Improved Canny's Method for Laser Scribes Contour Selection in Solar Cells

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Abstract. A modified Canny's method for contour image segmentation was developed. It is based on the configuration of the Gaussian filter core for the proposed image types. The method has been implemented using Matlab software in the form of executable m-scripts with the user interface developed in App Designer. The implementation of the developed method allows improvement of the laser scribes contour detection for the organic thin-film solar cells.

Keywords: Image Processing, Contour Segmentation, Solar Cells

1 Introduction

One of the main purposes of image processing is the image content interpretation. To fulfill this, it is necessary to separate the background from the objects. Segmentation enables to divide the image into components or objects, it separates the object from the background so that the image can be easily processed, as well as, its content can be easily identified. Highlighting contours in the image is a fundamental tool for a quality image segmentation. Contours significantly reduce the amount of data for image processing, while preserving important information about the objects in the image, such as their shape, size and amount [1-9].

Rapid development of the functional possibilities in the means of production control and the relatively low cost of digital technologies has led to their active use at various production stages. These innovations did not leave the industrial production of the flexible thin-film solar cells [10-18] without attention.

However, the solar panels manufacture is a very precise process that is why the damage detection and classification must be done with high accuracy and at a short period of time. For quality control while searching for the faults, the human eye is not as good as the specialized systems. Therefore, means of artificial intelligence and machine vision have become extremely helpful for those cases above [19-28].

However, in this area we have a lack of a system that would fully recognize the fault during the production. This caused by the fact that the resulting images are extremely specific, and not every image recognition system can be applied.

An extremely important procedure of the image recognition system (in damaged lines) is the selection of the processed image contours. Contours selected from non-trivial images are often damaged by fragmentation, which means that the contour borders are not connected, there are no contours, and there are false contours (the ones that do not correspond to the studied in the image) which is complicating further task of image data interpreting [29 -33].

This paper is devoted to improving the laser scribe contour detection of the organic thin-film solar cells and has the following structure: in section 2, an analysis of available sources-analogues is carried out, in section 3 the process of collecting images and an improved method of contour image segmentation are described. Section 4 presents the methodology and results of experimental studies, and section 5 summarizes the obtained results.

2 Related Work

A large number of contour and edges selecting algorithms is described in the literature. The most popular methods include the following ones: Roberts', Sobel's and Prewitt's operator, Canny's algorithm and LoG-algorithm [1-6]. For Canny's detector, high accuracy while detecting the objects edges in the image, is peculiar especially when it concerns their position. Roberts' detector is very easy to use, but it does not provide desired results when working with defocused images. The contour lines obtained this way are wide, blurred and indistinct, which makes it impossible for the automated systems to recognize them. The Prewitt's detector is characterized by a high degree of edge detection accuracy and noise resistance, but its disadvantages are the complexity of calculations, significant image processing time and low efficiency when working with blurred images.

However, there is currently no universal method or algorithm for selecting image contours. To determine the appropriate contour selecting algorithm, the orientation and structure of the contour, as well as the presence and type of noise in the image are taken into consideration. Each of the algorithms solves its own class of problems, qualitatively highlighting only certain type of contour that is why the task to create the contour segmentation methods of the image is relevant [32-36].

Existing contour selection methods also differ in the applied filters and smoothing methods. One of which is the Gaussian filter [34-36], which is based on the classical Gaussian function for two variables [1, 2]:

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (1)$$

were σ is a standard deviation of the normal distribution, which in this case specifies the "degree of blurring" of the processed image; x, y - the distance from the starting point (a pixel) to the point for which the value of the function is calculated vertically and horizontally, respectively.

Thus, based on the Gaussian function, we can construct a convolution matrix, according to which for each pixel of the image average weighted value of neighboring pixels is calculated [37]:

$$r_{mn} = \sum_{i=-k}^{k} \sum_{j=-k}^{k} r_{m+i,n+j} G(i,j) \qquad (2)$$

where k is the dimension of the convolution matrix. As a result of applying the Gaussian filter, all noised pixels (pixels whose brightness differs profoundly from the brightness of the neighboring pixels) take an average value, that is noise is suppressed, and the contours of objects are emphasized, which is very useful when recognizing images in digital images.

