International Journal of Multimedia and Ubiquitous Engineering
Vol. 10, No. 2 (2015), pp. 87-96
http://dx.doi.org/10.14257/ijmue.2015.10.2.08

Industrial Flame Edge Detection Algorithm Based on Gray Dominant Filter

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Abstract

Industrial furnace flame detection is directly related to the safety and economic operation of boiler. The flame edge detection is one of the most key parts of the flame detection. At present, there are many edge detection algorithms for normal object but few for industrial flame edge detection which cannot provide fully support for furnace flame combustion stability, flame 3D reconstruction and flame temperature field reconstruction. One new industrial flame image edge detection algorithm based on industrial flame image characteristics is proposed in this paper. This algorithm can effectively remove noise level in flame image and well maintain flame image edge features, compute the gradients from multiple-directions for entirely detecting flame edge information. Moreover, this algorithm is verified by experiment in this paper to present high performance in resisting noise, and clearly see continuous flame edge curve, which reveals better effect in industrial flame edge detection than other edge detection algorithms.

Keywords: *Flame edge-detection, Filter, Gray-dominant algorithm*

1. Introduction

Large boiler is important equipment in electric power plant, chemical industry, metallurgy and other fields. Industrial furnace flame detection is directly related to the boiler safety and economical operation [1]. When the boiler is in operation, wrong judgment on its internal combustion state will cause the flame out, and seriously will have explosive accident. Through detecting flame edge information we can learn the furnace flame combustion stability, the full extent of flame combustion, the 3D reconstruction of flame and the reconstruction of temperature field. Due to poor resistance to high temperature limit, detecting flame temperature field is only for a short time measurement, cannot realize real-time online monitoring. We have solved this problem by computer vision technology to achieve good intuitive, real-time detect flame image. Traditional image edge detection steps are shown as: filter, enhancement, computing gradient values and setting the threshold to extract the edge feature points. Because filter results directly decides the precision of edge detection [2, 3], there are plenty of conventional filtering methods including linear and nonlinear filtering. With the development of image processing, many people proposed several new filtering methods: C. Tomasi proposed the bilateral filter algorithm [4], in which considering the spatial filtering and increasing filtering window gray difference weight. Spatial coefficient and gray difference coefficient multiply the filter window gray value, which is very well to maintain image details [5, 6]. Then He Kaiming proposed guided image

ISSN: 1975-0080 IJMUE

filtering which is improved upon bilateral filter theory, by adding a guided image (color pictures without gradation) to calculate center filtering window gray image pixel weights [7]. These methods have achieved good results to treat conventional static images, while poor at industrial turbulent flame; because the flame is flash, edge fuzzy and surrounded by smoke, which results in these method application for filtering industrial flame image effect not ideal.

There are many edge detecting algorithms (*e.g.*, Roberts, Sobel and Prewitt). Roberts algorithm uses the bidirectional gradient strategy, horizontal and vertical directions effect is better than oblique edge. Because the flame edge shape is irregular, and the method is sensitive to noise, so the algorithm detection effect on the edge of industrial flame image is not good. Also Sobel algorithm is only in horizontal and vertical directions detection and got coarse edge results, which is not meeting the industrial flame detection requirements. Prewitt algorithm is seriously smoothed for image details, got coarse detection results. Gauss nonlinear filtering is used in Canny algorithm filter part [8, 9], which making the filter window weights calculation more flexible, very good at detecting conventional substance edge, but poor applied in industrial flame (gas-solid two-phase material) edge detection. Conventional detection algorithms are quite poor at flame image filtering edge detection because of flame edge contrast variation not strong and surrounded by smoke, which cannot be used in practical industrial process [10, 11]. Professor Yan Yong Team at Kent University in Britain has carried out some research work for industrial flame edge detection [12, 13]. They proposed the edge search method to solve the industrial flame edge detection which has the problem of edge dual directions lost. So this paper we propose one new industrial flame edge detection algorithm according to industrial flame characteristics. The algorithm is based on gray dominant filtering technique, and be very good to detect the flame edge of industrial flame image. This paper research work has obtained the Professor Yan Yong help: the experimental industrial flame images used in this paper is obtained by the industrial turbulent flame monitoring system developed by Professor Yan Yong team.

