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Defects' geometric feature recognition based on infrared image edge detection

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HIGHLIGHTS

- Defects' edge detection effect of classic edge detection operators was analyzed.
- FCM-Canny operator algorithm was proposed and to achieve defects' edges.
- The proposed algorithm has better effect than the classic edge detection operators.
- The defects' diameters have been calculated based on the image edge detection results.

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ABSTRACT

Edge detection is an important technology in image segmentation, feature extraction and other digital image processing areas. Boundary contains a wealth of information in the image, so to extract defects' edges in infrared images effectively enables the identification of defects' geometric features. This paper analyzed the detection effect of classic edge detection operators, and proposed fuzzy C-means (FCM) clustering-Canny operator algorithm to achieve defects' edges in the infrared images. Results show that the proposed algorithm has better effect than the classic edge detection operators, which can identify the defects' geometric feature much more completely and clearly. The defects' diameters have been calculated based on the image edge detection results.

1. Introduction

Infrared thermography techniques have been widely used for nondestructive evaluation because they are nonintrusive, rapidly deployable and applicable to a structure under harsh environments [1–3]. Edge detection is an important technology in image segmentation, feature extraction and other digital image processing areas. Boundary contains a wealth of information in the image, so to extract defects' edges in infrared images effectively enables the identification of defects' geometric features.

The classic image edge detection methods include Roberts, Sobel, Prewitt, LOG, Zerocross and Canny operators. Such algorithms take first-order derivative extremum and second-order derivative zero crossing points as candidate edge points of the processed images [4–6]. The image global threshold is set artificially as evaluation criteria, and the candidate edge points whose gradient values are smaller than the threshold value will be deleted, in order to remove the noise and weak edge points in the images. Each pixel's domain is examined and its gray change rate is quantified when used classical edge detection operators. However, a number of external factors interfere the infrared images' collecting process, which results to the acquired images' complex information. In the course of processing the infrared images, the selection of image information and the classification of sample points are often ambiguously and uncertainly. Therefore, the use of those classic operators only is often difficult to obtain the desired detection effect.

Cluster analysis is a relatively new method for image segmentation, which has been widely used in pattern recognition, image processing, automatic control, and many other fields [7–9]. The principle of cluster analysis is based on certain clustering rules, and the sample data with the same characteristics are clustered together in order to classify the sample data. This study presents the combination of the fuzzy clustering algorithm and Canny operator to achieve the identify defects in the infrared image, and then calculate the defects' diameters.

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2. Defects' edge detection based on classic detection operators

The specimen of SiC coated C/C composite matrix was tested using pulsed thermography testing system. Fig. 1 shows an infrared image which is obtained in pulsed thermography test, and its gradation-converted image. Fig. 2 shows the detection results using the above classic detection operators. It can be seen that the infrared image edge extraction is not fine using Roberts, Sobel and Prewitt operators, which may result to incomplete identification of defects' edges or even missed detection of defects. LOG, Zerocross and Canny operators can extract the image edges subtly, but sometimes the edges detected are not real edges of defects, especially in the relatively flat gray variation areas, a small noise may lead to the second derivative' zero output. LOG and Zerocross operators still identify individual defects incompletely. Through comparative analysis, Canny operator can identify almost all edges of the defects, but it also contains a lot of redundant information, which will bring some interference to identify the defects.

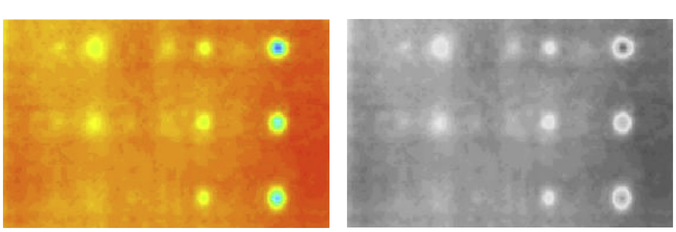
3. Defects' edge detection based on FCM clustering-Canny operator

K-means clustering and FCM clustering are two typical clustering algorithms. *K*-means clustering, that is, ordinary C-means clustering, which divided the sample data hard, and each sample data are strictly divided into a certain category. In practical problems, things are often not "either-or", so the vague should be considered, that is, some things or characteristics are not just belong to a particular class, but belong to different classes, just there are differences in degree. Therefore, the introduction of fuzzy math theory into clustering analysis, can describe the uncertainty of image information well [7–9]. So using fuzzy clustering analysis method detects the edges of infrared images, can achieve better detection results.

