Pattern Recognition Technique for PAD Inspection using Chain-Code-Discrete Fourier Transform and Signal Correlation

Anakkapon Saenthon and Somyot Kaitwanidvilai

Abstract—**This paper presents a new technique to recognize pattern for inspecting PAD, which is an important part in Hard Disk Drive (HDD) component and IC circuit. The proposed technique uses chain-code and discrete Fourier's transform for feature extraction, and uses signal correlation technique for classifying the pattern. The extraction of object's edge is performed to determine the position and alignment of PAD. The accuracy and inspection time of the proposed algorithm are investigated and compared with the other pattern recognition techniques, such as full template matching, coarse to fine method, etc. Experimental results show the effectiveness of the proposed technique.**

Index Terms—**Pattern Recognition, Discrete Wavelet Transform, Signal Correlation, Chain Code.**

I. Introduction

Nowadays, the inspection of electronic and mechanical components plays an important role in the electronic and HDD manufacturing. To develop a high performance HDD, several rigorous inspections of HDD components need to be performed; one of the most important inspections applied to the HDD manufacturing is automatic visual inspection. Several image processing [1] techniques are adopted in this inspection to extract the interesting information such as dimension, distance, position, alignment, etc. Many research works were proposed to develop several fast and high performance techniques. For example, full template matching [2] is an important and basic technique that can be used for finding the interesting pattern in the captured image. This technique is simple and efficient; however, the main drawback of this technique is the high computational time of image processing. In addition, this technique is not RST (Rotational-Scaling-Transform) invariants method, which is one of the most important issues in the pattern recognition. Coarse-to-fine technique was proposed to enhance the performance in terms of processing time; however, the accuracy of this technique is decreased due to the reduction of image resolution. Tretter et. al.[3] proposed the automatic visual inspection using the Bayesian estimation technique. Their proposed technique uses both the tree diagram and the expectation maximization (EM) algorithm to find the best matched pattern. Rube et. al. [4] developed a pattern recognition and classification technique using Dyadic Wavelet Transform. In their technique, rough shape is used for classification and the normalized cross correlation is adopted for the fine shape to analyze the similarity. As shown in their results, correlation is a popular technique used for checking the similarity. Fernandez et. al. [5] proposed the Kolmogorov-Smirnov technique for measuring the similarity of two images. As shown in their results, the proposed technique performed better performance compared to the conventional normalized correlation technique. Yen et. al. [6] developed the visual inspection system for PCB (Printed Circuit Board) trace inspection. They used some pattern recognition techniques to find the defects in PCB trace and background area of PCB.

Tsai and Hsieh [7] applied the Fourier's and Hough transforms for inspecting the defect in cloth manufacturing. In their technique, the high frequency components are ignored and the interesting features can be detected easily. Henry et. al.[8] adopted the Wavelet Preprocessed Golden Image Subtraction (WPGIS) to find the defects in an object. The accuracy of inspection is satisfied at 96.7%. Feng and Hai [9] solved the problem of high computational time by designing the multi-scale image using Haar-like binary transformation. The advantage of the robustness against image noise is achieved by this technique. Wen and Chin [10] used the Ring Projection Transform to perform the rotation invariant technique, and used the cross correlation technique to find the location of the interesting object. Jin and Hyoung [11] applied the Discrete Wavelet Transform (DWT) for the pattern recognition of PCB trace; the main advantages of the proposed technique are the low computational time and low memory usage. However, this technique reduces the image size; thus, the accuracy of detection is decreased when comparing with the full template matching technique.

As seen in the above mentioned research works, the processing time of the machine vision is one of the most important issues in the development of automatic visual inspection. Especially, in the HDD industrial, the specification of the rate of production in terms of UPH (Unit Per Hour) limits the applicable techniques in the visual inspection. In the other words, both fast algorithm and high accuracy performance of image processing are needed for

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Anakkapon Saenthon is with the faculty of engineering, King Mongkut's Institute of Technology Ladkrabang, Ladkrabang, Bangkok, 10520, Thailand. (email: sanakkapon@gmail.com)

Somyot Kaitwanidvilai is with the faculty of engineering, King Mongkut's Institute of Technology Ladkrabang, Ladkrabang, Bangkok, 10520, Thailand. (corresponding author , phone: 668-3-904-6164; e-mail: drsomyotk@gmail.com).

the development; unfortunately, two above mentioned specifications are trade-off relationships. To enhance and increase the performance of the automatic visual inspection system, in this paper, a new algorithm for finding the position of PAD, which is an important part in HDD components, is proposed. By adopting both the Fourier's transform and signal correlation technique for the 1-dimension chain-code signal, the fast and high accuracy algorithm is achieved. To clarify the performance and the effectiveness of the proposed algorithm, full template matching and coarse-to-fine techniques are performed for comparison purpose.

