The study of remote sensing dynamic monitoring for coalfield fire area in Shuixigou, Xinjiang

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Abstract. The dynamic monitoring of fire area is particularly important in the controlling of underground coalfield fire. This paper took the Xinjiang Shuixigou coalfield fire area as an example, through the normalized processing of the multi-temporal thermal infrared images a generalized single-channel algorithm was used to retrieval the surface temperature. Combined with the method of single band optimal density split Sec-segmentation followed by dividing the fire area into the background region, serious combust region and more serious combust region. Thermal anomaly information in the coalfield fire area and analyse the spatial and temporal dynamics change of underground coalfield were calculated as follows: ① fire area increased 2.03 times between 1990 and 2011, the annual average degree of dynamic changes was 1.28 in the first ten years and increased to 4.57 in the last ten years; ② the gravity of the little serious area of the coalfield fire integrally moved north to northwest from 1990 to 2001, then northeast from 2001 to 2011; ③ there were three original independent child fire area A, B and C, but A and B merged between 1990 to 2001, C also trended close A and B until 2011.

Remote sensing technology provides a feasible method for the dynamic monitoring of coalfield fire area and provides theory basis and scientific guidance for the prevention of coalfield fire disaster and implementation of coalfield fires fighting engineering.

1. Introduction

Coalfield fire not only caused a great waste of coal resources, but also threatened to the national economy and the ecological environment sustainable development. In the work of coalfield fire prevention, it is very important to locate the underground coal fire source and dynamic monitor the combustion situation. Because of the higher temperature, fire smoke diffuse and liable geological disasters in the coal fire area, these caused a certain difficulty for field detection, while remote sensing technology has some advantages such as detecting large area, timeliness strong, economic cost low, therefore it has become an important means of investigating and dynamic monitoring the coal fire area¹²³.

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At present, China and other countries have carried out many research and application of detecting coal fire area by using the remote sensing technology, which includes visible light, near infrared, short wave infrared to thermal infrared, from multispectral to high spectrum, from satellite, airborne to the ground remote sensing and so on\textsuperscript{[4,5,6]}. Remote sensing technology is mainly used in the detection of the large area underground coal fire, due to it usually take Landsat TM/ETM+, QUICKBIRD, IKONOS, ASTER as data source, it could use direct or indirect method to detect and dynamic monitor the present situation of coal fire area. In these data sources, Landsat 5 TM6 has been applied most widely due to its characteristics of data easily acquired, short visit cycle and higher spatial resolution. But the quantitative calculation, grades dividing and combust dynamic change of coalfield fire area are always the key point and difficulty for coal fire detection.

This paper will use normalization processing for the multi-temporal thermal infrared images, and to retrieval the surface temperature, employ the method of single band optimal density split Segmentation to divide the coalfield fire area grades and analyse the dynamic change of underground coal fire, so as to discuss the problem of providing a scientific and practical method by using remote sensing technology to dynamic monitor the coalfield fire.

2. Study area
This paper take the Xinjiang Shuixigou coalfield fire area as the study area(Figure1), which is situated 20 kilometers southwest of Jimsar county, located in the northern piedmonts of Tianshan mountain and the south of Junggar basin, its geographic coordinates: E88° 58′ 21″ , N43° 56′ 39″ . The southern terrain of coalfield fire area is higher than the northern part, the elevation in the study area is between 1158 and 1040 meter. The study area belongs to temperate zone continental arid climate, annual average temperature about 7°C, the highest temperature about 37°C and the lowest temperature about -29°C. North of the coalfield fire area shows deep collapse about 20 to 30m, southern surface reverse tide, coal tar precipitation, outcrop area have glauber's salt crystallization.

3. Method

3.1. Normalized processing of remote sensing image
There are many factors that may influence the extraction of thermal anomaly information in coalfield fire area, such as terrain, vegetation, soil moisture content, emissivity, thermal inertia, etc. According to the experience of remote sensing image normalized research, the normalized processing method could be divided into two classes: absolute normalized and relative normalized\textsuperscript{[7,8]}. The main workflow of simple normalized processing for thermal infrared remote sensing image which based on the long
time series and Multi-temporal can be summarized as follows:

1. To generate a high precision DEM image;
2. According to the satellite transit time, simulating solar radiation intensity at the time of satellite transit, then calculate the map of surface solar radiation intensity;
3. Multi-temporal image normalized processing. For thermal infrared image (TM6) of Landsat 5, use the original data of TM6 to reduce the solar radiation intensity that obtained by above second step, finally achieve to decrease the influence of solar radiation on the region of great topographic relief.