2. Industrial Flame Edge Detection Algorithm Based on Gray Dominant Filtering

Industrial flame is composed of flame core and outer flame always surrounded by lots of smoke, which cannot clearly identify the flame gray image due to not strong outer flame. Usually, the flicker industrial flame has no accurate boundary or obvious edge gradient change, which cannot make the ideal effect by the conventional edge detection algorithm. So in this paper, we propose one new industrial flame edge detection algorithm for effectively removing noise and maintaining the flame edge features, and finally detecting the accurate industrial image edge.

2.1. Industrial Flame Image Filtering

2.1.1. The Core Idea of Flame Filtering Algorithm: Image filtering is performed to remove the noise while preserving image details characteristics, as to the indispensable part of image pre-processing, the treatment effect will directly affect the subsequent image processing and analysis effect and reliability. When industrial flame image is shown as P, the output image is shown as Q, then

$$Q=\omega P \tag{1}$$

Where, ω is the filter kernel.

In contrast with conventional image, industrial flame image background is black, and the foreground is continuous, which will make industrial flame image gray value slowly transit from background to foreground. When the sliding window is 3 x 3 pixels, sliding window center point gray values should be determined by the surrounding pixel gray value weighed. During the calculation of window center gray value, if there is some noise in sliding windows and want to improve the results smoothing, we should give less weight to the noise points, and more weight to normal pixel points.

Since the industrial flame image foreground and background are both continuous, so when the filter window sliding, the row center point pixel gray value in front of window is close to other normal pixel point gray value of the window, but different from the noise point gray value of the window. Base on the difference, we can determine the weight between each pixel point gray value of the window and center gray value. If there is large difference value between pixel point and reference center point, we can deem the pixel point to noise point which only have less weight; rather, we can deem these pixel points to normal points if there is little difference, and give these points more weight. Figure 1 has shown the filtering window W and the basic reference point I_b.

	I_1	I_2	I_3
I_b	I_4	I_5	I_6
	I_7	I_8	I_9

Figure 1. The Filtering Window w

Firstly, we make the root mean square d by equation 2 between nine pixel points (I_1-I_9) gray values in the window and reference point(I_b) gray value to calculate the spatial weight.

$$D = \sqrt{\sum_{i=1}^{n=9}(I_i - I_b)^2} \tag{2}$$

Then, we invert the square value of between each pixel point gray value Ii and d by equation 3 to get the I pixel point spatial weight E_i. We can regard this pixel point as one noise point if E_i value is smaller. By this way, we can pick out noise point and diminish the noise effect in the image filtering process to achieve the industrial flame image smooth filtering results.

$$E_i = \frac{1}{(I_i - d)^2} \tag{3}$$

Where, E_i stands for the I pixel point in the window spatial weight value.

Supposing I_2、I_3、I_5、I_8、I_9 as the edge points in the window, I_1、I_4、I_7 as the background points and I_6 as the noise point, shown as in Figure 2, the spatial weight values E_i of I_1、I_4、I_7 points during the filtering process are a litter larger due to very close same as the reference point I_b gray value. Rather the spatial weight values E_i of I_2、I_3、I_5、I_8、I_9 are smaller, also including I_6 point. By which can smooth flame image edge to induce not ideal results during the filtering process, so this paper presents the correction factor to hold the window center point characteristics and avoid damaging the center point in the filtering process of smoothing flame image details.

I_1	I_2	I_3
I_4	I_5	I_6
I_7	I_8	I_9

Figure 2. Each Pixel Point Gray Value in the 3x3 Window

Base on Gaussian filter, we can take place of each pixel point gray value as the distance parameters in Gaussian filter method. If the non-center pixel point in the window gray value is very close to the center reference point gray value, we can assign the point more weight, otherwise less weight. By which can highlight the filtering window center pixel point features and primly hold this pixel point details. We define the industrial flame filtering Gaussian correction factor H_i as following:

$$H_i = e^{-\frac{1}{2}\left(\frac{I_i - I_5}{\sigma_r}\right)^2} \quad 1 \leq i \leq 9 \tag{4}$$

Where, σ_r stands for the gray variance of each pixel point in the filtering window.

For I_2、I_3、I_5、I_8、I_9 are all the boundary points and gray values are pretty close, so they can be assigned more weight for correction factor Hi and weaken other gray value difference points effect to maintain the flame edge features. The filtering formula after correction is shown as equation 5.

$$I_{mid} = \frac{1}{\sum_{i=1}^{9}(E_i H_i)} \left[\sum_{i=1}^{9}(E_i H_i I_i)\right] \tag{5}$$

Where, I_{mid} expresses the gray value for window center point after filtering.

