Detection of the Concentration and Size Distribution of Indoor Inhalable Particle Based on Mathematical Morphology

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Abstract

Adopting the microscopic observation imaging and digital image processing technologies, this paper researches a new measuring method of indoor inhalable particulate matter concentration and size distribution. It realizes denoising, binarization, filtering and edge detection to based on mathematical morphology, regional filled and calibration detection to particulate matter image, designs the parameters recognition algorithm for particulate matter size, fractal dimension, shape factors and so on, then calculates the concentration and size distribution of particulate matter using data fusion method. The experimental results show that the method has advantages with intuitive, high precision, fast processing speed ,easily data statistics, clearly data analysis and stable measuring results.

Key words: *Indoor Inhalable Particle， Mathematical Morphology， concentration and size distribution， Morphogical Parameters.*

1. Introduction

The indoor inhalable particulate matters concentration and particle size distribution not only affect all the other physical and chemical properties of particles, decide whether they could enter into the human body and the location of entering human organs, but are related to their deposition, detention and elimination in the human respiratory. Generally speaking, it is less possibility that the particles with diameter more than 30μm enter the lower respiratory tract, most of particles with diameters between 10 and 30μm Depositing in the nasal cavity. The particles with diameters between 5 and 10μm can enter the trachea and bronchi, and even the blood circulation causing the illnesses related to heart and lung dysfunction. It is more possibility that the particles with diameter less than 2μm deposit in pulmonary lobe, particularly the respiratory bronchiole and alveolar. Compared with the particles depositing in respiratory tract, the small particles depositing to the pulmonary lobe is more difficult to be cleared away. Therefore, the particles moe effect on human health is mainly inhalable particulate matter PM10(diameters less than 10μm below). The study of the concentration and size distribution of indoor inhalable suspended particulate matter contributes to understand the impact factors to particles, take positive measures to improve indoor air quality, reduce the harm to the human health[1].

The main methods to detect PM_{10} concentration are weight method, piezoelectric crystal oscillation method, β-ray absorption, light scattering method, and so on. And the main methods to detect particle size are screening method, settlement method, microscopy method and electron induction method. These detection method have their own best application, but there are some limitations such as long measurement time, complex measurement procedure, measurement accuracy being affected by subjective factor. Moreover, Although adopting the same measuring principle, the results of the same sample often vary greatly with different apparatus and operators .

With the development of image processing, and the improvement of photomicrography precision, the detecting method of the particulate matters based on image processing photomicrography have been used in more and more scopes. Particle concentration and size distribution are closely related to the morphological parameters of particulate matter. Because of irregular and complex shape, the vast majority of PM10 have the fractal characteristics, the particle size, the shape factor and the fractal dimension of mathematical morphology must be used to describe the physical characteristics of particles comprehensively. On this basis, particle concentration and particle size distribution can be calculated. Applying image processing technology and particle morphology to environmental protection detecting fielding of air particles, this paper studies a new detection method of indoor respirable suspended particle concentration and particle size distribution .

2.Preparation and Treatment of Particle Samples

2.1 Particulate Matter Collection

Sampled by The low flow air sampler, the suspended particulate matters of indoor air are classified by impact cutting machine. Through the constant weight microporous membrane, the particles are absorbed. The membrane to collect the particulate matter general adopt cellulose acetate membranes or Porous organic thin films that consist of acetic acid and cellulose nitrate. In order to make microscopy imaging easier, the membrane adsorbing particles need to be transparent and fixed by acetone vapor generation device.

Indoor particulate matter with particle size of 10μm below can aggregate. Particle cohesion is inherent nature of particle itself which interfere to measure particle size distribution accurately. Dispersant and exterior forces are often used to disperse particle cohesion. Dispersant can reduce the surface energy of particles, weaken the gravitational between particles, thus ease or even eliminate the cohesion phenomenon of particles. Different particles samples should chose different dispersant ,such as water, water plus glycerol, ethanol, ethanol plus glycerin, and so on. This paper uses glycerol acetate as dispersant to disperse the collected particulate matters.

