The Application of Computer Vision Technology in Real-time Monitoring System of Floating Ash Particle

Feng Guiliang[1], Lu Yiping[1], Qin Jing[2], Zhang Xiao[1], Zhao Sheng[1], Peng Wei[1]

1. HeBei North University
Hebei, Zhangjiakou, 075000,
2. HeBei University of Architecture
Hebei, Zhangjiakou, 075000,

***Abstract* — The computer visual detection technology is a non-contact detection method on computer vision method, which is comprehensively integrated with such technologies as image processing, precision measurement, pattern recognition and artificial intelligence. The floating ash particle real-time monitoring system is designed to acquire the survey information by analyzing the target image obtained by computer vision system. It uses computer vision detection technology to perform real-time monitoring of floating particle to achieve accurate collection of floating ash and image processing software. By adopting planar-array CCD camera, the image capture card forms a computer vision system with computer, which achieves real-time monitoring and data analysis of floating ash particle using digital picture processing technology.**

Keywords - Computer Vision Detection Technology, CCD; Image High-pass Filtering

I. INTRODUCTION

The air pollution mainly leads to respiratory disease for human beings and may restrain the plant physiological mechanism and cause other problems such as poor growth, weakening capacity in combating against disease and insect and even death. The air pollution also may exert unfavorable effect on climate, for example, it may reduce visibility and solar radiation (The data shows that the solar radiation intensity and ultraviolet intensity in downtown area dropped by 10% to 30% and 10% to 25% respectively comparing with that in rural areas); this may increase the morbidity of rickets; the air pollutants may cause object being corroded which affect its quality as a result. Over past ten years, an array of countries witnessed acid rains as well as acidity increase in rains and snows, leading to acidification of rivers, lakes and soil, and reduction and even extinction of fishes. In addition, the forest is poorly developed, which is closely associated with air pollution. Therefore, there are many countries that pay much heed to environmental protection. We need to carry out real-time monitoring of coal burning conditions inside flue, as the pulverized coal combustion efficiency bears on the particle size and concentration of pulverized coal. To increase pulverized coal combustion efficiency, the distribution of particle that is under best condition must be ensured; namely precisely measuring the particle granularity and particle size distribution of pulverized coal samples.

The monitoring object involving in the paper is the solid particle named “floating ash” that has big size among smoke dusts generated from thermal power plant boiler and the overall smoke concentration conditions. This floating ash particle appears milk white that has a diameter of over 0.5mm, which basically features sphere shape or ellipsoidal shape. Though smoke and floating ash has undergone electrostatic precipitation that makes it meet national emission standard before emitted into air, yet the emission that is being eventually discharged into air still contains certain number of floating ash particles. Due its large mass, the particle drops in the surrounding areas after being discharged into air; therefore, controlling the floating ash is imperative from the perspective of environmental protection. By introducing the advanced computer vision technology into the real-time monitoring of floating ash particles, the paper adopts planar-array CCD camera, and forms a computer vision system with image processing card, which achieves the real-time monitoring and data collection of floating ash particles using digital image processing technology.

II. THE COMPOSITION OF SYSTEM HARDWARE

Known as the industrial control computer, the industrial personal computer features better anti-interference performance comparing with commercial computer as a result of its each computer part that has experienced various compatibility performance test, which is more suitable for the on-site environment of industrial areas and can ensure the stability of the system. Based on this consideration, the industrial control computer is adopted, with basic configuration being Pentium □ 12 m in 1 g memory. Meanwhile, the industrial computer equipped with "watchdog" circuit is used, which can improve data processing speed while preventing mis-operation of workers and the system “crash down” caused by all sorts of unpredictable environmental factors, ensuring the fast and stable system operation .

Principle and Selection of Camera.

The camera is mainly comprised of image sensor. The rapid development of the image sensor type in recent years is the electronic scanner solid sensor array that consists of three main types: charge-coupled device (CCD) array, charge injection device (CID) arrays and photoelectric diode array, among which the charge-coupled device witnessed fastest growth that is more widely used in different areas.