Taking into account the given analysis, this paper proposes a method of contour selection based on the Canny's method with a modification of the Gaussian filter core, which enables to improve the results of laser scribes contour detection of the organic thin-film solar cells.

3 Material and Methods

3.1 Image Collection Process

During the production of organic thin-film solar cells, the laser scribes are photographed and analyzed autonomously. Images are taken using linear cameras and combined together into the one image. According to the technological process, the work is performed in a vacuum, which unfortunately reduces the image quality of the camera's optical system mirrors. The quality of the resulting image is also affected by the uneven lighting. Fig. 1 shows fragments of the images (packages) after brightness correction.

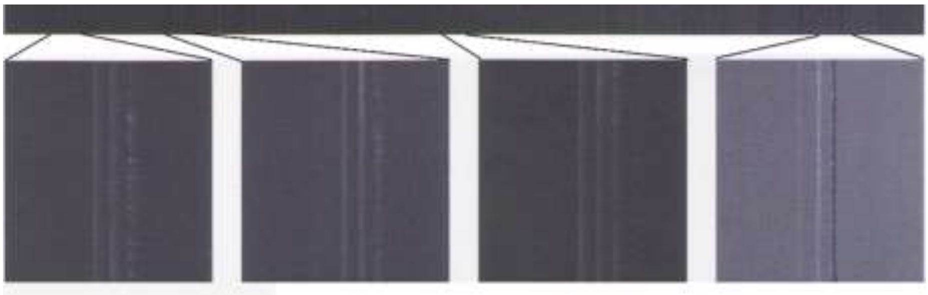


Fig. 1. Photos obtained from cameras on production. 4 Packages enlarged in the scale

In total there are 24 packages in the image. The width of the scribes in each package is 50, 80, 80 microns, respectively. As it can be seen, only part of the image is clear and well lit. Blurred lines will appear wider and will not have clearly defined edges. Images of lines that are too close together can be visually combined and presented as one broad line, which in turn can lead to misinterpretation. For example, extremely close vicinity of two scribes can lead to an error of "rather small distance" or, in the case of gluing two scribes, to several errors: "scribe too wide" and "no scribe".

3.2 Proposed Algorithm

The developed image contour segmentation algorithm differs from the classical Canny's one [1, 6] by modification of coefficients for image folding at calculation of the gradient figure 2.

The developed method of contour image segmentation differs from the classical Canny's [1, 6] by modification of coefficients for image folding at calculating of the gradient. The method is described in details at Fig. 2, and the modification of the coefficients is implemented in block 3 which work process will be described below.

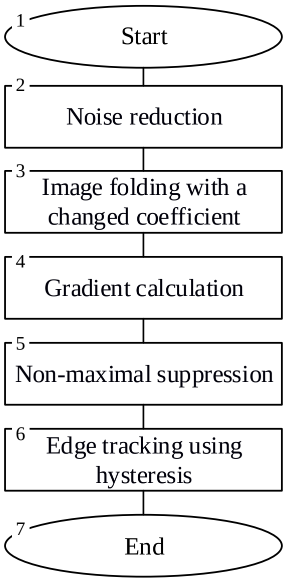


Fig. 2. Block diagram of the modified contour selection algorithm

According to the technological process, the images of the organic thin-film solar cells (see Fig. 1) are pre-processed by the existing software, after which it can be used by other third-party systems for further analysis (Fig. 3). As it can be seen, there are defects with gluing and breaking scribes on it. To obtain closed contours at the top and bottom, the input image has to be extended with the frame of background color.

Let's consider the work of algorithm for such image processing. The main task of the algorithm is to select the contours of the scribes, while the contours of individual elements should not be open to the possibility of their further analysis for defects - gaps, mergers or lack of contour.

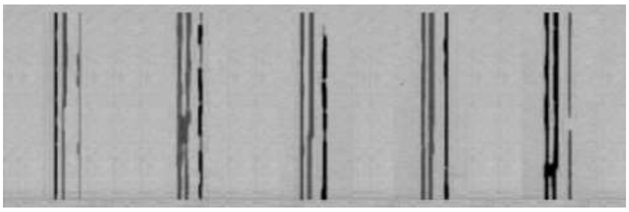


Fig. 3. Input image

One way to get rid of the image noise is to use Gaussian blur to smooth it out. To do this, use the technique of collapsing the image with a Gaussian core (3x3, 5x5, 7x7, etc.). The size of the core depends on the expected erosion effect. The smaller the core, the less noticeable the blur. As the main function for calculating the kernel matrix the following function can be used [37, 38]:

$$F(x) = \frac{e^{\cos(x^2)-2}}{ax^2+1} \tag{3}$$

where a - sets the degree of the blur.