2.2 Particulate Matters Microscope Imaging

Indoor suspended particulate samples are imaged by ORTHOPLAN polarizing microscope. Adjusting Magnification appropriately, CCD imaging equipment samples the images and transmit image data to computer by computer serial port or USB interface, then through image processing software to process and analyze the digital image, we can achieve the detection purposes of the indoor suspended particulate matter.
To ensure accuracy of measurement for observing more smaller particles, the different magnification microscope images are obtained in experiment. Pixel size calibration of image must be precise for the accurate measurement of particle. The results of calibration as a scale, its unit is μm. This detection system chooses Standard photolithography micrometer yardstick which is a slides. Through measuring the image of the slide under the microscope directly, we can calibrate the images. Additional the image pixel size varies different magnification microscope, so we must calibrate pixel size of each amplifying image in experiments.

3. Image Processing Based on Mathematical Morphology

Before measuring and recognizing, the particle images must be preprocessed. Image preprocessing includes the conversion of images, image enhanced, image denoising, threshold segmentation and binarization of image, so the objects and the background of image can be separated. For the binary images through the binarization morphological filtering and edge detection of the mathematical morphology, it is convenient to detect morphological parameters of the image and particle concentration and size distribution.

3.1 Binary Image Morphological Filtering

The binary image morphology filter may not only filter the noises, but remain the original information of image by means of geometry character information of image. Because of segmentation threshold determined by the law of pixel statistics, it is invitable to recognize the particle pixels of the target region as background or background as the objects mistakenly. The opened operation and closed operation of the morphology can eliminate some specific image details,and not produce overall geometric distortion. The operand is set in Morphology. Supposed A as the image set, B as the structural elements the operation is B operating to A . The Open-Close operation is a fundamental operation in mathematical morphology. Open operation can remove hole noise that formed by the Segmentation region, and close Operation can remove the noise points of the image background[2].
Assumed the particulate matter binary image is A, A was expanded, corroded, open operated and close operated which are defined as:
A corroded by B is shown as $A\Theta B$, A expanded by B as $A \oplus B$, open operation as $A \circ B = (A\Theta B) \oplus B$, and close operation as $A \bullet B = (A \oplus B) \circ B$.
The principal of the morphological filtering is open operation to binary image, then close operation. Equation (1) is the filtering formula :

$$(A \circ B) \bullet B. \tag{1}$$

Figure 1 is the binary image by threshold segmentation. Compared to other filtering methods, the binary image morphological filtering can efficiently remove the noise produced during the image process of binarization, and to some extent, smooth the borders of image.

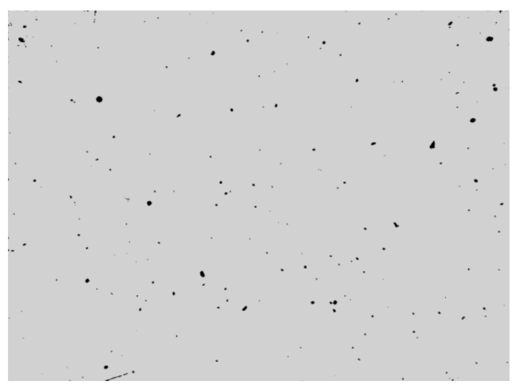

Fig. 1 the binary image of particles

3.2 Image Edge Detection Based on Mathematical Morphology

The fundamental principles of image edge detecting ,based on mathematical morphology, is subtract the original image after morphology operation adopting certain structure elements. As well known, the basic feature of image is the edge of image, and the edge of image is the pixels with a strong contrast of gray, named gray mutation points and gray discontinuous points. Common edge detection operators are sobel operator, Canny operator, Roberts operator, Laplacian-Gaussian operator, and several other nonlinear operators.

