

## System for an automatic analysis of defective Solar cells in the Solar Module

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### *Systém pre automatickú analýzu chybných solárnych dielcov v solárnom module*

This paper deals with the possibility of automated detection of defective solar cells within the whole solar module taken by electroluminescence methods. There is variety of possibilities to make a useful analysis of the quality of used material and technology processes during the manufacturing of solar cell and modules. One of the best from these methods that are capable to show the distribution of defects in the structure we can consider the electroluminescence which can detect defects in the fastest way. This method used in manufacturing process creates large array of data displaying local behavior of solar cell and panel structure.

During the manufacturing of solar cell there is possible to make a lot of useful analysis of the quality of used material and technology processes. Among methods that are displaying distribution of defect in the structure we can count the photoluminescence, which is possible to use on uncontacted material, electroluminescence and LBIC (Light Beam Induced Current) eventually LBIV (Light Beam Induced Voltage) which can be used on contact made solar cells. All this methods are creating large array of data displaying local characteristic of solar cell structure. This data can be displayed as images or can be analyzed by mathematic matrix software like Matlab. The advantage of matrix analyze is possibility to automate the analyze process and speed up the whole process. For useful analyze there must be decide what type of defect can be automatically detected (to make the defect database), mask contact grid of analyzed data and by comparison image analyzing process found out if the solar cell contain a defect and than what type of defect is it. The only usable method for analyzing of defects in whole solar module is electroluminescence because the other method are not able to get information of all solar cells in whole module.

**Key words:** Defects, Defect Density, Monitoring, Modelling, Solar Cells, Solar Module

### Introduction

The output data of defect detection method by electroluminescence contains lots of information about contacts structure and about the defects in the area of solar cell and whole module. This data can be analyzed by operator in image form or can be analyzed by computer system in row form.

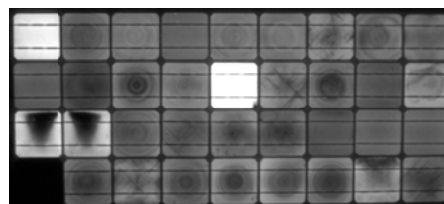
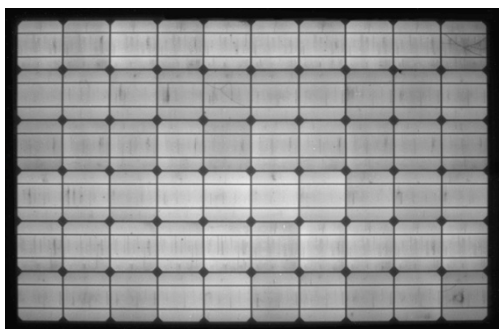


Fig. 1. Samples of photovoltaic modules.

### Image Analyzing - Thresholding

The method used to preparing analyzed data for comparing in image processor is thresholding used for image analyzing. During the thresholding process, individual data's point (pixel in an image) are marked as "object" pixels if their value is greater than some threshold value (assuming an object to be brighter than the background) and as "background" pixels otherwise. This convention is known as threshold above. Variants include threshold below, which is opposite of threshold above; threshold inside, where a pixel is

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labeled "object" if its value is between two thresholds; and threshold outside, which is the opposite of threshold inside. Typically, an object pixel is given a value of "1" while a background pixel is given a value of "0." Finally, a binary image is created by coloring each pixel white or black, depending on a pixel's label.

### Adaptive Thresholding

Thresholding is called adaptive thresholding when a different threshold is used for different regions in the image. This may also be known as local or dynamic thresholding.

