10.21611/qirt.2023.20

4th Asian Quantitative InfraRed Thermography Conference

Microporous Defect Detection in Airship Envelope Materials using Laser Infrared Thermography

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Abstract

Detecting micrometer-sized holes in the skin is a major problem in the NDT of stratospheric airships, and to the best of our knowledge, there are still very few researches so far on NDT methods for microporous defects in envelope materials. In this paper, we propose to accomplish the automatic detection of microporous defects using an improved network based on U-net. While using a laser beam as a heat source, three different laser beam extension methods were compared in order to improve the problems of uniform laser beam intensity distribution and small heating area, and a fiber laser beam shaper with excellent heating effect was chosen as the experimental method. Micron-sized holes of different sizes were produced in the epidermal material. The detection of pore defects with a minimum diameter of 75 μm can be accomplished using the improved network with an accuracy of 95.3%. The experimental results show that the proposed method is able to significantly detect debonding defects at the adhesive bond as well as pore defects at millimeter and micrometer scale.

1. Introduction

Airship was born in the late 1920s and has re-emerged as a research hotspot in recent years due to its advantage of long hover time, wide field of view, and high cost-efficiency ratio, and is widely used in military and commercial applications [1-3]. As the key material of airships, the defect detection of airship skin material directly affects the safety and reliability during flight. However, the size of hundreds of square meters on the surface of a floatation vehicle makes it very difficult to find small millimeter-sized holes on its surface[4,5]. Recent research on the air-tightness of airships is mainly focusing on the damage mechanism of envelope materials, gas permeation mechanism, and material structure optimization[6,7,8].To the best of our knowledge, there has been little research on NDT/QNDE methods for micropores in envelope materials.

In order to realize the automatic detection of pore defects in the surface material of airship bladders, this paper constructs an automatic defect detection system at the micrometer level and the lower millimeter level by using laser thermography based on beam shaping and a detection network based on the U-net network and the attention mechanism. Firstly, the beam expansion effects of linear laser, Gaussian beam, and beam shaper are compared respectively, and the beam shaper is selected as the beam expansion method used. U-net is selected as the algorithmic network for automatic defect identification. In order to enhance the detection performance of the network, an improved convolutional channel based on attention mechanism is proposed and compared with the previously proposed attention mechanism.

2. Experiments and discussion

2.1. Experiments

The experimental system consists of a mid-wave infrared camera, a continuous-wave fiber laser, control and acquisition software, a linear motion platform, a concave lens, a Fresnel lens and a beam shaper. In the experiment, a continuous-wave fiber laser with a wavelength of 808 nm and a maximum power of 100 W was connected to the concave lens, Fresnel lens and beam shaper, respectively. The laser power in the experiment is set to 50 W and the working distance is about 80 cm. The concave lens produces a Gaussian beam on the surface of the specimen with an area of about 15 cm × 15 cm, the Fresnel lens produces a linear laser beam on the surface of the sample with a length of about 25 cm and a width of about 3 mm, and the beam shaper produces a homogeneous beam on the surface of the sample with an area of about 15 cm × 15 m. The laser is connected to a continuous wave fiber laser with a wavelength of 808 nm, a maximum power of 100 W, and a working distance of about 80 cm. The camera used was a cooled thermal imaging camera with a resolution of 640 x 512 pixels, a sampling frequency of 50 Hz, a spectral range of 3-5 μm, and an image element less than or equal to 15 micrometers.

The skin material of the blimp used for the experiment consisted of a multilayer polymer material, specifically polyester fabric, polyester film, polyfluoroethylene, and polyester-type adhesive, and the thickness of the sample was about 0.5 mm. The size of the experimental sample was about 30 cm × 30 cm, and 16 circular holes with a size range of 50 μm-600 μm were made using a laser in a central area of 20 cm × 20 cm, and the distance interval of the air holes was 4 cm, and the experimental sample was fixed on a wooden frame. with a distance interval of 4 cm, and the experimental sample was fixed on a wooden frame.

