TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol.12, No.5, May 2014, pp. 3737 ~ 3744
DOI: http://dx.doi.org/10.11591/telkomnika.v12i5.5108

Development of a Machine Vision System for Solar Wafer Counting

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Abstract

The traditional manual counting wafers leaded to the silicon wafer cracked by operating frequently. Instead of the manual work, this paper proposed a system to counting wafers based on Machine Vision theory and Image Processing algorithm. We designed a counter system and adopted infrared led as parallel illumination source. In image pre-processing, this paper presented a series of algorithms, which contained image smoothing, uneven image correction and image morphology operation. This paper proposed a vertical projection counting based on statistics analysis substitute for the Hough straight lines detection, and the methods have achieved ideal effects by experimental results.

Keywords: *uneven Illumination, image pre-processing, counting algorithm*

1. Introduction

Photoelectric conversion efficiency, product quality rate and production of cost are the three key factors which play an important role in the solar cell production process. Not only the quality of material itself, but also the cracked wafer reduces the quality rate, and the principal element impacts the cracked wafer is the traditional manual counting wafers. Firstly, all the counting results are frequently inaccuracy. Secondly, due to the fragile properties of the material, hand operation may lead to the damage wafers and the economic losses. Finally, for a long time and boring manual counting may result in fatigue operator and reduce the work efficiency. To solve this above drawback, we adopted machine vision method instead of the manual work, which can provide accuracy and efficiency in wafer counting. In this article, the machine vision framework includes specially-designed machine, special parallel illumination source, high-resolution camera, personal computer and image processing technology. The framework can improves counting the numbers of wafer quickly, repeatedly, and accurately while minimizing handling to prevent wafer damage.

There are some researches on paper counting using machine vision technology [1-3], but it is very limited on the study of solar wafer counting. Some papers worked on paper counting based on Texture Feature [1-2], [1] presents a method based on analyzing texture feature of the paper image, obtaining the binary image through LOG filter. Then the counting numbers were obtained by pixel projection algorithm based on tilt correcting of the image and by difference algorithm based on statistic analysis respectively. A method respectively based on 2D Gabor filter and 1D line-by-line frequency analysis is proposed in [2], then counting numbers by extracting the filtered border information of paper. But when the side of paper has been abraded which lead to uneven in shadow, the results in [1] were error frequently, while [2] can not satisfying the real-time requirements .To solve these problem, [3] presents a method based on mathematical morphology, the results can be satisfied in practical production. A counting method based on textural property [4], which according to the common feature of piece and wafer, which firstly located wafer area employing first-order statistics method and edge detection projection, and then obtained the numbers by extreme value analysis in practical application.

The structure of this paper included: the solar wafer counter system and the parallel illumination source which restrained the uneven illumination in first part. The digital image

Received November 11, 2013; Revised December 23, 2013; Accepted January 8, 2014

processing method and the counting algorithm are application for solar wafer in second part. And the experiment results and analysis are shown in last part.

2. Solar Wafer Counter System

The solar wafer counter system includes protective exterior system, sleeve support system, display system and counting system. The role of the protective exterior system is protecting the camera from environment interference and holding it in the proper position steadily. The feature of the sleeve support system is assisting operator in loading and unloading the wafer easily, and providing identical sleeve positioning. The display system is showing the real-time image and the computed result. The above three system is the external system, and the last counting system is the internal system, which role is image processing and image analyzing. The schematic diagram of the system is shown in Figure 1(a), and the actual product is shown in Figure 1(b).

