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Machine Vision based Micro-crack Inspection in Thin-film Solar Cell Panel

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Abstract: Thin film solar cell consists of various layers so the surface of solar cell shows heterogeneous textures. Because of this property the visual inspection of micro-crack is very difficult. In this paper, we propose the machine vision-based micro-crack detection scheme for thin film solar cell panel. In the proposed method, the crack edge detection is based on the application of diagonal-kernel and cross-kernel in parallel. Experimental results show that the proposed method has better performance of micro-crack detection than conventional anisotropic model based methods on a cross-kernel. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Edge detection, Diagonal-kernel, Cross-kernel, Heterogeneously textured, Solar cell, Micro-crack inspection.

1. Introduction

Since various assembly lines became automatic, the machine vision systems have rapidly spread to the semiconductor, display, metal, and steel industries and have been used successfully in various fields. The main objective of the machine vision system used in solar cell manufacturing is to detect the defects on surface of solar cell panels. In this paper, we propose the micro-crack detection scheme for thin film solar cell panels. The proposed method is to apply the edge diffusion model based on a diagonal-kernel and conventional cross-kernel in parallel.

The edge diffusion model was first introduced by Peron-Malik in image processing for edge detection and scale-space description [1]. It has been widely used as an adaptive edge preserving smoothing technique for edge detection, image restoration, image smoothing, image segmentation and texture segmentation. The traditional machine vision defect detection algorithms based on spatial domain have been applied to timber inspection [3], carpet inspection [4] and metal inspection [5] and based on frequency domain have been applied to fabric [6], wafer [7] and steel quality inspection [8].

The disadvantage of these methods is that they can be applied only if the surface for inspection is uniform or repetitively patterned.

However, the thin film solar cell consists of various crystals so the surface of thin film solar cell has heterogeneous textures. Therefore, the conventional algorithms cannot be applied to this problem. Tsai et al. introduced the edge diffusion model based defect detection scheme, in which edge diffusion model was based on cross-kernel [2]. In this paper, we applied a diagonal kernel in parallel with Tsai et al. method [2]. It shows better performance for defect detection.

This paper is organized as follows. Section 2 overviews the micro-crack properties in thin film solar cell panel. Section 3 overviews the conventional and proposed edge diffusion model. Section 4 shows the experimental results from thin film solar cell surface images. The performance comparison with the Tsai et al. method is also discussed. Section 5 gives the conclusion of our research.

2. Micro-Crack Properties in Thin Film Solar Cell Panel

2.1. Micro-crack Properties in Thin Film Solar Cell Panel Images

The micro-crack in thin film solar cell panels has two main features: low gray-level and high gradient magnitude [2]. Fig. 1 displays a partial solar cell panel image that contains a diagonal micro-crack on the center of the image. If the width of the crack is wide then the gray-value of the pixels is low.

Generally, in the semiconductor and display industries, there are two defect detection schemes of the automated visual inspection system. The first method is to use the image subtraction and the second method is to use the statistical properties in ROI (region of interest). In the former, the reference and test images are subtracted and the difference area is detected, while in the latter the difference between the reference and test images is described by statistical model.

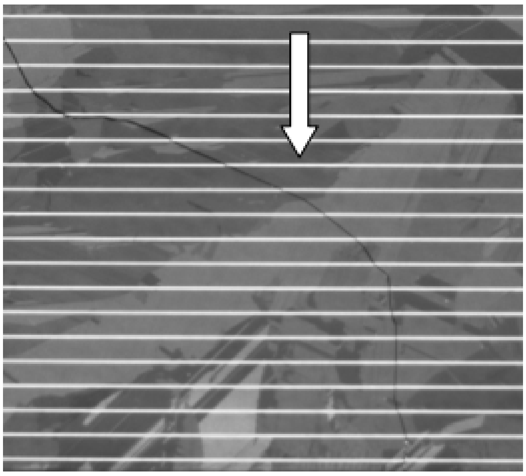


Fig. 1. Micro-crack in thin film solar cell.

2.2. The Limitations of Conventional Algorithms

ROI for inspection is set up using reference image and the defect is detected by statistical properties of the ROI in test image (e.g., mean, standard deviation, etc.). These two methods require that brightness of ROI in the test and reference image should be uniform. If the variation of gray-value of ROI on test images for each production is large, then the above-mentioned approaches are not available. Fig. 2 shows the defect detection scheme by statistical properties in ROI and Fig. 3 shows that the defect detection scheme by image subtraction.