Our measuring objects "floating ash" is located in a flue considered as black body; the color of floating ash particles is milk white; therefore under the circumstance of certain lights, the floating ash particle with more than 0.5 mm may be identified using camera the image; the following is the imaging formula:

$$\frac{D}{d}=\frac{U-f}{f} \tag{1}$$

Whereas: D represents the object length; d represents the image length; F stands for the lens focal length, with U standing for object distance;

Assuming that D is the diameter of floating ash particles, then d is the size of particle imaging. The each CCD pixel size is about 0.01 X0.01 mm if a camera with 7.95 mm X 6.45 mm size and a resolution of 795 (pixel) X 596 (pixel) of CCD is used to take photo; therefore we can obtain d = 0.01 mm; when U = 1000 mm (U value is within the scope of the actual size) and the lens focal length f = 50 mm is selected, the d = 0.19 mm < 0.5 mm according to the formula (2-1); it is thought that using the CCD camera floating ash particle to measure floating ash is theoretically feasible for measurement object--floating ash. At the same time, the floating ash in the flue, under the action of induced draft fan, moves at the speed of 10 m/s from top to bottom. So the CCD shutter speed must be fast enough to ensure that the image of the particles will not have a blurring trailing. We choose the camera featuring the highest shutter speed that can reach 100000 per second. If the shutter speed is set at around 1/100000, then the floating particle that moves at speed of 10 meters per second can be ensured around 0.1mm; such error is within the allowed range of measurement accuracy.

Finally, the performance of the CCD camera chosen by us is as follows: CCIR video system, 795 (H) X 596 (V) CCD pixels, 1/100000 of a second shutter speed which is matched with the 50-mm prime lens. CCIR camera system is the solid color of PAL mode of video signal, which is characterized by 25 frames per second, 625 lines of vertical resolution and 768 x576 pixel of image size.

Selection of Image Capture Card.

The system adopts a monochrome image card featuring PCI interface and support of RS - 170 and CCIR video standard. The PIXEL CLOCK is 14.75 MHz with setting image card being CCIR camera system. The system has 768 x576 PIXEL sampling window which can meet sampling speed of CCD25 frame. PCI-1407 can perform real-time image and send it directly to system memory. It can directly control and set image card using image acquisition driver software.

III. THE APPLICATION OF IMAGE PROCESSING TECHNOLOGY IN FLOATING ASH IMAGE

Space High-pass Filtering of Floating Ash Filtering.

Spatial filtering can be divided into linear filtering in iconography (also known as convolution operation) and nonlinear filtering, which can perform image directional edge detection, image contour extraction and image noise removal etc. It can also be classified as the high-pass filter and low-pass filter.The typical space linear high-pass filtering method features Gradient, Laplacian; while the typical space nonlinear high-pass filtering method features Gradient, Roberts, Sobel, Prewitt, Differentiation and the Sigma. The gradient operator is selected to remove the strip interference in the image.

a.The Theoretical Basis of Gradient operator (Gradient) theoretical basis

The gradient vector at point(x, y) is:

$$\nabla f(x, y) = [G_x G_y]^T = \left[\frac{\partial f}{\partial x} \frac{\partial f}{\partial y}\right]^T \tag{2}$$

Two important properties of gradient are:

The direction is towards the direction of largest change rate of function (x, y) of gradient

$$\phi(x, y) = artc \tan\left(G_y / G_x\right) \tag{3}$$

b. The gradient range can be indicated by mag (∇f), with value being:

$$mag(\nabla f) = \left[G_x^2 + G_y^2\right]^{\frac{1}{2}} \tag{4}$$

The conclusion can be arrived by formula (4) that the value of the gradient is the increased amount of unit distance in the direction of largest change rate of f (x, y).

b. Formula Determination

Convolution operator is a two-dimensional space filter designed to remove the interference in the image by means of gray image grayscale convolution, which can enhance edge information to meet the testing requirements. If there is a 3 x3 convolution operator, then the pixels around the pixel P (I, j) and convolution operator coefficient are shown in TABLE I below.

TABLE I. 3*3 THE COEFFICIENT OF CONVOLUTION OPERATOR

P(i-1,j-1)	**P(i,j-1)**	**P(i+1,j-1)**
P(i-1,j)	P(i,j)	P(i+1,j)
P(i-1,j+1)	P(i,j+1)	P(i+1,j+1)

K(i-1,j-1)	**K(i,j-1)**	**K(i+1,j-1)**
K(i-1,j)	K(i,j)	K(i+1,j)
K(i-1,j+1)	K(i,j+1)	K(i+1,j+1)

The following formula is calculated as follows:

$$f(i, j) = \frac{1}{N}\sum_{a=i-1}^{i+1}\sum_{b=j-1}^{j+1} P(a, b)K(a, b) \tag{5}$$

$$N = \sum_{a=i-1}^{i+1} \sum_{b=j-1}^{j+1} K(a, b) \qquad (6)$$

Then the new value of P(I,J) is:

$$P(i,j) = \begin{cases} 0, & f(i,j) < 0 \\ f(i,j), & 0 \le f(i,j) \le 255 \\ 255, & f(i,j) > 255 \end{cases} \qquad (7)$$