The key parameter in the thresholding process is the choice of the threshold value (or values, as mentioned earlier). Several different methods for choosing a threshold exist; users can manually choose a threshold value, or a thresholding algorithm can compute a value automatically, which is known as automatic thresholding (Shapiro, et al. 2001:83). A simple method would be to choose the mean or median value, the rationale being that if the object pixels are brighter than the background, they should also be brighter than the average. In a noiseless image with uniform background and object values, the mean or median will work well as the threshold, however, this will generally not be the case. A more sophisticated approach might be to create a histogram of the image pixel intensities and use the valley point as the threshold. The histogram approach assumes that there is some average value for the background and object pixels, but that the actual pixel values have some variation around these average values. However, this may be computationally expensive, and image histograms may not have clearly defined valley points, often making the selection of an accurate threshold difficult. One method that is relatively simple, does not require much specific knowledge of the image, and is robust against image noise, is the following iterative method:

1. An initial threshold ( $T$ ) is chosen, this can be done randomly or according to any other method desired.
2. The image is segmented into object and background pixels as described above, creating two sets:
  - i.  $G1 = \{f(m,n):f(m,n)>T\}$  (object pixels)
  - ii.  $G2 = \{f(m,n):f(m,n)\leq T\}$  (background pixels) (note,  $f(m,n)$  is the value of the pixel located in the  $m$ th column,  $n$ th row)
3. The average of each set is computed.
  - i.  $m1 =$  average value of  $G1$
  - ii.  $m2 =$  average value of  $G2$
4. A new threshold is created that is the average of  $m1$  and  $m2$   
 $T' = (m1 + m2)/2$
5. Go back to step two, now using the new threshold computed in step four, keep repeating until the new threshold matches the one before it (i.e. until convergence has been reached).

This iterative algorithm is a special one-dimensional case of the k-means clustering algorithm, which has been proven to converge at a local minimum—meaning that a different initial threshold may give a different final result.

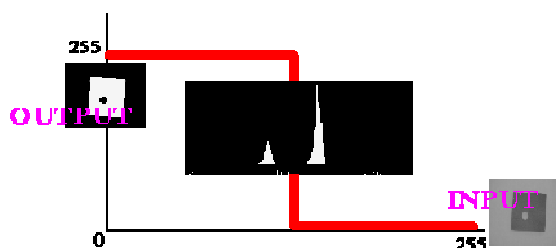


Fig. 2. Usage of thresholding for image preparation for analyzing.

### Solar cells image analyzing

The output data of defect detection method like LBIC or electroluminescence image contains lots of information about contacts structure and about the defects in the area of solar cell. This data can be analyzed by operator in image form or can be analyzed by computer system in row form. It is important to analyze data only which are contain information about defects. So in first stem must be made differential image of the new image and reference image. This process masks the structure of contacts which is no more analyzed.

The analyse is made in MathLab software and is full automatic.

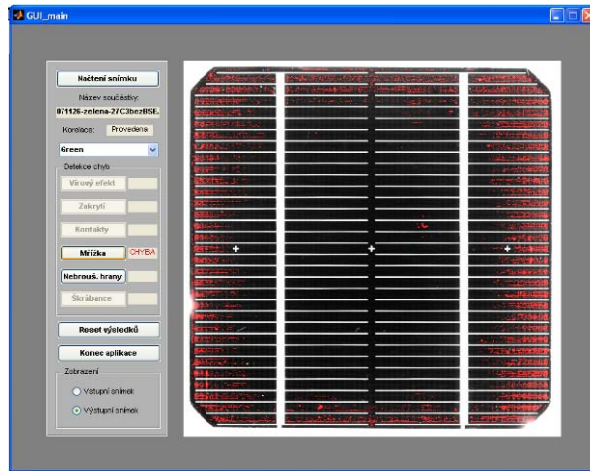


Fig. 3. Software GUI application of defect detection.

