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Pulsed infrared thermography processing and defects edge detection using FCA and ACA

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HIGHLIGHTS

- CFRP sheet with delamination defects was detected using pulsed infrared thermography.
- A new polynomial fitting the derivative time-related coefficient algorithm (FCA) was proposed.
- Defects' edge features have been extracted using ant colony algorithm (ACA) effectively.

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ABSTRACT

CFRP sheet with delamination defects was detected using pulsed infrared thermography. The principle of polynomial fitting the derivative time algorithm (FDA) and related coefficient algorithm (RCA) was described. A new polynomial fitting the derivative time-related coefficient algorithm (FCA) was formed by combining FDA and RCA, which improves the signal to noise (SNR) of feature images, and is benefit for the detection and identification of defects. The defects edge identification procedure using ant colony algorithm (ACA) is given, and the defect edge features in the infrared image have been extracted using ACA effectively.

1. Introduction

Infrared thermography has become one of the most promising techniques for non-destructive testing and evaluation in a variety of materials, including concrete, high-density polyethylene, aerospace composites, wood-based materials, and adhesive bond evaluation [1–3]. In active thermography inspection, the specimen is stimulated by external heat sources, and the existence of defects will lead to abnormal thermal distribution, which can be captured by an infrared thermal camera [4,5]. Pulsed thermography (when a pulsed heat source is used for external heating) is used widely because of its short thermal stimulation pulse and inspection efficiency [6–8]. However, as the existence of non-uniform heating, inconsistent surface emission rate, ambient noise and the performance of infrared thermal camera, the pulsed infrared thermography obtained is of complexity usually. How to extract the weak heat change of the component surface is the key for defects detection.

In this paper, CFRP sheet with delamination defects was detected using pulsed infrared thermography. The principle of polynomial fitting the derivative time algorithm (FDA) and related coefficient algorithm (RCA) was described. A new polynomial fitting the derivative time-related coefficient algorithm (FCA) was formed by combining FDA and RCA, which improves the signal to noise (SNR) of feature images, and is benefit for the detection and identification of defects. The defects edge identification procedure using ant colony algorithm (ACA) is given, and the defect edge features in the infrared image have been extracted using ACA.

2. Inspection on CFRP sheet with subsurface defects using pulsed thermographic technique

2.1. Specimen description

The three dimensional model of CFRP sheet with subsurface defects is shown in Fig. 1. 12 artificial flat-bottomed hole defects with different diameter and depth were made in the CFRP sheet, which is shown in Table 1.

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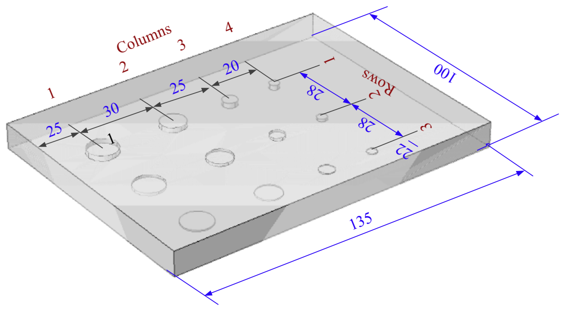

Fig. 1. The CFRP sheet specimen with flat-bottomed hole defects.

2.2. Inspection results

The above CFRP sheet specimen was detected using pulsed thermography system. Two flash lamps were used to generated pulsed heat 2160 J and stimulate the specimen surface without defects. And an infrared camera SC7000 was used to capture the infrared thermography. Multiple detection tests show that, when the frame rate and acquisition duration was 10 Hz and 10 s respectively, the inspection results was relatively good. Fig. 2 shows the original thermal image with maximum contrast captured by the infrared camera, and it can be seen that the surface temperature difference is almost lost in the strong noise, which is because the inconsistent emissivity of the specimen surface, uneven heating, and the influence of ambient noise. From Fig. 2, only 3–5 hole defects can be detected. Therefore, in order to distinguish defective and non-defective areas effectively, it is necessary to carry out further processing to the original pulsed thermography, and thus improve the defect detection ability of this testing technology.

