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Surface Defect Inspection of a Cutting Tool by Image Processing with Neural Networks

Shinichiro INOUE *
Division of Electronic and
Information System Engineering
Graduate School of Natural Science and Technology
Okayama University
3-1-1, Tsushima-Naka Okayama, 700-8530

Masami KONISHI and Jun IMAI
Division of Industrial Innovation Science
Graduate School of Natural Science and Technology
Okayama University
3-1-1, Tsushima-Naka Okayama, 700-8530

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In this research, an image processing method and a system for inspection support of a rod figured cutting tool are developed. As is well known, the visual inspection of a cutting tool by image processing is not easy, because cutting blade have a helical blade structure. To cope with the problem, an experimental facility with rotation and longitudinal tool shift functions to enable acquisition of blade surface pictures along a cutting rod is developed. The type of the defect treated in this paper is the spot of coating on blade surface. To judge the quality of the processed image of blade surface, neural network with autonomous learning is used. The processed image of cutting tool is divided into 64 × 64 blocks used for the input to the neural networks. Before input, each block data is preprocessed applying a edge detection filter and a transformation by the discrete fourier transform (DFT). Using these technologies, the experimental inspection system is built and tested to check the capabilities of the inspection algorithms. The diagnostic performance of the surface defect of a cutting tool was confirmed. There remained a problem to mis judge the normal tools as the defect.

1 INTRODUCTION

In this research, an image processing method and a system for inspection support of a rod figured cutting tool are developed. It is needed to assure a finished cutting tool with no minute defect on the surface and usually expert skills for visual inspection are employed for inspection. As it is the excessive load for human expert, human support inspecting technologies are required. To cope with the requirement, image processing method is studied. As is well known, the visual inspection of a cutting tool by image processing is not easy, because cutting blade have a helical blade structure. To prove the difficulty, an experimental facility with rotation and longitudinal tool shift functions to enable acquisition of blade surface pictures along a cutting rod is developed. The type of defect treated in this paper is the spot of coating on blade surface. To judge the quality of the processed image of blade surface, neural network with autonomous learning is used. Conventional detection methods need special processing to extract the striking feature of the defect to match the defect and it is difficult, because the shadow and the curve of the object affect accuracy of the inspection. It is thought by using neural net work, a lot of features can be considered as nearly same with human eyes can obtain. The processed Image of cutting tools is divided into 64 × 64 blocks used for the input to the neural networks. Before input, each block data is preprocessed applying a edge detection filter and a transformation by the discrete fourier transform

*inoue@cntr.elec.okayama-u.ac.jp

(DFT). By the preprocessing, frequency domain data used for neural network showing the characteristics of the image data are made. Based on these technologies, the experimental inspection system is built and tested to check the capabilities of the proposed inspection algorithm.

2 INSPECTION OBJECT

2.1 Cutting Tool

The cutting tool treated in this paper is a kind of the cylinder shape cutting tool shown in Fig.1. It is used to cut down the surface of a metallic material, and to process it to the desired shape. At the end of the manufacturing process of the tool, the experts inspect all products by watching.

Fig. 1: Cutting tool

2.2 Defect on The Surface of Cutting Tool

In this paper we treated the defect by spot of the coating on a cutting blade as shown in Fig.3. Fig.3 shows spot of coating on the surface of a cutting tool. In manufacturing of cutting tools, failure in coating process and contact with something after coating may occur and results in the spot of the coating. Coating defect by spall tend to occur on periphery of the cutting tools. The coating defect by spall is observed as white or black spot compared with its surroundings like in Figs.3 and 4.

Fig. 2: Normal surface

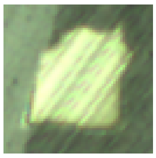

Fig. 3: Spot of the coating (After coating process)

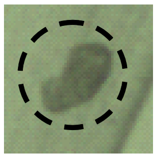

Fig. 4: spot of the coating (Before coating process)

3 EXPERIMENTAL APPARATUS

The picture and the diagram of the experimental apparatus are shown in Figs.5 and 6. Fig.5 shows picture of a defect inspection system which involves C-MOS camera to acquire image data, motor pulse controller for camera movement,information of processed position of cutting tool, fluorescent lamp and so on. Fig.6 shows diagram of the defect inspection system. The cutting tool can be set up by inserting it in the hole. The pulse is transmitted from the computer to the drive motor which control the cutting tool position in the vertical direction and also in the rotating direction. Further, the camera moved back and forth to change focus. The fluorescent lamp is set up in the apparatus, because fluorescent lamp can cast high diffusible light. There is a white Lev boards that reflect the light. The place where a reflected light from the Lev board hit is used for the inspection. As a result, light uniformly lies on the cutting tools.