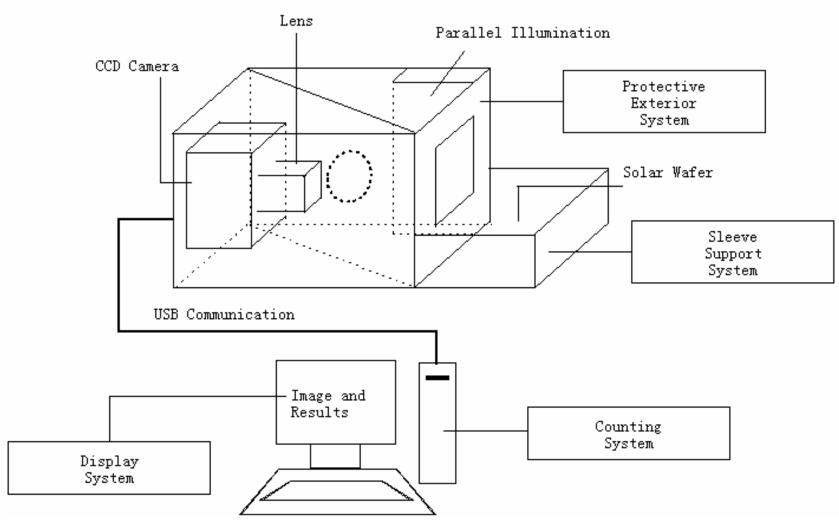
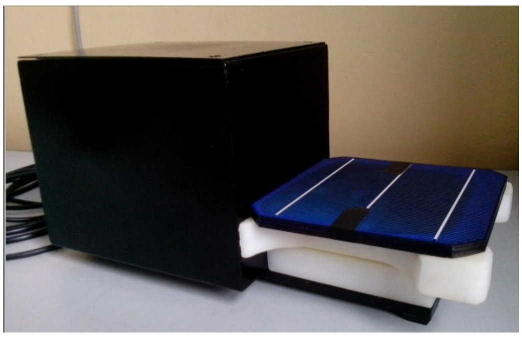


Figure 1(a). The Schematic Diagram of Counter System

(1)



(2)

Figure 1(b): (1) The Protective Exterior System and Sleeve Support System, (2) The Actual Product

According to the experiment, the camera is impacted by the illuminant in the protective exterior system. When uneven luminance, the wafer border can not be captured by the camera due to the low contrast and low frequency noises. In the present study, a sealing dark box was designed to avoid this problem. The camera is fixed in the back of the box inner, and the front is cutting a square gap to the camera capture image. In the right of the box inner, the parallel illumination source is placed to provide even illumination. To avoid the noise affected by visible spectrum, we adopt infrared led instead of common led. The illumination schematic diagram is shown in Figure 2(a), and the dark box in Figure 2(b).

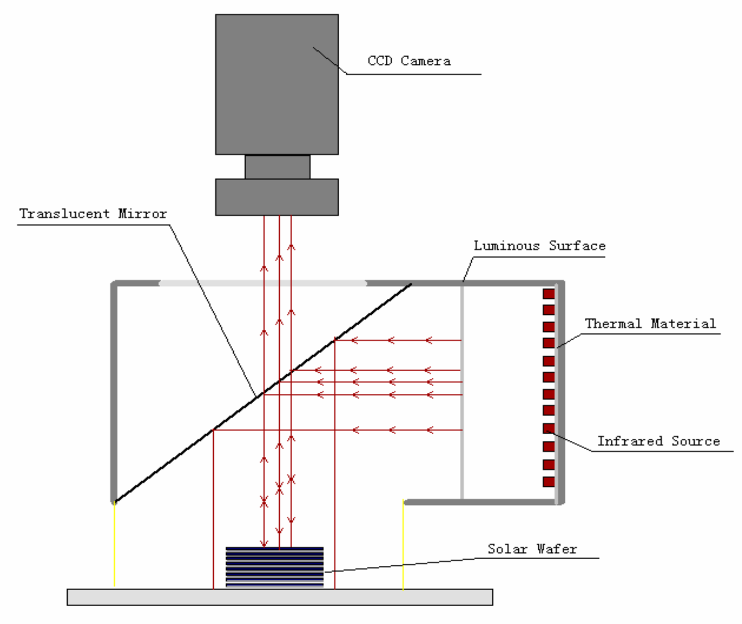


Figure 2(a). The Parallel Illumination Principle

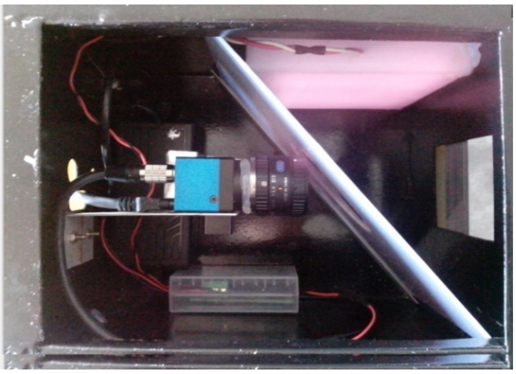


Figure 2(b). The Sealing Dark Box

3. Image Processing for Solar Wafer

The mechanism of employ image processing to count the wafers number was illustrated in the following chart (Figure 3).

