MVA '96 IAPR Workshop on Machine Vision Applications, November. 12-14, 1996, Tokyo, Japan

Matching of IC patterns under Non-uniform Illumination

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Abstract

The use of hierarchical Chamfer Matching (CM) to match die patterns on VLSI wafers for the alignment of semiconductor chips is presented. This method can extract images with non-uniform lighting (without loss) for matching, and somehow it is invariant to some environment changes. Here, it is applied to align IC patterns under non-uniform lighting while the normalized correlation method fails. Experimental results are given.

I. Introduction

Normalized cross-correlation (CN) method [1] is commonly used to align IC die patterns in semiconductor industry. This method is useful in aligning two similar patterns, for example, to align memory-cell-patterns in an automatic wafer inspection system [2]. This method is effective because position error is rather small. However, it cannot be applied to more general cases with large position error because it requires a large amount of computational resources. This method performed well when the lighting varies uniformly on the image. However, it suffers a drawback when the image is illuminated with a non-uniform light source, which in effect occurs in a tilted die. This phenomenon causes a sudden drop of the correlation score.

Here, we suggest a remedial method. We use the hierarchical Chamfer Matching (CM) [3] to carry out the matching process whenever the normalized cross-correlation fails. It works because the edge extractor depends on the relative magnitude between neighbor pixels and hence it does not vary too much with the non-uniform lighting. This algorithm is not very complex since it can be achieved by using some simple arithmetic operations. It can prove that if the model of the non-uniform lighting follows some rules, the edge matching method is able to locate the desired image pattern.

The non-uniform lighting occurs in a tilted die and it will not happen if the die is well mounted on the leadframe. But it often happens in the die formation process. Slightly tilting of the die can cause defocusing seriously with a high magnification power camera. It will be presented in Section II. The failure of CN will be discussed on Section III. The detailed description of CM will be given on Section IV, where it states the assumptions and the limitations of CM. Finally, a computer simulation result will be given in Section V to compare the performance of CM and NC under non-uniform lighting.

II. The formation of non-uniform illumination

As state above, tilting often happens in the die formation process. The amount of glue between the die and the PCB determines the degree of die tilting. The tilting of an IC on a leadframe will produce different images as shown in Fig.1. Fig.2, shows a non-tilted IC where the spatial intensity does not have a gradual change.

In the case of a tilted die on leadframe, the light intensities of pixels depend on the degree of tilting of the IC. Some parts of the die can reflect more light to the camera while the other cannot. Fig. 3 shows the 1-D plot of the white line in Fig.1 and 2. Line labeled "nontilted" is the original 1-D image while "tilt4" and "tilt7" have suffered from different degrees of non-uniform lighting.

III. Normalized Cross Correlation (NC)

It is a well-known method to locate the position of a template inside a larger image (source image). The process first shifts the template image over the source image and then compares the correlation score. The place with the largest correlation coefficient will indicate that the template is most likely to occur in the source image. The correlation score is given as

$$S(u,v)=\frac{\sum_{j=1}^{J}\sum_{k=1}^{K}[f(j,k)-\overline{f}]\times[g(j-u,k-v)-\overline{g}]}{\sqrt{\sum_{j=1}^{J}\sum_{k=1}^{K}[f(j,k)-\overline{f}]^{2}\times\sum_{j=1}^{J}\sum_{k=1}^{K}[g(j-u,k-v)-\overline{g}]^{2}}} \quad (1)$$

where $f(j, k)$ and $g(j, k)$ are the template and source image with sizes $J \times K$ and $U \times V$ respectively. It is insensitive to images with different offsets, such as its average brightness. It is independent on the local properties of the source and template images. The score is equal to one if the corresponding offset pattern matches the template exactly, i.e. $g(j-u, k-v) = f(j, k)$ for particular u and v.

For convenience, Equ. 1 can be modified as a 1-D signal. That is,

$$S'(u)=\frac{\sum_{j=1}^{J}[f(j)-\overline{f}]\times[g(j-u)-\overline{g}]}{\sqrt{\sum_{j=1}^{J}[f(j)-\overline{f}]^{2}\times\sum_{j=1}^{J}[g(j-u)-\overline{g}]^{2}}} \quad (2)$$

Similarly, the matched pattern occurs when $f(j) = g(j - u)$ for particular $u = u_0$. Equ. 2 becomes

$$S'(u_0)=\frac{\sum_{j=1}^{J}[f(j)-\overline{f}]\times[f(j)-\overline{f}]}{\sqrt{\sum_{j=1}^{J}[f(j)-\overline{f}]^{2}\times\sum_{j=1}^{J}[f(j)-\overline{f}]^{2}}} \quad (3)$$

Assuming that the object is under the non-uniform lighting with a linear increment, it can be modeled as :

$$f'(j) = f(j) - n(j) \quad (4)$$

where $n(j) = mj + c$;

