INFRARED THERMOGRAPHY MONITORING AND EARLY WARNING OF THE SPONTANEOUS COMBUSTION OF COAL GANGUE PILE

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KEY WORDS: Mine Rock Dump, Infrared Thermography, Spontaneous Combustion, Decision Support

ABSTRACT:

Spontaneous combustion of mine rock dump (coal gangue pile) has posed a constant threat to the safety of mine areas by polluting its atmosphere, water, soil and even the threat of unpredictable explosion. Traditional monitoring techniques like utilizing thermocouples and thermometers can only measure the surface temperature on a point-by-point basis and hence are costly and time-consuming. Infrared thermograph, compared with the traditional techniques, has the greater coverage area and higher precision temperature results. But, for lacking of spatial information in the thermo-image, it is proposed to integrate GPS and infrared thermograph to monitor spontaneous combustion of mine rock dump. Some key issues including principles of setting control net, the method of mining spatial coordinates from thermo-image and data processing steps are investigated in detail. Finally, the capability of infrared thermography for its application in monitoring and early warning the spontaneous combustion of mine rock dump is emphasized.

1. INTRODUCTION

Mine rock dump is the solid castoff produced in the process of coal mining and washing, which approximately accounts for 10%-15% of the total coal product according to the current coal mining technology level in China (Min, 2003). According to incomplete statistics, the accumulation of mining waste rock in China has reached up to 5 billion tons, taking up approximately 15,000 hectares of land, and the accumulation is increasing at a speed of 150-200 million tons per year (Yu et al, 2007). A series of environmental problems and geological hazards has been caused by the mine rock dump, especially the spontaneous combusting ones (Huang, 2004). Therefore, finding an effective instrument or technique to monitor the spontaneous combustion of mine rock dump is very urgent.

Monitoring the spontaneous combustion of mine rock dump is one of the important approaches to keep it from exploding. The key problem of monitoring work is how to acquire the surface temperature distribution information of mine rock dump quickly and accurately. Traditional monitoring techniques like using thermocouples and thermometers can only measure the surface temperature on a point-by-point basis and hence, are costly and time-consuming. Infrared thermography has been studied as a high-precision and high-efficient instrument for measuring the surface temperature in a remote sensing way (Li Guohua et al, 2004; Dattoma V. et al, 2001; Desideri U. et al, 2004; Schulz A., 2000). But, for lack of spatial information in the thermo-image, there are some problems that need to be solved before using the infrared thermography to monitor, early warn and research the mechanism of the spontaneous combustion of rock dump, such as how to mining spatial information from the thermo-image, how to analyze these temperature information and how to estimate the combusting tendency (Sheng, 2007), all of what would be discussed in this paper.

2. MINING SPATIAL COORDINATES FORM THERMO-IMAGE

The monitoring work needs the surface temperature distribution information, as the coordinates and temperature of every point on the surface of mine rock dump. The temperature information could be acquired from the thermo-image, but the thermo-image consists of temperature information and its pixel coordinates (not the spatial coordinates). For the next analysis, the pixel coordinates should be transferred into spatial coordinates first.

If we obtain the geometric relationship between the pixel and its corresponding target (rock dump surface), the pixel coordinates could then be transferred into spatial coordinates. However, there are many incidental and variable factors, such as shooting angle, shooting distance, optical distortion and shape of target, will affect the process of taking thermo-images. So it is hard to describe the geometrical relationship between the pixel and its corresponding region in the surface of the mine rock dump use a mathematical model.

