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An automatic optical inspection system for the detection of three parallel lines in solar panel end face

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ABSTRACT

This study inspected and tracked the location state of a test object in the telemetry monitoring of a wafer or solar panel, and the relevant optoelectronic devices. A CCD camera, triggered by the proposed system, captures the test target image in real time, which is transferred to the system for low-pass filtering, image binarization, spatial masking, boundary tracing, and other means of image processing. The new edge point detection algorithm is then applied to identify the edge points of three parallel lines. Three different group edge points are determined using the edge point detection algorithm, and the three groups are computed using a single linear regression equation. Multiple-linear regression is conducted to obtain the sections of straight lines of the groups that can best satisfy the expected requirements. Finally, whether the detection results are consistent with the expected requirements is determined to inspect whether the test object is consistent with the process specifications in order to reduce undesirable losses, as caused by inappropriate placement angle in subsequent manufacturing, thus, enhancing subsequent manufacturing to achieve high yield.

1. Introduction

In recent years, semiconductor, electronics, communications, and solar panel industries are thriving. In the operating production lines of factories, reducing labor and costs, and improving product quality and productivity of the components, the positioning and placement status detection of optoelectronic devices has become very important [1,2]. Most current studies on monitoring solar panels and related optoelectronic devices under test use the non-contact sensing ability of optical image monitoring in order to avoid interference and damage to the object, however, edge detection has a larger impact on test results [3,4].

General edge detection methods [5–7] use the contrast between the target object and the background of the image to convert the target object into a brightness value with actual meaning [8]. Meanwhile, by using the linear relationship, the detailed parts of the image are used to present the location of the object, and determine the accurate positioning of the target object by linear regression [9,10]. There are varied methods of image edge inspection, which differ in perspectives of application. Regarding general linear edge inspection, when it detects straight lines in a specific direction, appropriate masks are generally considered. If an image with a constant background and various types of straight lines is filtered by the first mask, the maximum response should occur at the position of the horizontal line passing through the middle column of the mask, then standardization is conducted according to image brightness value and contrast.

CANNY line characteristics are used in image edge line detection [6]. By using the parallel distance and collinear distance of each line section as the condition and the image pixel as the unit, the mapping function of the regional pixel in the image is calculated to obtain the pixel corresponding relationships for computation of the line section difference image.

Image template matching rules and image differential are used to mark the target object. Then, linear regression is conducted to compute the image edge section information. After obtaining the image edge information, the central coordinates and degree of rotation of the target object are determined. The training background module can be trained by the statistical method. Next, the differences between the current image and the background module are divided into color and brightness losses. By selecting the appropriate threshold values, the pixel can be determined as belonging to the foreground shadow or background. Afterwards, by using linear regression, the contour data can be determined, and the characteristic contour is used to identify the target object and determine the state of the target object accordingly [11,12].

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This paper studied and designed an optoelectronic device placement inspection system, where its target object is three parallel edge lines in the upper, medium, and lower parts of the optoelectronic devices. However, when processing these edge lines in the image, due to image noise, some deviations may occur, resulting in three non-parallel edge lines. Therefore, it is necessary to propose a method to consider the three edge lines as a whole in order to obtain more accurate results. This study connected a CCD camera to a computer to monitor the placement state of the optoelectronic devices, including solar panel by telemetry. After sending the image captured by the camera to the computer, image processing methods, such as low-pass filtering, image binarization, spatial masking, and edge point detection are applied. An innovative linear regression method is applied to compute the horizontal placement state of the object under test. Low-pass filtering is mainly to reduce the production of noise during the process of binarization, which is completed using the distinguishing standard measurement method. Using the previous binarization method of fixed threshold values may result in misjudgment of the subsequent results due to the impact of light or ambient environment during the tracing process. The distinguishing standard measurement method uses the principle of probability statistics to compute the pixels of the two clusters of the segmented binary image, obtain the maximum threshold values of the image to achieve the purpose of automatic threshold acquisition, and reduce misjudgment during the image determination process. It then filters the slight noise and compensates for omissions, and fills the test object with colors [13,14]. The image edge points can be obtained using this method. After obtaining the edge points, the edge will be restored to a straight line using the linear regression method. The straight line equation is corrected, using the linear regression method, by comparing the linear equation with all edge points. If the distance between an edge point and the linear equation is beyond the preset threshold value of γ, the point is removed [10]. After comparing all edge points and the linear equation, the program will conduct a second linear regression computation of the remaining edge points to determine the new linear regression straight line equation. The edge point detection algorithm is used to identify the edge points of three different groups. A single linear regression equation will be used to calculate the three different groups. Afterwards, the multiple linear regression method is applied to straight lines of the various groups to identify the line sections that can best meet the expected requirements.