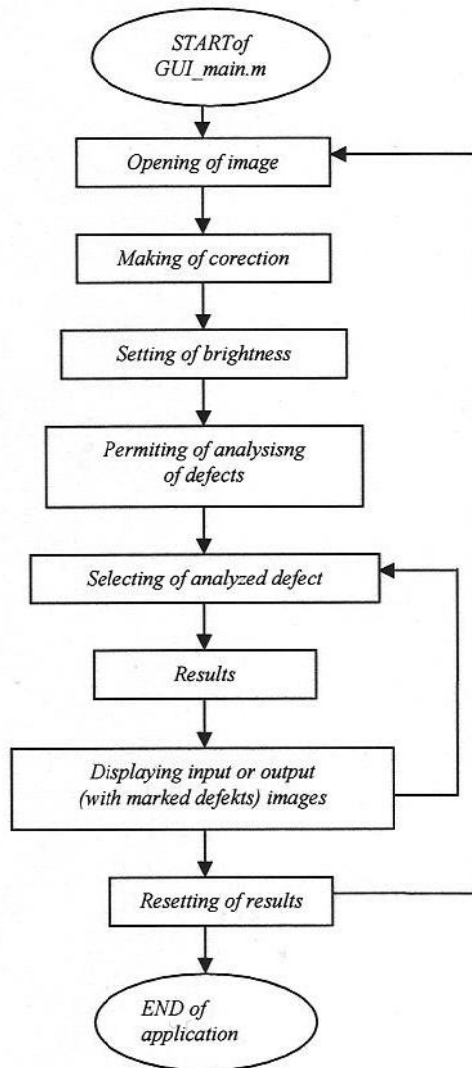


Fig. 4. Application algorithm.

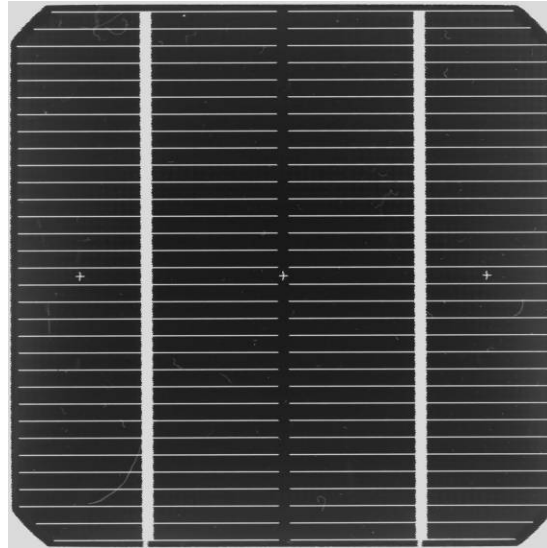


Fig. 5. Input image.

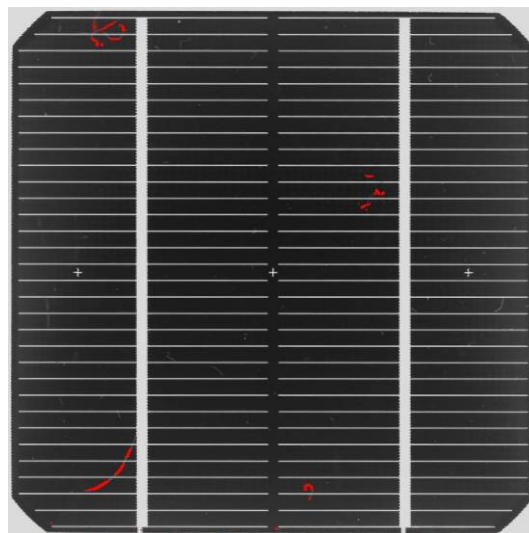


Fig. 5. Output image with detected highlighted scratches.

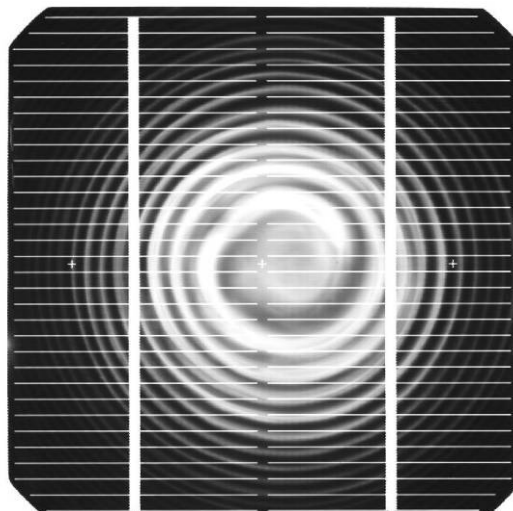


Fig. 6. Input image.