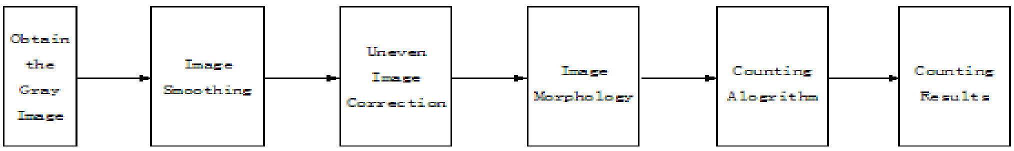


Figure 3. Image Processing Flowchart

After the camera capture an image of solar wafer, the original image is RGB image, so the first procedure is necessary to transform the original image to gray image (Figure 4(a)), which also remains most of the useful information and do not affect the subsequent processing [5].

3.1. Image Smoothing

Since the noise exists in surrounding and solar wafer, it is essential for restraining it in the process of image preprocessing. Median Filter [6] is used in [4], which can eliminate the isolate noise effectively, but it not use for the stripe analysis. According to the horizontal stripe feature of the object image, Average Filter [6] is used to smooth the picture, instead of the conventional 3×3 square kernel, 1×3 kernel to accommodate the image was be adopted, which can be eliminating pixel values which are unrepresentative of their surroundings. Meanwhile the filtering algorithm causes image fuzzy, so the improved Sobel [6] operator is used in edge detection in order to sharpen the image.

The Sobel operator is a discrete differentiation operator, computing an approximation of the gradient of the image intensity function. The Sobel operator is based on convolving the image with a small, separable, and integer valued filter in horizontal and vertical direction and is therefore relatively inexpensive in terms of computations. Because the horizontal feature of the solar wafer, we use the improved Sobel horizontal operator (as 2-2) to instead of the default (as 2-1), which is fitting for the image preferably. The result is shown in Figure 2-3, comparison Figure 4(b) and Figure 4(c), the improved method can enhance the low contrast part is superior to the default operator.

Default Sobel horizontal operator:

$$\begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \tag{1}$$

Improved Sobel horizontal operator:

$$\begin{bmatrix} 1 & 1 & 2 & 1 & 1 \\ 1 & 1 & 2 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 \\ -1 & -1 & -2 & -1 & -1 \\ -1 & -1 & -2 & -1 & -1 \end{bmatrix} \tag{2}$$

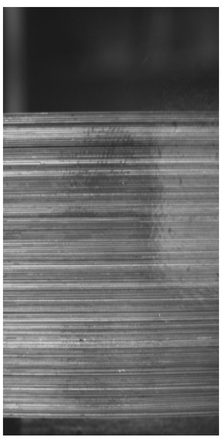


Figure 4(a). The Original Gray Image

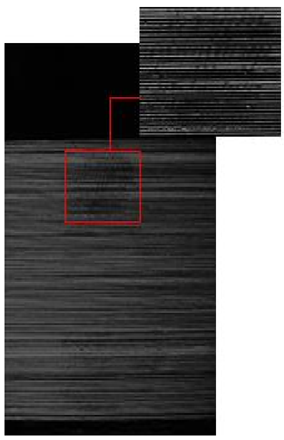


Figure 4(b). Default Sobel Operator

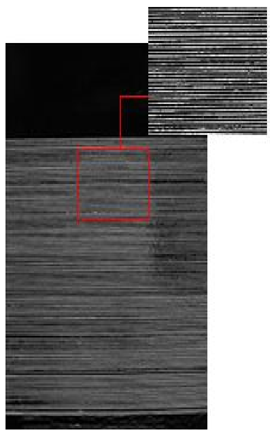


Figure 4(c). Improved Sobel Operator

3.2. Uneven Image Correction

Ahead of image correction, it must extract the wafer from background. As the theory of mean value of the image can measure luminance, firstly, taking horizontal projection by mean value of each row, we denote by matrix $M(i)$. Secondly, we averaging $M(i)$ and the result is A. Last, operating formula $N(i)$ =$M(i)$-A, and $N(i)$ is a nonnegative number. Figure 5(a) can illustrate the procedure, $M(i)$ is shown in the upper graph, and $N(i)$ is displayed in the under graph. We extract wafer from background using edge information of the image from above method. The result of image extraction is shown in Figure 6.

