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Full Length Research Paper

Pattern recognition technique for integrated circuit (IC) pins inspection using wavelet transform with chain-code-discrete fourier transform and signal correlation

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This paper proposes a new technique for recognizing integrated circuit (IC) pins in an IC chip. The proposed technique applies the wavelet transform and discrete Fourier's transform to extract the interesting features for classifying the IC pin pattern. The accuracy and inspection time of the proposed method are investigated by comparing with other pattern recognition techniques such as full template matching, coarse to fine method, etc. 40 images are adopted to test the effectiveness of the proposed algorithm. As seen in the results of classification of images with 5 degrees rotation, the proposed method gains the average maximum cross correlation of 0.9986 with the standard deviation of 0.0004. Experimental results show the effectiveness of the proposed method which is better than the other conventional techniques.

Key words: Classification technique, feature extraction, visual inspection, image processing.

INTRODUCTION

Machine vision plays an important role in manufacturing process for inspecting and controlling the quality of products. Especially in semiconductor industry, the requirement of high accuracy and fast inspection is required for improving the manufacturing process. Recently, several techniques were developed to accomplish the aforementioned task; however, the requirement of increasing both the speed and the accuracy of inspection is still a challenging issue for automatic visual inspection development. To enhance the ability and capacity of machine vision system, several new techniques in image processing were developed. Kang (2009) proposed a fast region of interest (ROI) method based on JPEG2000 to inspect the IC pattern recognition. In image processing, pattern recognition is an important step to recognize the object by comparing with several known templates. One method for pattern recognition (Pratt, 2007) called "full template matching" is a very simple technique to classify object. This technique adopts the counting of different pixels between original and test images to find the best matched position of the interesting object. The main drawback of this method is time consumed in recognition process. In addition, this method does not have property of RST (rotation, scaling and transformation) invariant which is required in many classification approaches. To resolve this problem, several researchers use the coarse-to-fine technique. Tretter (1995) presented the development of auto-inspection by using Bayesian estimation to inspect and compute the correlation factor of the component. In their paper, expectation maximization algorithm (EM) is adopted to find the optimal matching model. Experiments of inspection between 2 different image types of the proposed method showed the effectiveness of their proposed algorithm. Rub (2004) developed the recognition technique to separate the two shapes by applying dyadic wavelet transform. The classified groups were analyzed by using normalized cross correlation. Fernandez (1997) adopted the Kolmogorov-Smirnov technique for analyzing the similarity of images. As results indicated, this technique is better than the normalized correlation technique. Yen (1996) developed

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an auto-inspection for PCB by using the recognition technique; the proposed technique could analyze the fail position and the completion of the background of PCB. The results showed that the proposed system can detect all failure types and the failed positions. Moreover, image processing techniques were adopted in many applications (Lu et al., 2010; Arash 2010; Ahmed, 2010) including industrial applications.

Transformation technique is applied to transform the image data to other domain for easier analysis. Tsai and Hsieh (1999) applied the Fourier transform and Hough transform to find the defect positions on a cloth surface. Henry et al. (2005) adopted the wavelet preprocessed golden image subtraction) WPGIS(to find the missed positions on a cloth surface. The results were satisfied with the correlation value of 96.7%.

In this paper, the proposed method is adopted to find the positions of IC pins by using discrete wavelet transform (DWT), Fourier transform and signal correlation. The inspection performance of full template matching, coarse-to-fine method and DWT are investigated in comparison with the performance of the proposed technique.

TEMPLATE MATCHING TECHNIQUES

Template matching is a method applied to search the most similar object in the image. In this paper, template matching techniques, that is, full template matching, coarse-to-fine, discrete wavelet transform, and chain-code discrete Fourier transform are illustrated.

Full template matching

Full template matching is a well known technique to find the position of interesting object in an image. This technique uses a matching algorithm to determine the similarity degree based on the different intensity of the corresponding pixels between input image and template image. The mean square error (*MSE*) shown in (1) is adopted for evaluating the similarity of images.

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

where $T(x,y)$ is the intensity value of the original image at pixel *x, y*; $I(x,y)$ is the intensity value at pixel *x, y* of the input image. *MSE* is the value that can be used to determine the similarity of the two images; the values *M, N* are the width and height of the template image, respectively.