3.2. Temperature retrieval of coalfield fire area
Landsat 5 have only one thermal infrared band (TM6), the main applied algorithms of surface temperature retrieval at present include radiation transfer equation, mono-window algorithm\(^9\), generalized single-channel algorithm\(^10\) and Weng algorithm\(^11\). This paper employed the generalized single-channel algorithm to retrieval surface temperature of coalfield fire area in Shuixigou, and then validated the results by field temperature which measured by thermal infrared thermometer.

3.3. Thermal anomaly information extraction of coalfield fire area
The combustion of the underground coal could cause unusual surface temperature, according to this phenomenon, coalfield could be distinguish to the background region and combust region more accurately. However, to confirm that whether the thermal anomaly area for real fire area need more means and methods. For example, using high resolution remote sensing image for visual interpretation, or collect more geographic and geomorphic data so that can use expert knowledge to test it, all of these are in order to extract the real fire area more high-efficiency.

It is very important on how to set threshold value to obtain the thermal anomaly information for coalfield fire area during the course of using remote sensing image to extract thermal anomaly area. At present, the threshold value is mainly determined by artificial threshold value method, it needs the actual measured data and expert knowledge system to select the discontinuity point between the fire region and background region. Generally, there are three methods to determine the threshold value: trial-and-error method\(^12,13\), exclusive method\(^14\) and statistical method\(^15\). The former two methods both need the actual measured data and expert experience, therefore it usually used in the area of known threshold value. However, it is not need the actual measured data for statistical method, so it is easy to popularize. Statistical methods often use the mean, standard deviation, variance and statistical data of remote sensing image data to set threshold. So that this paper use the optimum density segmentation method Wu\(^16\) to set the threshold value.

4. Results and discussion

4.1. Coalfield fire combust region dividing
Normalized processing simply to the three of Landsat 5 image data in 1990, 2001 and 2011 in Shuixigou coalfield fire are, then used the optimum density segmentation method to extract the thermal anomaly information in coalfield fire area from each remote sensing image, and divided the Shuixigou coalfield fire area into three grades which are the background region, the serious combust region and the more serious combust region (Figure 2).
4.2. Time variation analysis of the thermal anomaly in coalfield fire area

The area of the serious combust region was gradually increasing from 1990 to 2011 in Shuixigou coalfield fire area, During this period, the percentage of serious combust region increased 1.33 and the area has increased 12600m² from 1990 to 2001; its percentage increased 5.24 and the area increased 49500m² during 2001 to 2011, so the growth trend of the serious combust region is increasing fast. The area of fire area in 2011 increased to 203% to the area of 1990, the annual average degree of dynamic change is 1.28 in the first ten years, and increased to 4.57 in the last ten years. The area of the more serious combust region was smooth and slightly increased from 1990 to 2011, in which, it almost no change from 1990 to 2001, and form 2001 to 2011, it increased the percentage of 0.09 and its area expanded 900m²(Table 1).

Table 1. The area statistics of the thermal anomaly in Shuixigou coalfield fire area in 1990, 2001 and 2011

| Grades                      | 1990     | 2001     | 2011     |
|-----------------------------|----------|----------|----------|
|                             | Area(m²) | Percentage(%) | Area(m²) | Percentage(%) | Area(m²) | Percentage(%) |
| Background region           | 882900   | 93.52    | 870300   | 92.18    | 819900   | 86.84      |
| Serious combust region      | 45000    | 4.77     | 57600    | 6.10     | 107100   | 11.34      |
| More serious combust region | 16200    | 1.72     | 16200    | 1.72     | 17100    | 1.81       |

4.3. Spatial dynamic analysis of the thermal anomaly in coalfield fire area

There were three independent child fire area in Shuixigou coalfield fire area in 1990(Figure 3), in 2001 the child fire area of A and B had merged, then the C also had the trend of closing to A and B in 2011. The main part of serious combust region moved to northwest from 1990 to 2001, then moved to northeast from 2001 to 2011. Overall, the development trend of coalfield fire is extended to north, the situation that induced by fire disaster is gradually serious, more and more coal resources will be waste.
5. Conclusion
This paper uses the three of Landsat 5 image data in 1990, 2001 and 2011 to do simple normalized processing, then employed the generalized single-channel algorithm to retrieve the surface temperature, and combined with the method of single band optimal density split Sec-segmentation. Lastly, realized the coal fire area grades dividing and space-time dynamic change information extraction. Remote sensing technology provides a feasible method for the dynamic monitoring of coalfield fire area, and provides theory basis and scientific guidance for the prevention of coalfield fire disaster and the implementation of coalfield fires fighting Engineering.

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