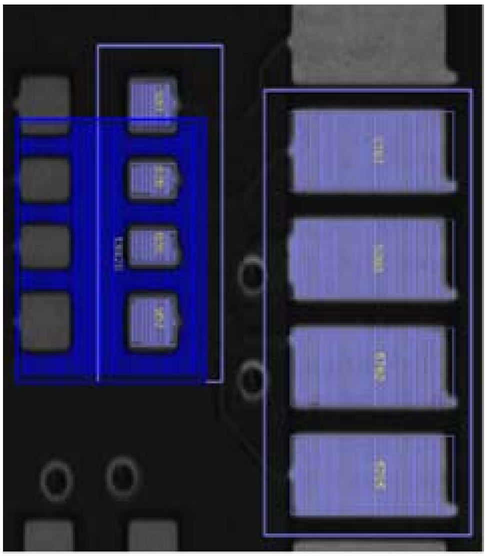


Fig. 2. Defect detection scheme by statistical Properties in ROI.

Fig. 3. Defect detection scheme by image subtraction.

As can be seen from Fig. 1, the surface of thin film solar cell panel is very irregular and varies with each product. Therefore, detection of the micro-crack on these wafers is a very difficult issue. To solve this problem, Tsai et al. introduced the edge diffusion model based defect detection scheme that was anisotropic model based on cross-kernel [2].

3. Edge Diffusion Model

3.1. Micro-crack Properties in Thin Film Solar Cell Panel Images

Edge diffusion model was first introduced by Perona-Malik in image processing for scale-space description and edge detection. It has been used as an adaptive edge-preserving smoothing process for texture segmentation and image segmentation. It is diffusion filter using the pixel information from cross-kernel [1].

In the edge diffusion model (1), $I_t(x, y)$ denotes the gray-level at coordinates (x, y) of a digital image at iteration t. The cross-kernel represent the gradients of four neighbors in north, south, east and west directions, respectively, i.e.

$$I_{t+1} = I_t(x,y) + \left(\sum_{i=1}^{4} c_t^i(x,y) \bullet \nabla I_t^i(x,y) \right) / 4, \quad (1)$$

Edge diffusion model uses the cross-kernel in Eq. (2) and smoothes the neighbors in the north, south, east and west direction pixels. However, if we use the gradient magnitude directly, the edge will be smoothed, and therefore, we cannot preserve the edge. Hence, we need the diffusion coefficients

$$\begin{array}{l} \nabla I_t^1(x,y) = I_t(x, y-1) - I_t(x,y) \\ \nabla I_t^2(x,y) = I_t(x, y+1) - I_t(x,y) \\ \nabla I_t^3(x,y) = I_t(x+1, y) - I_t(x,y) \\ \nabla I_t^4(x,y) = I_t(x-1, y) - I_t(x,y) \end{array}, \quad (2)$$

$$c_t^i(x,y) = g(\nabla I_t^i(x,y)), \quad (3)$$

3.2. Tsai, Chan and Chao Diffusion Model

The micro-crack in thin film solar cell panels has both low gray-level and high gradient magnitude in image. The Tsai et al. introduced the edge diffusion based defect detection scheme that was anisotropic model based on cross-kernel [2]. The proposed method smooths the micro-crack and preserves the pixel-value of all pixels in the faultless region. After this process, the subtraction between diffused image and original image will significantly intensify the micro-crack in difference image. After that, the micro-crack in difference image can be detected.

The diffusion coefficients function of the Tsai et al. diffusion model for micro-crack detection is given by

$$g(\nabla I, f) = \left(1 + \left[f(x,y) \cdot \left(\frac{K}{\nabla I(x,y)} \right)^2 \right] \right)^{-1}, \quad (4)$$

and $f(x, y)$ is given as

$$f(x,y) = I_0(x,y)/255, \quad (5)$$

where $f(x, y)$ is the normalized gray-level of an original image with 8-bit display, i.e. and K is the regularization parameter.

The difference image between original image and diffused image is then defined as

$$\nabla I(x,y) = \left| I_0(x,y) - I_T(x,y) \right|, \forall (x,y), \quad (6)$$

In order to segment micro-crack defects in the difference image, we use the simple statistical control limit to set up the threshold. It is given by

$$H(x,y) = \begin{cases} 0, & if\ \Delta I(x,y) > \mu_{\Delta I} + C \cdot \sigma_{\Delta I} \\ 255, & otherwise \end{cases}, \quad (7)$$

where $\mu_{\Delta I}$ and $\sigma_{\Delta I}$ are the mean and standard deviation of the difference image, and *C* is a control constant.