Similar to high-pass filtering, Laplacian operator only plays a role to sharpen image edge. Using these operators to detect the edge of images, the results are not ideal, especially, when images are more complicated and contain rich details, to some nonlinear operator involving anisotropic behaviours, it is difficult to detect the edge of the image completely. In addition, the general gray image always inevitably contain noise, these operators are sensitive to noise, and often strengthen the noise in the process of detecting the edge of image, so the detecting result is not satisfactory. With the study of mathematical morphology, to some extent, we found that morphological operations can filter the noise less than structural elements , meanwhile retain the original image information, so the extracting edge is relatively smooth. For this edge detecting method ,it is very easy to realize data parallel process and not high requirement to hardware[3].
The morphological dilation and erosion influence the edge of images, and the difference between the dilated and eroded image and the original image is the edge of image, but these operations are less effective for filtering noise. Obviously the filtering effciency of morphological open operation and close operation is better, because it used the complementarity of dilate and erode. Only related to the concave, convex location of image edge, the process result do not, so the difference of images can obtain concave, convex features of image, but not reflect all edge features of image. The paper researches an advanced complex edge detecting algorithm, which filters noise with pretreatment of open operation and close operation, smooth images by morphology close operation, and then do dilate operation, finally get better image edge by calculating the difference between dilated image and not dilated image[4]. This algorithm can be described by Equation 2.

$$(M \bullet B) \oplus B - M \bullet B. \qquad (2)$$

Where $M = (A \bullet B) \circ B$, A is the original noise images. Figure 2 is the edge detecting image based on mathematical morphology. From figure 2, we can found that the image has smooth edge, continual skelton and less breakpoints. So it is less breakpoints.

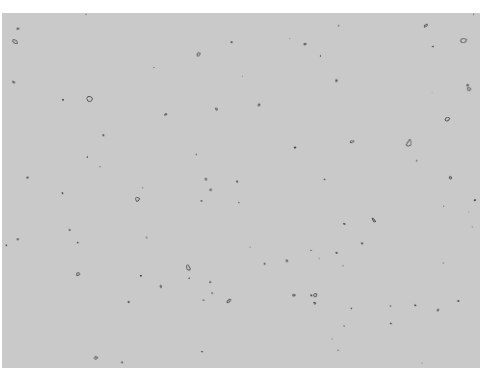

Fig. 2 Complex mathematical morphology Edge Detection

4. Concentration and Size Distribution Detection of PM10

The concentration of indoor particulate matter include the number concentration, total surface area and weight concentration . The number concentration is defined as the number of particles in unit volume air, and the total surface area refers to the all particle's surface area in a certain range of diameter. In the condition of the same volume, the total surface area of small size particles is large, meanwhile the total surface area of large size particles is small, so the total surface area is not only an important index to measure concentrations of particulate matter ,but also a very important parameter to research the toxicological mechanisms of particulate matter. Weight concentration refers to the weight of particles in the unit volume air .

4.1 Inhalable Paticle Morphogical Parameters Detection

The inhalable particle morphological parameters include size, size distribution , shape characterization of particles and so on. The particle morphology is important to study the basic information of particles. In order to facilitate the analysis and calculation, at first, We must mark the particles in binary image, secondly extract the edge contour of particles, began to tracking the edge from the first contour points, calculate particle perimeter. finally calculate each particle area by scanning Label algorithm.
Supposed A as particle area, p as particle perimeter, the particle equivalent diameter is defined as

$$d = \frac{4A}{p}. \qquad (3)$$

Because the same diameter particles may have different shapes, it is isolated to use one parameter to describe the particles character. Therefore, Here introduce the shape factor and fractal dimension to analysis quantitatively and describe particle character[5,6]. The formula of the particle shape factor F is:

$$F = \frac{p^2}{4\pi A}. \qquad (4)$$

The edge of indoor suspended particles have the random curve , the self-similarity abstracted by a large number of the stoical only exists in the so-called "scale-free interval", therefore, the calculation of its fractal dimension is very complicated. Among many calculation methods of fractal dimension are many, we adopt the calculation method of box dimension. Supposing the side length of box is n (n is the number of pixels included in the side length of box), we divide the edge image into the blocks, each of which has the same number of row and column, then gradually scan all the pixels in a box, Count the number of box N_r pixel whose gray value is zero. According this way, changing the value of side length n, the corresponding number of box N_r can be calculated by the following equation.

$$\log N_r = -D \times \log n + c. \tag{5}$$

Where D is particles fractal dimension, c is a contant[7,8].

