A Technology of Surface Defects for the Solar Wafer by Dual Vision

Yuanmin Huang*, Ming Yi, Weihang Yang and Man Yang

Electro mechanic Engineering Institute, Foshan Polytechnic, Foshan, 528137, Guangdong, China

*Corresponding author: fzhym27@fspt.net

Abstract. For overcoming the defects of the existing method of surface defect for the solar wafer. A automatic measurement technology by dual vision is presented. Frst the principle and flow of the automatic measurement technology are introduced. Second the technique of camera calibration, technique of center extraction of edge and technique of automatic matching are researched. At the end, using the technology realized the rapid defects detection including crack, cavern, smudge and broken so on and so forth which can be concluded that the application of this technology helps to enhance the inspection efficiency

1. Introduction
With the upgrading of solar wafer manufacturing process, solar wafer becomes thinner and thinner, so solar wafer becomes more vulnerable to damage. In order to reduce the fragmentation rate in the production process and avoid the impact of poor solar cells on related processes, it is necessary to use the size measurement, hidden crack detection, whole detection and dirt detection of the visual system, so as to improve the power generation efficiency and service life of the module. Therefore, effective defect detection method is very important to improve the process quality of solar silicon wafer.

Ultrasonic resonance scanning and contact resistance scanning are two kinds of detection methods for solar wafer defect detection. Ultrasonic testing method has the characteristics of non-destructive and rapid, but the sensitivity is not high, which is suitable for silicon wafer and battery wafer; contact resistance scanning method has high sensitivity, but it is time-consuming and destructive, which is only suitable for battery wafer. The biggest difficulty of surface quality inspection is defect feature extraction and defect classification. Traditional machine vision detection methods generally use gray feature, geometric feature or texture feature to describe defects. At the same time, neural network and support vector machine are widely used in surface defect detection and recognition. These methods have realized the surface defect detection and recognition to some extent. Ultrasonic resonance scanning and contact resistance scanning are two kinds of detection methods for solar wafer defect detection. This paper designs a method based on binocular scanning measurement, which not only realizes the automatic detection of solar wafer, but also improves the detection efficiency and the reliability of detection results.

2. Detection principle
In order to strive for the texture features of the detected solar wafer, a laser emitter is used to project the artificial texture onto the solar wafer. As shown in Figure 1, plane II projected by the laser emitter is
modulated by the surface of the silicon wafer to form a laser line \( L \). Two cameras take images of silicon wafer with laser line at the same time. Firstly, the image plane coordinates of the line are obtained by locating the line center. Then, the image point pairs \( A_1 (U_1, V_1) \) and \( A_2 (U_2, V_2) \) with the same name are obtained by image point matching technology. Finally, the image point pairs with the same name are substituted into the collinear equation \( (1) \) and \( (2) \)

\[
\frac{X - X_s}{Z - Z_s} = \frac{a_1u + a_2v - a_3f}{c_1u + c_2v - c_3f} = m \\
\frac{Y - Y_s}{Z - Z_s} = \frac{b_1u + b_2v - b_3f}{c_1u + c_2v - c_3f} = n
\]

In the equation, \( X_s, Y_s \) and \( Z_s \) are exterior orientation elements; \( a_1, a_2, a_3, b_1, b_2, b_3, c_1, c_2 \) and \( c_3 \) are rotation matrix elements; \( f \) is the focal length of the camera. Therefore, it can be concluded that:

\[
\begin{pmatrix}
1 & 0 & -m \\
0 & 1 & -n \\
1 & 0 & -m
\end{pmatrix}
\begin{pmatrix}
X \\
Y \\
Z
\end{pmatrix} = \begin{pmatrix}
X_s - mZ_s \\
Y_s - mZ_s \\

\end{pmatrix}
\]

If the object point \( a \) is imaged on two images, the two image points of point \( a \) can be obtained according to the equation \( (3) \).

\[
\begin{pmatrix}
1 & 0 & -m_1 \\
0 & 1 & -n_1 \\
1 & 0 & -m_2 \\
0 & 1 & -n_2
\end{pmatrix}
\begin{pmatrix}
X \\
Y \\
Z
\end{pmatrix} = \begin{pmatrix}
X_{s_1} - m_1Z_{s_1} \\
Y_{s_1} - n_1Z_{s_1} \\
X_{s_2} - m_2Z_{s_2} \\
Y_{s_2} - n_2Z_{s_2}
\end{pmatrix}
\]
Then the approximate coordinate value of point $a$ can be solved by the following equation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = L$$

(5)

In order to obtain the three-dimensional structure of solar silicon surface, the laser projector needs to rotate continuously. In this paper, we take a pair of pictures without projected laser lines, and get the image plane coordinates of the edge of the solar silicon wafer by edge positioning, and then use the same follow-up processing as the laser lines to get the three-dimensional coordinates of the edge points. The whole image processing process is shown in Figure 2.

