IC Printed Mark Quality Inspection Algorithms

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Abstract

This paper presents a new effective method for IC printed mark quality inspection. The printed mark includes a logo pattern and characters. Due to the alignment error of the inspection machine, the mark can be rotated or translated. Main printing error of an IC mark includes: distortion, missing ink, wrong position, double print, smear print, bad contrast (global or partial character), misprint, and mis-orientation print as shown in Figure 1. We propose a method to inspect IC printed marks and implement it on an IC inspection machine. To develop the inspection algorithm, binary and grayscale digital image processing and computer vision techniques including projection, normalized cross correlation, and mathematical morphology are used.

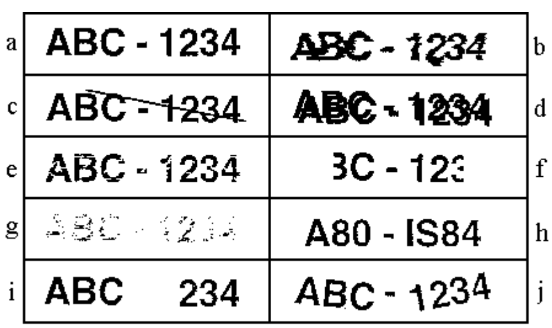

Figure 1: Main IC printed mark errors: (a) good, (b) smeared, (c) scraped, (d) double print, (e) broken, (f) missing ink, (g) bad contrast, (h) misprinted, (i) partial bad contrast, and (j) mis-orientation.

1 Introduction

Integrated Circuits (IC) are the fundamentals of computer and electronic industry. IC industry is also the important topic and weapon to enhance our industry and to compete in worldwide market. IC industry includes wafer fabrication process in the front end and chip packaging in the back end. IC printed marking is the final stage of chip packaging to print product number and trade mark on the chip to identify product function and classification. IC printed mark is the first and most prominent part a user sees. The user usually associates IC printed mark quality with chip function and quality. In the endless pursuit of quality perfection, enhancing IC printed mark quality is of utmost importance.

IC chips are mass produced. Traditional inspection is manual and relies on eyes. In industrialized countries, labor is expensive and inspection is monotonous, laborious, fatiguing, and prone to mistakes. Employees are unwilling and it is impossible to do IC printed mark quality control or inspection manually with eyes. Automatic IC printed mark quality inspection with computer vision is a natural and unstoppable trend.

In this paper, we present a new effective method to inspect the IC printed marks. Digital image processing and computer vision techniques including projection, normalized cross correlation, and mathematical morphology are used to develop the inspection algorithm. The inspection process includes teaching and inspection.

Before inspection, human should do teaching and find a golden image of a perfect IC. The system will perform character segmentation and feature extraction during teaching, and then perform inspection based on the taught data.

For nonrotated IC or IC with small rotation angle ($\pm 2°$), projection is used to do character segmentation. To deal with larger rotation angle ($\pm 15°$), we will use normalized cross correlation to match characters to find the rotation angle of the test IC and rotate back the IC image. After using correlation to search and find two *fiducial marks*, we can compute the rotation angle and solve the IC rotation problem.

We use projection to do location matching and use pattern difference to do inspection. Due to the alignment error, segmentation error, and some inevitable noises of CCD camera and frame grabber, some edge noise will remain after pattern difference. We will do defect enhancement after pattern subtraction and do edge noise removal via grayscale morphological opening. The last step is to compute the defect detected and make decision to accept or reject this part.

Grayscale image is used throughout the inspection process, so appropriate threshold values are important and greatly affect the inspection performance. These system parameters are related to the environment, the defect expected to be detected, the criterion of inspection, and the accuracy of alignment of ICs. The environment factors include the light source, the IC surface texture and reflection, and the contrast of IC printed marks.

After inspection the IC will be classified into accepted part or rejected part. Reliability, repeatability, false alarm rate, and mis-detection rate will be used to justify and adjust the algorithm and parameters. The inspection time is critical and influences industrial implementation. Our proposed method uses modified correlation to save inspection time and preserve the accuracy. The modified correlation is hierarchical (pyramid) structure including coarse searching and fine searching.

This paper is organized as follows. Section 2 describes the theoretical background knowledge about projection, normalized cross correlation, and mathematical morphology. Section 3 explains the pyramid structure of the modified correlation we used. Section 4 gives a complete explanation to the teaching and inspection process, including discussion about the threshold parameters of the system. Section 5 shows some experimental results. Section 6 gives some conclusions.

