Dust concentration estimation of underground working face based on dark channel prior

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Abstract: In this paper, combined with video monitoring system for each working face under the mine, distance measurement system under the mine and Matlab software, real-time monitoring, analysis and calculation of dust concentration under the mine are carried out. Firstly, the image of dust degradation was obtained according to the video monitoring system in the underground dust environment, and the transmission chart with block effect was obtained. Secondly, the obtained transmission figure is processed by Matlab to obtain the corresponding transmission of each pixel in the dust image. Then according to the dust dispersion measurement system to calculate the extinction coefficient, according to the distance measurement system measured the length of the radiation channel distance;Finally, according to the established dust image degradation model, the dust concentration change process and dust mass concentration at each moment and point can be obtained from the extinction coefficient, transmission rate and length of radiation channel. The research method in this paper is rapid and can be used for real-time and online continuous detection, so as to obtain the dust mass concentration and dust distribution in the dust environment.

1. The introduction

When people inhale coal dust, Coal dust accumulates in the respiratory system and causes many diseases. Coarse particulate matter can damage the respiratory system and induce asthma. Fine particulate matter may cause heart disease, lung disease, respiratory diseases and reduce lung function[1].

The existing dust detection methods at home and abroad have Filter membrane weighing method, piezoelectric method, sound method, ray method, laser measurement method, charge induction method, digital image dust measurement method, etc[2-8]. The above measurement methods have advantages and disadvantages, but generally speaking they are inconvenient.

With the development of digital image technology, digital image processing dust has become one of the very important methods to measure dust. We can get accurate information according to the dust image processing, and then analyze the specific information related to dust concentration. In addition, digital image processing technology greatly improves the reliability and stability of dust concentration detection in underground mines, greatly improves the calculation time of dust and dust measurement accuracy. Therefore, in this paper, jiangyong Matlab carried out specific dust concentration calculation research on the pictures obtained from the mine.
2. Principles and methods

2.1 Dark channel prior theory
Dark channel prior theory is a rule obtained by He et al. through analysis, experiment and research of a large number of images. It's called priori. Under the mine, which is in the non-sky area the image pixels obtained will always have at least one color channel with a very low strength value close to 0, known as the Dark channel prior whose expression is

$$J^\text{dark}(x) = \min_{y \in \Omega(x)} \min_{c \in \{R,G,B\}} J_c(y) \to 0 \quad (1)$$

Where, $J_c(y)$ is a color channel in dust-free image, $J(x)$ below the mine, $\Omega(x)$ is a square, centered on $x$. $J^\text{dark}$ is dark channel prior of dust-free image $J(x)$ under the mine. We call this method dark channel prior theory$^{[10]}$.

2.2 Calculate the transmittance
When calculating the transmittance, the most commonly used formula is$^{[11]}

$$I(x) = J(x)t(x) + A(x)(1-t(x)) \quad (2)$$

Where, $J(x)$ is the observed dust image and, $J(x)$ is the dust-free image, $t(x)$ is the transmittance, and $A$ is the atmospheric light value.

In order to figure out the transmittance $t(x)$, Let’s assume that $A$ is a fixed value, According to the conclusion $J(x) \to 0$ in dark channel prior theory, we can get the transmittance $t(x)$.

So let's divide both sides of this equation by $A$ to get this

$$\min_{y \in \Omega(x)} \left( \frac{J_c(y)}{A_c} \right) = \tilde{t}(x) \min_{y \in \Omega(x)} \left( \frac{J_c(y)}{A_c} \right) + (1 - \tilde{t}(x)) \quad (3)$$

Minimize operations on RGB channels

$$\min_{c \in \{R,G,B\}} \left( \frac{J_c(y)}{A_c} \right) = \tilde{t}(x) \min_{c \in \{R,G,B\}} \left( \frac{J_c(y)}{A_c} \right) + (1 - \tilde{t}(x)) \quad (4)$$

According to the dark channel prior theory $J^\text{dark} \to 0$ and

$$J^\text{dark}(x) = \min_{y \in \Omega(x)} \left[ \min_{c \in \{R,G,B\}} J_c(y) \right] \quad (5)$$

We can conclude that

$$\min_{y \in \Omega(x)} J_c(y) = 0 \quad (6)$$

Substitute (6) into (4) to get

$$\tilde{t}(x) = 1 - \min_{c \in \{R,G,B\}} \left( \frac{J_c(y)}{A_c} \right), c \in [R,G,B] \quad (7)$$

In order to more close to the real life in our formulas, we add a parameter $\omega$, where $\omega \in (0,1)$, the value of $\omega$ can be obtained by experiments. in this paper, $\omega = 0.9$ is assumed temporarily, so we should change the expression into

$$\tilde{t}(x) = 1 - \omega \min_{c \in \{R,G,B\}} \left( \frac{J_c(y)}{A_c} \right), c \in [R,G,B] \quad (8)$$

When $t(x) \to 0$ is larger, the noise is larger, so in order to be more accurate, we select the first 0.1% pixel.

