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An infrared thermal image processing framework based on superpixel algorithm to detect cracks on metal surface

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HIGHLIGHTS

- A proper superpixel algorithm was selected for infrared thermal image processing.
- Proper texture features of superpixels were selected for clustering.
- A new infrared thermal image processing frame was proposed to detect cracks automatically.
- Experiments were implemented to verify the effectiveness of the image processing frame.

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ABSTRACT

Infrared thermography has been used increasingly as an effective non-destructive technique to detect cracks on metal surface. Due to many factors, infrared thermal image has low definition compared to visible image. The contrasts between cracks and sound areas in different thermal image frames of a specimen vary greatly with the recorded time. An accurate detection can only be obtained by glancing over the whole thermal video, which is a laborious work. Moreover, experience of the operator has a great important influence on the accuracy of detection result. In this paper, an infrared thermal image processing framework based on superpixel algorithm is proposed to accomplish crack detection automatically. Two popular superpixel algorithms are compared and one of them is selected to generate superpixels in this application. Combined features of superpixels were selected from both the raw gray level image and the high-pass filtered image. Fuzzy c-means clustering is used to cluster superpixels in order to segment infrared thermal image. Experimental results show that the proposed framework can recognize cracks on metal surface through infrared thermal image automatically.

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1. Introduction

Infrared (*IR*) thermography is a non-destructive and non-contact technique which is widely applied in predictive and preventive maintenance programs [1–4]. In this technique, there are two ways to get the IR thermal image, the active and passive heating [5]. When IR thermography is applied to detect cracks on metal surface, the former heating way is used widely [6–9]. When a metallic part with surface cracks is heated, the heat will diffuse differently through cracks and sound area. Cracks will prevent the heat diffusion and lead to a heat convergence. Consequently, the area around cracks will show higher temperature than sound area. This abnormal temperature distribution can be captured using an IR thermal imager. Therefore, cracks can be recognized by finding out the abnormal temperature area in the IR thermal image by an engineer. However, one limitation of the technique is that to determinate the location and size of cracks by glancing over the whole thermal video is laborious. Moreover, the inspection result is easily affected by the engineer. Consequently, to construct a proper image processing framework to pick out crack areas from sound ones is needed eagerly to realize the automatic crack detection using IR thermography.

Using image processing technique, picking out cracks from sound areas can be accomplished by segmenting the image into crack areas and sound ones. Many image segmentation algorithms have been widely used in image processing field, such as mean shift [10], normalized cuts [11], watersheds [12], graph-based

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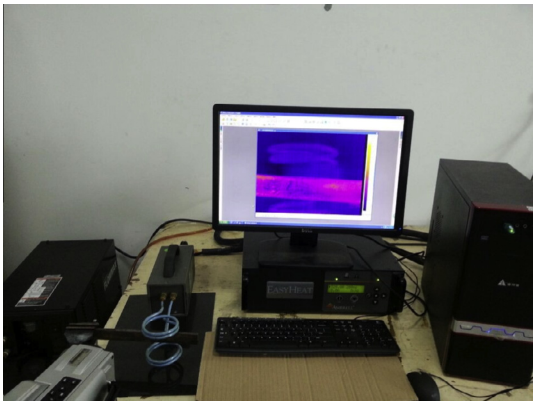
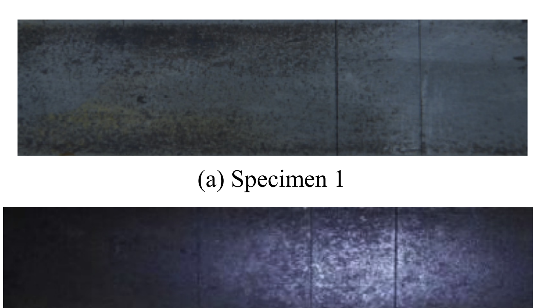


Fig. 1. Experimental equipment.

Table 1
The characters of SAY-HY6850 IR.

