IMAGE PROCESSING FOR LASER SPOT THERMOGRAPHY

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Tematiche attinenti: Tecniche Innovative nel controllo NDT in campo Civile e Industriale.

SOMMARIO

La metodologia “laser spot thermography” fa parte delle tecniche di controllo non distruttivo, che si basano sull’analisi di immagini termiche. Questa tecnica prevede l’utilizzo di un laser, continuo o a impulsi, per incrementare localmente la temperatura della struttura soggetta ad ispezione; e di una videocamera a infrarossi per il rilevamento della temperatura superficiale. Il calore generato dal fascio di luce tende a propagarsi nel materiale in ogni direzione. La presenza di una cricca superficiale, o di un difetto prossimo all’superficie, rallenta o impedisce il flusso di calore, alterando quindi la distribuzione di temperatura. Tale alterazione viene visualizzata dalla camera a infrarossi. Comunelemente, il metodo del laser spot thermography è condotto da un tecnico specializzato e richiede l’attenta osservazione delle immagini per una corretta interpretazione.

Con la presente memoria, si intende presentare un algoritmo per la rielaborazione automatica delle immagini a infrarossi, in grado di localizzare aree danneggiate eventualmente presenti nel componente analizzato. Le immagini del componente in esame vengono analizzate al fine di estrarre parametri caratteristici da confrontare con gli stessi parametri associati a provini integri. In caso di discordanza tra i parametri del componente e i parametri di riferimento, le immagini vengono ulteriormente processate per la localizzazione del difetto. In questa memoria, i risultati sperimentali di prove effettuate su strutture di tipo piastra in materiale composito sono presentati e discussi.

ABSTRACT

In this paper an algorithm for the analysis of raw thermal infrared images obtained by using the nondestructive evaluation method of the laser spot thermography is proposed. A
A laser was used to scan a test specimen through the generation of single pulses. The temperature distribution produced by this thermoelastic source was measured by an infrared camera and processed with a two-stage algorithm. In the first stage, few statistical parameters were used to flag the presence of damage. In the second stage, the images that revealed the presence of damage were processed computing the first and second spatial derivative. Two spatial filters were also used to enhance contrast, and to locate and size the defect.

The algorithm is experimentally validated by scanning the surface of a CFRP composite plate with induced defects.

1. INTRODUCTION

Nondestructive evaluation (NDE) methods based on the analysis of active or passive infrared images have recently gained new attention due to the technological improvement of the infrared detectors. Infrared-based NDE provides a non-contact method able to accomplish full-field defect imaging to virtually any material. Active thermography utilizes an external stimulus to create a rise in temperature in part of the structure and infrared cameras to capture the surface’s thermal pattern. Depending upon the type of the external stimulus, techniques such as lockin thermography, pulsed thermography, vibrothermography, thermosonics, and laser-spot thermography have been developed [1].

In this paper, we use the technique of laser spot thermography to detect surface cracks. In laser spot thermography, CW or pulsed laser realize the transmission of a well-controlled and positioned beam into the test object which can be scanned. The heating at the surface, caused by absorption of laser light (CW laser) or by thermoelastic shock (pulsed laser), spreads radially producing a circular heat spot that can be imaged by an infrared camera. A surface breaking crack near to the illumination point prevents the lateral flow of heat and produces a perturbation to the thermal image that can be useful to detect the presence of such cracks [2-5].

To enhance the outcomes of the laser-spot thermography, we propose a dual-stage algorithm for the analysis of raw infrared images. In the first stage, the presence of a defect is detected by correlating testing images to baseline images and by comparing the eccentricity of the testing images to the eccentricity of the baseline. Once the presence of damage is flagged by either the correlation coefficient or the eccentricity or both, the defect’s location and size are determined by using the first and the second spatial derivatives of the surface’s temperature and two spatial filters. This latter approach does not require baseline data.

2. ALGORITHM BACKGROUND

First, we calculate the eccentricity, skewness, kurtosis, and correlation coefficients of the infrared images. The eccentricity $e$ of an arbitrary 2-D boundary is defined as:

$$e = \sqrt{1 - \frac{b^2}{a^2}} \tag{1}$$

where $a$ is the line segment connecting the two farthest points of the boundary, and $b$ is the line segment perpendicular to $a$ and of such length that a box passing through the outer four points of intersection of the boundary with the two line segments completely encloses
the boundary. An eccentricity equal to zero corresponds to a perfect circle, given that \(a\) and \(b\) have the same length. Any deviation from this shape can be inferred to the presence of a structural anomaly, and the value of the eccentricity is expected to increase. The skewness and the kurtosis are very popular statistical parameters often used in the signal processing and probability. The first one measures the asymmetry of a data set around the data mean. The kurtosis is a measure of how outlier-prone a distribution is.

Then the correlation coefficient is used to establish a relationship between two or more images. When the variables are two-dimensional such as images, the coefficient can be written as:

\[
r = \frac{\sum \sum (A_{mn} - \bar{A})(B_{mn} - \bar{B})}{\sqrt{\sum \sum (A_{mn} - \bar{A})^2 \sum \sum (B_{mn} - \bar{B})^2}}
\]

(2).

where \(A\) and \(B\) are two images represented by two matrices, and \(\bar{A}\) and \(\bar{B}\) are respectively the means of the elements populating matrix \(A\) and matrix \(B\). In the framework of our algorithm, we expected correlation coefficients close to 1 for tested regions with no damage and low correlation values for damaged areas.