3. The principle of polynomial fitting the derivative time-related coefficient algorithm

3.1. The principle of polynomial fitting the derivative time algorithm (FDA)

The value of temperature for each pixel (x, y) on the multi-frame images at a time t_i, recorded by infrared camera, can be expressed by a set of data collection $\{(t_i, T_i),\ i = 1, 2, \ldots, N\}$. Polynomial coefficients and the mapped intensity images can be obtained, according to least squares fitting rule. Polynomial fitting is a smoothing operation, and the polynomial coefficients can be used to restore the original thermal image sequence without high-frequency noise.

3.2. The principle of related coefficient algorithm (RCA)

The base of related coefficient algorithm is signal processing and pattern recognition theory. The relevant indicators of temperature change process to different pixels can be calculated, and the index value will be mapped into a intensity map. According to the theory of signal processing, two n points sampled discrete signals, $s(x_1, x_2, \ldots x_n)$ and $s_r(y_1, y_2, \ldots y_n)$, the correlation coefficient r can be defined as follows:

Table 1
Size of subsurface defects in the CFRP specimen.

Rows	Columns 1	2	3	4
1	DA = 12.0 DP = 0.5	DA = 10.0 DP = 0.5	DA = 6.0 DP = 0.5	DA = 4.0 DP = 0.5
2	DA = 12.0 DP = 1.0	DA = 10.0 DP = 1.0	DA = 6.0 DP = 1.0	DA = 4.0 DP = 1.0
3	DA = 12.0 DP = 2.0	DA = 10.0 DP = 2.0	DA = 6.0 DP = 2.0	DA = 4.0 DP = 2.0

DA-Defect diameter and DP-Defect depth.

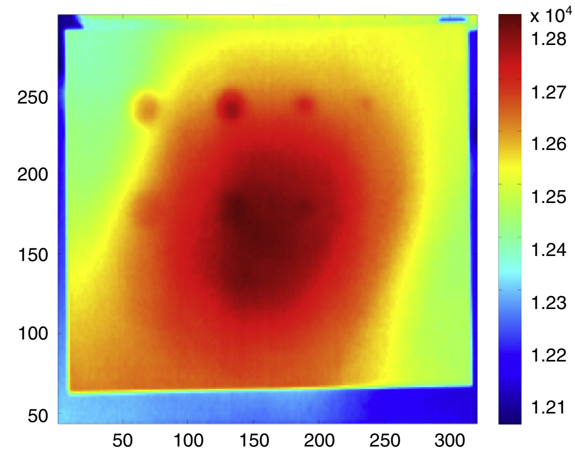

Fig. 2. Original thermal image of maximum contrast.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{1}$$

where $\bar{x}$ means the average component of s; $\bar{y}$ means the average component of s_r.

3.3. The principle of polynomial fitting the derivative time-related coefficient algorithm (FCA)

The infrared thermal image sequence processing steps using FCA is as follows: first, applying polynomial fitting to the logarithmic temperature versus time variation curve, in order to reconstruct the original temperature signal; then, assess the degree of approximation between the reconstructed signal and the reference signal of each pixel. Fig. 3 shows the polynomial fitting schematic diagram of logarithmic temperature versus time.

The temperature change process of a certain point in thermal image sequence can be expressed by Eq. (2).

$$\Delta T(x, y, n) = T(x, y, t_n) - T(x, y, t_\infty) \qquad x = 1, 2, \cdots X; \quad y = 1, 2 \cdots Y \tag{2.a}$$

$$\Delta t_n = t_n - t_1 = n \cdot \Delta t \quad n = 1, 2, \ldots N - 1 \qquad \Delta t = \frac{t_E - t_1}{N} \tag{2.b}$$

where $\Delta T(x, y, n)$ means the temperature change process of a certain point in thermal image sequence; Δt_n means the time change.

Polynomial fitting of the logarithmic temperature and logarithm time can be expressed by Eq. (3).

$$\ln[\Delta T(x, y, n)] = polynomial\,[\ln(n \cdot \Delta t)] = polynomial\,\{[\ln(t_N - t_1) + \ln(n) - \ln(N)]\} \tag{3.a}$$

$$\xi = \ln(n) + C_1, \quad C_1 = \ln(t_N - t_1) - \ln(N) \tag{3.b}$$

$$\ln[\Delta T(x, y, n)] = \sum_{m=0}^{K} a_m(x, y) \cdot \xi^m + R(\xi)^{K+1} \tag{4}$$