2. Linear regression of three parallel lines

In the development process of the solar panel end face detection system, image processing principles, including low-pass filtering, binarization and distinguishing standard measurement method, chain code, noising processing, edge point detection, and linear regression are applied in monitoring of the placement state of the solar panel, and related optoelectronic devices, under test for inspection. To determine the edge points of the image, this study used a 3×3 mask for scanning from left to right and top to bottom. Regarding each pixel, the various statues of the scanning mask are as shown in Fig. 1.

In this study, the scanning of edge points is mainly for horizontal and vertical detection. The two groups of edge detection methods use the neighboring points of the scanning point coupled with horizontal mask M_{hor}, and vertical mask M_{ver}, to obtain horizontal edge response value R_{Hedge} and vertical edge response value R_{Vedge} by equations, as shown in Eqs. (1) and (2). Horizontal mask R_{Hedge} is used as an example, as follows:

$$R_{\mathrm{Hedge}} = \sqrt{(f(x-1,y)\times M_{\mathrm{ver}}(2,1)+f(x+1,y)\times M_{\mathrm{ver}}(2,3))^2+f(x,y-1)\times M_{\mathrm{hor}}(1,2)-f(x,y+1)\times M_{\mathrm{hor}}(3,2)} \quad (1)$$

$$R_{\mathrm{Vedge}} = \sqrt{f(x-1,y)\times M_{\mathrm{ver}}(2,1)+f(x+1,y)\times M_{\mathrm{ver}}(2,3)+(f(x,y-1)\times M_{\mathrm{hor}}(1,2)-f(x,y+1)\times M_{\mathrm{hor}}(3,2))^2} \quad (2)$$

For a point scanned by the mask, the pixel values of the neighboring points are multiplied by the values of horizontal mask M_{hor} and vertical mask M_{ver}. The square root of the result is the horizontal edge response value R_{Hedge} of the scanned point.

Next, the threshold value δ is defined. When determining whether the scanned point is the target edge point P, Eq. (3) is used for determination by order. When encountering the image edge, the points beyond the image size all have a pixel value of 255, meaning they are completely white.

$$P(R_{\mathrm{Hedge}}) = \begin{cases} 0, & \forall R_{\mathrm{edge}} \geq \delta \\ 255, & \text{Otherwise} \end{cases} \quad (3)$$

If the scanned point is an edge point consistent with the threshold value, the pixel of the coordinate corresponding to the newly established edge image is replaced by 0, otherwise it is 255.

After obtaining the edge points by the above method, this study used the linear regression method to obtain an optimal straight line from the detected edge points using the linear regression method [9,10]. In this case, detection errors caused by some deviated edge points should be avoided in order to prevent impact on the final detection results. The main application of the linear regression method is to conduct regression of all the identified edge points and compute a straight line with the minimum error with the target. The straight line is the formed by the regression of the edge points closest to the target edge contour. This study designed the method by using the upper, middle and lower edge lines of the image contour edge for edge point detection, and group the edge points into three clusters, as represented by edge points of m, n, and p. The linear regression equations of the three groups of edges are as shown in Eqs. (4)–(6).

$$\widetilde{y_{1i}} = a + bx_{1i} \quad (4)$$

$$\widetilde{y_{2j}} = a + bx_{2j} \quad (5)$$

$$\widetilde{y_{3k}} = a + bx_{3k} \quad (6)$$

The edge points detected using the edge point detection algorithm may result in errors in detection due to poor image capturing or edge points of similar masks. As a result, it may not be able to accurately and effectively conduct the regression of the straight line according to the target edges.

To remove the edge points of error detection, a correction method is added after linear regression. The correction method is mainly to capture the edge points of relatively closer distances from the linear equation for the first order linear regression to obtain the new straight line equation. Regarding the straight line equation after linear regression computation, all the edge points are compared individually. If the distance between the edge point and the linear regression straight line equation d is greater than, or equal to, the preset threshold value γ, the edge point is thus removed and represented, as shown in Eq. (7):

$$d = \frac{|a_1 + b_1 x_i - y_i|}{a_1^2 + b_1^2} \geq \gamma \quad (7)$$