Local maximum of this function are used to construct the matrix. For each pixel of the image, the weighted average value of the nearest pixels is calculated, but the brightness of the nearest pixels is averaged at an earlier step of the iterative procedure. Depending on the distance to the central pixel for which the new brightness value is calculated, a local maximum of the function is assigned to each neighboring pixel. Based on this technique, the authors proposed a modified Gaussian core sized 5x5:

$$\frac{1}{156}\begin{bmatrix} 0 & 0 & 2 & 0 & 0 \\ 0 & 0 & 6 & 0 & 0 \\ 2 & 6 & 10 & 6 & 2 \\ 0 & 0 & 6 & 0 & 0 \\ 0 & 0 & 2 & 0 & 0 \end{bmatrix}$$

After applying the blur, we proceed to the calculation of the gradient, during which the intensity and direction of the contour is determined. The simplest is the use of filters that highlight the change in intensity in both directions: horizontal (Ox) and vertical (Oy). Figure 4 shows the image obtained after calculating the gradient intensity:

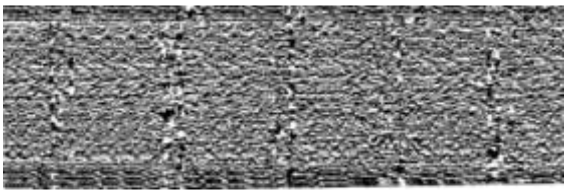


Fig. 4. Images after applying the gradient

After applying the gradients, some ribs become thick and others are thin. The stage of non-maximal suppression helps with softening the thick edges. Final image should have fine contours, so it is necessary to ensure non- maximal suppression. To do this, the algorithm passes through all points on the gradient intensity matrix and finds pixels with the maximum value of suppression in the edge directions.

Each pixel has two main criteria: edge direction in radians and pixel intensity (0 to 255). Based on these data, the following non-maximal suppression steps can be formed: (i) create the matrix initialized to 0, which has the size of the original gradient intensity matrix; (ii) determine the direction of the edge based on the value of the angle from the angular matrix; (iii) check whether the pixel in the same direction has a higher intensity than the pixel being processed; (iv) return the image processed by the non-maximal suppression algorithm.

The result is the same image, but with thinner edges in Figure 5. However, it is possible to see some changes in the intensity of the edges: some pixels look brighter than the others.

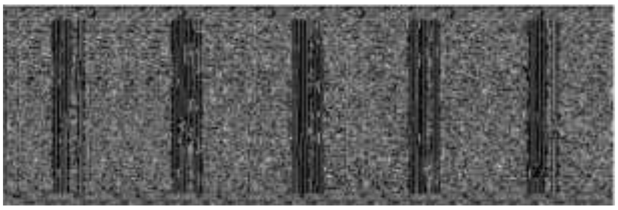


Fig. 5. The result of the non-maximal suppression

Based on the threshold results, the hysteresis consists of converting weak pixels into strong ones, if and only if at least one of the pixels around the calculated pixel is strong. The results of the hysteresis can be seen in Figure 6.

Fig. 6. The results of the hysteresis process

4 Case study

4.1 Experimental Technique

The proposed method is preferable to implement in the Matlab software in the form of executable m-scripts, the user interface is developed on the basis of App Designer [39-42] (Fig. 7).