2 Theoretical Background

2.1 Projection

Projection can be used to do segmentation and matching especially for segmenting blocks where bounding boxes separate from each other. Projection can be horizontal, vertical, or at any direction.
horizontal projection:

$$P_H(r) = \#\{c|(r,c) \in R\}$$

vertical projection:

$$P_V(c) = \#\{r|(r,c) \in R\}$$

2.2 Normalized Cross Correlation

Normalized cross correlation is used to match picture, i.e. match a pattern to another image and return the best matching position. The correlation coefficient $\mathbf{r}(u,v)$ is scaled in the range -1 to 1, independent of image translation and linear shifting and scaling of image gray level. The correlation coefficient is defined as follows:

$$\mathbf{r}(u,v) = \frac{\sum_{i=0}^{m}\sum_{j=0}^{n}\left[\mathbf{I}(i+u,j+v)-\bar{\mathbf{I}}\right]\left[\mathbf{M}(i,j)-\bar{\mathbf{M}}\right]}{\sqrt{\sum_{i=0}^{m}\sum_{j=0}^{n}\left[\mathbf{I}(i+u,j+v)-\bar{\mathbf{I}}\right]^2\sum_{i=0}^{m}\sum_{j=0}^{n}\left[\mathbf{M}(i,j)-\bar{\mathbf{M}}\right]^2}}$$

Position (u_{max}, v_{max}) is the best matching position, if $\mathbf{r}(u_{max}, v_{max}) \geq \mathbf{r}(u,v), \forall u, v$. Region $\{\mathbf{I}(i+u, j+v)|0 \leq i \leq m, 0 \leq j \leq n\}$ is a subimage of $\mathbf{I}$ best matching image $\mathbf{M}_{m\times n}$. Coefficient $\mathbf{r} = 1$ means a perfect matching.

2.3 Mathematical Morphology

Mathematical morphology works on shape, and can be used to simplify image data, preserve shape, and eliminate outlier noise. Mathematical morphology includes four main operations: dilation, erosion, opening, and closing.
binary dilation of A by B: $A \oplus B$

$$A \oplus B = \{c \in E^N | c = a + b \text{ for some } a \in A \text{ and } b \in B\}$$

binary erosion of A by B: $A \ominus B$

$$A \ominus B = \{x \in E^N | x + b \in A \text{ for every } b \in B\}$$

binary opening of A by B: $A \circ B$

$$A \circ B = (A \ominus B) \oplus B$$

binary closing of A by B: $A \bullet B$

$$A \bullet B = (A \oplus B) \ominus B$$

The second set B is referred to as the structuring element or the kernel as shown in Figure 2. Grayscale morphology is similar to the binary morphology, but extends the binary value to grayscale value. First define two dual functions: top and umbra:

- top surface of A: denoted by $T[A] : F \rightarrow E$:

$$T[A](x) = \max\{y|(x,y) \in A\}$$

- umbra of f: denoted by $U[f] : U[f] \subseteq F \times E$

$$U[f] = \{(x,y) \in F \times E | y \leq f(x)\}$$

Then grayscale morphology can be defined as the following:
gray-scale dilation of A by B: $A \oplus B$

$$A \oplus B = T\{U[A] \oplus U[B]\}$$

gray-scale erosion of A by B: $A \ominus B$

$$A \ominus B = T\{U[A] \ominus U[B]\}$$

gray-scale opening of A by B: $A \circ B$

$$A \circ B = (A \ominus B) \oplus B$$

gray-scale closing of A by B: $A \bullet B$

$$A \bullet B = (A \oplus B) \ominus B$$

Morphological opening with disk kernel can eliminate sharp edge noise and preserve main shape of the image. So it will be used to do noise removal after pattern difference during inspection. It can make the inspection algorithm robust to character alignment and segmentation error of $1 \sim 2$ pixels.