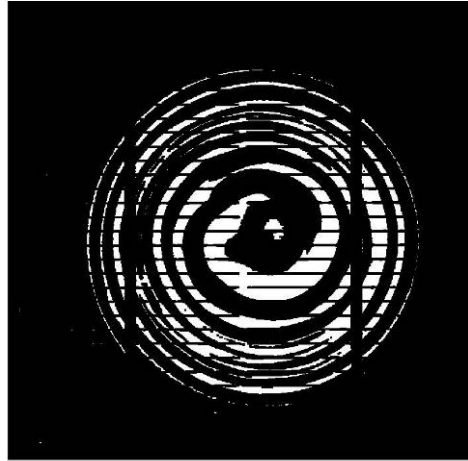


Fig. 7. Semireresults after thresholding and erodovation.

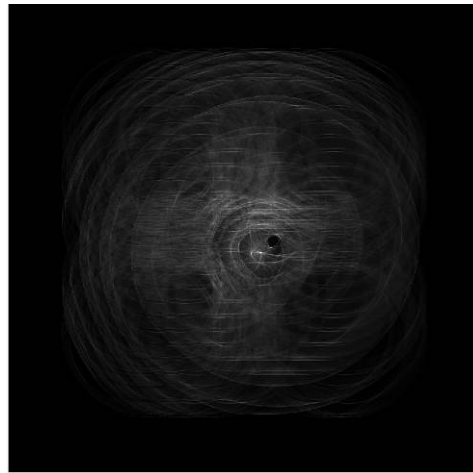


Fig. 8. Houghs space of swirl defect.

Then on the image is applied the thresholding and the defects are analyzed by image processor in Matlab and compared with known defects shape and characters.

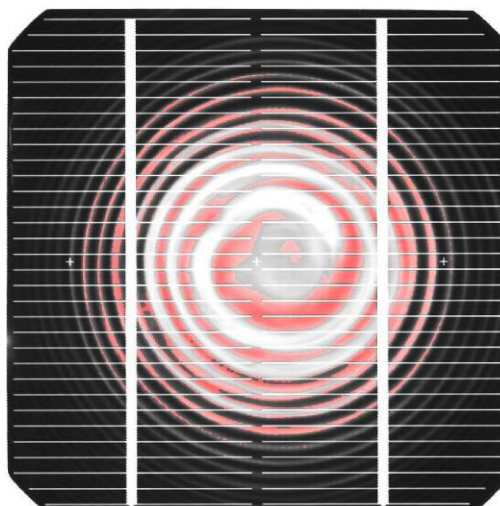


Fig. 9. Output results.

The image processor compare the know defects shapes and structures with gained images. We are able to detect missing contacts, random curves which represents scratches and dust and regular shapes like circles which represents swirl defects.

### Solar module image analysing

The first step of computer analyzing of whole solar module electroluminescence image is separating of single solar cells from the module by image slicing. Then is made the black and white color weighing. To obtain really useful analyses there must be decided what type of defect can be automatically detected (from the defect database), separated analyzed solar cells in panel area, analyze intensity of the luminescence light of the cells, mask contact grid of analyzed data and by comparison image analyzing process found out if the solar cell contain a defect and than what type of defect it is.

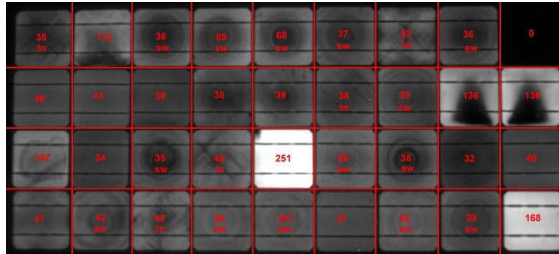


Fig. 10. Analyzed electroluminescence images of monocrystalline silicon solar panel (displayed in 256 gray-scale).

### Conclusion

By the averaging of luminescence intensity light of the separated solar cells we are able to recognize defected solar cells of unconnected solar cells. By the adaptive thresholding of particular solar cell image and comparison with defect database we are able to recognize what type of defect of the solar cell structure was detected..

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