The new value of P (I, j) is the value by calculating its original value and its surrounding value; if the coefficient of convolution operator is both positive and negative, then this operation is a sharpening transformation or a high-pass filter, whose size transformation of the image depends on the extent of operator; it can be multiplication of odd pixel such as 3x3, 5 x5 and 7 x7. The operator of gradient convolution filtering is as follows if 3 x3 is taken as an example:

$$\begin{matrix} a & -b & c \\ b & x & -d \\ c & d & -a \end{matrix} \qquad (8)$$

a, b, c and d is integer; x=0 or x=1。

The direction is shown based on the combination of a, b, c, d used in array, such as:

$$\begin{matrix} 1 & 1 & 0 \\ 1 & 0 & -1 \\ 0 & -1 & -1 \end{matrix} \qquad (9)$$

The direction of this operator is 45 degree. If the direction of the positive coefficient is set to negative coefficient as the positive direction, then convolution in the positive direction will brighten up the increased edge of the gray level and weakens the reduced edge of gray level at the same time. Meanwhile, the value of x is changed that caused two different functions of gradient convolution filter. If x = 0, then the convolution operation will increase the edge characteristics and extracts the black and white border. If x = 1, then image would be processed based on original image of x = 0 and that the edge characteristics of overall plaque is extracted on the basis of extracting edge.

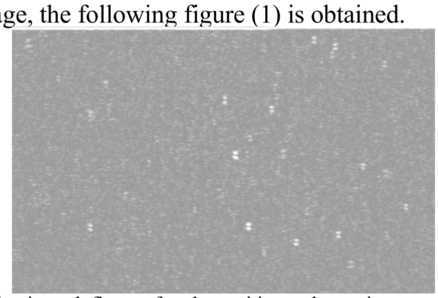
We would like to remove floating ash background stripe so that the particle information is extracted, namely increasing grain edge information. Considering the direction of the gradient operator, the multiple gradient image filtering must be conducted to floating ash image in all directions simultaneously. As the sharpening edge particles, the 3 x3 operator operations should be selected in consideration of small particle assembly.

To select two operators first, namely operators of negative and positive directions in vertical directions

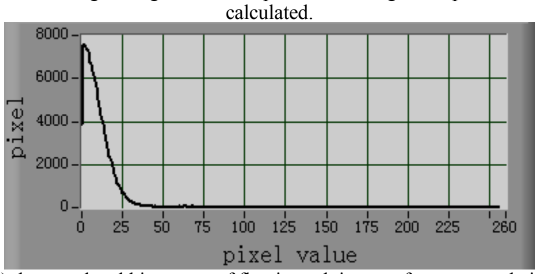
$$\begin{matrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{matrix} \qquad (10)$$

$$\begin{matrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{matrix} \qquad (11)$$

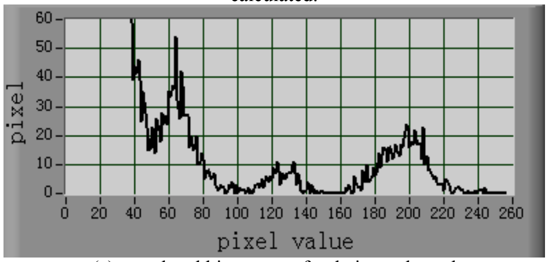
By applying (10), (11) two operators to floating ash grey level image, the following figure (1) is obtained.



(a) the floating ash figure after the positive and negative operator being calculated.



(b) the grey level histogram of floating ash image after operator being calculated.



(c) grey level histogram after being enlarged

Figure.1 The floating ash fig and its analysis processing fig after gradient operator in one direction being calculated

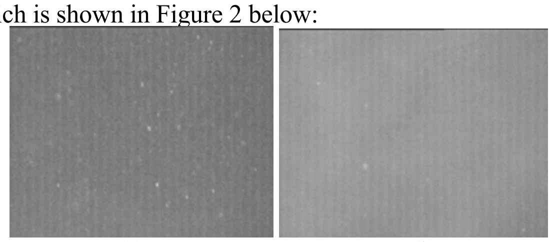
Thresholding Processing of Floating Ash Particle.