2.1.2. Filtering Algorithm Analysis:

(1)As the foreground and background of industrial flame image is regional, so compare some pixel point gray value with the basic reference point I_b gray value, to determine the point property and give its relevant weight value. This algorithm has simple process and well filtering effect.

(2)There will bring some tropism for flame image gray during the filtering process which only affects the flame image boundary transition smoke area between background and flame. Hence there is non-existent impact for the flame area on the flame image gray tropism.

By correction factor H_i, can quite maintain flame edge detail information.

2.2. Industrial Flame Image Edge Detection

There are sets of pixel points to constitute image edge. Due to the gray value differences of both edge sides is larger than the gray transition differences of two various image foreground area, so we can realize the image edge by calculating image gradient modulus maxima points or the second derivative zero point after filtering. The gradient direction stands for the orientation of image gray change most violently, so we can confirm the image edge pixel point's perpendicular to the maximum gradient direction. Moreover, the second derivative is relatively more sensitive to noise level, which cannot be precisely detected by regular both ways gradient algorithm. So in this paper we improve the Prewitt gradient operator to exact flame image edge. We expand traditional Prewitt operator template size 2x2 to 3x3 for calculating differential operator, and extend two gradient directions to eight directions, which can fully consider flame edge irregularity. Figure 3 presents the image pixel point relative coordinates.

(x-1,y-1)	(x-1,y)	(x-1,y+1)
(x,y-1)	(x, y)	(x,y+1)
(x+1,y-1)	(x+1,y)	(x+1,y+1)

Figure 3. Image Pixel Point Relative Coordinates

Base on the filtering window information shown as Figure 3, there will be expanded Prewitt operator displayed as equation 6. We can make two edge detection convolution operators for horizontal and vertical direction, in which A operator for the horizontal direction convolution template, B operator for the vertical direction convolution template.

$$A=\begin{bmatrix}-1 & 0 & 1\\ -1 & 0 & 1\\ -1 & 0 & 1\end{bmatrix} \qquad B=\begin{bmatrix}-1 & -1 & -1\\ 0 & 0 & 0\\ 1 & 1 & 1\end{bmatrix} \tag{6}$$

We can obtain gradient formula by multiplying the template number by relative coordinate corresponding position and summing up. Then we can acquire horizontal and vertical direction of Prewitt gradient operator according to the equation 7 and equation 8.

$$g_3=\left|\begin{matrix}\{f(x-1,y+1)+f(x,y+1)+f(x+1,y+1)\}-\\ \{f(x-1,y-1)+f(x,y-1)+f(x+1,y-1)\}\end{matrix}\right| \tag{7}$$

$$g_5=\left|\begin{matrix}\{f(x+1,y-1)+f(x+1,y)+f(x+1,y+1)\}-\\ \{f(x-1,y-1)+f(x-1,y)+f(x-1,y+1)\}\end{matrix}\right| \tag{8}$$

In this algorithm, we make gradient operator more large value as coordinate pixel point(X, Y) new gray value. Base on this view, we employ gradient template in turn detecting image to get operator different new output value, and use the maximum value to take place of the filtering window center point gray value. Figure 4 shows eight directions by each 45 degrees for calculating gradient direction. Also, Figure 5 expresses the 1-8 direction convolution template operators.