2.2. Discussion

In order to verify the effectiveness of the proposed method, we add the attention mechanism to the up-sampling process of the network and compare the detection performance of the following five algorithms: (1) U-net network; (2) Adding CBAM mechanism; (2) Adding ECA-Net; (3) Adding CA mechanism and (4) the algorithm proposed in this paper. Table 1 gives the comparison of detection mIoU, Accuracy, Recall and other parameters of each network. From the comparison of the results, it can be seen that the mIoU value and accuracy of the algorithm proposed in this paper are higher than the competitors, and the recall is only slightly inferior to the U-net model and is higher than the other models compared. The experimental results show that U-net-CA-ECA can effectively optimize the network structure and appropriately adjust the weight allocation, thus improving the detection ability of the network with the addition of a small number of parameters.

Figure 1 shows the detection results of each network on the experimental data. For defects above 200 μm, all networks are able to accurately complete the detection. For defects below 200 μm, only the algorithm proposed in this paper is able to detect all the labeled defects

3. Figures and tables

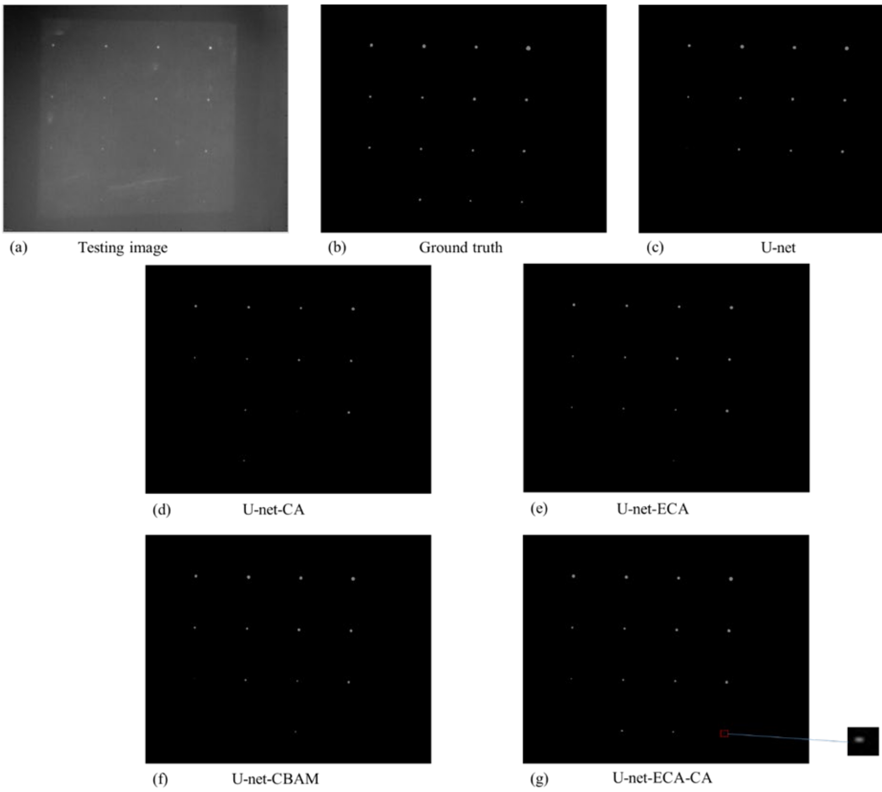

Fig. 1. *Comparison of the prediction results of the dataset*

Table 1. *Comparison results of different U-Net networks.*

Models	Miou	Map	Recall
U-net	80.95	0.910	**0.859**
U-net-CBAM	81.54	0.949	0.838
U-net-CA	78.64	0.941	0.811
U-net-ECA	79.41	0.940	0.820
U-net-CA-ECA	**81.80**	**0.953**	0.849

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