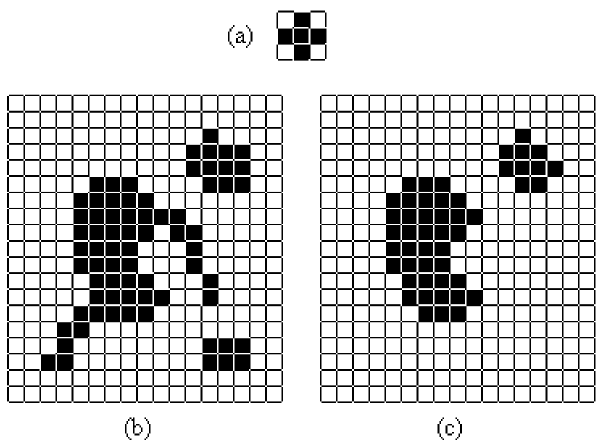

Figure 2: Morphological opening and kernel. (a) the kernel. (b) image before opening. (c) image after opening.

3 Use Modified Correlation to Detect IC Rotation

3.1 The Modified Correlation

The complexity of normalized cross correlation is $O(n^4)$, i.e. computing the correlation of one $m \times n$ image and another $M \times N$ image needs time about $m \times n \times M \times N$. In order to keep inspection fast, we must speed-up the correlation speed and keep the accuracy and reliability. The improved modified correlation is two level hierarchical, pyramid structure, coarse-to-fine approach as shown in Figure 3. The coarse search down-samples the original image and finds some possible candidate positions in a step manner, and the fine search searches finely near the candidate positions to get the best matching.

For speed, the modified correlation bypasses the variance normalization step, so the output correlation value is an integer, instead of from -1 to 1. But we do not bypass the average gray level subtraction, because we assume that the lighting environment might change, and the average gray level between taught data and test IC is different.

The coarse search speeds-up the correlation computation by two parameters: *the outer step size* and *the inner step size*. The outer step size is the step of each correlation location, and the inner step size is the sub-sampling rate. The modified coarse search uses outer step size of 4 pixels and inner step size of 2 pixels horizontally and vertically, so the coarse search will be $4^2 \times 2^2 = 64$ times faster than the original correlation. The modified fine search uses step size of 1 pixel horizontally and vertically but without normalization.

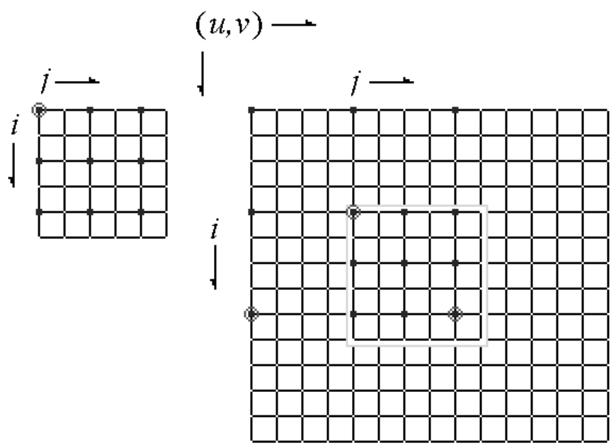

Figure 3: Two level pyramid structure modified correlation.

3.2 Two Fiducial Marks to Detect IC Rotation

We can use two fiducial marks to detect IC rotation as shown in Figure 4. Fiducial marks are two characters or logos assigned by user during teaching. By searching fiducial marks in some bounded area, we can locate the test IC and compare the slope angle to the taught data, and then the rotation angle can be found. Choosing good fiducial marks is important and related to correlation performance. Selecting good fiducial marks can decrease inspection false alarm and increase inspection speed. The selection criteria are as the following:

- choose the globally or locally distinct fiducial marks, avoiding the ambiguity problem.
- choose the smaller fiducial marks when possible to reduce the processing time.
- choose the farthest fiducial marks when possible to preserve more precise information for slope angle.

After detecting the rotation angle, we can rotate back the test IC image using rotation formula:

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}$$

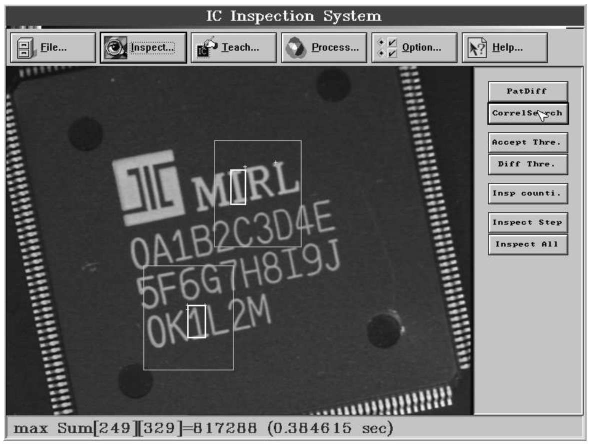

Figure 4: Use two fiducial marks to detect IC rotation.