Measurement range	−10 °C–600 °C (standard) −40 °C–2000 °C (extensions)
Sensitivity	0.08 °C
Accuracy	±2%
Infrared image resolution	320 × 240
Spatial resolution	1.3 Mrad
Field angle	24° × 18°

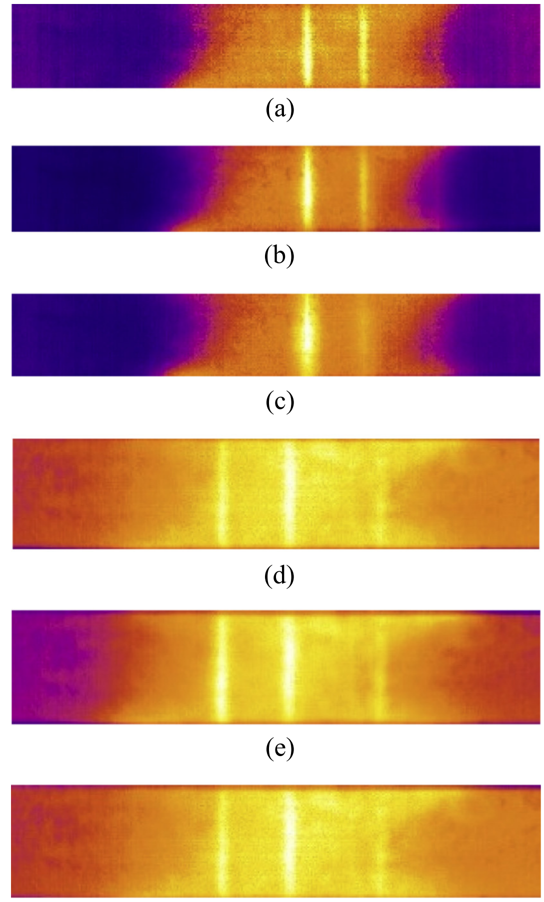
[13] and so on. All these classic segmentation algorithms process an image as gather of pixels. Ren X proposed another method for image segmentation named superpixel algorithm [14]. Using existing segmentation method, superpixel algorithms over-segment an image into perceptually meaningful atomic regions which can be used to replace the rigid structure of the pixel grid. Superpixels can capture image redundancy and greatly reduce the complexity of subsequent image processing tasks. Moreover, superpixel algorithms can supply additional information, such as mean and variance of gray levels in a superpixel, to subsequent segmentation algorithm. We applied the superpixel algorithm to the IR thermal image segmentation in order to improve the accuracy of detection and speed up the detection process. Many segmentation methods have been used to generate superpixels. The Normalized Cuts algorithm was used to generate superpixels in [13]. AchantaIn et al. proposed a superpixel algorithm named *simple linear iterative clustering (SLIC)* based on K-means in [15]. David Martin and Charless Fowlkes' boundary detector was used in [16,17]. In this paper, the watersheds algorithm was compared to SLIC which is the latest popular superpixel algorithm and the former one was selected to generate superpixels in this application.



(a) Specimen 1

(b) Specimen 2

Fig. 2. Specimens with cracks.



(a) (b) (c) (d) (e) (f)

Fig. 3. IR thermal frames (a)–(c) are frames obtained at 100 ms, 200 ms, 250 ms from specimen 1 and (d)–(f) are frames obtained at 100 ms 160 ms 200 ms from specimen 2.

After over-segmenting one thermal image into superpixels, the next work is to cluster the similar superpixels and obtain the final segmentation of the thermal image. *Fuzzy c-means* (*FCM*) clustering algorithm in [18] was used to cluster superpixels. We chose proper features of superpixels as the input of FCM algorithm. Compared with visual image, IR thermal image has low signal to noise ratio due to a great deal of noise coming from electronic noise, photon noise, aberrations of the optical system, environment temperature disturbance, and some other random factors [19]. When only using the superpixels' features in raw gray level image, the segmentation result is found to be very poor. Because much noise can be eliminated by using a high-pass filter, the combined features of superpixels in both raw gray level image and high-pass filtered image were selected as the input of the clustering algorithm. We recognized the crack cluster as the one with biggest mean gray level. Finally, tiny noise still existing was removed using morphologic operator.

We validated our frame by conducting experiment on test specimens with surface cracks manufactured by wire electrical discharge machining. The accurate information of cracks was automatically determined in a short time using the proposed thermal image processing framework.

2. Experimental procedure

The experimental setup shown in Fig. 1 was made of a computer, an inductor, an IR thermal imager and two specimens. The

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