Coarse-to-fine method

Coarse-to-fine method is a pattern recognition technique which can reduce the processing time. The resolution of the input image is reduced by resizing the image. Low resolution image is used for searching the matching position of interesting object for decreasing the processing time and then high resolution image is adopted to find the accurate matching area.

Discrete wavelet transform

Discrete wavelet transform (Wahler and Shih, 1989) is a technique which can be used to compress the image data; this technique gains more attention from many researchers because of its high compression ratio with low computation time and high memory efficiency. As shown in previous research works, the discrete Haar wavelet transformation is widely used for image compression due to its simplicity and high speed. This technique consists of the computation of mean values and different values in both directions (horizontal and vertical directions). The following equations describe the computation of wavelet transform.

$$s_{i,j}^{h} = \frac{a_{2i-1,j} + a_{2i,j}}{2} \quad , i = 1, ..., \frac{M}{2}, \; j = 1, ..., N \tag{2}$$

$$d_{i,j}^{h} = \frac{a_{2i-1,j} - a_{2i,j}}{2} \quad , i = 1, ..., \frac{M}{2}, \; j = 1, ..., N \tag{3}$$

where $s_{i,j}^{h}$ and $d_{i,j}^{h}$ are the mean and different values at coordinate *i, j* in the horizontal direction, respectively. *M* and *N* are the width and height of the size of original image. A new image calculated from the wavelet transform can be achieved as shown in the following equation.

$$I_{new} = \begin{bmatrix} B_{UL} & B_{UR} \\ B_{ULL} & B_{LR} \end{bmatrix} \tag{4}$$

where the parameters $b_{i,j}^{UL} \subset B_{UL}$, $b_{i,j}^{UR} \subset B_{UR}$, $b_{i,j}^{LL} \subset B_{ULL}$ and $b_{i,j}^{LR} \subset B_{LR}$ are obtained by

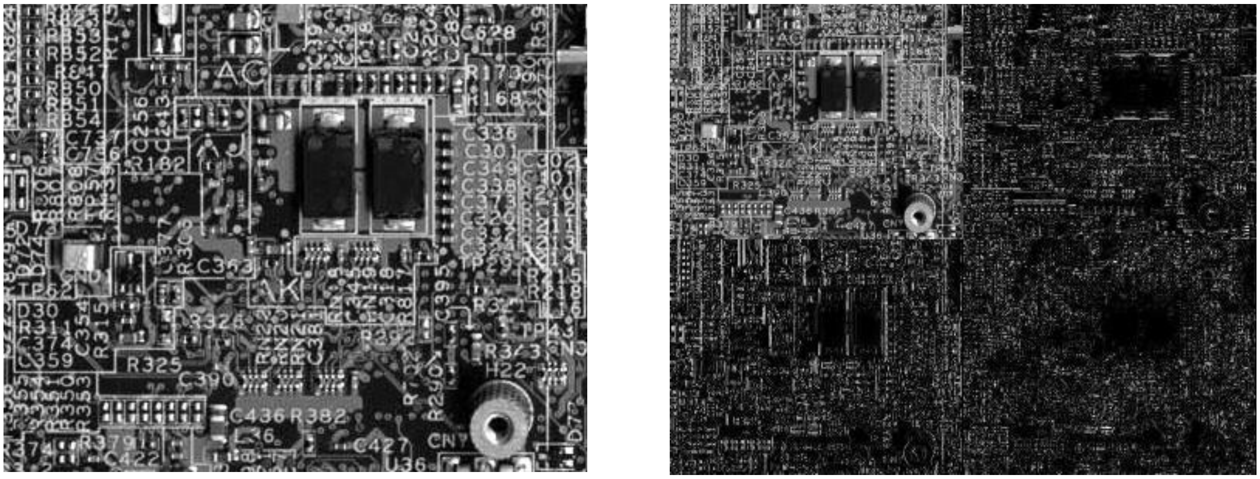
$$b_{i,j}^{UL} = \frac{s_{2i-1,j} + s_{2i,j}}{2} \quad , i = 1, ..., \frac{M}{2}, \; j = 1, ..., \frac{N}{2} \tag{5}$$

$$b_{i,j}^{UR} = \frac{d_{2i-1,j} + d_{2i,j}}{2} \quad , i = 1, ..., \frac{M}{2}, \; j = 1, ..., \frac{N}{2} \tag{6}$$

$$b_{i,j}^{LL} = \frac{s_{2i-1,j} - s_{2i,j}}{2} \quad , i = 1, ..., \frac{M}{2}, \; j = 1, ..., \frac{N}{2} \tag{7}$$