The thresholding processing involves the division of image grey level into two parts by setting a threshold value T: the pixels with no less than T and the pixels less than T. If the input image is f (x, y), then the output image is f (x, y), there are:

$$f_b(x,y) = \begin{cases} 255, & f(x,y) \ge T \\ 0, & f(x,y) < T \end{cases} \qquad (12)$$

Thus it can be found that the thresholding lies in seeking of thresholding segmentation value T; such threshold value will determine if floating ash particles can identified. There are many methods for threshold selection, which should be selected as per the characteristics of the processing object and the specific application requirements.

Due to different fueling in different times, the floating ash in different stages differs slightly, causing the difference of floating ash images; the image quality is also different, which is shown in Figure 2 below:

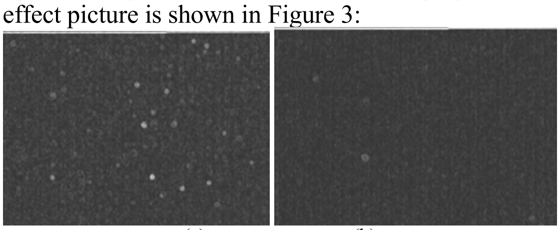


(a) (b)

Figure 2 the original floating ash images taken at different times

Comparing the above two images, it can be easily found that the brightness of image (b) the brightness is larger than figure (b); by contrasting floating ash particles with background, the particle in figure (a) are more easily identified from background, while the particle in figure (b) the particles has small difference with background gray and the gray gradient also changes little.

In order to extract particle information of floating ash particle image, the image has undergo preprocessing--image space filtering, to increase the image edge information; the gradient operator is used to conduct convolution computation to two pictures, so as to strengthen the edge gradient, remove background stripe, and exert the effect of high-pass filtering; the effect picture is shown in Figure 3:



(a) (b)

Figure 3. The original floating ash image after being calculated at different times by gradient operator

IV. SOFTWARE IMPLEMENTATION AND ERROR OF REAL-TIME MONITORING SYSTEM OF FLOATING ASH PARTICLE

Procedure and Interface of Software Design.

The software of this system is developed under WinXP system, with development tools being LabVIEW and Visual c + +. The Visual c + + is mainly used to formulate image processing program, data processing program, exit program of Windows XP. Other programs including the main program are prepared using LabVIEW to compile.

The real-time monitoring system of floating ash particles is designed to perform real-time monitoring of floating ash generated from flue, and serves as an equipment for data analysis of floating ash particles. The software should be designed to meet the working condition of the factory and the testing requirements of floating ash particles; it can be found through main interface of the system that the system software can achieve following functions:

(1) it can perform real- time monitoring of floating ash images and conduct relevant processing. It can display real-time image taken and pro-processing image.

(2) the collection of floating ash particles diameters; As per the fact that the diameter of floating ash particle is mainly scattered between 0.5 mm to 5.0 mm, we classify the floating ash particle as 0.0 ~ 0.5, and 0.5 ~ 1.0, and 1.0 ~ 1.5, and 1.5 ~ 2.0, and 2.0 ~ 2.5, and 2.5 ~ 3.0, 3.0 ~ 3.5, and 3.5 ~ 4.0, 4.0 and above) and collect the number of particles as per its classifications. This makes us more clearly understand the distribution of various diameter particles.

(3) the real-time alarm function. The exceed limit of particles can be set and perform alarm according to the real-time image data.

(4)During the process of real-time monitoring, the floating ash granularity and floating ash diameter statistical data will be stored into hard disk; this can be printed or used for data analysis, and printed out as statement as per actual needs.

Digital image detection system involves two tasks including data acquisition and data processing, among which data acquisition includes the acquisition of original image and acquisition of the initial value. By using image measuring principle and various methods of image processing, the data processing is to calculate the parameters of object coordinates and display as request. All of these processes are complex that may cause inevitable errors at different stages. If such error sources are not analyzed and handled, the image measurement system will not generate accurate or wrong results. The paper will analyze the impact of these errors on measurement precision of image measurement system, and presents effective method to eliminate or reduce errors, so as to improve measurement accuracy and the stability of the system.

Noise Effect in Illuminated Field.

The illuminated-filed noise includes two kinds: one kind is random fluctuation noise that is change with time, which is generated by power supply fluctuation and unstable glowing light; the other kind is the noise that is changed along with space fluctuation. This paper uses the image spatial filtering method and software to eliminate the influence of illuminated-field of non-uniformity, which can greatly reduce the demand for lighting system and can remain measurement accuracy of the system at the same time.