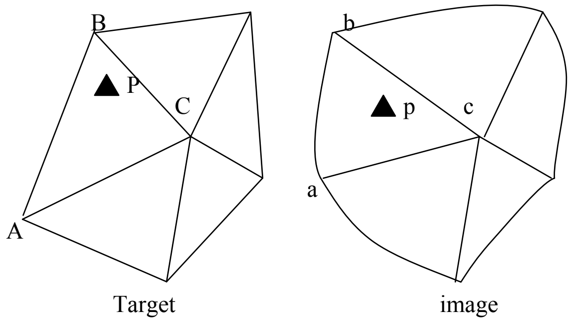

Figure 1. Relationship between the target surface and image

As seen in figure 1, the geometrical relationship between the target surface and thermo-image is unknown, But there is another kind of relationship could be found between them. As seen in Figure1, A, B, C and P are four points on the target surface, a, b, c and p are their positions in the thermo-image. ABC is a triangle plan in the surface of rock dump, and P is in ABC. In the thermo-image, abc is another triangle area, and the p is in abc. If we have the spatial coordinates (X, Y, Z) of A, B and C and know their positions in thermo-image, and the pixel coordinates (x, y) of a, b, c and p could be measured in the thermo-image, then according to the coplanarity equation, the coordinates of P(X_P, Y_P, Z_P) could be calculated using equations (1)and (2).

$$\begin{pmatrix} x_p & y_p & X_P & 1 \\ x_a & y_a & X_A & 1 \\ x_b & y_b & X_B & 1 \\ x_c & y_c & X_C & 1 \end{pmatrix} = 0 \quad \begin{pmatrix} x_p & y_p & Y_P & 1 \\ x_a & y_a & Y_A & 1 \\ x_b & y_b & Y_B & 1 \\ x_c & y_c & Y_C & 1 \end{pmatrix} = 0 \qquad (1)$$

$$\begin{pmatrix} X_P - X_A & Y_P - Y_A & Z_P - Z_A \\ X_B - X_A & Y_B - Y_A & Z_B - Z_A \\ X_C - X_A & Y_C - Y_A & Z_C - Z_A \end{pmatrix} = 0 \qquad (2)$$

3. MONITORING PROCEDURE

The monitoring procedure can be divided into two parts: acquiring data and analyzing data. As shown in Figure 2, the procedure can be divided into 5 detailed steps

3.1 Background

On May 15, 2005, the spontaneous combustion mine rock dump exploded and collapsed twice in No.4 coal mine of Henan PingDingShan coal mining district in China, eight people died and 123 people were injured in this explosion (Zhao, 2007). Figure 3 is the photos of the combusting mine rock dump and its exploded area.

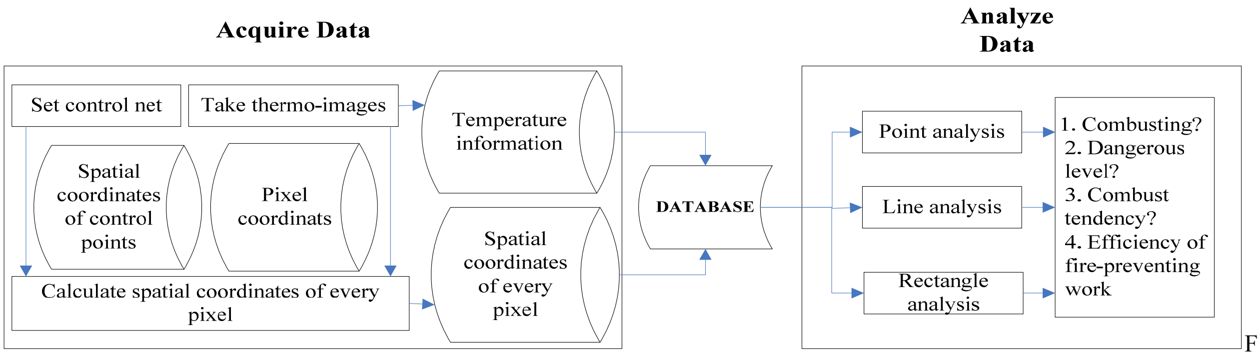

Figure 2. Flow of monitoring spontaneous combustion of rock dump using infrared thermography

Figure 3. Combusting rock dump and its exploded area, No.4 coal mine in PingDingShan coal mining district

3.2 Thermography

Thermography detection was conducted using DL-700E thermographic-IR imaging system with a 320×240 pixels focal-plane-array detector that is sensitive to a radiationwavelength of 8 to 14μm. The temperature sensitivity is less than 0.1℃ at 23℃, while the spatial resolution can be as small as 1.1mrad. The system has a highest-speed data-acquisition capability of 250 Hz at a full frame of 320×240 pixels.