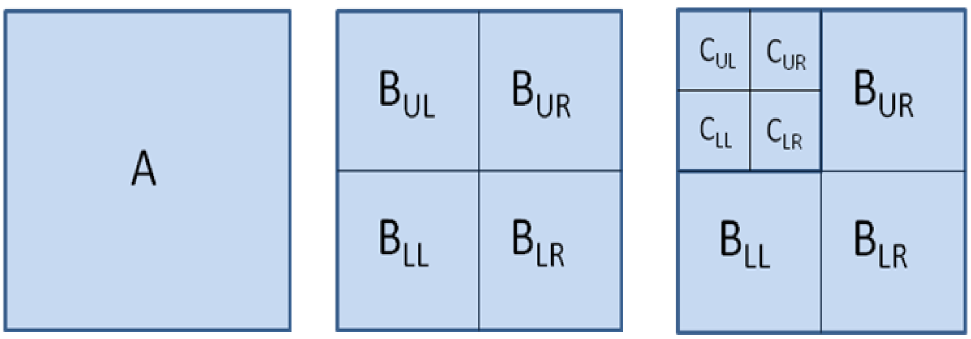
$$b_{i,j}^{LR} = \frac{d_{2i-1,j} - d_{2i,j}}{2} \quad , i = 1, ..., \frac{M}{2}, \; j = 1, ..., \frac{N}{2}. \tag{8}$$

In the wavelet transform, there is the specification of the order needed for the transformation. In the first order transform, the original image is divided to four sub-images. Thus, each image has a size equal to $\frac{MxN}{4}$ pixels. The upper left image, B_{UL}, is obtained from the vertical and horizontal averaging; the lower left



(a) Original image **(b) 1st transform**

Figure 1. 1st order wavelet transform.



(a) original image **(b) 1st order wavelet transform** **(c) 2rd order wavelet transform**

Figure 2. 2rd order wavelet transform.

image B_{LL} is obtained from the vertical difference and the horizontal averaging. The lower right image, B_{LR}, is obtained from the vertical and the horizontal difference; the upper right image B_{UR} is obtained from the vertical averaging and the horizontal difference. An example of transformed images of 1st and 2rd order wavelet transforms are shown in Figures 1 and 2, respectively.

Cross correlation

Cross correlation technique is a well known technique which can be applied for finding the most matching position in the template matching. The following equations are used to describe this approach:

$$d^2(u,v)=\sum_{x,y}\left[f(x,y)-t(x-u,y-v)\right]^2 \quad (9)$$

where $f(x,y)$ is the intensity value of the input image at the coordinate *x, y*. $t(x,y)$ is the intensity value of the input image at the coordinate *x, y*. By extending the formula, Equation (9) can be rewritten as:

$$d^2(u,v)=\sum_{x,y}\left[f^2(x,y)-2f(x,y)t(x-u,y-v)+t(x-u,y-v)^2\right] \quad (10)$$

Since the term $t(x-u,y-v)^2$ is a constant and $f^2(x,y)$ is approximately a constant; thus, the remained term of cross correlation can be written as:

