The Simple Sprayed Concrete Dust Density Measurement by using Flashed Digital Camera Image

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1. INTRODUCTION

There are two types of typical suspended dust which arises in tunnel construction works. One is the concrete dust which arises in spraying concrete, the other one is the rock dust produced by mechanical drilling work or blasting work. The bronchi can discharge most of the inhaled suspended dust by expectoration except dust lesser than one micron in size which accumulates in the pulmonary alveolus. This can cause “pneumoconiosis” in which lungs loses its respiratory function. The guideline of dust control for tunnel construction works, published by the Ministry of Health, Labor and Welfare of Japan, dictates that the employer has a management duty to control the suspended dust density for the safety of workers in the tunnel construction work. Therefore the requirement for measurement of the suspended dust density has become more stringent in Japan.

It is also well known among the tunnel engineer that suspended dust reflects flashlight during flashed photography. Photo-3 shows a flashed photograph. Photo-4 also shows a same photograph without flash. Based on this phenomenon, the authors propose a new technique for measuring dust density.

The “Low Volume Air Sampler” (LVS) is the most accurate in dust density measurements. Photo-1 shows the
Low Volume Air Sampler. This instrument draws the air in tunnel construction site pre-setting quantity through the air filter, and it measures the dust density from an amount of increase weight of the filter. However this method gives the average dust density. To overcome this shortcoming, the "Digital dust Indicator" (DDI) was developed. Photo-2 shows the DDI. In DDI, the air drawn in measuring instrument was irradiated with laser beam light, and the number of the dust was counted, and the number of the dust was converted into the dust quantity. As DDI is very simple to operate, this instrument is generally used in tunnels in Japan. However, DDI is also expensive, and it require the measuring time for 10 minutes. Therefore this motivates the development of a cheaper and simpler method of measuring dust density.

In this paper, the authors propose two types of simple dust density measuring methods which measures the dust density from the flashed photography. Then, the author applied it in a real tunnel construction site, and compared with the results obtained from DDI. As the result, there was the high correlation in this study and DDI, and the effectiveness of this new method was confirmed.

2. THE INVESTIGATION OF SUSPENDED DUST DURING SPRAYING CONCRETE WORK

2.1 Field test
The field test was executed during the spraying concrete work in the two-lane road tunnel construction site. Figure 1 shows the location of main construction machines such as the ventilation pipe (ventilation capacity: 2100m³/sec, 30m behind from the tunnel face) and the electrostatic dust collector (capacity: 2300m³/sec, 100m behind from the tunnel face). In this situation, the suspended dust was collected by LVS (suction velocity: 0.02 liter/min, total volume: 0.5m³) 50m behind from the tunnel face. It was observed with the scanning electron microscope, the content and particle size distribution were investigated by The energy disperseable X-ray analysis.

2.2 Experimental results
(1) Component analysis of the suspended dust
Figure 2 shows the comparison of the component between the suspended dust and the typical portland cement by the energy disperseable X-ray analysis using the scanning electron microscope. It was clear from this figure that the constituent element of the suspended dust collected by field test was almost similar to the general composition of portland cement.

(2) Particle size distribution of the suspended dust
The particle size distribution was obtained by the following procedures.

1) The suspended dust collected by LVS is photographed by the scanning electron microscope at a magnification of 2000 times (see Photo-5).
2) Using image of Photo-5, the number of the suspended dust of each particle size is counted, where each particle size category is differentiated from another by one micron.
3) The particle size distribution curve is then obtained from the accumulation of the size of each particle size category (see Figure-2).
It is clear from Figure-3 that the average particle size is 1.8 micron meter, and it distributes from 0.1 micron meter to 10 micron meter.

3. THE DENSITY MEASUREMENT METHOD

3.1 The principle in which the suspended dust is projected by the flash light of digital camera

Generally, the wavelength of flash light of digital camera has the peak of characteristic curve for the wavelength region near 0.5 micron meter. As the suspended dust distributes from 0.1 micron meter to 10 micron meter, the flashed photograph is caused by the Mie scattering that the particle size is almost equal to wavelength of flash light. The brightness of the dust which is projected scattered by flash light intensity of digital camera is almost proportional to the square of the particle size. Regardless of the size of actual suspended dust, the size of the dust in flashed photograph decides the diameter in the diffraction phenomenon by the diaphragm of the camera. From the above fact, it is also possible that the measurement of the particle size distribution requires using the intensity of digital camera, because the particle size is obtained by the brightness of particles.

3.2 The counting method

(1) The decision of photographic domain of the digital camera

As it is shown in photo-3, the flashlight which scattered by the suspended dust project as a white round. However, it is photographed as an image out of focus, since the photographed position is very near to the lens. The range at which the image goes out of focus is clarified by the indoor test.

Firstly, The relationship between transverse distance and photographing range from the lens was examined to specify the range which can be photographed by the digital camera. Secondarily, In order to clarify the photographing region of the suspended dust, the photograph which limited the range of flash is projected in the photograph. By using these limited photographs, the possible photographing region of the suspended dust was specified.