In order to remove the noisy pixels in the binary image, the noise-removal process proceeds as follows.

$$\begin{array}{l} If\ H(x-1,y) + H(x,y) + H(x+1,y) = 0, or \\ \quad H(x,y-1) + H(x,y) + H(x,y+1) = 0, or \\ \quad H(x-1,y+1) + H(x,y) + H(x+1,y-1) = 0, or \\ \quad H(x-1,y-1) + H(x,y) + H(x+1,y+1) = 0 \\ then \\ \quad let\ \hat{H}(x,y) = 0\ (retain\ the\ defect\ point) \\ else \\ \quad let\ \hat{H}(x,y) = 255\ (remove\ the\ noisy\ point) \\ end \end{array}, \quad (8)$$

After post-processing, some pixels of the micro-crack are also erased. In order to refill the disconnected micro-crack region, a filling process is carried out right after the noise-remove process.

$$\begin{array}{l} If\ \hat{H}(x,y) = 0\ and\ H(x+i, y+j) = 0 \\ then \\ \quad let\ \hat{H}(x+i, y+i) = 0, \\ \quad for\ any\ (x+i, y+i) \in N(x,y) \\ end \end{array}, \quad (9)$$

3.3. Proposed Edge Diffusion Model

The conventional diffusion model uses four neighbors in the north, south, east and west. Therefore, it reflects the four neighbors' pixel information well, but it cannot reflect the diagonal pixel information [2].

The micro-crack in thin film solar cell can occur in all directions. Therefore, the conventional method has a drawback that it cannot reflect the diagonal pixel information. In this paper we propose to apply the edge diffusion based on a diagonal-kernel in parallel with conventional cross-kernel.

The difference image between original and diffused images of the north, south, east and west directions is defined in Eq. (10) as

$$\nabla I_{NSWE}(x,y) = \left| I_0(x,y) - I_T^{NSWE}(x,y) \right|, \forall(x,y), \quad (10)$$

In Eq. (11), the difference image between original and diffused images of the diagonal directions is then defined as

$$\nabla I_{diag}(x,y) = \left| I_0(x,y) - I_T^{diag}(x,y) \right|, \forall(x,y), \quad (11)$$

And the diagonal-kernel represent the gradients of four neighbors in northeast, southeast, northwest and southwest directions, respectively, i.e.,

$$\begin{aligned} \nabla I_t^1(x,y) &= I_t(x-1,y-1) - I_t(x,y) \\ \nabla I_t^2(x,y) &= I_t(x+1,y+1) - I_t(x,y) \\ \nabla I_t^3(x,y) &= I_t(x+1,y-1) - I_t(x,y) \\ \nabla I_t^4(x,y) &= I_t(x-1,y+1) - I_t(x,y) \end{aligned}, \quad (12)$$

The reconstruction image between cross-kernel diffused image and diagonal-kernel diffused image is then defined as

$$\nabla I(x,y) = \nabla I_{NSWE}(x,y) + \nabla I_{diag}(x,y), \forall(x,y), \quad (13)$$

4. Experimental Results

In this section, we present the experimental results. We use the sensed image under front LED illumination and evaluate the proposed algorithm performance.

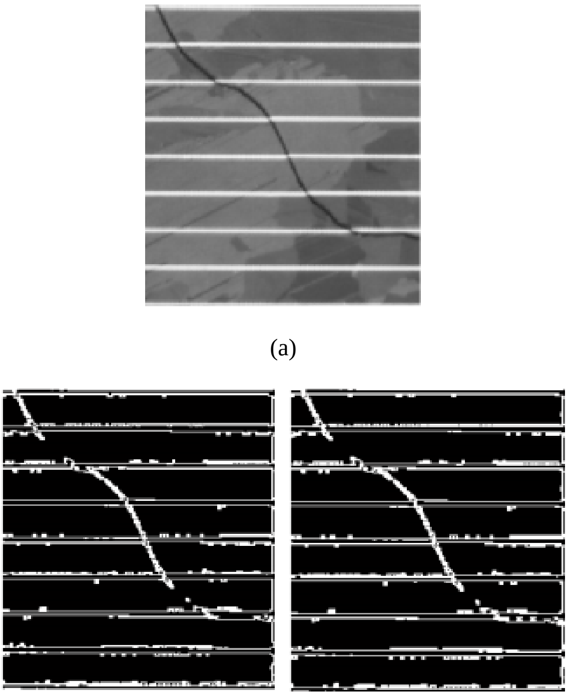
Fig. 4 shows the result of experiment. We can check the edge pixels that are a comparison between the result of conventional method and the result of proposed method.

5. Conclusions

We discuss edge diffusion model for micro-crack defect detection in thin film solar cell panel. The anisotropic model is widely used technique in the field of image processing.

The thin film solar cell panel consists of various crystals so the surface of solar cell panel has heterogeneous textures. Therefore, the conventional algorithms cannot be applied to this problem. Tsai et al. announced the edge diffusion model based defect detection scheme that utilized anisotropic model based on cross-kernel. In this paper, we applied a diagonal kernel to Tsai-Chang-Chao method. It shows better performance for defect detection.

Experimental results have shown that the proposed edge diffusion model can be well applied to the micro-crack detection of thin film solar cell panels.



(a)

(b) (c)

Fig. 4. Performance evaluation (a) micro-crack image, (b) Tsai et al.'s method, (c) proposed method.

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