In the second stage, the we process those images whose correlation or eccentricity deviate from the baseline. The first and the second spatial derivatives are calculated by evaluating the image thermal gradient across two consecutive pixels along the horizontal and the vertical axis. The first derivative reflects the amplitude change rate in an image and thus extracts the edge effect in an image. In order to highlight the contour of the defected area, we also propose to apply two image filters. Image filtering can be successfully used in applications such as smoothing, sharpening and edge detection. In the present work, we applied the Roberts and the Laplacian filters as they provide good results.

3. EXPERIMENTAL SETUP AND RESULTS

A unidirectional carbon fiber plate of dimensions 605 x 100 x 2 mm was inspected. Surface damages were previously performed by means of a cutter. The specimen was fixed to a marked horizontal guide to ease the scan of the specimen. For each scanning point, few seconds sequences were recorded in order to capture enough information about the temperature distribution prior and after the release of the laser pulse.

A 10 Hz repetition rate Nd:YAG pulse laser operating at 1064 nm wavelength and intensity equal to 3.85 mJ/mm\(^2\) was used to impart a single 8 nanosecond 7 mm diameter pulse on the test specimen. The use of a large circular spot instead of a focused line or point as conventionally done in laser-spot thermography, was done to increase the scanning speed because the region of interest (ROI) associated with each scanning point.

The infrared images were recorded with a FLIR SC660 camera at full frame dimensions 640 x 480 pixels and at sampling frequency equal to 30 Hz. The distance between the camera and the test specimen was approximately 300 mm. A photo of the experimental setup is shown in Fig. 1(a).
We machined four cracks of a width gap and a depth of approximately 0.5 mm. The length of these cracks varied from 4 to 150 mm. We scanned the plate over 16 points, the first eight associated with pristine areas and the last eight associated with damaged areas. Figure 1b illustrates the location and the extension of the defects (thick blue line) with respect to the points irradiated with the laser.

Following the procedure explained in the previous section, a baseline video was created by averaging the acquisitions associated with the eight pristine regions of the sample to reduce the effect of thermal noise. For each scanning point the mean
temperature, variance, skewness, and kurtosis of the frames were computed. Figure 2 shows these features as a function of the frame number for an acquisition associated with a pristine zone. When compared to the average temperature, which is a parameter widely used in active and passive thermographic methods, the three statistical parameters denote a much sharper increase immediately after the laser pulse. These parameters were used to identify the frame of the sequence taken immediately after the release of the laser beam.

For each scanning point, the frame with the largest skewness and kurtosis was selected and processed further by using the two-stage algorithm proposed. Figure 3 presents images from four ROIs of 90 x 90 pixels, covering an area of 625 mm². Figure 3a and Figure 3b are recorded from sound regions, whereas Figure 3c and Figure 3d are associated with two damage cases. The overall temperature of the damage cases is higher. The temperature difference is largely due to the presence of the defect that entraps heat and partially due to time gap between the laser shot and the infrared snapshot.

Figure 3. Thermal images of (a, b) undamaged areas and (c, d) damaged areas.

Figure 4a shows the correlation coefficient associated with the 16 ROIs considered in this study. All 16 frames are compared to the baseline frame. The first eight points refer to damaged areas. A clear step between damaged and undamaged cases is visible and it is possible to set a threshold level for instance at 0.98. The coefficients that fall below the threshold, warn about the possible presence of a defect. Figure 4b shows the eccentricity as a function of the scanning point. The discrimination between the two structural states is not as evident as in Figure 4a. Moreover, the eccentricity of the sound regions is expected to be close to zero. The reason for such a discrepancy is two-fold. First, the laser spot is not perfectly circular probably due to the optics of the laser. Second, the directionality of the fibers implies that the thermal conductivity of the specimen is not homogeneous.
Figure 4 – Correlation and eccentricity for the 16 scanning points

Figure 5 – Images’ absolute first and second derivatives
Figure 5 displays the absolute first and second derivatives of the temperature. Each column refers to one of the four cases illustrated in Fig. 3. The top two rows are the first derivatives with respect to the horizontal and vertical axis, respectively. The bottom two rows are the second derivatives with respect to the horizontal and vertical axis, respectively. While the first derivative produces false positives around the circular edge of the spot, the second derivative clearly highlights the presence of the vertical cracks.

Finally, Figure 6 shows the results of the Laplacian (grey background) and Roberts (dark background) filters applied to the frames presented in Figure 3. The two columns in the left represent the undamaged case. The two columns in the right are the damaged case.

Both identify properly the location of the crack. Overall, the application of the Laplacian filter outperforms the Roberts filter, although the latter seems to better isolate the contour of the defect.

CONCLUSIONS

In this paper, we presented an automatic algorithm to process infrared images collected during the nondestructive evaluation method of the laser-spot thermography. The algorithm consisted of two stages. First statistical features were extracted to identify the frame of interest within a short video sequence and then the eccentricity and the correlation were computed to detect the presence of damage. Then, the correlation or eccentricity or both from the baseline signature, the thermal spatial derivatives and two filters were applied to localize and size the damage. In this study, the method was validated into a unidirectional composite plate inspected by means of the laser spot thermography.

For each scanning point, five seconds sequences were recorded in order to capture enough information about the temperature distribution prior and after the release of the
laser pulse. Although the algorithm presented here is designed to analyze one single frame, the acquisition of a video sequence was made to have data available for future studies and improvements. Results show that the algorithm is able to capture, size, and localize damage by simply analyzing the frame after the laser trigger.

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**REFERENCES**