2.3 Calculate the extinction coefficient
Approximate calculation methods have been studied in some literatures$^{[12]}$. At this point, when the particle size of dust particle $r << 1$, In this case, Mie scattering theory can be replaced by Rayleigh scattering theory, and the extinction coefficient at this time can be expressed$^{[13]}$ as
Among them $\alpha < 0.8$, $\alpha = \pi D / \lambda$, $\lambda$ for the wavelength. According to the dust particle size $D$ and negative refractive index $m = m_i - ni$ We can calculate the extinction coefficient at this time. $m_i$ represents the phase delay of the scattered light when the light propagates in the medium. Where the speed $v$ plays a decisive role $v = c / m_i$, $C$ is the speed of light in a vacuum. The imaginary part $n$ is the attenuation of light as it passes through the medium.

2.4 Concentration calculation
The formula for calculating dust concentration is

$$T = \exp(-a \cdot c \cdot l)[1 + \frac{p(0, 0)}{4\pi} a \cdot c \cdot l]$$

(10)

Where $T$ is the transmission rate mentioned above, $a$ is the extinction coefficient, $c$ is the dust concentration, $l$ is the length of the radiation channel, and $p(0, 0)$ is the phase function. The unit of dust mass concentration $c$ is $mg/m^2$

The phase function is written as

$$p(0, 0) = \frac{\lambda^2}{8\pi r^2} \left[|s_1(0)|^2 + |s_2(0)|^2\right]$$

(11)

Where, $\lambda$ is the radiation wavelength; $r$ is the particle radius; $s_1, s_2$ is the scattering function adopted by Vander Hulst.

3. Experiment and research

3.1 Transmission calculation
First get the original image such as figure 1, figure 2.

Fig. 1 The original image three

The transmission of each original image is calculated by Matlab, and the calculation results are shown in figure 3, figure 4.

Fig. 2 The original image four

Fig. 3 Transmission image three

Fig. 4 Transmission image four

As the transmission rate of each picture is too high, we analyze the points A(100, 100), B(150, 150) and C(200, 100) of each picture. The three points of ABC are shown in figure 5, figure 6.
3.2 The extinction coefficient is calculated and the radiation channel length is measured

In this paper, we assume that the wavelength \( \lambda \) of the light wave is 540nm and the particle size \( r \) is 10nm. According to the relevant literature, the average refractive index of coal dust is \( m = 1.76 - 0.45e^{14} \). At this point, we have an arithmetic extinction coefficient of 2.056. As shown in the figure 7 below:

![Figure 7 Calculation diagram of extinction coefficient](image)

The length of radiation channel can be measured together. The length of radiation channel measured in this paper is 10m.

3.3 Calculation of concentration

According to the formula, the phase function in the concentration formula is related to the wavelength \( \lambda \). So let's take 540. The phase function \( \rho(0,0) \rightarrow 0 \). The concentration formula is \( T = \exp(-\alpha l) \). At this point, we can calculate the concentration at points A, B and C in figure 8, figure 9 below by Matlab.

![Figure 8 Calculate the corresponding point concentration three](image)

![Figure 9 Calculate the corresponding point concentration four](image)

The transmittance, refractive index, extinction coefficient and radiation channel length are calculated. The dust concentration was calculated, and the actual dust concentration was measured and the deviation was measured, as shown in Table 1.

| point | Transmittance | The refractive index | Extinction coefficient | Radiation channel length | Calculate dust concentration \( mg/m^3 \) | Measuring dust concentration \( mg/m^3 \) | Measurement deviation |
|-------|---------------|----------------------|-----------------------|--------------------------|----------------------------------|-------------------------------|----------------------|

Table 1. The values are shown in the table below.
4. Conclusion
This paper presents a new method of image measurement based on dark primaries. Firstly, the image of dust degradation was obtained according to the video monitoring system in the underground dust environment, and the transmission chart with block effect was obtained. Secondly, the obtained transmission figure is processed by Matlab to obtain the corresponding transmission of each pixel in the dust image. Then the extinction coefficient is calculated and the length of the radiation channel is measured by the distance measurement system. Finally, the variation process of dust concentration and dust mass concentration at each moment and point are obtained by extinction coefficient, transmission rate and length of radiation channel. This calculation method can greatly improve the reliability, stability, and the calculation of the dust of time, but the calculation method of dust in an image is just a rough calculation. During the process of calculation in the future, according to the dust inside the influence factors of the different plans, we can merge refinement analysis, so as to improve the calculation precision of image processing dust.

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