4 The Teaching and Inspection Process

4.1 Teaching

The main purpose of teaching is to find the golden image by help of human intelligence. We perform feature extraction on the golden image and extract information needed for inspection. Figure 5 shows the teaching process. The golden image can be from image file or frame grabber. Teaching contains two main parts:

- indicate the inspection range, input the proper binarizing threshold to do character segmentation.
- select two fiducial marks.

After indicating the inspection range, horizontal projection is performed to get each *block* of characters or logos, followed by vertical projection which is performed on each block to get each *sub-feature* (character or logo). Small outlier noises will be discarded at this step. Sub-feature is the basic unit of pattern difference. After segmentation of each sub-features, the width, height, location, centroid, and number of pixels of each one will be recorded and it can be saved to a teaching file.

The operator can check the results of teaching at this time. If the marks can not be segmented perfectly or have broken edge, user can adjust the binarizing threshold or segment the marks manually. Environmental factors about lighting, aperture and focus of CCD camera, and IC alignment is also important factor to teaching.

After correctly segmenting all the sub-features, two fiducial marks will be chosen according to the previous rules. The operator can save taught data to file or start inspection after teaching.

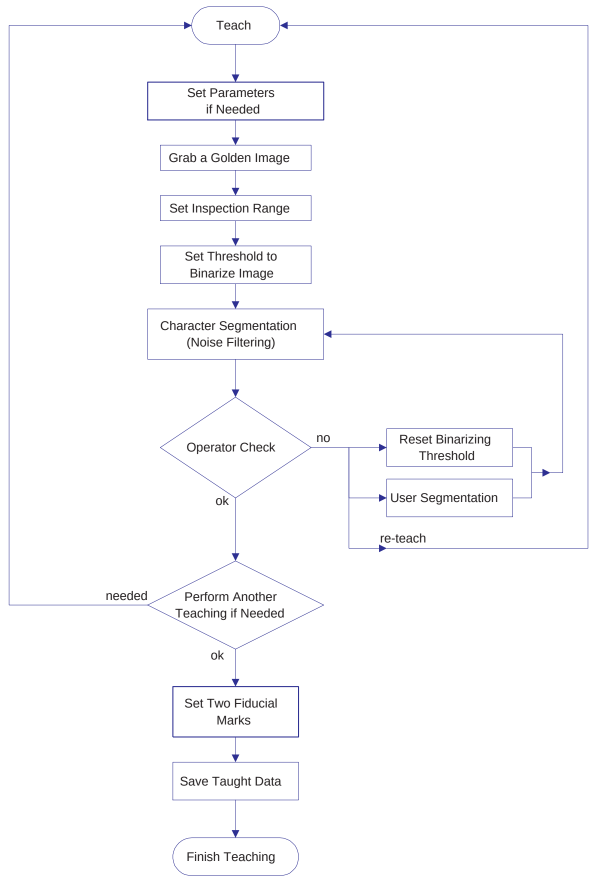

Figure 5: The teaching process.

4.2 Inspection

The inspection process was shown in Figure 6. Before inspection, the taught data is checked first. We use the *binarizing threshold* to binarize the test image, segment the printed mark, and match the blocks. If the block matches well, we bypass the searching and rotating step and perform inspection directly. If the block does not match well, the test IC might have some rotation or translation, and we should search two fiducial marks and rotate back the IC image as shown in Figures 4 and 10.

We do block matching and sub-feature number matching first as shown in Figure 12. If both steps match well, we will perform pattern difference on each sub-feature. Figure 7 shows the matching process in detail. The test IC printed mark may overlap or disappear due to the bad contrast, so the number of sub-features of the test IC may not equal to the taught data. To solve this problem, for each block, we check the width of projection of the leftmost sub-feature. Once the leftmost sub-feature has been matched, we can locate each other sub-feature by the taught data.

If the block number and the sub-feature number are checked, we should perform pattern difference to inspect each sub-feature on the next step. Due to the alignment error and segmentation error, some edge noise will remain after pattern difference. Because the average gray level of the area under subtraction is lower than the IC background, we should do enhancement on this region. The enhancement is as follows: if the pixel value of the subtraction region is greater than the *difference image threshold*, then it is set to be 255, otherwise it is set to be 0. After the enhancement, we can perform grayscale morphological opening to eliminate the edge noise as shown in Figures 9 to 11.