Noise Effect of Hot Electron.

The CCD camera, A/D converter and acquisition system are all fitted with scores of resistive components. Due to the hot electron fluctuation, the thermionic noise is generated; this is a kind of white noise and is also a kind of additive noise. It can be found by observing monito that there are many corrugated dancing on the screen before the completion of image acquisition "frozen"; once the image acquisition is "frozen", these dancing corrugations will disappear which can make image stable and clear. According to the characteristics of the additive noise, the processing method used in this paper is: image high-pass filter and de-nosing using morphology.

The Impact of Temperature Change on CCD Camera Performance.

The thermal expansion of CCD silicon array is due to CCD camera that is comprised of the electronic circuits and semiconductor devices, which will be affected by temperature. The main factors that affect camera preheating is thermal expansion, namely CCD chip. The expansion of the fixed point of each camera is different, but it has same order for target image value. Considering this factor, we adopt a solution that collects images after preheating.

Error of Image Processing Algorithm.

As the CCD conducts interlaced scanning, the particles from image are some stripes that are close to each other; to make up for the defects, we use the image morphology processing algorithms in the software named "closed operation". This algorithm is capable of achieving our requirements in practice, which reflects in the previous algorithm and the experimental data introduced as below:

TABLE II. ASSESSMENT TABLE OF "CLOSED OPERATION" PERFORMANCE

object	Original particle diameter	"Close Operation" result		
		Particle Dia.(mm)	Absolute Deviation(mm)	Relative Deviationi(%)
0	0.67	0.61	-0.06	-8.96
1	1.11	1.08	-0.03	-2.70
2	1.68	1.58	-0.10	-5.95
3	2.42	2.34	-0.08	-3.31
4	3.58	3.55	-0.03	-0.84

The closed operation adopts 5*5 structural element.

Absolute deviation=closed operation result-original particle diameter (mm)

Relative deviation is obtained from calculation formula E=(closed operation minus original diameter) divide (original diameter) multiply 100 percent.

It can be seen from table that the biggest deviation of particle diameter for "closed operation" is 0.10 mm, which is less than the minimum diameter of distinguished particle $D_{\min} = 0.165 \cdot \sqrt{1} = 0.165mm$, therefore it is reasonable to use "closed operation" to adjust the stripe particle error.

Meanwhile, the following diameter formula can be obtained based on above area calibration and diameter calculation.

$$D = 2\sqrt{\frac{S}{p' \cdot \pi}} \cdot \sqrt{p} = K\sqrt{p}$$

The p' herein is the reason for the calibration error. It can be seen from table 2 that such deviation value has very small impact on particle diameter although the p' value is of some deviation. By taking the minimum value $p'_{\min} = 126394$, the maximum value $p'_{\max} = 126440$, the particle size (pixels) $p = 1000$ (it represents the particle diameter $0.165 \cdot \sqrt{1000} = 5.2mm$)in the table 4-1, the diameter formula is $D_{\min} =$ 5.2204 mm, $D_{\max} =$ 5.2195 mm; therefore when the particle diameter is less than 5.2 mm, the calibration error is $\Delta D < 0.001mm$. The target particles measured by us is between 0.5 ~ 5.0 mm in diameter, so we can ignore the error of particle diameter error caused by calibration.

As the diameter of the floating ash particles generally ranges from 0.5 mm to 5.0 mm regarding its diameter, we obtain from table 5-1 that the maximum absolute deviation of the particle diameter is 0.1 mm, therefore the measuring error of floating ash particle diameter is ≤0.1 mm / 5.0 mm = 2%.

V. SUMMARY

By successfully drawing on computer vision detection technology, the real-time monitoring system of flue floating ash uses various image processing methods including high-pass filter, threshold segmentation, image threshold processing and image morphology method to achieve the real-time monitoring and data processing analysis of flue floating ash that is under high-speed movement. It features high flexibility, intuition and real time capability, which introduces computer vision technology into real-time monitoring system of flue floating ash and design the corresponding image acquisition hardware system as required by detection. The system consists of camera system, lighting system, image acquisition card, industrial personal computer, display; which can realize continuous and automatic monitoring based on user requirements. Still, the system studies the image space filtering, the method of gradient operator image filtering, the adaptive threshold value method and image morphology method. To improve the operation speed of the algorithm and avoid the influence and interference of noise alongside image subset, the method used in this paper is to conduct adaptive binary image segmentation for high-pass filtering and then further performing de-noising of image morphology to extract floating ash particle information for analysis.

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