As the result of the indoor test, The minimum and maximum photographing range of the suspended dust is 1.0cm and 4.0cm respectively. So, the photographing range of the suspended dust is defined $2.45 \times 10^{-5} \text{m}^3$ obtained by using Equ.-1 as follows;

(1) $V = \int_{0}^{4} (0.56x^2 + 1.46x + 0.96)dx$

The photographing range of the suspended dust by flash of the digital camera specifically clear, as it was shown in the above. As the number of the dust which was projected in the image can be counted, the dust weight is calculated by the weight of the average particle size. The dust density converts into the dust weight divided by the region volume of the dust. The flowchart of the dust density conversion algorithm is as shown in Table-2.
The outlines of the algorithm are as follows.
1) The number of the dust each which was projected by the flash photography is counted.
2) Since the suspended dusts are almost the cement from the result of the component analysis, it is converted into the weight using the general $2.1 \times 10^9 \text{mg/m}^3$ density, as it is shown in Figure-2.
3) It is converted into the dust density that the dust weight divided by the region of photographing range which is clarified at the above chapter.

3.3 The Image processing method by using artificial neural network
(1) Artificial neural network
Artificial neural network (ANN) is a form of artificial intelligence that attempts to mimic behaviour of human brain and nervous system. Because of its generality in forming a built relationship between input and output parameters, it has been widely used in many different application examples in science and engineering. We employ 'Back Propagation Neural Network (BPNN)' which is the most popularly used ANN suited for problem of classification, prediction, adaptation control and system identification.

BPNN is operated in two phases; that is ‘learning phase’ and ‘testing phase’. The information is processed through input layer to a hidden intermediate layer until it reaches an output layer during learning (Training) of a network, as shown Figure-5. The output is compared with the targeted value that are regarded as the ‘true’ output or in other words ‘measured value’. The difference or error between the input and output value is processed back through the network, as is called backward process, updating the individual weights of each connections and the bias of the individual neurons. The input and output data

<table>
<thead>
<tr>
<th>Photograph</th>
<th>Dust density ($\text{mg/m}^3$)</th>
<th>Count value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.6</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>4.2</td>
<td>66</td>
</tr>
</tbody>
</table>

Figure-6 The relation the distance from the lens and the photographing range
are mostly represents as vectors called ‘training pairs’. The process as mentioned above is repeated for all the training pairs in the data set, until the network error converge to a threshold minimum.

Testing phase is a calculation process that is undertaken after the training has been completed as also shown Figure-5. The correct solutions and those produced by the network may be compared in a qualitative manner or in a quantitative manner using as index such as correlation coefficient.

Network training process is affected by such factors as database size and partitioning, data preprocessing, balancing, data normalization, input/output representation, network weight initialization, BPNN learning data and momentum coefficient, transfer function, convergence criteria, number of training cycle, training mode, hidden layer size and parameter optimization so on. One needs therefore to arrange or search for best combination of these factors to build the ANN having desired level of quality verified in the testing process.

(1) BPNN Model

Five layers model which consists of input layer, three intermediate (hidden) layers and output layer was adopted. Firstly, the photo image was transferred (n x m elements) matrix which the luminance value of 1 to 255 by the gray scale conversion. The average of luminance value of the whole camera image is obtained.

$$\bar{a} = \frac{1}{n \cdot m} \sum_{i=1}^{n} \sum_{j=1}^{m} a_{ij}$$

The dispersed mean value of the image is obtained using the difference in mean value and component value of each matrix.

$$\sigma^2 = \frac{1}{n \cdot m} \sum_{i=1}^{n} \sum_{j=1}^{m} (\bar{a} - a_{ij})^2$$

In making an optimized ANN model for density measurement procedure, the average, standard deviation, the dispersed mean and real the dust density by DDI of each photo image as training pairs. 121 photo image is adopted in the education process. And 31 photo image is used in the testing process.

4. SITE APPLICATION

4.1 The counting method.

Figure-6 shows the count number of dust result of flash photography and the suspended dust density measured by DDI. It is clear from this figure that the count number of the dust by the flash photograph increases with the rise of the dust density measured by DDI. Figure-4 shows the correlation diagram between dust density measured by DDI and dust density obtained from the counting method proposed in this study. From this figure, it is clear that the correlation with the dust density proposed by this study has a good relationship with the dust density measured by DDI.

The correlation coefficient of dust density by DDI

<table>
<thead>
<tr>
<th>Table-2 Dust density conversion algorithm by the image processing method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photograph image (3072 by 2304)</td>
</tr>
<tr>
<td>Gray scale conversion</td>
</tr>
<tr>
<td>Calculation of the characteristics of image</td>
</tr>
<tr>
<td>Artificial neural network</td>
</tr>
<tr>
<td>Density of the suspended dust</td>
</tr>
</tbody>
</table>

Figure-7 The correlation diagram of dust concentration by the image processing method
with this study was 0.91. The proposed method has higher correlation than the dust density by statistical analysis$^6$.

4.2 The Image processing method

Figure-7 shows the correlation diagram between dust density measured by DDI and dust density obtained from the image processing method proposed in this study. From this figure, it is clear that the correlation with the dust density proposed by this study has more strictly good relationship with the dust density measured by DDI.

The correlation coefficient of dust density by DDI with this study was 0.98. The proposed method has higher correlation than the dust density by the counting method.

CONCLUSIONS

The flash photography was carried out using the digital camera in tunnel, and two conversion methods that estimated the dust density from the flashed photograph was proposed. The field test was done for sprayed concrete work in the road tunnel construction site. And the effectiveness of proposed method was verified.

At the field test, the black panel(see Photo-6) was installed in the photographing direction in order to verify the correlation between dust density which converted from the number of the dust which is projected. However, we will improve the conversion technique which measures the dust quantity from the photograph without black panel in the future.

REFERENCES