By analyzing of the defect image after opening, we can detect many types of defective printed marks. We count the defect pixel of each sub-feature first: if the pixel value after opening is larger than the *defect threshold*, than it is a defect pixel, otherwise it is not a defect pixel. We compute the ratio of defect pixels over the white pixels (after binarization) of each sub-feature. If the ratio exceeds the *accept threshold*, the printed mark of this sub-feature is defective and should be rejected by our method. If all the ratio of each sub-feature is lower than the accept threshold, the test IC is thought to be a good part and we should accept this IC.

We can count the defect pixel of the background to check the IC background: if the defect pixel exceeds the *background defect threshold*, we should reject this part.

All the values of the thresholds should be set very carefully, and they affect the inspection performance very much. Proper threshold values can increase the detection accuracy and decrease false alarm and misdetection. The threshold values are related to the environmental factors, the preferred accuracy of the inspection, and the types of defect we want to detect.

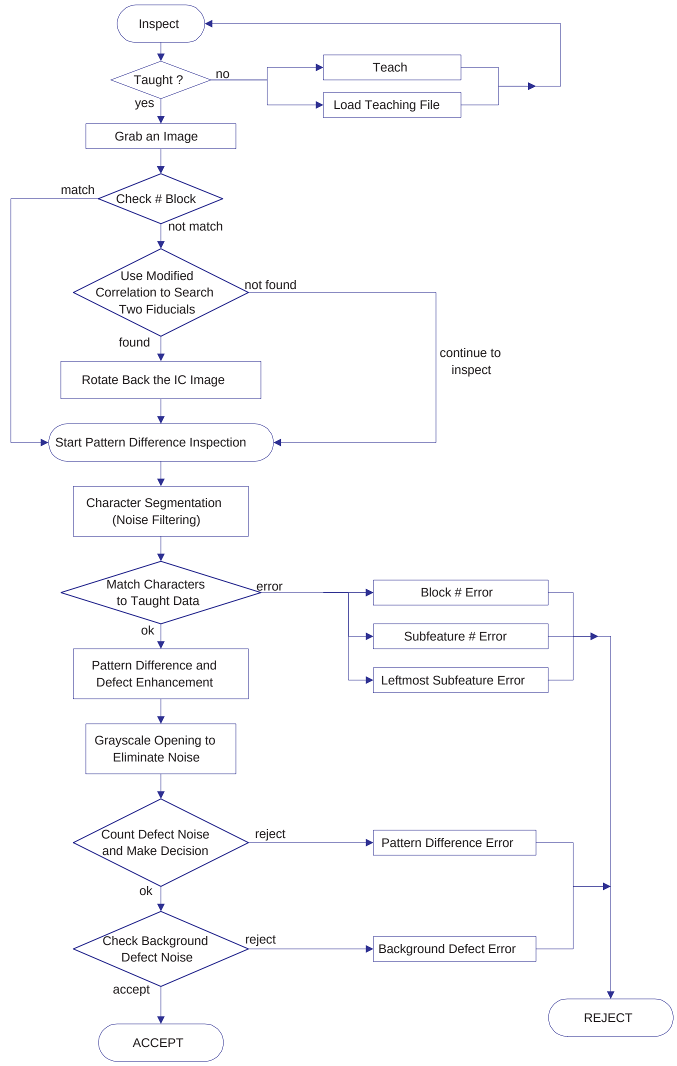

Figure 6: The inspection process.

5 Experimental Results

We show some experimental results of our research in Figures 8 to 12. Our system takes about 1.2 sec without rotation and 1.6 sec with rotation for each chip on Pentium-75 PC.

6 Conclusions

In this paper, we have proposed a new efficient method for IC printed mark quality inspection. The IC may be translated or rotated. We use digital image processing and computer vision techniques including projection, normalized correlation, pattern difference, and mathematical morphology to develop the inspection algorithm. We also use modified cor-