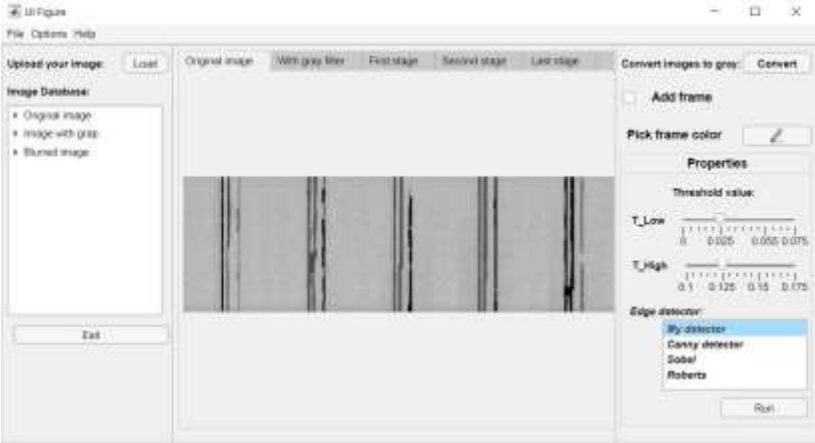


Fig. 7. User interface

To create an ergonomic and intuitive interface, it was decided to divide the interface into three parts. In the left control panel, images are downloaded and managed. In the central part, we may employ a group of tabs to view images at different stages of its processing and the results of the program. Use the toolbar on the right to configure and launch the contour selection program. The "Convert" button converts the input image to gray using a gray filter. Checkbox “Add Frame” with a color selection module enables to create a frame for the input image to prevent the merging of contours of the image. The updated image is displayed on the second tab of the program. In “Properties” group there are two sliders that are responsible for increasing and decreasing the lower and upper thresholds of the contour detector. The list below the sliders enlists the available contour detectors. The "Run" button launches the selected detector and in the third and fourth tabs of the central window, intermediate images appear, and in the fifth - the final image with selected contours.

4.2 Experimental Results and Discussion

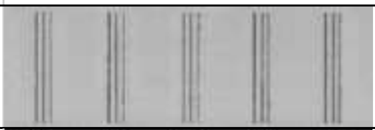
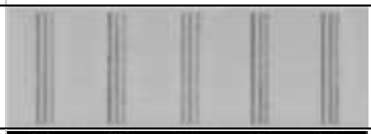
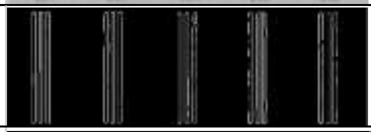
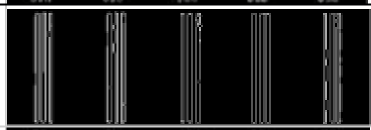
To compare the differences of the contours both subjective -with the visual quality assessment of the received contour of the object (table 1), and quantitative - using the PSNR-criterion [43-46] methods can be used.

The following formula is used for evaluation while using the PSNR criterion [43-46]:

$$PSNR(n,m) = 20Lg\frac{255}{\sqrt{\frac{1}{N}\sum_{i=1}^{N} d(n_{i,},m_i)^2}} \tag{4}$$

where N is the total number of pixels in each image; ni, mi - pixels of two images that are being compared; d(ni, mi) is the difference between the colors of the corresponding pixels. To do this, we used the image of the contour obtained from the noiseless one, which was defined as ideal, and the image of the contours obtained by the above detectors from the noisy ones. According to the criterion that the higher the PSNR value of such contour images, the higher the quality of the detector.

Table 1. Visual representation of detectors work

	Noise-free image	**Image with noise**
Original		
Canny's		
Improved		
Sobel's		
Roberts'		

The results of PSNR criteria calculations using Matlab [42] according to formula 4 for each detector with original and blurred images are presented in table 2.

Table 2. The results of detectors operation research

	PSNR	
Methods	**Ideal image**	**Image with noise**
Canny's	26.0180	23.5640
Improved	27.0501	24.0289
Sobel's	23.9911	20.8987
Robert's	21.8889	19.3546

Analysis of the results shows that the modified Canny's method with comparison to the other's has shown for 2-19% better results by PSNR-criteria while selecting the contours of the laser scribes in organic thin-film solar cells. It also satisfies such conditions when there are no gaps in the contour.

5 Conclusions

In this paper, we have proposed the modified method of Canny's contour segmentation to detect the laser scribes contours in organic thin-film solar cells. It enabled to improve the mechanism of defect recognition in the manufacturing of such panels. The developed method is compared with others, namely with the Canny's algorithm, the Sable's and Roberts' operators. During case study, the modified method showed better results for 2-19%, so its use is appropriate for this type of tasks.

The future research will be dedicated by automated detection of various contours defects - "distance too short", "scribe too wide", "no scribe", "scribe break".

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