3.3 Acquiring Data

As mentioned in before, if want to acquire spatial coordinates of every pixel in the thermo-image, we have to know the spatial coordinates of some points on the surface of rock dump and its pixel coordinates, it means that we have to set a control net which could cover all of the monitoring areas first and these control points could be high-colored in the thermo-image.

Most of the control points should be placed along the ridge and valley of the rock dump and make sure that there are at least three control points in every thermo-image. To make sure these control points are high-colored in the thermo-image, we should bury metal pipes at the position of these control points and survey its spatial coordinates by GPS.

After taking thermo-images of the combusting rock dump, the thermo-image data are read into the computer and stored as a matrix (the values are temperature information). Based on the control points in the thermo-image, we can transfer all of the pixel coordinates into spatial coordinates which will be inputted into a dataset with the temperature information. The precision of the spatial coordinates revealed cm-level, which could meet the need of practical application (Sheng, 2007).

3.4 Analyzing Data

3.4.1 Analyze with One Thermo-image: As seen in figure 4, with one thermo-image, we can judge whether the monitored area is combusting (if the temperature of the monitored area is higher than the atmosphere temperature, it is combusting; if it is almost equal to the atmosphere temperature, it is not combusting at the moment). In the combusting area, the highest temperature and its position could be certain. Besides, by analyzing the temperature distribution in line, we can estimate which direction the combusting situation is most dangerous in; by analyzing the temperature distribution in plan, we can find which combusting area is most dangerous (many places in one rock dump may combust at the same time).

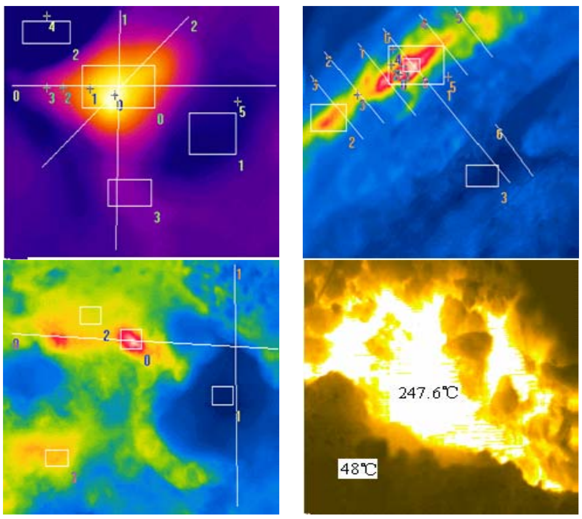

Figure 4. Analyze with one thermo-image

3.4.2 Analyze with Time Series Thermo-Images: As seen in figure 5, using time series thermo-images covering the same area and taken in different times, we can find the overspreading tendency of the combusting area inside the mine rock dump and its direction. Besides, if we have taken some measures to prevent the combustion inside the rock dump, these information could be used to check the fire-preventing work.

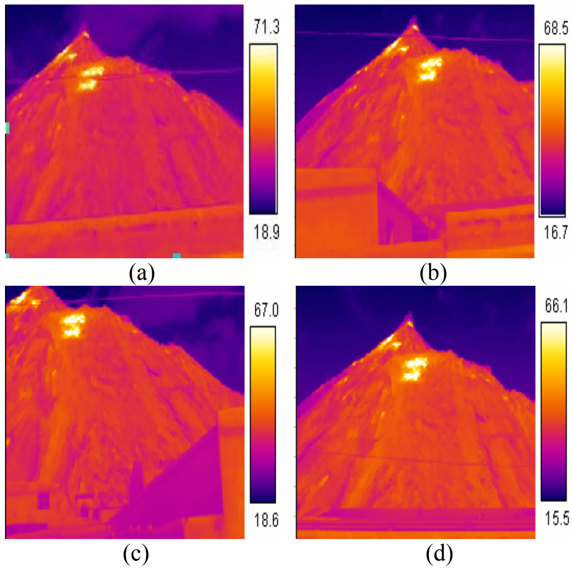

Figure 5. Analyze with time series thermo-images

3.4.3 Analysis of Mechanism of Spontaneous Combustion Of Mine Rock Dump Based On Thermo-Images: The dynamic changing rules of the temperature distribution would be revealed after analyzing the time series thermo-images. For instance, from the thermo-image, we can find that there is no combusting area in which the temperature distributes regularly. So, in mechanism research, we have to realize that in different parts of the rock dump, the character of rock is different. Besides, as seen in figure 6, there is a high colored area in the thermo-image, it shows a funnel that may cause the gas seepage inside the rock dump which is vital to the spontaneous combustion of the rock dump.