Then Equ. 3 becomes

$$\begin{aligned}S'(u_0)&=\frac{\sum_{j=1}^{J}[f(j)-\overline{f}]\times[f'(j)-\overline{f'}]}{\sqrt{\sum_{j=1}^{J}[f(j)-\overline{f}]^{2}\times\sum_{j=1}^{J}[f'(j)-\overline{f'}]^{2}}}\\&=\frac{\sum_{j=1}^{J}[f(j)-\overline{f}]\times[f(j)-\overline{f}-n(j)+\overline{n}]}{\sqrt{\sum_{j=1}^{J}[f(j)-\overline{f}]^{2}\times\sum_{j=1}^{J}[f(j)-\overline{f}-n(j)+\overline{n}]^{2}}}\\&=\frac{\sum_{j=1}^{J}[f(j)-\overline{f}]\times[f(j)-\overline{f}-mj+m\overline{j}]}{\sqrt{\sum_{j=1}^{J}[f(j)-\overline{f}]^{2}\times\sum_{j=1}^{J}[f(j)-\overline{f}-mj+m\overline{j}]^{2}}}\end{aligned} \quad (5)$$

Equ. 5 reveals the fact that, the score of the corrupted object can not equal to one. This equation can be analysed further in order to give the score profile under the variation of m. But if we apply the method stated in the following Section, no further analysis is needed since all linear non-uniform lighting object can be matched correctly by using CM.

IV. The hierarchical Chamfer Matching (CM)

The hierarchical Chamfer Matching (CM) first extracts the edge pixels with an edge detection algorithm, then it determines the best match from the measure of similarity of those matching points. The operation first extracts edge pixels from the source and template images respectively. The edged template is called the prepolygon image. The edged source image is transformed by the distance transformation [4] to form a predistance image. In the predistance image, each pixel is replaced by the distance magnitude measured from the nearest edge pixel. Thus, all edge pixels in the predistance image should be zero.

The matching algorithm is then as follows. First, we shift the prepolygon image over the predistance image and calculate the mean square of their convolution at each point - the edge coefficient. This edge coefficient indicates the difference in distance between the deformed edge of the source and the template images. The best matching point is the minimum edge coefficient. When compared with the correlation coefficient, the edge coefficient is normalized between 0 to 1 and 1 represents the best matching.

In fact, the most important part of CM in this case of non-uniform lighting is the edge detector being used. Here, the zero-crossing edge detector is chosen because the model of non-uniform lighting is assumed to be linearly varied. Therefore the edge detector can extract the information without error. Thus, the edge matching method CM can match the reference exactly.

V. Experiment Results

The experiment use different search areas (e.g. Fig. 4 & 5) which have different degrees of non-uniform lighting applied. This non-uniform lighting effect is considered as an added noise so that the SNR is calculated. We select a small region on the noiseless image as the template (the black square in Fig. 4) and use it to search on the different non-uniform lighting images (Fig. 5). The results are shown on Table 1.

Table 1 shows that the correct search position should be (61, 81) when it is noiseless. NC gives the correct answers from image 1 to 5 and fails in image 6 to 8. While CM gives the correct results in all cases and the perfect matchings occur in image 1 to image 5 (edge coefficient = 1). The reason can be explained using a 1-D analysis.

First of all, we model the 1-D non-uniform lighting as Fig. 6, the intensity varies with the spatial location of each pixels. Then using a 1-D noiseless signal "nontilted" (the blocked line in Fig. 7), to subtract a model of this non-uniform lighting (Fig. 6), it becomes the noisy signal "tilt" (the dotted line in Fig. 7). Laplacian zero-crossing [5] is used to extract the edges from both noisy and noiseless images. The edges extracted from both cases must be the same since the second derivative of the noise signal is zero (except the impulse in Fig. 8). The edges of both signals are shown by the zero-crossing points in Fig. 9 and we observe that these two signals are the same.

Fig. 10 shows the 1-D distance transformation (DT) of the source image. It shows the distance of a pixel from the nearest edge pixel, so it is zero at all edge points. The distance transformations of image 4 (labeled "tilt4") and the original noiseless image (labeled "nontilted") are the same because same edges are extracted from these two images.

Finally, the edge matching technique (CM) of two images is independent of the non-uniform lighting as it is not corrupted (the line labeled "tilt7" in Fig. 3). If the non-uniform lighted signal is corrupted, the edges extracted and the corresponding edge DT (the line labeled "tilt7" in Fig. 10) will not be the same as the original signal. Thus the perfect matching cannot happen (the matching results of image 6 to 8).

VI. Conclusion

For the analysis of non-uniform lighting in N. C., the degree of non-uniform lighting is determined by the slop of the linear model of the noise added. The effect is complex if we want to analyse it further. In fact, without doing experiments in N. C., we have demonstrated that the hierarchical Chamfer matching method improves the matching measure under the non-uniform illumination. It produces better result than the normalized correlation since it measures the distance of the edge pixels which usually does not vary with non-uniform lighting.