$$c(u,v)=\sum_{x,y}\left[f(x,y)t(x-u,y-v)\right] \quad (11)$$

Equation (11) can be adopted to compute the similarity degree

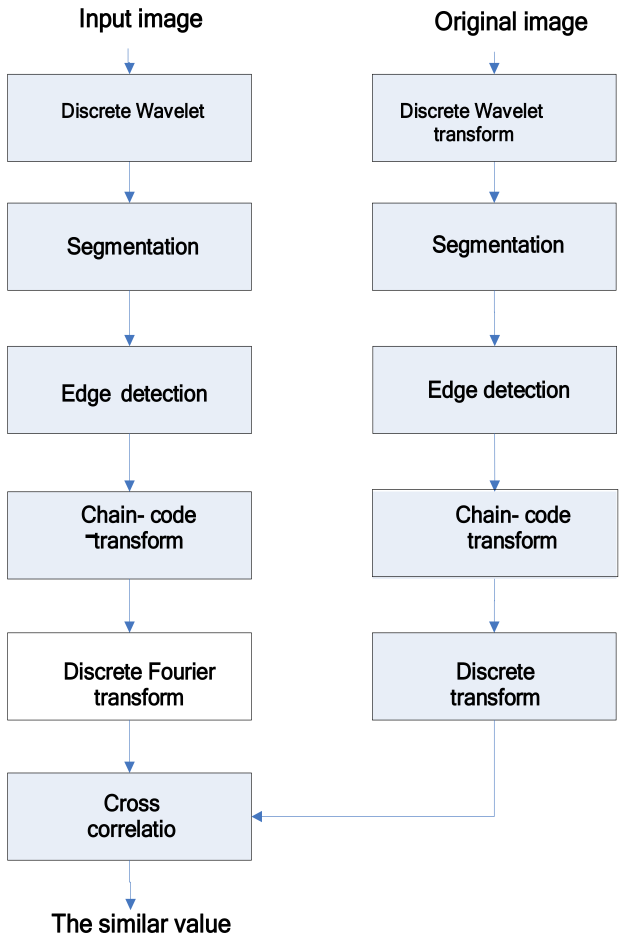


Figure 3. Diagram of the proposed method.

between two images; however, this equation is not feasible when the brightness of image has been changed. To reduce this problem, normalizing technique is used to adjust the coefficient before cross-correlation.

$$\gamma(u,v)=\frac{\sum_{x,y}\left[f(x,y)-\bar{f}_{u,v}\right]\left[t(x-u,y-v)-\bar{t}\right]}{\sqrt{\sum_{x,y}\left[f(x,y)-\bar{f}_{u,v}\right]^2\sum_{x,y}\left[t(x-u,y-v)-\bar{t}\right]^2}} \qquad (12)$$

where $\bar{f}_{u,v}$ is obtained by the averaging of the mask window of image and $\bar{t}$ is obtained by averaging of the original image.

Transformation

Considering Equation (12), define $f'(x,y)=f(x,y)-\bar{f}_{u,v}$ and $t'(x,y)=t(x,y)-\bar{t}$, thus

$$g(u,v)=\sum_{x,y} f'(x,y)\,t'(x-u,y-v). \qquad (13)$$

Equation (13) is the convolution operation of the image. By transforming the original image to frequency domain, the computation of Fourier transform can be achieved as:

$$Conv=F^{-1}\{F(f')F^*(t')\} \qquad (14)$$

where F and F^* are the Fourier transform and reverse complex conjugate of the original image, respectively.

THE PROPOSED TECHNIQUE

In this paper, the proposed method combines all techniques for achieving a fast and high accuracy pattern recognition technique. Figure 3 describes the proposed technique. As seen in the figure, the original (template) and input images are converted to gray color; then applying the 1st order wavelet transform to compress both images. Next, convert the upper left image to binary image by using Otsu's method (Pratt, 2007). Next step, the edge detection technique, Sobel edge detection is applied. Then, the coordinate (x, y) of edge image is transformed by using chain-code:

$$Chain(n)=\begin{cases} if\ (P_{xn}-R_{xn},P_{yn}-R_{yn})=(0,1) & then\ 0\\ if\ (P_{xn}-R_{xn},P_{yn}-R_{yn})=(1,1) & then\ 1\\ if\ (P_{xn}-R_{xn},P_{yn}-R_{yn})=(1,0) & then\ 2\\ if\ (P_{xn}-R_{xn},P_{yn}-R_{yn})=(1,-1) & then\ 3\\ if\ (P_{xn}-R_{xn},P_{yn}-R_{yn})=(0,-1) & then\ 4\\ if\ (P_{xn}-R_{xn},P_{yn}-R_{yn})=(-1,-1) & then\ 5\\ if\ (P_{xn}-R_{xn},P_{yn}-R_{yn})=(-1,0) & then\ 6\\ if\ (P_{xn}-R_{xn},P_{yn}-R_{yn})=(-1,1) & then\ 7. \end{cases} \qquad (15)$$

where the P_x, P_y are the pair values of coordinate x, y, R_x and R_y are the neighborhood pixel values which has edge . $Chain(n)$ is the number of constants from 0 to 7 and n is number on the edge line as shown in Figure 4.