![Fig 2. Image processing method.](image)

Because the solar wafer defect detection is a real-time detection system applied in the production line, the system has strong real-time and fast performance, so it needs a very large amount of image data. In order to improve the processing speed of the system, in addition to using high-performance hardware, we also need to consider the software operation mode and operation speed. This system only uses Halcon language to meet the requirements of the system [8-10]. At the same time, it also considers the selection of the corresponding algorithm. The main task of solar wafer defect detection is divided into: processing, analyzing and extracting silicon image, realizing the automatic recognition of solar wafer defects. The system can be divided into twelve steps, as shown in Figure 2.
For any point A (x, y) in the image, the corresponding first and second derivatives are $r_x$, $r_{yy}$, $r_{xy}$, $r_{yx}$, $r_{xx}$, $r_{yy}$, respectively. Then the Hessian matrix corresponding to point $a$ can be expressed as:

$$H(x, y) = \begin{bmatrix} r_{xx} & r_{xy} \\ r_{yx} & r_{yy} \end{bmatrix}$$ (7)

All eigenvalues and eigenvectors of $H(x, y)$ are obtained. Let $n = (n_x, n_y)$ be the corresponding eigenvector. According to the properties of Hessian matrix, it is the equivalent gradient amplitude, and $n$ is the gradient direction. $r_x$, $r_{yy}$, $r_{xy}$, $r_{yx}$, $r_{xx}$, $r_{yy}$ can be calculated by convolution with the following template (8, 9).

$$m_x = \frac{1}{6} \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

$$m_y = \frac{1}{6} \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

$$m_{xx} = \frac{1}{6} \begin{bmatrix} 1 & 1 & 1 \\ -2 & 0 & -2 \\ -1 & 0 & 1 \end{bmatrix}$$

$$m_{yy} = \frac{1}{6} \begin{bmatrix} 1 & -2 & 1 \\ 1 & -2 & 1 \\ 1 & -2 & 1 \end{bmatrix}$$ (8)

$$m_{xy} = m_{yx} = \frac{1}{4} \begin{bmatrix} 1 & 0 & -1 \\ 0 & 0 & 0 \\ -1 & 0 & 1 \end{bmatrix}$$ (9)

After the direction vector $n = (n_x, n_y)$ of the edge point has been obtained, the gray distribution function in the vertical direction of the edge point is expanded by the second-order Taylor expansion based on the point $(x, y)$.

3. Experimental results and analysis
The defects of solar silicon wafer are tested by this method. The results are shown in the following figure (Fig.3~ Fig.5).

Fig 3. Solar wafer to be detected.  
Fig 4. Broken gate of solar wafer.
Fig 5. Broken gate and cavern solar wafer.

Table 1 shows the defect detection results of several defect samples collected from a large domestic solar wafer factory.

| Types of surface defects | Cavern solar wafer | Dirty solar wafer | Broken gate solar wafer | Total |
|--------------------------|--------------------|-------------------|--------------------------|-------|
| Samples                  | 1600               | 1700              | 1650                     | 4950  |
| Identification           | 1592               | 1691              | 1645                     | 4928  |
| Detection rate           | 99.50%             | 99.47%            | 99.70%                   | 99.56%|

It can be seen from the experimental results that the method in this paper is used to detect the solar silicon wafer, and the results are satisfactory.

4. Conclusion
The detection technology based on Halcon image processing has become more and more mature. It is also widely used in enterprise production and social life. However, these technologies are relatively less used in the emerging solar industry. With the development of the solar industry and the increasing demand for solar wafer products, especially the continuous improvement of the requirements for the surface quality of silicon wafer, its quality will seriously affect the conversion efficiency of solar cells. Therefore, the control of the surface quality of solar wafer is also a very important work. Therefore, it is very necessary to study Halcon image processing technology in the production of solar silicon wafer, which not only has a certain theoretical value, but also has practical application value.

The main work of this paper is as follows:
1) The overall design scheme of solar wafer surface defect detection system based on Halcon image processing is proposed.
2) This paper briefly describes the composition of solar wafer detection system and introduces some basic algorithm flow based on Halcon image processing.
3) Using this method can reduce labor intensity, reduce production costs, reduce human factors in the process of product testing, achieve a high degree of automation of product production, improve the quality of product testing, and produce good social and economic benefits.

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