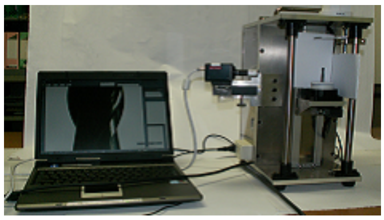

Fig. 5: Picture of defect inspection system

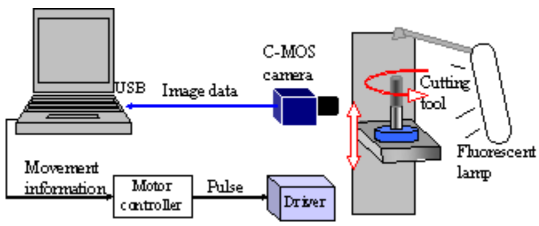

Fig. 6: Diagram of defect inspection system

First, a picture of the entire tool for the inspection is taken. The area used for the inspection is area of 448 $\times$ 768 sizes that the lighting uniformly hits as shown in

Fig.7. As the result, it becomes possible to inspect it without being obstructed by the reflection of the light source.

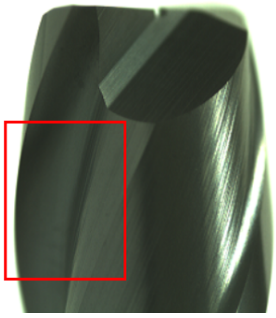

Fig. 7: Inspection area of tool

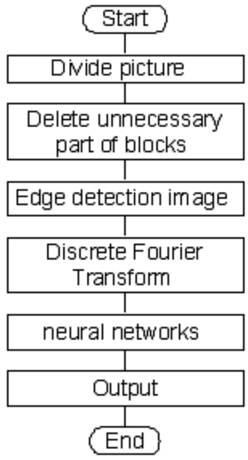

Fig. 8: Diagram of defect inspection system

The picture in the area of the entire tool is taken two times or more in the inspection.

4 CONSTRUCTION OF INSPECTION SYSTEM

4.1 Flowchart of Inspection

The flowchart of the inspection algorithm is shown in Fig.4.Firstly, the image of cutting tools is divided into 64 × 64 blocks. Next, the unnecessary part of blocks that is not used for inspection is deleted. Following which, each block is transformed to edge detection image, which is using Prewitt operator. Then, the picture is transformed into the frequency domain using the Discrete Fourier Transform (DFT) for the extraction of image characteristics. After that, it is input to the neural networks. Finally, inspection results are output.

1	0	-1
1	0	-1
1	0	-1

Δ_x

1	1	1
0	0	0
-1	-1	-1

Δ_y

Fig. 9: Operator of Prewitt filter

$i-1, j-1$	$i, j-1$	$i+1, j-1$
$i-1, j$	i, j	$i+1, j$
$i-1, j+1$	$i, j+1$	$i+1, j+1$

Fig. 10: Area of 3 × 3 pixels

4.2 Extraction of Image Characteristics

4.2.1 Edge Detection With Prewitt Filter

The Prewitt filter is used for an outline extraction of the image which is a kind of the differentiation filter of one dimension. Because Prewitt filter considers the area of 3 × 3 pixels, it is strong to the noise. The operator of the Prewitt filter is shown in Fig.9, and the area of 3 × 3 pixels is shown in Fig.10.