The following equation is used to convert the chain-code signal to discrete Fourier transform:

$$F(u)=\sum_{n=1}^{N} Chain(n)\times\exp\left(\frac{-2\pi i}{N}u_n\right)\ ,u=1,...,N. \qquad (16)$$

After the converting process, the normalization cross-correlation is adopted to find the coefficient of the most matched position:

$$\gamma_{best}=\max(\gamma(F(f(x,y)),F(t(x,y)))) \qquad (17)$$

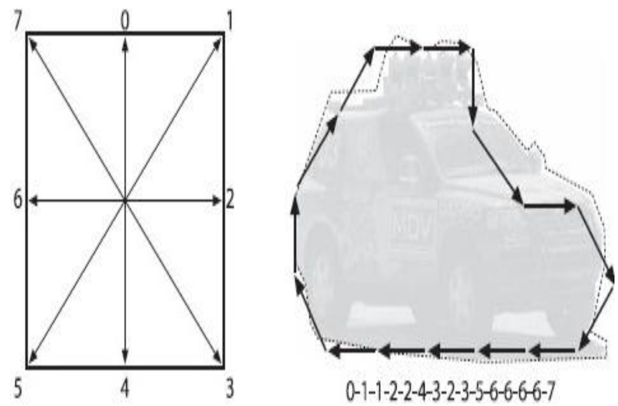


Figure 4. Example the chain-code.

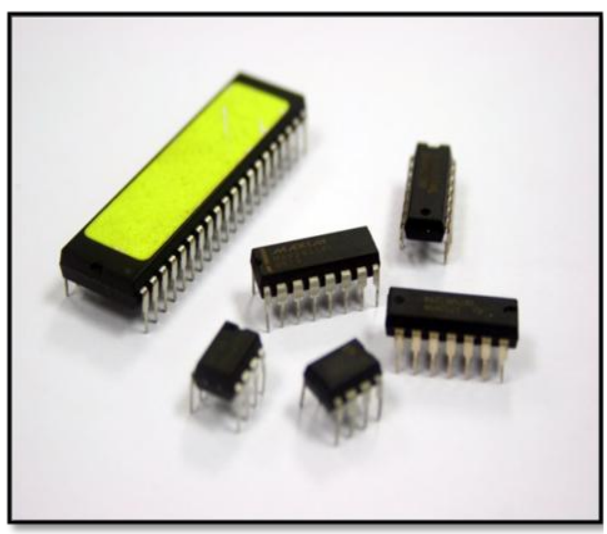


Figure 5. Types of IC.

where $F(f(x,y)$, $F(t(x,y))$ are the Fourier transform components of the original and input images, respectively. γ_{best} is best matching value which is a real number between the interval 0 to 1. If the value γ_{best} is 1, then two images are exactly matched. However, in this research, the minimum value of cross-correlation that specified for the object is assigned as the following.

$$Test\,image = \begin{cases} \gamma_{best} \geq 0.8 & \gamma_{best}\ \ is\ IC\ \ pin. \\ \gamma_{best} < 0.8 & \gamma_{best}\ isn't\ IC\ \ pin \end{cases} \quad (18)$$

EXPERIMENTAL RESULTS

In this paper, the proposed method is implemented on the Borland C program language and MATLAB, and is examined on the desktop PC with Pentium 4, 1.73 GHz, 2 Gb Ram. Two types of ICs with 40 pins and 16 pins are tested in the proposed system. In addition, the images with rotation of 0, 3, 5 and 10 degrees are adopted for testing the rotation invariance of the proposed and conventional techniques.

