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the crack pattern shown in figure 15 a is shown in figure 14 a. this figure shows examples of micro-cracks with different orientations, that is 0, 45 and 90 degrees. the diagonal lines forming the star-like artifacts are the edges of the crack as seen from the crack pattern. these cracks have been divided into two classes: crack class 1 and crack class 2. in this study, the crack class 1 consists of cracks having the orientations of 0, 45 and 90 degrees while the crack class 2 consists of cracks having orientations of 15, 30, 45, 60, 75 and 90 degrees. the crack length is denoted by c. the values of c and d are set to 5 and 2 pixels, respectively. the number of pixels used in the algorithm is 20. the result obtained by the algorithm is shown in figure 14 b. as seen from this figure, the crack pixels are highlighted by the algorithm. since the crack class 1 is characterized by straight lines, it can be more easily detected than crack class 2. the challenge of detecting micro-cracks in a multicrystalline solar cell is overcome by performing the following image processing steps. first, the background is extracted by eliminating the dark area in a solar cell using a thresholding method. the threshold is adjusted manually to improve the detection and segmentation accuracy. an example of this procedure is shown in figure 2 c (ii). the dilation of the edges of the dark area is also performed to remove the false detections caused by the edges of the grains. the image processing steps are presented in the flowchart of figure 2 d. the thresholding method produces a binary image and the dilation further enhances the edge, increasing the selectivity of the detection process. the procedure to extract the background is as follows:

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art is an unsupervised learning technique with a three-step process. first, a set of training samples is used to learn the descriptor parameters. second, the trained art is used to determine the optimal thresholding level for the given training set. finally, the optimal thresholding level is used to classify the segmented image into two different classes of pixels (i.e., micro-crack and non-micro-crack). this process is repeated in order to remove the noisy pixels from the segmented image. this three-step process of art is illustrated in figure 1. it is evident that the proposed algorithm is more effective in extracting micro-crack pixels compared to the other segmentation techniques. this is confirmed by the results shown in figure 15, and the corresponding table 1. this implies that the proposed segmentation technique is able to correctly and completely extract micro-cracks from solar cell images, while other methods could be applied to extract micro-crack pixels but could fail to extract the micro-cracks correctly or completely. these results are expected because the proposed method considers the micro-cracks with gradient. therefore, the proposed technique is able to extract the micro-cracks even if their shapes are not exactly aligned with the gradient of the image. this is not the case for the other techniques which are not able to extract micro-cracks if their shapes are not exactly aligned with the gradient. however, it is important to mention that the proposed algorithm is more time-consuming compared to the other segmentation techniques since the algorithm has to consider the gradient of the images and extract the micro-cracks using the threshold function. as the number of micro-cracks increase in the image, the processing time of the proposed method increases. the processing time of the other segmentation techniques is independent of the number of micro-cracks in the image. however, the processing time of the proposed technique is dependent on the gradient. in general, the number of micro-cracks can be controlled by adjusting the threshold values. thus, an algorithm which has lower processing time is obtained. it should be mentioned that the processing time depends on the gradient of the image. a gradient profile of a solar cell image is usually simple and is characterized by horizontal and vertical edges. thus, the processing time of the proposed technique is much lower compared to the existing segmentation techniques. it is evident that the proposed technique is more effective in extracting micro-crack pixels compared to the other segmentation techniques. 5ec8ef588b