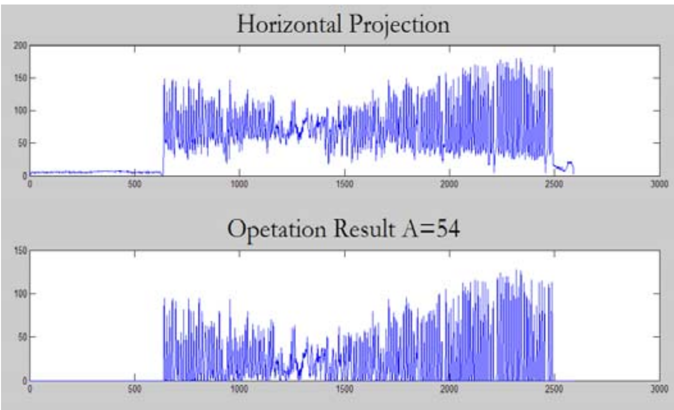


Figure 5. Image Location Method

In spite of using the infrared parallel illumination to solve the influence of uneven luminance for the solar wafer, there is still some low contrast part in picture, as shown in green square of Figure 6(a). Remove the bias light from the original image is an effective method to uneven illumination correction, such as estimating background with morphological operation [6], and using a polynomial to fitting bias light. We adopt spatial filtering to correct uneven illumination, in addition, thickness of one piece is about 5~8 pixels, so using the improved Sobel operation (formula 2-2) to filtering the object image, which achieved a good result as displayed in green square of Figure 6(b).

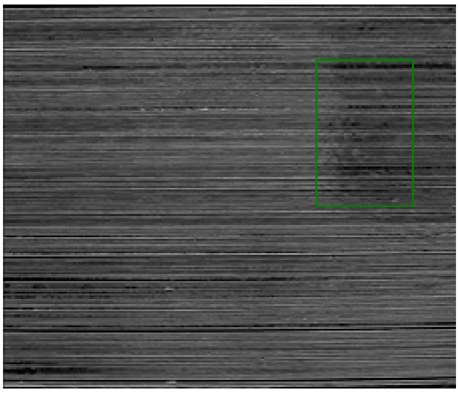


Figure 6(a). Low Contrast (green square)

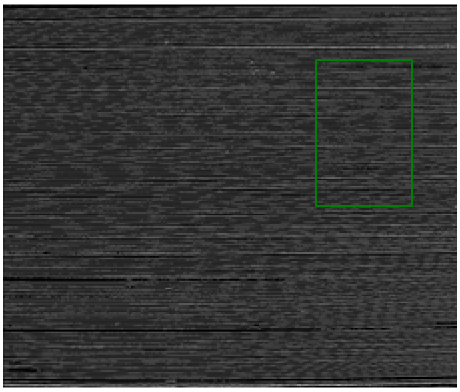


Figure 6(b). Uneven Correction (green square)

3.3. Image Morphology

Sobel operator is a discrete differentiation operator, so the processed image is disconnected after filtering. To solve the problem, the opening and closing operation from mathematical morphology are used. The opening operation is defined as erosion followed by dilation using the same structuring element for both operations. On the contrary, it is the closing operation. According to the experiment analysis and the horizontal character of the image, we adopt 1×3, 1×7 and 1×11 structuring element is used for this step, and the 1×7 element can be suit for morphology operator (Figure 7). The disconnected area of the image was shown in red round of Figure 7(a), in addition the result of image morphology operating was displayed in red round of Figure 7(b).

