adjustment factor of HB;

PC is the credible probability of the wildfire corresponding to the human environment, taking the sum of the sub-items, HC is the corresponding weight of the human environment, QC is the corresponding dynamic adjustment factor of HC; PD is the credible probability of the wildfire corresponding to the historical data, HD is the historical data corresponding weight, QD is the dynamic adjustment factor corresponding to HD; PE is the credible probability of the wildfire corresponding to the historical data, HE is the historical data corresponding weight, QE is the dynamic adjustment factor corresponding to HE. The variables of Equation 4 are specified as shown in the following table:

Table 2. Credibility calculation model variables in Satellite wildfire monitoring

Identification element	Low-lying plants	Bare rocks	Lakes or rivers	Farmlands	Industrial plants
P_A	$P_{A1}=0$, True	$P_{A2}=0$, true	$P_{A3}=0$, true	$P_{A4}=0.4$, true	$P_{A5}=0$, true
	$P_{A1}=1$, Densely growing trees	$P_{A2}=0.5$, false	$P_{A3}=0.5$, false	$P_{A4}=0.5$, false	$P_{A5}=0.5$, false
	$P_{A1}=0.5$, Others				
Weights, $H_A=0.3$					
Wide-area meteorology	Temperature and humidity	Precipitation	cultural environment	Resident habit	Season
P_B	$P_{B1}=1$, High temperature and dry	$P_{B2}=0$, Heavy precipitation	P_C	$P_{C1}=0.4$, used to fire	$P_{C2}=0.6$, Ching Ming Festival
	$P_{B1}=0.2$, Large humidity	$P_{B2}=0.1$, normal precipitation		$P_{C1}=0.1$, others	$P_{C2}=0.5$, Crop harvesting period
	$P_{B1}=0.5$, others	$P_{B2}=0.5$, no precipitation			$P_{C2}=0.6$, others
Weights, $H_B=0.1$			Weights, $H_C=0.1$		
historical data	Historical fire point	Fire point distribution	Fire point aggregation		
P_D	$P_D=0.5$, no records	P_E	$P_E=1$, Fire spots gathered>3		
	$P_D=0.8$, Recorded but less than 3		$P_E=0.7$, 1< Fire spots gathered ≤3		
	$P_D=1$, Recorded and more than 3		$P_E=0.5$, Fire spots gathered = 1		
Weights, $H_D=0.2$			Weights, $H_E=0.3$		

The dynamic adjustment factor Q is used to adjust the corresponding weight according to the probability distribution of the influence factors. With Q, the system gets the ability of adjusting the proportion of other influencing factors according to the key factors (the factors about earth surface and strong precipitation that cannot produce fire). And the initial value is:

$$Q = [1 \ 1 \ 1 \ 1 \ 1]^T \tag{5}$$

The dynamic adjustment factor can be adjusted according to the operation experience. Take an example and use pseudo code to illustrate as follows:

If ($P_{Amin} = 0 \parallel P_{Bmin} = 0$) // P_{Amin}, P_{Bmin} are the minimum of the P_A and P_B sub-items.

$$Q = [0 \ 0 \ 0 \ 0 \ 0]^T \text{ // Exclude wildfire}$$

Else if ($P_{Amax} = 1 \ \&\& \ P_{Bmax} = 1$) // Surface vegetation and meteorology is prone to fire

$Q = [0.5 \ 0.5 \ 2 \ 1.5 \ 1]^T$ // Increase the weight of the cultural environment and historical data

Else if ($P_C = 1$) // Residents nearby and season are prone to fire

$$Q = [0.5 \ 1 \ 2 \ 2 \ 0.5]^T \text{ // Increasing the weight of historical data}$$

6. Conclusion

The wildfire identification logic and credibility calculation model proposed in this paper analyzes various satellite data sources, surrounding environment, and introduces historical monitoring records into consider. During the period of April to May 2018, 51 wildfires had been confirmed in 69 fire alarms issued by the satellite-based fire monitoring system in China Southern Power Grid EHV Power Transmission Company. The accuracy of fire alarm improved significantly, reaching almost 75%.

7. References

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