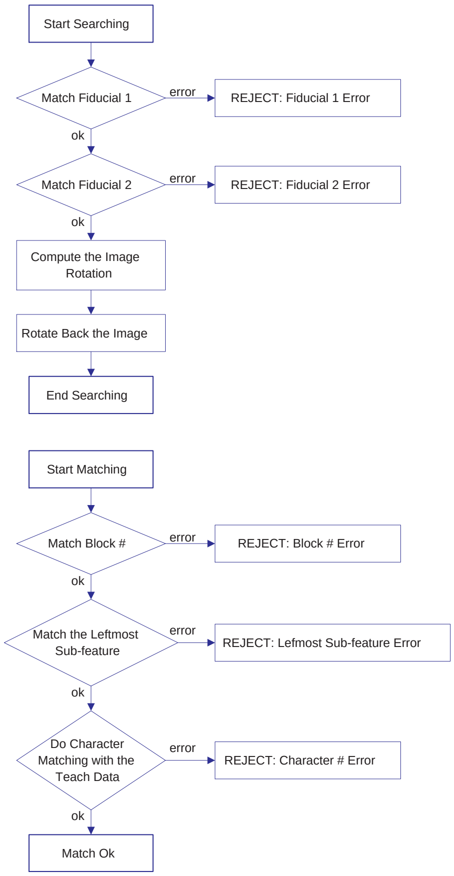

Figure 7: The matching process.

relation to solve the IC rotation problem.

As shown in the experimental results, our method achieves high accuracy and reliability with high speed for industrial requirement. We have successfully designed and implemented a system for automatic IC printed mark quality inspection.

Acknowledgements

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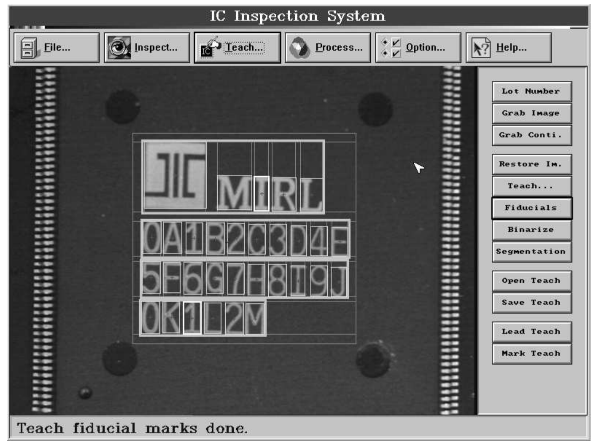

Figure 8: The IC printed mark quality inspection system.