II. Conventional Technique

This section roughly describes the studied pattern recognition techniques, i.e. full template matching and coarse-to-fine techniques.

A. Full template matching

Full template matching technique evaluates the similarity by considering the intensity of pixel in the image pattern and input image. The mean square error (MSE) shown in (1) is mostly used for evaluating the similarity index.

$$MSE = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N}\left[T(x,y) - I(x,y)\right]^2 \qquad (1)$$

where $T(x,y)$ is the intensity value of the pattern image at the position (x, y), and $I(x,y)$ is the intensity of the input image at position (x, y). M and N are the width and height of the image, respectively.

B. Coarse-to- fine method

Template matching performs high performance of pattern recognition; however, this technique results in the high processing time, and is not a RST invariants technique. To improve the processing time, coarse-to-fine technique is proposed. This technique resizes the original image, and then uses the full template matching on the resized image. Thus, the processing time is reduced due to the small input image. Normally, instead of using MSE for evaluating the similarity, cross correlation value shown in (2) can be applied to both full template matching and coarse to find methods. *f(x,y)* and *t(x,y)* are the intensity values at position *x,y* of input and pattern images, respectively. Normalizing coefficient can be computed in (3).

$$c(u,v) = \sum_{x,y}\left[f(x,y)t(x-u, y-v)\right] \qquad (2)$$

$$\gamma(u,v) = \frac{\sum_{x,y}\left[f(x,y) - \bar{f}_{u,v}\right]\left[t(x-u,y-v) - \bar{t}\right]}{\sqrt{\sum_{x,y}\left[f(x,y) - \bar{f}_{u,v}\right]^2 \sum_{x,y}\left[t(x-u,y-v) - \bar{t}\right]^2}} \qquad (3)$$

where $\bar{f}_{u,v}$ is the average value computed from the mask, and $\bar{t}$ is the average value computed from the original image.

III. The Proposed Technique

The proposed technique is briefly described by the following steps:

1. Find the region of interest (ROI) and use the simple edge detection technique, Sobel filter, to extract the edge of PAD,

2. Find the chain-code of the edge of PAD,

3. Transform the chain-code signal from step 2 to the frequency domain using Fourier's Transformation,

4. Use the cross correlation to evaluate the similarity index of the input image. Note that the chain-code signal of the pattern image must be evaluated before by using the above steps 1-3, and its data is kept in the database.

Chain-code technique and Fourier's Transformation are the simple techniques which the reader can be found in several image processing textbooks. However, we roughly review the concept of both techniques as followings.

Chain-code: The following equation describes the chain-code technique. The direction evaluated from the next consecutive pixel is converted to the code, and is used as the signal in our proposed algorithm.

$$Chain\ (n) = \begin{cases} if\ (P_{xn} - R_{xn}, P_{yn} - R_{yn}) = (0,\ 1) & then\ \ 0 \\ if\ (P_{xn} - R_{xn}, P_{yn} - R_{yn}) = (1,\ 1) & then\ \ 1 \\ if\ (P_{xn} - R_{xn}, P_{yn} - R_{yn}) = (1,\ 0) & then\ \ 2 \\ if\ (P_{xn} - R_{xn}, P_{yn} - R_{yn}) = (1,-1) & then\ \ 3 \\ if\ (P_{xn} - R_{xn}, P_{yn} - R_{yn}) = (0,-1) & then\ \ 4 \\ if\ (P_{xn} - R_{xn}, P_{yn} - R_{yn}) = (-1,-1) & then\ \ 5 \\ if\ (P_{xn} - R_{xn}, P_{yn} - R_{yn}) = (-1,\ 0) & then\ \ 6 \\ if\ (P_{xn} - R_{xn}, P_{yn} - R_{yn}) = (-1,\ 1) & then\ \ 7 \end{cases} \qquad (4)$$

Where P_x, P_y are the pixel positions of the next edge pixel, R_x and R_y is the current pixel (at no. *n*). Thus, the possible values of each element of the chain-code are 0 to 7. Fig. 1 shows the chain-code direction and an example of coding.

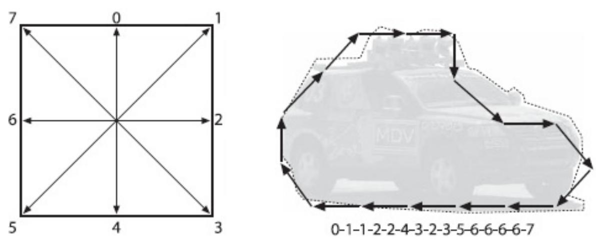

Fig. 1 Chain code and an example.