4.2 Number Concentration and Size Distribution

Observed by microscope with different rate multiplying factor, the imaging areas are different, so indoor particulate matter volume conversion factors and calibration coefficients are also different. In 16 × 12.5, 40 × 12.5 and 63 × 12.5 multiplying factor, the calibration coefficients were 14.75, 92.21 and 204.91. Because the reasons of the resolution ratio, single sample in 16 ×12.5 multiplying factor, can only detect the smallest size above 0.5μm particles, the particles with diameter less than 0.5μm can not be detected, therefore, particle detection datas must be integrated with that of particles in 40 × 12.5 multiplying factor and 63 × 12.5 multiplying factor, to obtain single-sample particle size distribution of particles by the weighted average method.

N_{ij} is the number of particles that detected in a range of the different particle size, so

$$N_j = \sum_{i=1}^{3} W_i \times n_{i,j},\ j = 1,2,\cdots,20. \tag{6}$$

Where i refers to different multiplying factor, W is the and j is the number of interval of particles diameter. The range of particle diameter is divided into 20 interval with less than 0.5 μ m, 0.5～1.0μm, 1.0～1.5μm，……，9.5～10.0μm.

4.3 Total Surface Area and Size Distribution of Particles

The harm of indoor particulate matter to health is not only reflected in the amount of respirable particulate matter, but also in that of toxic substances absorbed by particulate matter, so the surface area is an important atmospheric particulate matter character. The greater the surface area, the more absorbed toxic substances, the more hazards to health. Moreover the more complex form of particles, the surface area more greater.

Supposed the indoor particles as spherical particles, the diameter is D_0, the formula for calculating the surface area is:

$$\delta = \frac{s}{V} = \frac{4p}{\pi A}. \tag{7}$$

Because the particle image is two dimension, we can not get the diameter of particles precisely, and use estimate method to calculate.

The surface area of particle s is calculated by the following equation：

$$s = \delta \cdot V = \frac{4p}{\pi A} \cdot V = \frac{2p}{3A} D_0^3. \tag{8}$$

4.4 Weight Concentration and Particle Size Distribution

In order to get the weight concentration of particulate matter, we need to calculate the total particle volume in the rang of diameter. Because particles with different diameter have different densities, it is necessary to correct the calculating results. The weight of particles M is shown as

$$M = \omega_1 V_1 + \omega_2 V_2 + \cdots + \omega_n V_n. \tag{9}$$

Where ω_i is correct coefficient, which is relevant to particle density.

Because the large particles consist of dust and material from machining, and the small particles are derived from the original combustion particles and aerosols, so the particle density is not a constant in the entire particle diameter range, density of small particles is closed to 1 $g \cdot cm^{-3}$, and the density of larger particles closed to the density of 2.5 $g \cdot cm^{-3}$[9].

5. Experimental Results

In experiment, We choose three images with different multiplying factor of microscope , six images with different scenes in each multiplying factor. Through analysing and detecting 18 images of the particle, we can obtain number concentration distribution surface concentration distribution and mass concentration distribution of indoor respirable particulate matter, which are shown in figure 3, 4 and 5 respectively. The diameters of all the particles are lesser than 10 μm, the majority of which distribute in the range of 0.5μm and 4.5 μm, and the proportion of PM2.5 is the largest. The mass concentration distribution curve is very close to the volume concentration distribution curve, and the volume concentrations of smaller particles is very small as a result of small mass concentration. The surface concentration and volume concentration with diameters of less than 5μm are absolute advantage, so these particles increase harmful to human health .

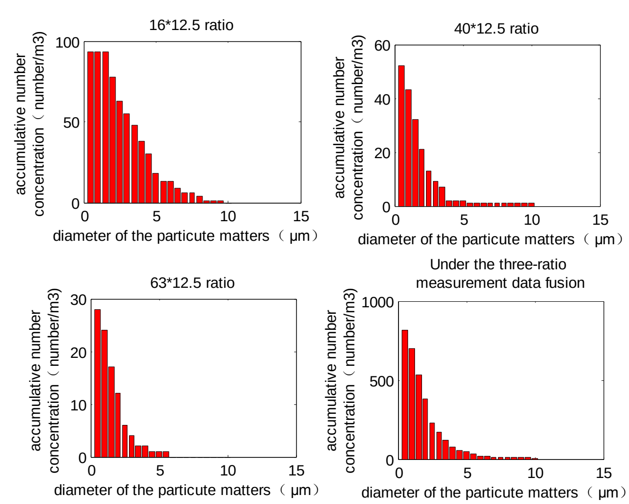

Fig.3 number concentration and size distribution curve of indoor inhalable paticulate matters