References

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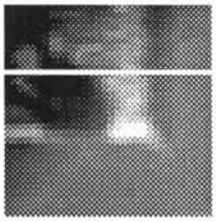

Fig.1 Tilted IC

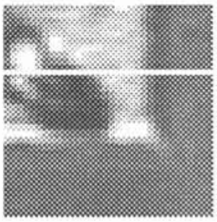

Fig.2 Non-tilted IC

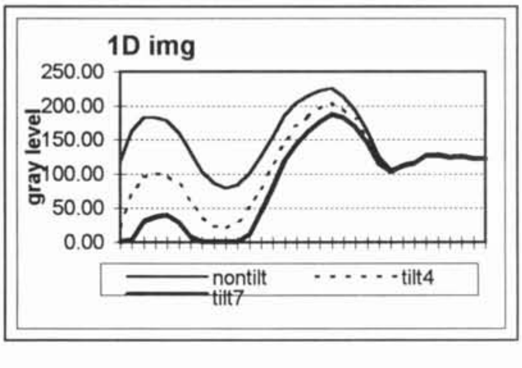

Figure 3 1-D plot of line in Fig. 1 and 2.

Figure 4 - Image no. 0, noiseless source image for searching

Figure 5 - Image no. 5, noisy image for searching

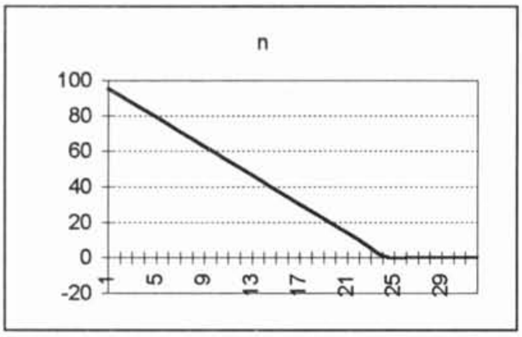

Figure 6 - The 1-D non-uniform lighting

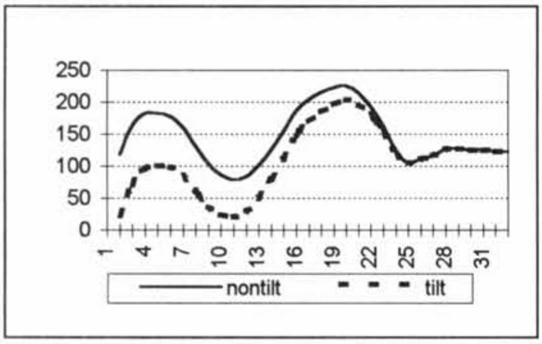

Figure 7 - The 1-D noiseless (nontilted) and noisy (yntmpl) signal

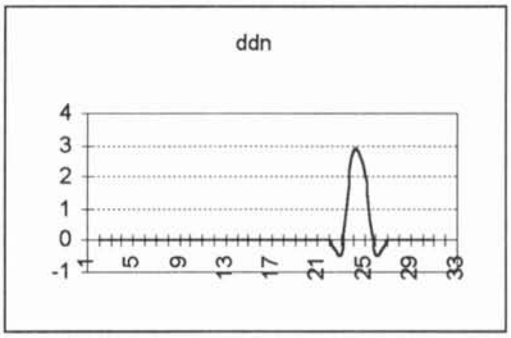

Figure 8 - The 2nd derivative of Fig. 5

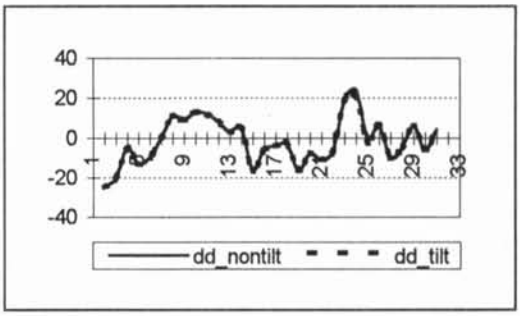

Figure 9 - The 2nd derivative of Fig. 6

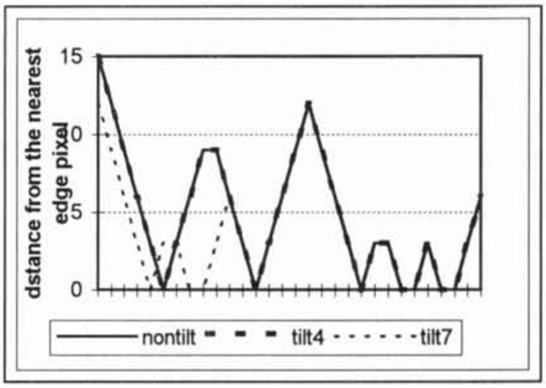

Figure 10 - 1-D Distance Transformation of original image, image 4 and 7.

Img No.	SNR	Correl. Coeff	x-coord	y-coord	Edge Coeff	x-coord	y-coord
0	**noise-less**	**1**	**61**	**81**	**1**	**61**	**81**
1	84.27	0.9806	61	81	1	61	81
2	56.55	0.9165	61	81	1	61	81
3	40.33	0.8114	61	81	1	61	81
4	29.39	0.6868	61	81	1	61	81
5	21.88	0.5652	61	81	1	61	81
6	16.16	0.5353	39	79	0.9910	61	81
7	11.74	0.5375	39	79	0.9779	61	81
8	8.21	0.5384	39	79	0.9591	61	81

Table 1 - Matching result of the correlation and edge coefficient.