Fourier Transformation: Using the chain-code and Fourier transformation, the signal can be transformed to the frequency domain by (5).

$$F(u) = \sum_{n=1}^{N} Chain\ (n) \times \exp\left(\frac{-2\pi i}{\mathrm{N}}\mathrm{un}\right) \ , u = 1, ..., N \qquad (5)$$

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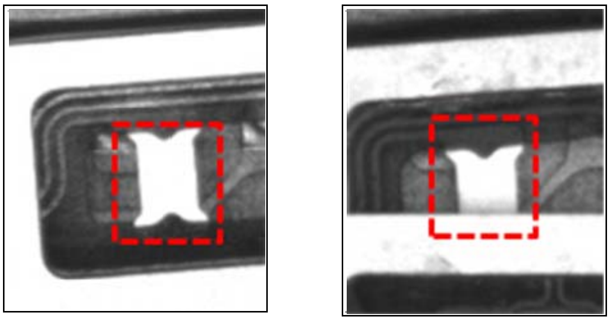
Where N is the number of data points. Based on (3), the cross correlation in frequency domain can be computed.

$$\gamma_{best} = \max(\gamma(F(f(x,y)), F(t(x,y)))) \quad (6)$$

$\gamma_{best} \in$ [0-1]. The best of value γ_{best} is 1, which means that the two images have the same components.

IV. RESULTS

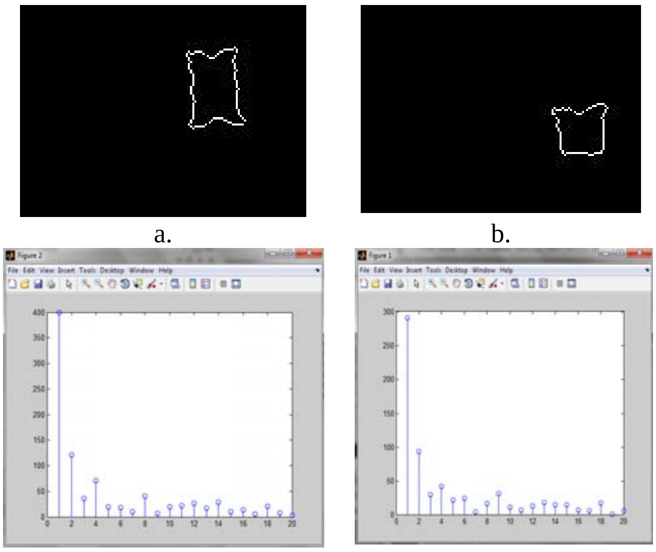
Experimental results in this research work were done on a Pentium 4, 1.73 GHz with 2GBytes Ram. In our study, the interesting patterns are Pad with 100% and PAD with 50% (half-PAD) as shown in Figs. 2(a) and 2(b), respectively. As seen in these figures, the detection of type and location of PADs is the main task of the developed vision machine.



a. 100% PAD b. 50% PAD

Fig. 2 Interesting Patterns

When applying our proposed algorithm, as seen in Fig. 3, the edges of PADs can be detected and transformed to chain-code signals. Next, when applying the FFT, the frequency domain components of PADs are determined. These components are used as our pattern for making the cross correlation.



a. b. c. d.

Fig. 3 Pattern image: (a) edge image of 100%PAD, (b) Edge image of 50%PAD, (c) frequency domain components of 100%PAD and (d) frequency domain components of 100%PAD.

In this research work, we applied 8 input images with rotation (0-5 degree) to all techniques for investigating the performance. Tables 1 and 2 show the results. As seen in these tables, our proposed technique can find the PAD with higher cross correlation when compared to the other studied techniques.

Table 1 Cross correlation of 100% PAD

100% PAD	Rotation Angles of PAD			
	0	1	3	5
Full template matching	0.9795	0.9497	0.9305	0.8903
Coarse-to-fine	0.9851	0.9579	0.9423	0.9061
The proposed technique	0.9890	0.9882	0.9607	0.9233

Table 2 Cross correlation of 50% PAD

50% PAD	Rotation Angles of PAD			
	0	1	3	5
Full template matching	0.9537	0.8737	0.8606	0.8486
Coarse-to-fine	0.9612	0.8859	0.8753	0.8634
The proposed technique	0.9802	0.9702	0.9649	0.9592

Table 3 shows the comparison results in terms of processing time. As seen in this table, our proposed technique has the processing time only 2.38ms for the 100% PAD image and 1.83ms for the 50% PAD image. This concerns that the proposed technique can perform much faster than the conventional full template matching and coarse-to-find techniques.

Table 3 Processing time of all techniques.

Techniques	**100%PAD (ms)**	**50% PAD (ms)**
Full template matching	50.32	36.22
Coarse-to-fine	8.18	7.66
the proposed technique	2.38	1.83

V. CONCLUSIONS

As seen in the experimental results, our proposed technique can detect PADs by using the signal correlation, chain code and Fast Fourier Transform. The improvement in terms of the accuracy of inspection and fast inspection time is clearly shown. The implementation on a real machine vision system in the HDD manufacturing is also illustrated. In conclusion, the proposed technique is promising for future automatic visual inspection.

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