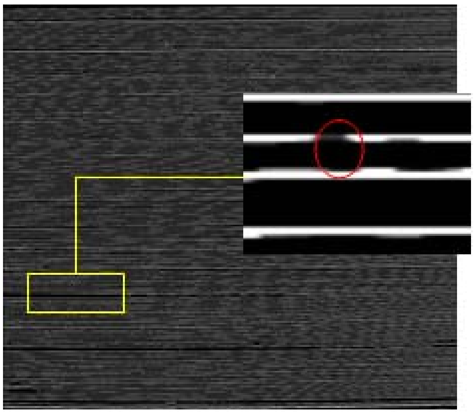


Figure 7(a). Disconnected Image (red round)

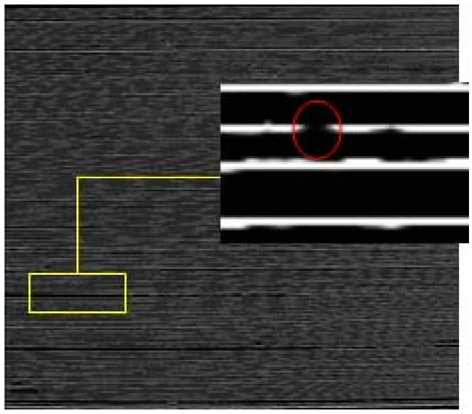


Figure 7(b). Image Morphology (red round)

3.4 Counting Algorithm for Solar Wafer

Hough transform [7] is the common method for detecting straight lines, in the image space, the straight line can be described as $y = ax + b$ where the parameter 'a' is the slope of the line and 'b' is the intercept. This is called the slope-intercept model of a straight line. In general, the Hough transforms changes into the polar coordinate space, and the equation of the line is written as:

$$r = x\cos\theta + y\sin\theta$$

The parameter r represents the distance between the line and the origin, while θ is the angle of the vector from the origin to this closest point. The plane of (r, θ) is sometimes referred to as Hough space for the set of straight lines in two dimensions.

The Hough detection needs traversing each pixel and confirming the proper (r, θ), so it is poor performance in efficiency and adaptability for counting numbers (results in Table 1). So the paper proposed a new method which based on statistics analysis illustrated:

Step 1: The monochrome image after processing by step 2-3 regards as M, casting out both the left and right 20 columns pixels, which are more apt to disturbing by the noise than the centre pixels, and the result as N.

Step 2: Dividing the image N into 5 sub-images equally, which regard as N1~N5.

Step 3: According to the horizontal feature of the wafer, using the vertical projection to each column of Ni (i=1~5), when current pixel is 1, and the next 2 pixel is 0, so regard as there is a line in current position ,the lines number add 1,obtaining the matrix Ri (i=1~5).

Step 4: Using the majority voting by statistics analysis, finding the most times number in Ri (i=1~5) and storing the number in ri (i=1~5). Similarly for the ri (i=1~5) processing the majority voting and getting the result C, which is the horizontal lines'

The results with above method are shown in Table 2.

4. Results and Analysis

In Table 1, the (30 50 80 100 120 135 150) samples were separately counted in non-repeat 10 times based on the method of the paper proposed. The sample correct counting ratio is about 98% where $\theta \subset (-10,10)$ & $r = 2$, but it spends over 3 second when the sample numbers is 150. By contrast Table 2, the (50 100 150) samples were separately counted in non-repeat 5 times based on the theory of Hough detection straight lines. The correct ratio is nearly 100% and has a good aging. In addition, the 50, 100 and 150 samples were separately counted 100 packages without repeating, and the results as shown in Figure 8(a) to Figure 8(c). It achieved ideal effects equivalently and the correct ratio is over 95%, so the counting algorithm based on statistics analysis was adapted to solar wafer counting.