FCM clustering algorithm is based on fuzzy division. The objects which are divided into the same cluster are of greatest similarity, while objects which are divided into different clusters are of smallest similarity. FCM clustering algorithm divides the sample data $X = \{x_1, x_2, \ldots, x_n\}$ into c categories. x_k is assumed to be arbitrary sample of X, $u_{ik}(0 \le u_{ik} \le 1)$ is the subjection of x_k belonging to the ith category. So the classification results can be expressed as $c \cdot n$ order matrix U, which is called fuzzy matrix. It has the following properties:

$$\begin{cases} u_{ik} \in [0,1] & \forall i,\ \forall k \\ \sum_{i=1}^{c} u_{ik} = 1 & \forall k \\ 0 < \sum_{k=1}^{n} u_{ik} < n & \forall i \end{cases} \tag{1}$$

In order to seek reasonable classification results in so many possible classifications, a reasonable clustering criterion should be determined. In this case, the objective function is defined as the weighted sum of class squared error



(a) The input infrared image (b) Gray level transformation

Fig. 1. The input image.

$$J(U, c_1, \ldots, c_c) = \sum_{i=1}^{c}\sum_{k=1}^{n} u_{ik}^m d_{ik}^2 \tag{2}$$

where U is fuzzy classification matrix, and $U = [u_{ik}](i = 1, 2, \ldots, c; k = 1, 2, \ldots, n)$, $\sum_{i=1}^{c} u_{ik} = 1, \forall k$; c_i the cluster center of fuzzy set i. d_{ik} is the Euclidean distance between the ith cluster center and the kth data point, $d_{ik} = ||c_i - x_k||$; m is the weighted index, $m \in [1, \infty)$.

Through the iteration of FCM clustering algorithm, the necessary conditions for formula (2) to reach minimum are

$$c_i = \frac{\sum_{k=1}^{n} u_{ik}^m x_k}{\sum_{k=1}^{n} u_{ik}^m} \tag{3}$$

$$u_{ik} = \frac{1}{\sum_{j=1}^{c}\left(\frac{d_{ik}}{d_{jk}}\right)^{1/(m-1)}} \quad 1 \le i \le c,\ 1 \le k \le n \tag{4}$$

When the data X to be classified, the category of clustering number c and the weighted index m are known, the FCM iteration steps are as follows: (1) According to Eq. (1), taking a random number in the range of $[0, 1]$ to initialize the fuzzy classification matrix U; (2) Calculate the clustering centers $c_i, i = 1, 2, \ldots, c$ according to Eq. (3); (3) According to the values obtained in the last two steps and Eq. (2), calculate the objective function. If the target function is less than a determined threshold, or the change amount comparing to the last target function is smaller than a threshold value ε, then the algorithm stops at this time; (4) Calculate the new fuzzy matrix U according to Eq. (4), and return to the step (2). Then the cluster center of each category c_i and the subjection matrix of each sample can be determinated, thus completing the division of fuzzy clustering.

The realization process using Canny operator for image edge detection is shown in Fig. 3. The infrared image edge detection algorithm flow of FCM clustering-Canny operator is shown in Fig. 4. First, take overall gray-scale transformation of the input infrared image. Do image segmentation using FCM clustering algorithm, and label the segmented regions with different gray values. Second, each region after clustered is extracted and binarized. Third, superimpose each area in order to get continuous edges of the infrared images. Finally, Canny operator is used to edge detection of the processed images, and thus the defects can be recognized.

The number of clusters c is usually less than the number of sample data, and also to ensure $c > 1$. The weighted index m is used to control the algorithm' flexibleness. If m is too large, it will lead to poor clustering effect; If m is too small, it will cause the algorithm close to *K*-means clustering algorithm. Usually, take $m \in [1.5, 2.5]$ according to experience. For the input image shown in Fig. 1, take $c = 2$, $m = 1.7$ and $\varepsilon = 0.05$. Fig. 5 shows images processed by the above FCM clustering algorithm and detected by the Canny edge operator. Compared with the recognition results of classical edge detection operators, after processed by FCM clustering-Canny operator, the defects' edges are identified more complete and clear, at the same time, it does not contain redundant information, which is more conducive to the determination and identification of defects.

4. Defects' diameter calculation based on edge detection

The defects' diameter can be calculated according to the image edge detection result in Fig. 5(b). The number of pixels of the image is set to $t_{px} \times t_{py}$, and its corresponding length and width dimensions are $L \times B$. The number of pixels corresponding to the defect edge diameter is expressed as d_p, then the actual size of the defect d_{rp} can be expressed as: