

Shape-based Micro Crack Detection in Plastic through Image Processing

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Abstract

Image-based crack detection methods are increasing in practical applications, because they are automatically nondestructive inspections and provide the quantitative information. To investigate the tiny and unclear cracks on the surface of plastic, we employ a novel method based on image processing and optimization to identify the cracks. Cracks are discerned in the gradient image reconstructed with four different angular orientations. Circularity is used as the description of region shape to measure the quality of binarization. After noise reductions, cracks are apparent in the binary image. Experimental results show the proposed method is an effective way to inspect micro cracks in plastic. It could be found that our method is robust to the number of sub-images. Hence, it is very suitable for the micro crack inspections in practical applications.

Keywords: *micro crack detection; optimal thresholding; region shape modeling; image gradient*

1. Introduction

Image processing is widely employed in optical applications, especially in the field of automatic inspection such as remote-sensing analysis [1] and damage identification using laser [2]. Image-based crack detection method is one of the nondestructive testing (NDT) techniques, so it attracts many researchers in deferent areas. Since cracks shorten the life-circle of materials, crack inspection assists in estimating the current condition and future performance of the materials. In the research of crack propagation through digital image process, crack detection is the fundamental and crucial step for other processes. Plastics are used as experimental materials in our research. Cracks are formed on the surface of plastics under the irradiation of natural light or ultraviolet. The following section outlines the state of the art in crack inspections.

Recently, a lot of studies have been made in the field of crack detection [3-6]. Yamaguchi *et. al.*, [7-8] introduced a percolation-based image process to detect cracks, where local window size can be changed. Li *et. al.*, [9] developed an F* seed-growing method based on the idea of the shortest path method to detect crack-line with no point set first. Nishikawa *et. al.*, [10] presented a crack inspection algorithm using iterative applications of image filter created by genetic programming (GP). However, all these methods are based on the assumption that the crack brightness is darker than the background, which will make the results in failure. Oliveira *et. al.*, [11] employed an unsupervised two-step pattern recognition system with the learning paradigm for crack detection. Kabir [12] applied the gray level co-occurrence matrix (GLCM) texture analysis and artificial neural network (ANN) classifier to obtain the crack information. Chen *et. al.*, [13] also designed a feature extraction method to inspect cracks. These approaches are based on pattern recognition, which means many samples should be

obtained first. Quek *et. al.*, [14] examined the sensitivity of wavelet technique in the detection of cracks in beam structures. Iyer *et. al.*, [15] also proposed a method based on mathematical morphology and curvature evaluation that detected crack-like patterns in a noisy environment.

To solve the above limitations of existing methods, we proposed a novel crack detection method. In order to reduce the impacts of illuminations, gradient operator is used to reconstruct the raw image. Hence, it is more robust to the bad contrast. The key contribution of our research is the threshold is achieved by an optimal program. Shape and size are both employed to describe the cracks. It guarantees that most of the cracks-like pattern could be found.

The rest of this paper is organized as follows: Section 2 analyses the features of micro cracks in plastic. Section 3 presents the proposed method based on the characters of cracks in plastic. Section 4 reports our experiments study. Section 5 concludes our works and points out the future study directions.

2. Analyses of Micro-Cracks in Plastic

The images of plastic with cracks are achieved by camera in the lab. Figure 1 shows examples of micro-cracks and noises in plastic. Cracks are small and indistinct. Besides, the brightness of cracks is either lighter or deeper than the background. Since cracks possess such characteristics, they cannot be successfully inspected with gray-level binary approaches such as Otsu method or clustering method.

Although cracks hold the unexpected qualities, the features they have in common are that most of them are line-like cracks, and their shape is thinner than those of other textural patterns. Hence, in this paper we focus on detecting cracks with the features of their shapes and size.

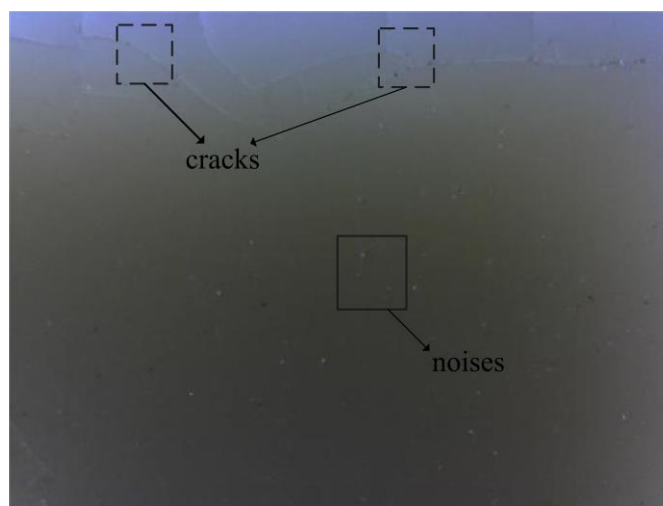


Figure 1. Cracks and Noises on the Surface of Plastic

3. Proposed Crack Detection Methods

3.1. Outline of the Method

A shape-based approach is presented for inspecting the micro cracks in plastic. Firstly, crack image is reconstructed with image gradient operators. Then, it is divided into some sub-images. For each sub-image, an optimal model based on region shape and size is built to measure the quality of image binarization. Finally, the cracks are segmented with the

optimal threshold and the information of cracks could also be obtained. Flowchart of the proposed method is illustrated in Figure 2.

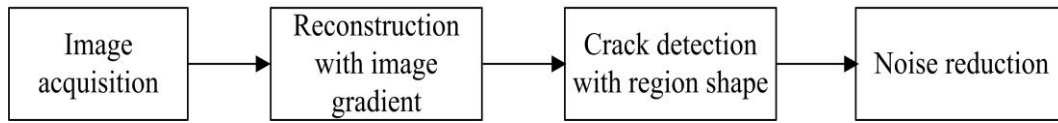


Figure 2. Flowchart of the Proposed Method

3.2. Image Reconstructions with Image Gradient

Owing to the qualities of cracks, it is unsuitable to locate cracks with the brightness in the plastic image. Therefore, image gradient is employed to reconstruct the crack image. The gradient of the whole image is expressed as follows:

$$\nabla I = \sqrt{I_x^2 + I_y^2} \quad (1)$$

Where, I_x and I_y are vertical and lateral gradient. The gradient can be obtained with Robert, Prewitt or Sobel operator. However, we use an approximation to evaluate the image gradient. The formula is written as:

$$\nabla I(i, j) = \max\{|I(i, j-1) - I(i, j+1)|, |I(i-1, j-1) - I(i+1, j+1)|, |I(i-1, j) - I(i+1, j)|, |I(i-1, j+1) - I(i+1, j-1)|\} \quad (2)$$

In the formula, the maximum of absolute difference between pixels, which are eight neighbors of the central pixel, is utilized to represent the gradient with four angular orientations (0° , 45° , 90° and 135°). The reconstructed crack image is shown in Figure 3. Cracks and noises are lighter than the background, thus we utilize the binarization method to detect the cracks.

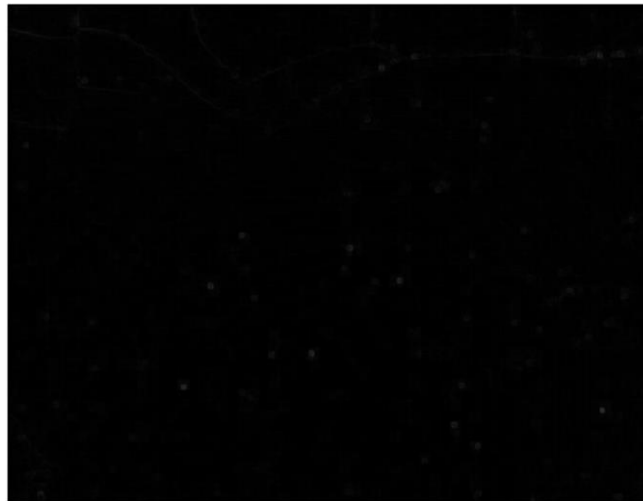


Figure 3. Crack Image Reconstructions with Image Gradient

3.3. Crack Detection with Region Shape

A shape-based optimal model is built to identify the cracks after the achievement of reconstructed crack image. Circularity is employed to describe the shape of cracks, which is used as an objective function in the optimal program. The formula of circularity is as

follows:

$$\rho = 4s/(\pi d^2) \quad (3)$$

Where, s symbolizes the size of the region R in the foreground. d denotes the maximum length of R . ρ ranges from 0 to 1. If the region denotes a crack, ρ is close to 0. However, when considering the shape of noises or circular regions, we notice that ρ is close to 1. Thus, cracks can be distinguished from noises by the circularity of regions.

The reconstructed crack image is divided into $M \times M$ sub-images to obtain the expected detection results. Each sub-image is converted to the binary image with a given threshold. Let T_j denote the binarization threshold and n_j be the number of regions in sub-image j . The circularity of sub-image j is:

$$C_j = \sum_{i=1}^{n_j} \rho_{i,j} \quad (4)$$

Therefore, our aim is to find a proper threshold T_j to minimize C_j . The range of T_j is:

$$\max\{\min \nabla I_j, \text{const}\} \leq T_j \leq \max \nabla I_j \quad (5)$$

Where, const is a given constant. If the threshold is proper, the best result can be achieved. This means the circularity and number of connected regions should both be small. Thus, we set $n_j \leq 2$.

Figure 4 shows the result of crack detection with the proposed optimal program. As Figure 4 illustrated, the optimal algorithm performs well, and cracks are clearly distinguished from the background. However, there are still many noises in the image.

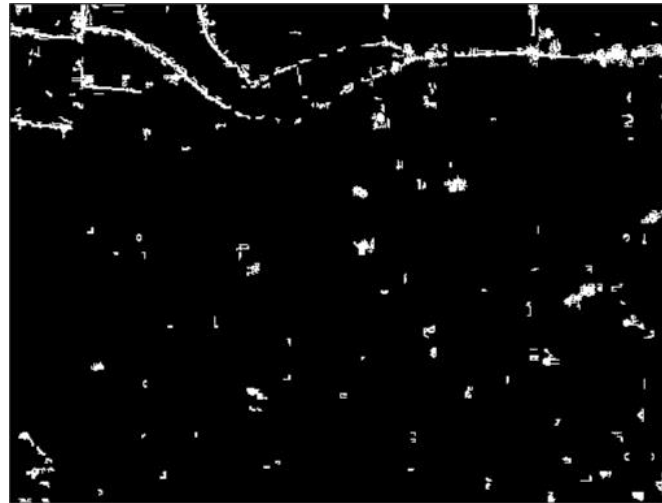


Figure 4. Result of Crack Detection with the Optimal Thresholding

3.4. Noise Reduction

Noise reduction is frequently used in image processing. Dependable results of noise reduction are achieved based on the reduction method and specific issues. We reduce the noise from two aspects, including region size and circularity. Region whose size is less than s_0 or circularity is larger than ρ_0 is removed. In experiment, we set $\rho_0 = 0.3$ and $s_0 = 25$. Figure 5 shows the results after noise reductions. It can be found most of the micro cracks are successfully detected.

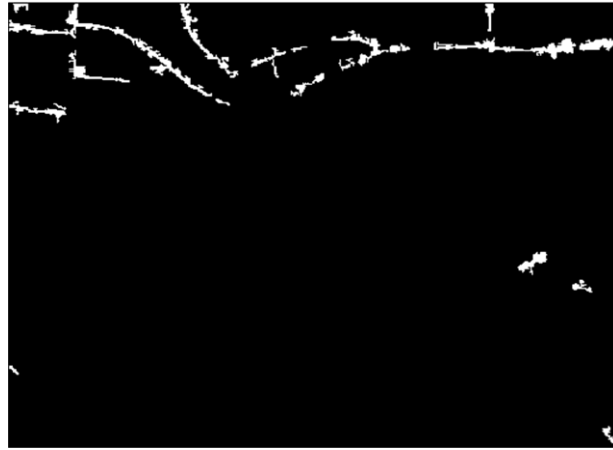


Figure 5. Noise Reductions with the Region Shape and Size

4. Experiments and Discussions

4.1. Results and Analyses

In this section, we test our algorithm with images gained in lab. The image resolution is 384×512 pixels, and it is divided into 10×10 sub-images, which means $M = 10$. It is worth noting that the optimal algorithm should be carried out $M \times M$ times. So the running time must be considered. Due to the unclear and small cracks, the gradient holds a small value; the best threshold T can be quickly found in iterations. It indicates that the optimal program is not time consuming in each sub-image. Parts of detection results are shown in Figure 6. It could be found the proposed method performs well, regardless of the bad contract and complex noise conditions.

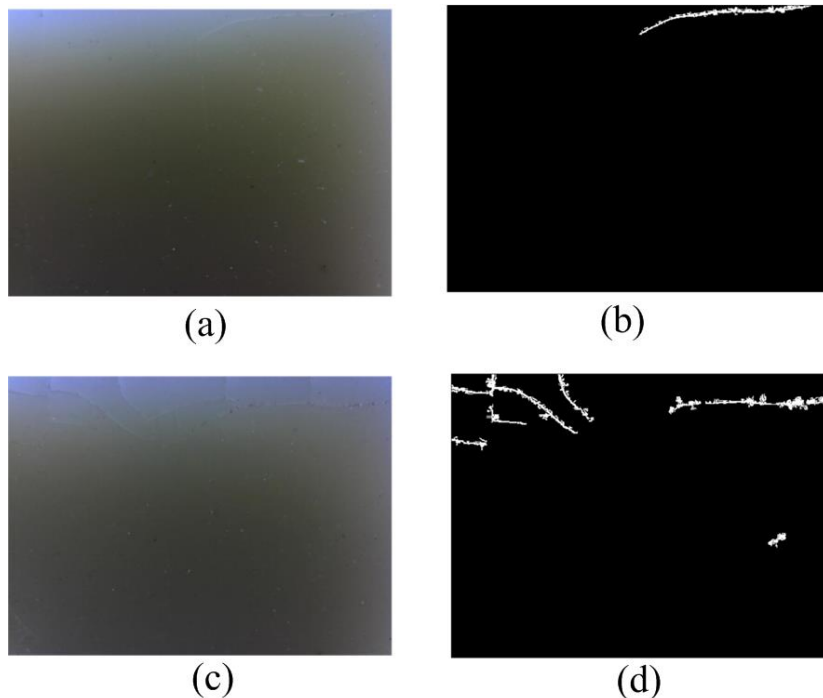


Figure 6. Detection Results of the Micro Cracks in Plastic: (a) and (c) are Original Images; (b) and (d) are Detection Results.

4.2. Performance Comparisons

The proposed is compared with the Otsu and clustering method. The results of other two methods are poor because of the unsuitable thresholds. However, the proposed optimal threshold works well. It could be concluded our method is better than the other two approaches. It is worth to notice that the same noise reduction parameters are used in these three methods. Meanwhile, binarization was conducted with the gradient image to remove the impacts of the bad contrast in gray-level.

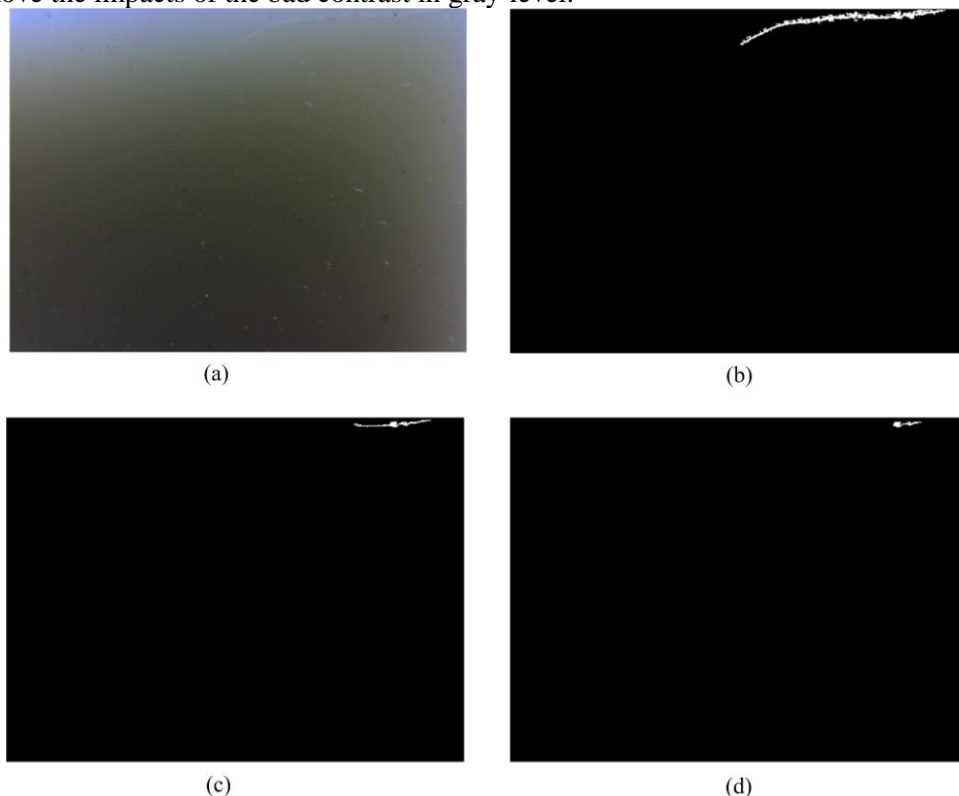


Figure 7. Comparing with Otsu and Clustering Method. (a) is the Original Image; (b) is the result of the Proposed Method; (c) is the Result of Otsu; (d) is the result the Clustering Method.

4.3. Effects of the Size of Sub-Images

All aforementioned experiments are conducted out with fixed M value. Figure 10 illustrates the detection results for changing the number of sub-images. It could be seen that the detection results change slightly. Hence, we can conclude the proposed method is robust to the number of sub-images.

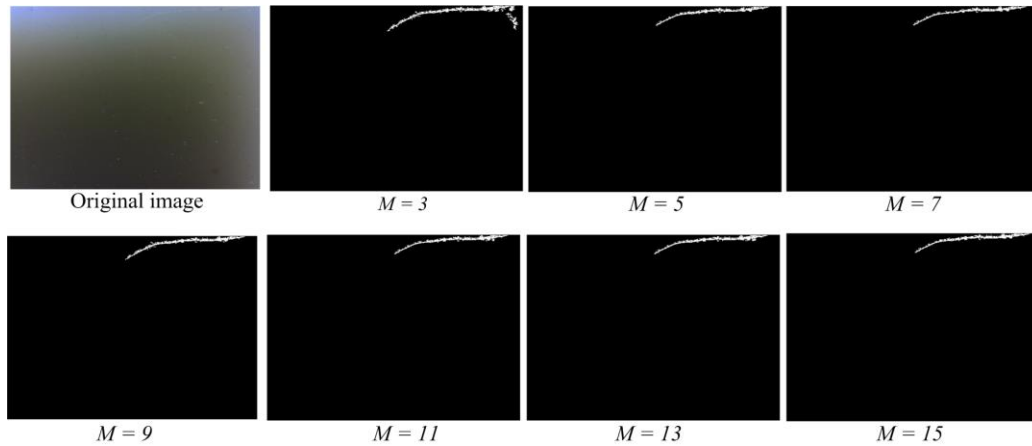


Figure 8. Robustness to the Number of Sub-Images

5. Conclusions

We have used image processing technique to characterize the crack on the surface of plastic. Image gradient is evaluated with approximately four angular orientations. The assumption that crack color is darker than the background is overcome with the given image gradient. The region shape is used as an objective function in our crack detection algorithm to measure the quality of binarization. Experimental results show the algorithm is very effective in detecting micro and unclear cracks. Another conclusion is that our method is better than the other two classical methods. It can also be concluded the proposed method has certain robustness to the number of sub-images.

In our future research, the connective of crack will be discussed in detection procedure. Furthermore, the length, width and orientation of the cracks will be researched.

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