The differentiation value of the Prewitt filter of horizontal and vertical direction which is Δ_x, Δ_y is shown in Eqs.(1) and (2).

$$\Delta_x \equiv Y(i-1, j-1) + Y(i-1, j) + Y(i-1, j+1) \\ -Y(i+1, j-1) - Y(i+1, j) - Y(i+1, j+1). \quad (1)$$

$$\Delta_y \equiv Y(i-1, j-1) + Y(i, j-1) + Y(i+1, j-1) \\ -Y(i-1, j+1) - Y(i, j+1) - Y(i+1, j+1). \quad (2) \\ (i = \{2, 3, \cdots, m-1\}, j = \{2, 3, \cdots, n-1\})$$

Heres Δ is defind as the an inclination that shows outline strength and obtained in as shown in Eq.(3).

$$\Delta = |\Delta_x| + |\Delta_y|. \quad (3)$$

4.2.2 Two Dimension DFT

DFT is a Fourier transform treating discrete value. Signal $s(t)$ and value $S(t)$ of the DFT are given by the expression of Eq.(4).Which, N is a number of data on $s(i)$.

$$S[k] = \frac{1}{N}\sum_{i=0}^{N-1} s(i)\exp(-j\frac{2\pi}{N}ki).$$
$$(k = 0, 1, \cdots, N-1) \tag{4}$$

Eq.(4) correspond to two dimensions in Eq.(5) as Image size $M \times N$ and the brightness of each pixel data $g[m,n]$

$$G[k,l] = \frac{1}{MN}\sum_{n=0}^{N-1}\sum_{m=0}^{M-1} g[m,n]$$
$$\exp(-j\frac{2\pi}{M}km)\exp(-j\frac{2\pi}{N}ln) \tag{5}$$

By the method stated above, two dimensional DFT are calculated by repeating one dimensional DFT. The position on the left $(k = 0, l = 0)$ shows a direct current element in the two dimensional DFT image shown in Fig.11. The four edges of the left side figure in Fig.11 are the low frequency elements. A center part of the left side figure becomes a high frequency element. In this research, position of the DFT data is replaced like the right side figure in Fig.11 the center may become a direct current element to make the feature comprehensible.

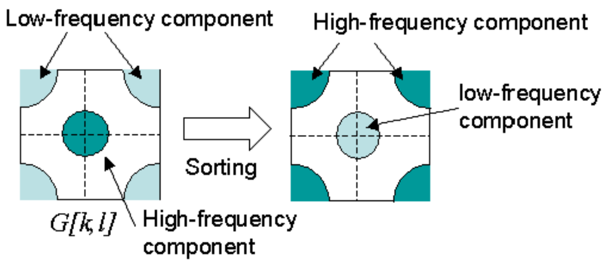

Fig. 11: Sorting of images DFT

4.3 Evaluation of Focus

In one inspection image,there exists the part where picture is not focused. So, pictures are taken changes focus on the same position of the tool three times and qualities of focuses are compared. Focuses at the same position of each picture is compared by the image divided into 64 × 64 blocks. Each block data is preprocessed applying edge detection filter and transformation by DFT. It is focused when the total of the brightness of DFT image becomes maximam as shown in Fig.18

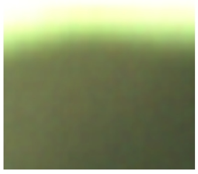

Fig. 12: Block Image(Not Focused)

Fig. 13: Edge Detection Image(Not Focused)

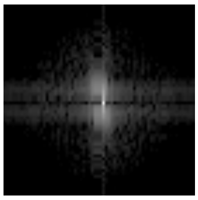

Fig. 14: DFT Image (Not Focused)

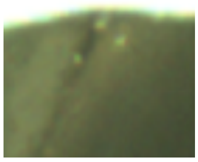

Fig. 15: Block Image(Focused)

Fig. 16: Edge Detection Image(Focused)

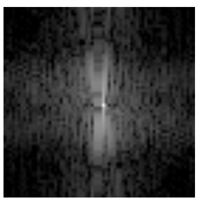

Fig. 17: DFT Image (Focused)

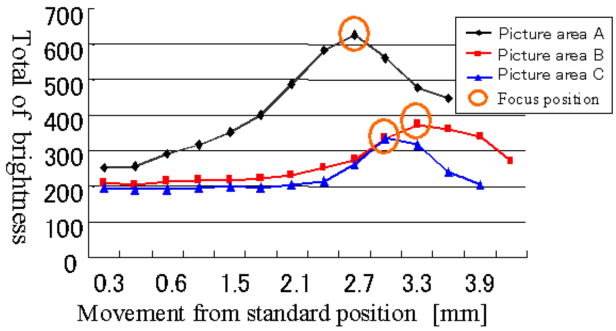

Fig. 18: Evaluation of qualties of focuses

4.4 Hierarchical Neural Network

To judge the quality of the processed image, neural network with autonomous learning is used. Fig.19