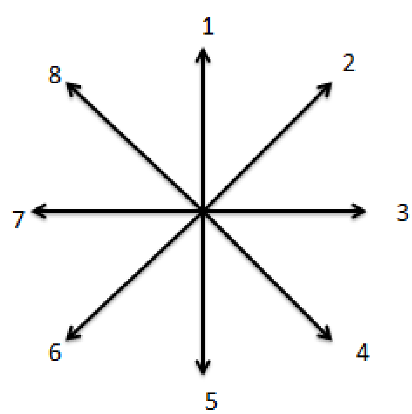


Figure 4. Gradient Template Directions

$\begin{bmatrix} 1 & 1 & 1 \\ 1 & -2 & 1 \\ -1 & -1 & -1 \end{bmatrix}$	$\begin{bmatrix} 1 & 1 & 1 \\ -1 & -2 & 1 \\ -1 & -1 & 1 \end{bmatrix}$
1-direction template operator	2-direction template operator
$\begin{bmatrix} -1 & 1 & 1 \\ -1 & -2 & 1 \\ -1 & 1 & 1 \end{bmatrix}$	$\begin{bmatrix} -1 & -1 & 1 \\ -1 & -2 & 1 \\ 1 & 1 & 1 \end{bmatrix}$
3-direction template operator	4-direction template operator
$\begin{bmatrix} -1 & -1 & -1 \\ 1 & -2 & 1 \\ 1 & 1 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & -1 & -1 \\ 1 & -2 & -1 \\ 1 & 1 & 1 \end{bmatrix}$
5-direction template operator	6-direction template operator
$\begin{bmatrix} 1 & 1 & -1 \\ 1 & -2 & -1 \\ 1 & 1 & -1 \end{bmatrix}$	$\begin{bmatrix} 1 & 1 & 1 \\ 1 & -2 & -1 \\ 1 & -1 & -1 \end{bmatrix}$
7-direction template operator	8-direction template operator

Figure 5. Eight Directions Template Operators

Through calculating the mask operator, each pixel point gray value of the image has been the maximum value respectively by gradient calculation. And then set the point gray value to 255 if the mask results greater than threshold value TH(g_i >TH), otherwise set to 0, finally form the flame edge.

In this algorithm, by automatically adjusting the filter weight and correction factor according to each pixel point gray value can remove flame image noise level and well keep flame edge information. Innovatively increase basic reference point into this algorithm and practically apply to industrial flame edge detection. The first algorithm part is used to solve industrial flame filtering problem, the other part is to complete denoising industrial flame image edge detection.

3. Experimental Results

3.1. Filtering Experiment

We will contrast new filtering algorithm results with other three common filtering algorithms (linear filtering, Gauss filtering and bilateral filtering algorithm) results. Figure 6 is presented the experimental filtering results with four algorithms, in which, Linear filtering algorithm results is poor pertinence, fuzzy and serious distortion, due to adopting distance to decide spatial weight; Gauss filter algorithm results is a little better than Linear filtering algorithm results since using nonlinear filtering and flexibly selecting spatial weight; there increase gray weight in bilateral filter algorithm, so its filtering results is much better. But bilateral filter algorithm has not been considering industrial flame edge characteristics, which lead to the results edge relatively vague. Gray dominant filter algorithm results is the best, because there has been taking spatial weight and gray weight into account and proposing correction factor well keeping image edge information.

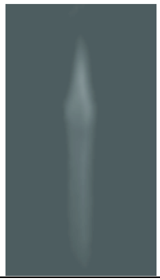
Original picture	Linear filter	Gauss filter	Bilateral filter	Gray dominant filter
				

Figure 6. Filter Results

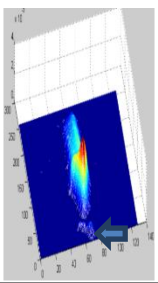
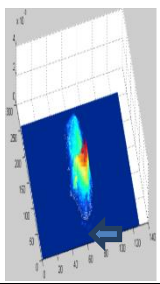
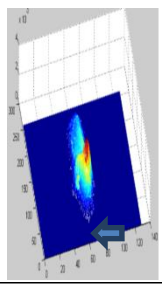
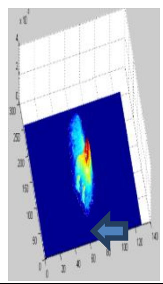
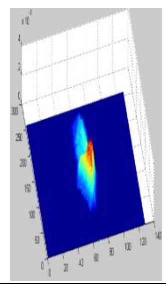
Original picture	Linear filter	Gauss filter	Bilateral filter	Gray-dominant filter
				

Figure 7. 3D Gray Images of Four Filter Algorithm Results

Figure 7 shows various industrial flame image filtering 3D gray images for four algorithms. In 3D gray images, X, Y represent each pixel coordinates in the image, Z means gray value, and various colors contour represent different brightness. There is some noise (white point marked by arrow) in original 3D image. But the noise above the flame still reserve and contour blur through Linear filtering algorithm; However, Gaussian filtering algorithm denoise results is better than Linear filtering algorithm, while a little poor at image edge filtering results and contour become darker after filtering. Bilateral filtering is better to keep color contour, less damage to the image. Gray dominant filtering algorithm can effectively remove noise information in the original image and make color contour bright, which means there is well edge information for flame image after filtering.

3.3. Flame Image Edge Detection Experiment

We will compare the gray dominant algorithm performance on extracting flame edge information with traditional algorithms, which is shown in Figure 8, respectively using Sobel, Gaussian Laplacian and gray dominant filter to detect flame edge on four kind flame images presented in Figure 8.