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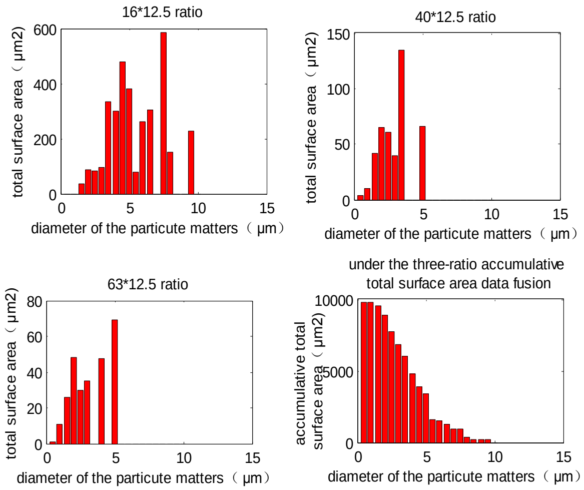

Fig. 4 total surface area concentration and size distribution curve of indoor inhalable paticulate matters

Adopting this new detecting method ,the total weight of indoor inhalable particulate matters is 135μg·cm^{-3}, meanwhile, the total weight is 143μg·cm^{-3} by the standard weighing method in accordance with the national relevant regulations. The main reason of error is that the smaller inhalable particulate matters can not be detected due to the lower resolution of microscope.

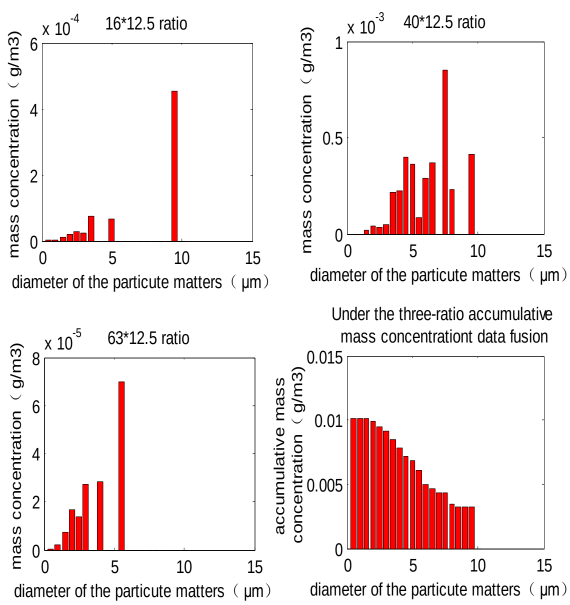

Fig. 5 mass concentration and size distribution curve of indoor inhalable paticulate matters

6. Conclusion

Based on microscopic observation and image process, applying the particle morphology and fractal theory to calculate the particle morphology parameters and fractal dimension, this paper has put forward to a new method to detect the concentration and size distribution of indoor inhalable particles. Because of the restrictions of experimental conditions and detecting theory, There are many works need to be perfected and improved in the following of research:

(1) Improve the resolution of microscope to obtain ultra-fine particles images.

(2) The mass concentration of inhalable particulate matter was related to the volume and the density of single particles. Because of the two dimension particles image, we can not calculate the accurate volume of particles by the estimate method. Diameter, shape factor and fractal dimension are used to describe the shape of particles. According to the previous calculation of a single particle shape factor and the fractal dimension, we can compare the shape of the particle with that of some standard particles, then use the volume of this standard shape to estimate the volume and mass concentration of the particles approximately.

(3) This paper research the two-dimensional images of particles mainly. With the development of image process and recognition technology, we can study three-dimensional characteristics of the inhalable particles by three-dimensional reconstruction method to obtain the morphology parameters, surface area and volume. The particle image processing to be more specific, there are more particle parameters to reflect the characteristics of particles.

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