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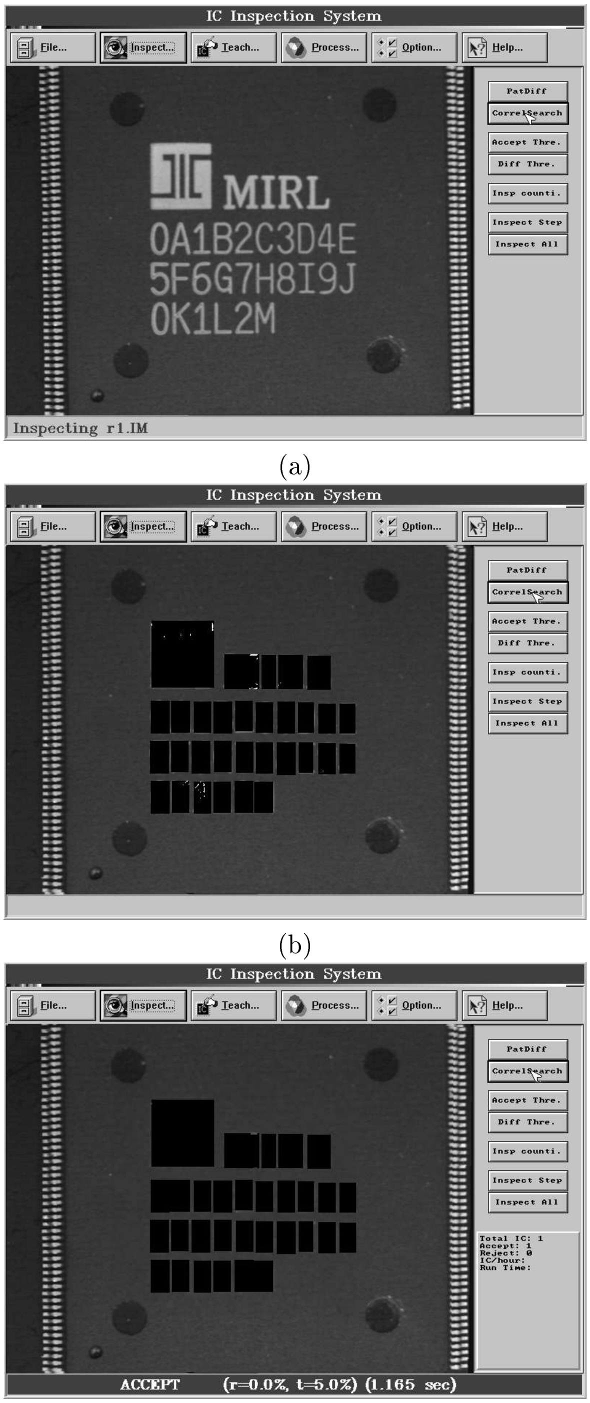
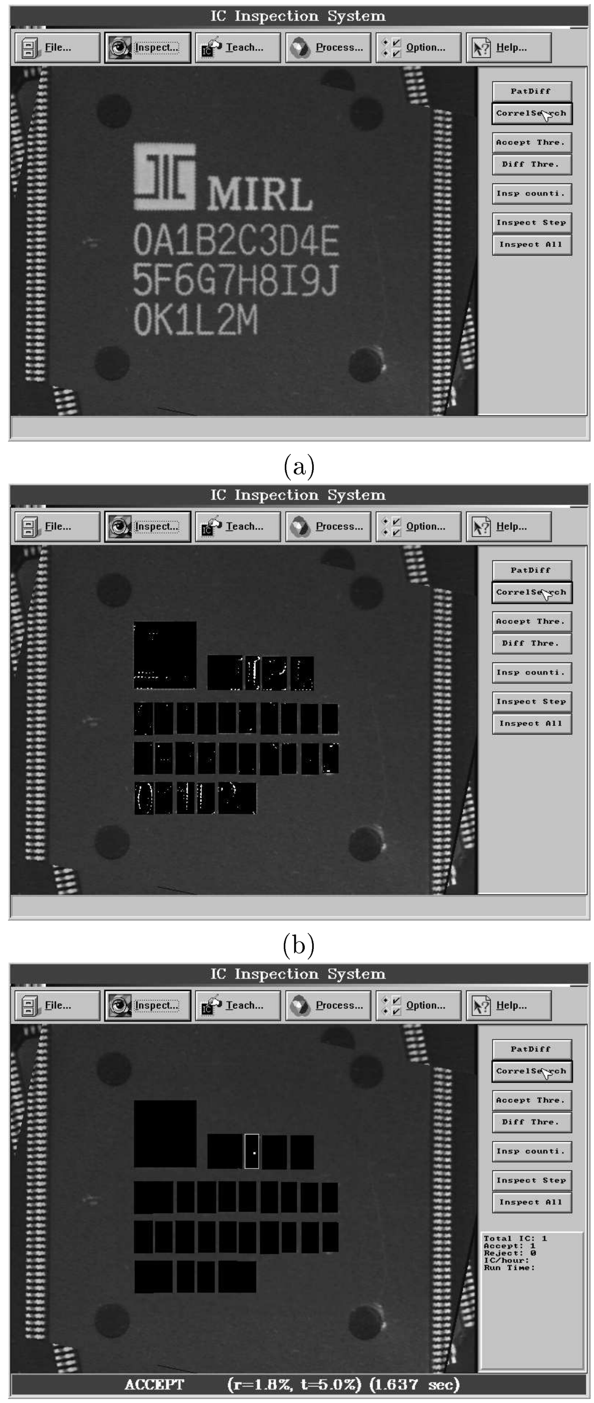


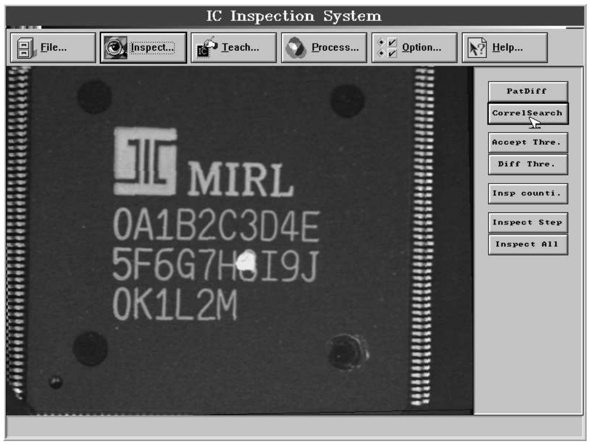
(a) (b) (c)

Figure 9: (a) Test IC with good printed mark. (b) Edge noise remains after pattern difference during inspection. (c) Grayscale opening eliminates all the edge noise.