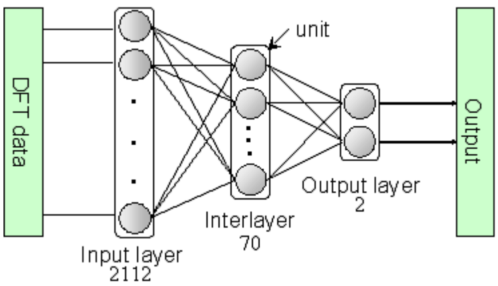

Fig. 19: Illustrate of HNN

shows illustrate of HNN. In this system each input data is preprocessed applying edge detection filter and transformation by DFT. The number of input layers of HNN is taken 2112. Because two dimensional DFT

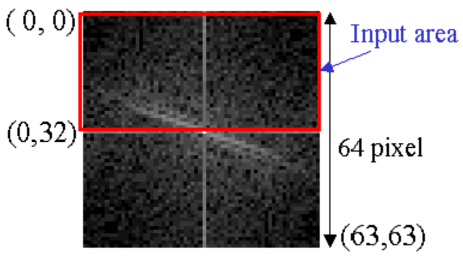

Fig. 20: Input area of DFT image

image has 64 × 33 effective pixels as shown in Fig.20

The number of hidden layer was decided to be 70 pieces empirically. The number of output layers taken 2, showing the defect and the normal. The input DFT image which has 256 shades of gray is divided by 255 to regularize within the range from 0 to 1. When studying,teaching imeges of normal and defective are alternately studying for improvement of settling performance to teaching data. The end condition of learning is that the value of differences between the true value and output of NN is less than 0.15 when the teaching data is input. When inspection image is input, output of normal and defect is compared. The larger one was assumed to be inspection result. It is not possible to judge when each output difference is less than 0.3.

5 EXPERIMENT

We examined the performance of inspection program for the defect by spot of cutting tools. The different amount of the teaching data of normality and defect was prepared three patterns to teach NN. The teaching data is not used for the inspection data. For about 2520 image blocks, images are taken form cutting tools, with no defect, that corresponded to the entire one tool for input. 188 image blocks are taken from defect tools.It contains picture of the same defect from a different position. Table 1 shows the inspection results. NN3 which is studied 150 nomal cutting tool images and 97 defect images, has highest recognition rate. About 0.28% of the normal product blocks were inspected as defect and about 0.32% of the defect blocks were inspected as normal product for NN3. When the teaching data is increased, the recognition rate has been improved. From these results, this NN has a high recognition ability for surface defect.

Table 1: Inspection result of each block (64x64)

	Number of teacher block images		Inspection result (recognition/input)	
NN1	50	50	2113 /2520	163 /188
NN2	100	75	2429 /2520	175 /188
NN3	150	97	2513 /2520	182 /188

In the fault recognition of normal images, the curve of tool has a large color variation.(Fig.21) In the fault recognition of defect images is a part of unstudy and defect exists on the edge of the image block. (Fig.22)

6 CONCLUSION

In this study, we developed the inspection system for the defect by spot of cutting tools. The system contains HNN and preprocess of images by edge detection and

Fig. 21: Fault recognition of normal images

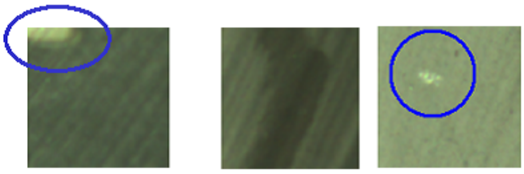

Fig. 22: Fault recognition of defect images

DFT. The detection performance of the defect inspection system was confirmed. There remained a problem to inspect the normal tools where is the place with the reflected light in a curve part as the defect. It is because the outline image of them has the feature that closely resembles the defect. It is thought the method of improving recognition rate of normal tool is to expand the size of input data to attain judges of a lot of information. Another one method is thought that the information of location of the tool is added to input data to consider the influence of curve shape of cutting tool. The other problem is to inspect the defect image of the unstudied part as the normal.

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