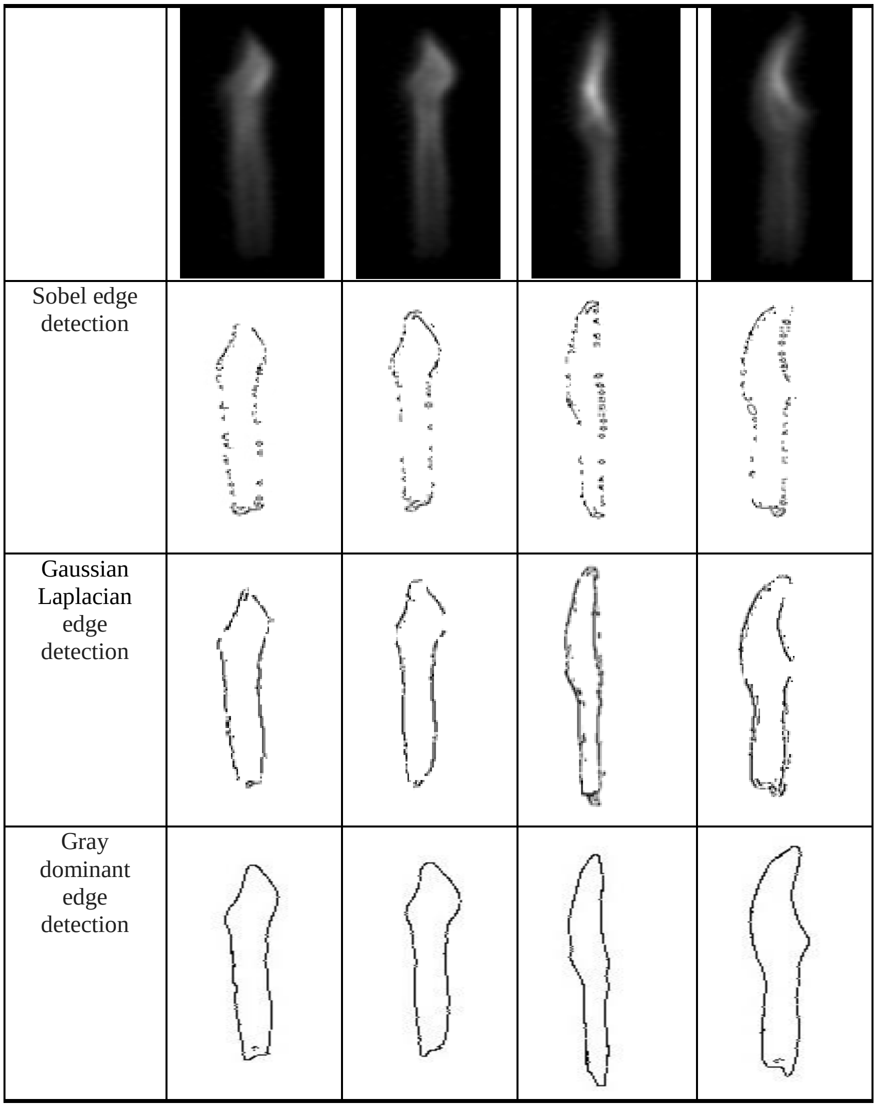


Figure 8. Results of Three Algorithms Detecting Flame Edge Information

Due to the flame image edge features, Sobel and Gaussian Laplacian algorithms results still have shown no-continuous edge curve and multiple-edge error which is induced by edge detail damage in filtering process. Because Sobel is adopted linear filtering algorithm which is seriously lost edge detail information to lead test results quit no-accurate and no-continuous. Then Gaussian Laplacian is used Gaussian filtering algorithm, flexibility in calculating spatial weight and better continuity in image edge curve, but poor antinoise performance for second partial derivative in gradient calculation. There is increased gray correction factor in gray dominant filtering algorithm which can reserve image edge detail information and multiple directionally calculate gradient to get continuous clearly flame edge finally through gray dominant algorithm.

4. Conclusion

According to the characteristics of industrial flame image, this paper puts forward one industrial flame edge detection algorithm based on gray-dominant filter. There includes two parts of gray dominant filtering and multiple directional edge extraction. Moreover, we verify this flame filtering algorithm advantage in detecting industrial flame image edge curve by experiment. New gray correction factor can maintain image edge detail information and multiple directionally calculate gradient to get continuous clearly industrial flame edge finally through gray dominant algorithm.

Acknowledgements

This paper is supported by the Programme of Introducing Talents of Discipline to Universities(B13009).

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