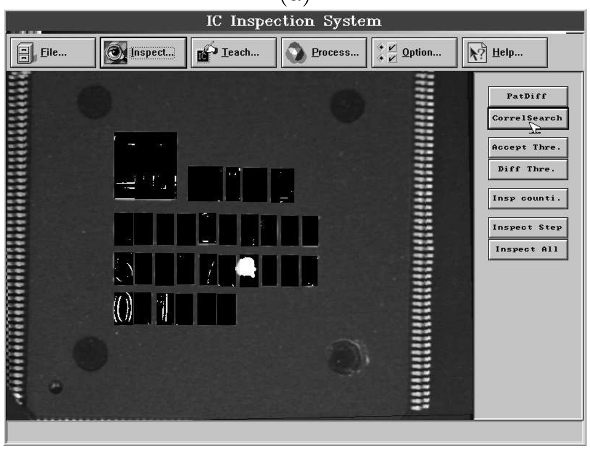


(a) (b) (c)

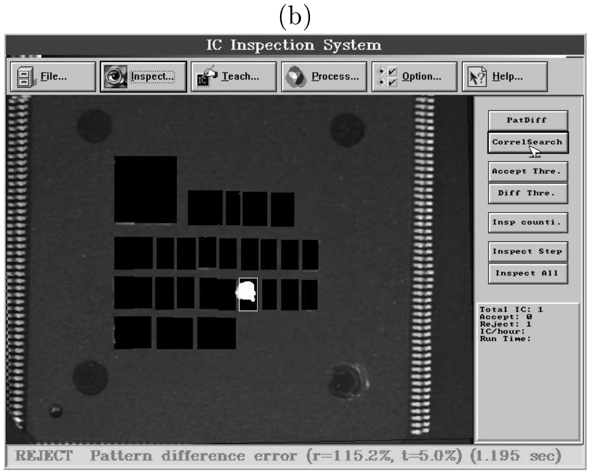
Figure 10: Refer to Figure 4, inspect IC with 10° rotation. (a) Rotate back the test IC image after detecting the rotation angle. (b) Some edge noise remains after pattern difference. (c) The inspection result.



(a)

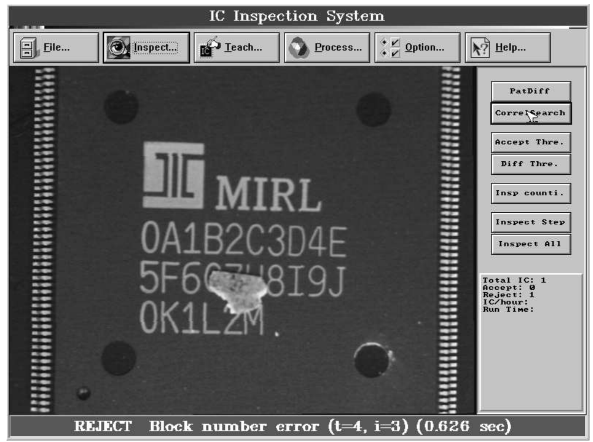


(b)

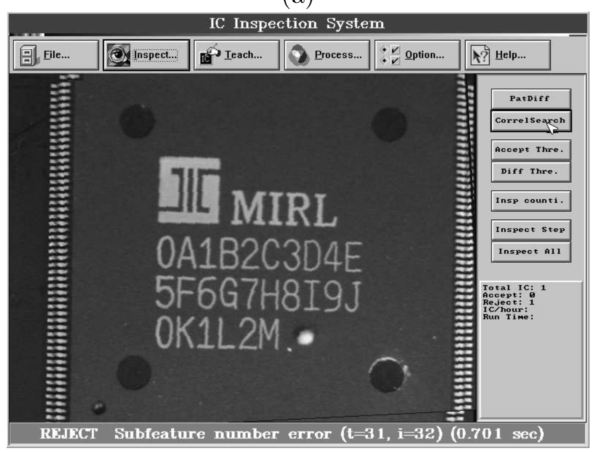


(c)

Figure 11: (a) Test IC with defective printed mark. (b) After pattern difference, the defect and the edge noise remain. (c) Grayscale opening eliminates the edge noise but preserves the defect for inspection.



(a)



(b)

Figure 12: (a) Large defect block causes block number error. (b) Isolated defect causes sub-feature number error.