Figure 5 shows several examples of ICs. In this study, sizes of testing images are 1528 × 378 pixels and 711 × 378 pixels for 40 and 16 pin ICs, respectively. The examples of the resulting images from the proposed method are shown in Figure 6.

In this paper, experiments were performed by using 10 test images. The results of experiments are shown in Tables 1 and 2.

As seen in Table 1, the proposed technique provides the best matching compared to the others. The conclusion of results of the accuracy of inspection of the proposed technique is strongly concerned by the statistical data in Table 1. Table 2 shows the average time used for recognition process of each method.

As shown in Table 2, the computational time for analyzing the images from the proposed technique is faster than that of the conventional template matching and the chain code matching methods. Although the coarse-to-fine and DWT methods have faster inspection time than the proposed technique, the accuracy of inspection of these methods is much deteriorated when the images were rotated. The results of cross correlation values versus positions plotted in 3-D when inspecting ICs with 40 and 16 pins are shown in Figure 7.

Conclusions

The proposed method applies the wavelet transform with chain-code, discrete Fourier transform and signal correlation for IC pins inspection. The results show that the correlation result of the proposed technique is similar to that of the chain code and DWT methods, and is much better than the full template matching and cross-to-fine methods when the rotated images were applied. As shown in the results of computational time, the computational time of the proposed technique is significantly less than the other methods. In conclusion, the proposed method can be properly applied to the automatic visual inspection system in which fast and accurate inspections are extremely required. Also, this technique can also be applied to the 'on the fly' vision system.

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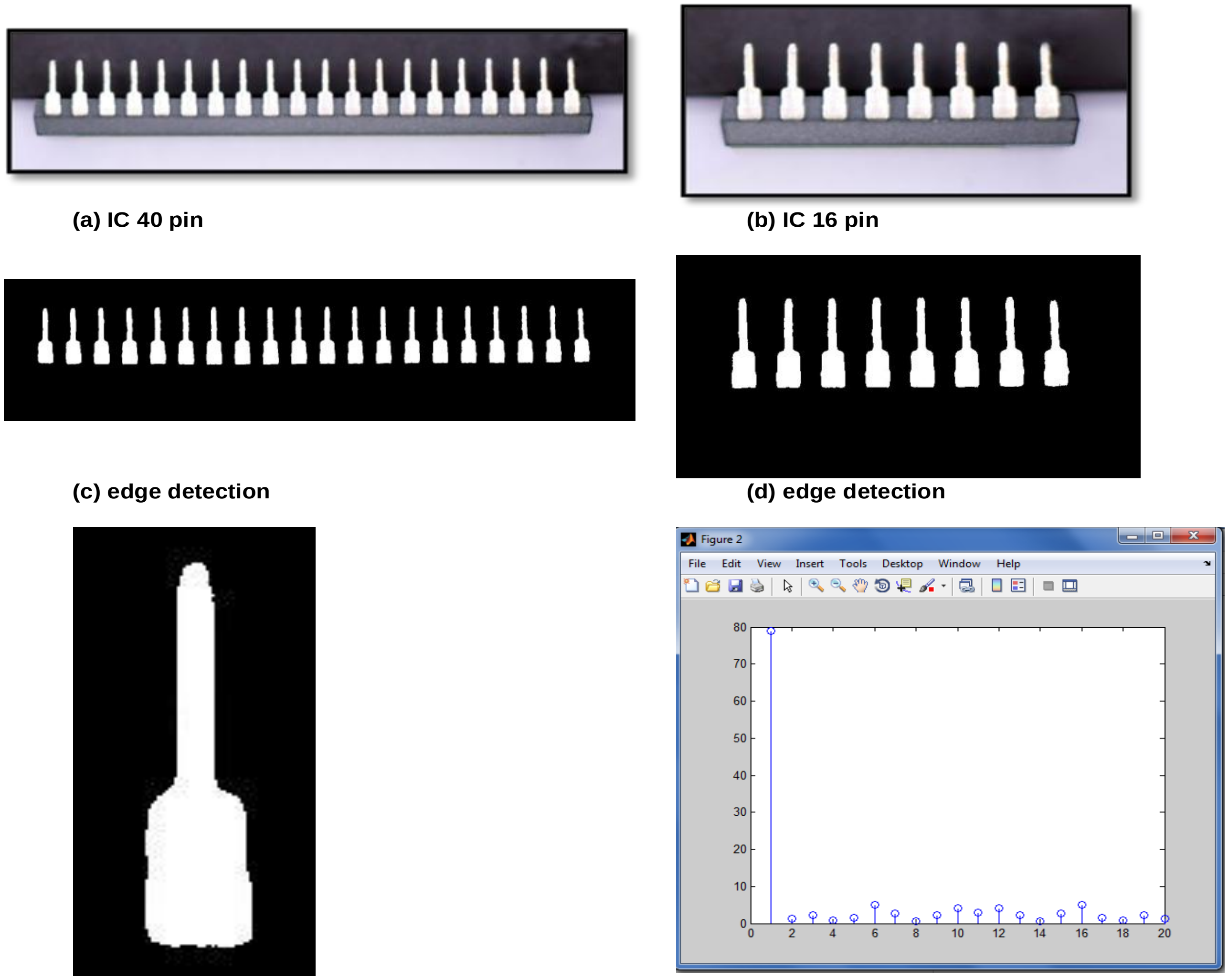