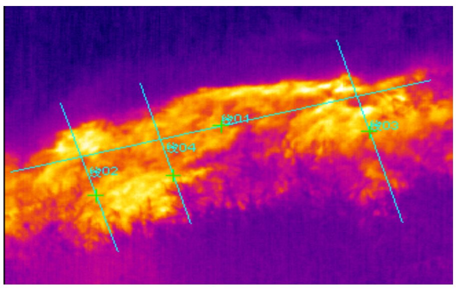

Figure 6. Evidence of gas seepage

4. MONITORING AND MANAGEMENT OF MINE ROCK DUMP BASED ONE INFRARED THERMOGARPHY

Based on the database of the thermo-images, we built a mine rock dump disaster early warning and management information system which can help us manage the rock dump. The structure and functions of the system are shown in figure 7.

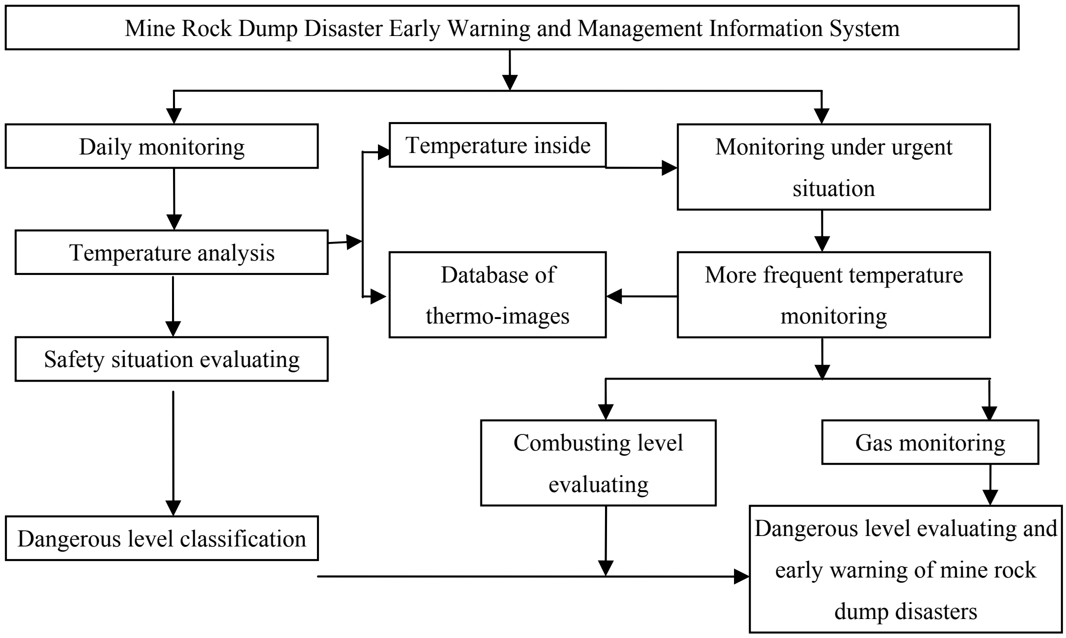

Figure 7. Mine Rock Dump Disaster Early Warning and Management Information System

5. CONCLUSIONS

In this paper, we talked about how to use infrared thermography to monitor spontaneous combustion of mine rock dump, presented its workflow and discussed how to mining spatial coordinates from the thermo-image including the principles of setting control net, the coordinates transferring equations and the method of data analysis. This method havs been used in Pingdingshan coal mining district to help prevent the fire inside 7 mine rock dumps.

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ACKNOWLEDGEMENTS

We would like to gratefully acknowledge the research funds granted for this project from the Special Foundation for 100 Outstanding Doctoral Dissertation (No 200348) and the National Science Foundation of China (No 50534050).