Table 1. Hough Count Numbers $\theta \subset (-10,10)$ & $r = 2$

Sample Count	Hough Count Wafer Numbers Non-Repeat 10 Times										Mean Time
30	30	30	30	30	30	30	30	30	30	30	1s
50	50	50	50	50	50	50	50	50	50	50	1.2s
80	80	80	80	80	80	80	79	80	80	80	1.4s
100	100	100	100	99	100	100	100	100	101	100	1.6s
120	120	120	120	119	120	121	120	120	120	120	1.9s
135	135	135	134	135	133	135	135	135	136	135	2.4s
150	150	151	150	150	150	149	150	150	150	150	3.1s

Table 2. Partitioning Vertical Objection Count Numbers

Sample Count	Non-Repeat 5 Times	r1	r2	r3	r4	r5	C	Time
	50-1	50	50	49	50	50	50	1.2s
	50-2	50	51	50	50	50	50	1.2s
50	50-3	49	50	50	50	49	50	1.2s
	50-4	50	49	50	50	50	50	1.2s
	50-5	49	50	50	50	51	50	1.2s
	100-1	101	100	100	101	100	100	1.3s
100	100-2	100	100	100	99	99	100	1.3s
	100-3	99	99	100	98	100	100	1.3s
	100-4	100	101	100	100	101	100	1.3s
	100-5	100	100	101	100	101	100	1.3s
	150-1	149	150	150	150	150	150	1.5s
150	150-2	149	151	152	150	150	150	1.5s
150	150-3	150	151	150	149	150	150	1.5s
	150-4	150	150	150	148	151	150	1.5s
	150-5	151	150	150	152	149	150	1.5s

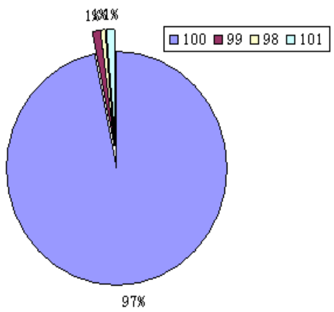


Figure 8(a). 50 Pieces

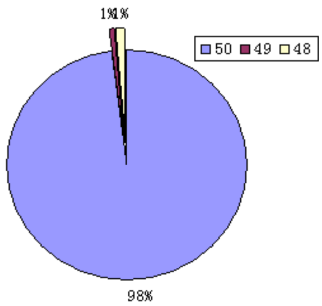


Figure 8(b). 100 Pieces

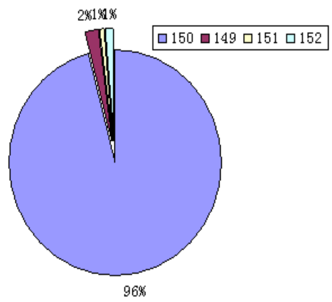


Figure 8(c). 150 Pieces

5. Conclusion

This paper presented image processing algorithms: image smoothing, uneven image correction and image morphology operation. This paper proposed a vertical projection counting based on statistics analysis substitute for the Hough straight lines detection. By experimental results, the methods have achieved ideal effects and correct ratio.

References

[1] MIAO Liang, PING Xijian. Algorithm of Paper Counting Based on Texture Feature. *Journal of Information Engineering University*. 2005; 6(4): 47-50.
[2] LI Yi, RUAN Qiuqi. Algorithm of Paper Counting Based on Texture Analysis. *Journal of Image and Graphics*. 2004; 9(9): 1042-1048.
[3] ZHEN Guang, CHEN Yaoping, YU Wenyong. The study of algorithm of paper counting based on mathematical morphology. *Microcomputer Information.* 2007; 23(21): 214-216.
[4] FANG Chao, TAN Wei, DU Jian-hong. Solar energy wafer counting based on textural property. *Information and Electronic Engineering.* 2011; 9(2); 185-189.
[5] Jean-Luc Starck, Fionn Murtagh, Emmanuel J Candès, David L Donoho. Gray and Color Image Contrast Enhancement by the Curvelet Transform. *IEEE Transaction on Image Processing*. 2003; 12(6): 706- 717.
[6] Rafael C, Richard E. *Digital Image Processing.* 2nd ed. Translated by RUAN Qiuqi. Beijing: Publishing House of Electronics Industry. 2006.
[7] https://en.wikipedia.org/wiki/Hough_transform
[8] https:// www.math.washington.edu
[9] Yuelin Zou, Xiaoqiang Liang, Tongming Wang. Visible and Infrared Image Fusion Using the Lifting Wavelet. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2013; 11(11): 6290-6295.
[10] Yushu Xiong. A Clustering Algorithm Based on Rough Set and Genetic Algorithm. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2013; 11(10): 5782-5788.