(a) IC 40 pin (b) IC 16 pin

(c) edge detection (d) edge detection

(e) template image (f) Spectral of template image

Figure 6. Examples of the testing images and results.

Table 1. Comparison of maximum cross-correlation of method by using 40 images (each image is single pin image).

Parameter	Statistical values	Full template matching	Coarse to fine matching	Wavelet matching	Chain-code matching	Proposed method
Images with 0 degree rotation	Average	0.9671	0.9664	0.9666	0.9985	0.9991
	Standard deviation	0.0205	0.0178	0.0177	0.0007	0.0003
	Max	0.9999	0.9932	0.9933	0.9999	0.9999
	Min	0.9173	0.9202	0.9210	0.9964	0.9982
Images with 3 degrees rotation	Average	0.8969	0.9000	0.8999	0.9977	0.9991
	Standard deviation	0.0330	0.0329	0.0326	0.0007	0.0003
	Max	0.9356	0.9377	0.9374	0.9989	0.9997
	Min	0.8313	0.8326	0.8332	0.9960	0.9982
Images with 5 degrees rotation	Average	0.8320	0.8346	0.8350	0.9976	0.9986
	Standard deviation	0.0349	0.0346	0.0343	0.0008	0.0004
	Max	0.8816	0.8869	0.8867	0.9990	0.9996
	Min	0.7687	0.7721	0.7730	0.9957	0.9977

Table 2. Computational time of all techniques.

Matching method	Processing time per 1 pin inspection (s)
Full template matching	0.056
Coarse-to-fine	0.024
Discrete wavelet transform	0.026
Chain-code matching	0.058
The proposed method	0.042

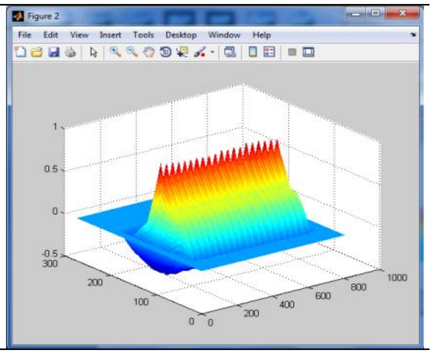
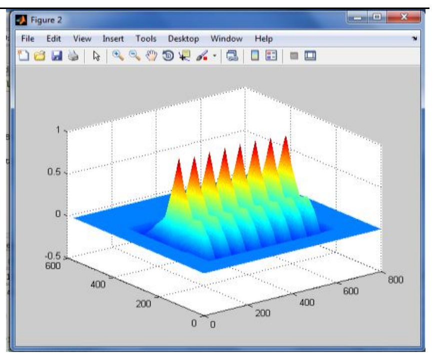
Inspection types	Correlation factors
IC with 40 pins	
IC with 16 pins	

Figure 7. Correlation values versus positions of the proposed algorithm.

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