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Cracks detection on glass object based on active thermography approach

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ABSTRACT

Thermal imaging is nowadays widely used in many industrial areas for non destructive analysis. This paper focuses on the detection by active thermography of cracks in a transparent and specular piece of glass. A continuous laser scans the target by creating a hot spot that is acquired by a thermal camera. A thermal map is computed by averaging of thermal measurements for all the positions of the hot spot on the target. Then edge filters are applied to highlight the cracks. Experimental results demonstrate the validity of the material damage estimation in a short processing time.

Keywords: Active Thermography, NDT, cracks on glass, Machine Vision

1. INTRODUCTION

Damage of materials is a very complex phenomenon. Internal defects are inevitable originated from manufacturing process or manipulation. Those defects may affect the integrity of those structures. In many industrial applications in production as well as in maintenance works contactless inspections easily used in service conditions are required. Estimation of the failure evolution and interactions with the overall structural design, create the need for the Non Destructive Testing (NDT) methods for localizing internal or external defects.¹ The infrared thermographic technologies is a efficient NDT tool for examination of a wide range of materials. Active thermography analyse means that an additional energy must be supplied to the object to be inspected. It can be a strong lamp, a laser or something else. If some cracks are presented in the material, the heat distribution of the hot point can be disrupted, and the crack should be highlight. In this article, we used a thermal camera associated to a laser. Scanning From Heating (SFH),² is 3D measurement approach based on an active thermography system. A laser source is used to cause a local elevation of temperature. The hot spot, created by the laser, can be observed in the images obtained by an IR camera. Then, the 3D coordinates of each point are computed with a prior geometric calibration of the system. The laser source scan the whole image and the sequence made by the concatenation of the acquired IR image for each laser position provides the internal composition description of the inspected object.

The laser-based methods are grouped in three main families : pulsed-laser,³ lock-in⁴ and continuous laser. The pulsed-laser based methods use a laser pulsing at a known frequency. Those rapid pulses of heat generate waves in the target and can be acquired with a fast thermal camera and used to find damaged parts even under the surface of the target. This provides accurate estimation with low processing time that cannot be used to analyze broken parts hidden deep under the surface of the target because the heat impulsion are not strong enough in a short time. The second family of laser-based SFH methods is the lock-in family. Those methods are deviated from the first family, this mean they also use pulsed lasers to check the target defaults. The lock-in based methods also use pulsed lasers to check the target defaults. However, if the pulsed-laser methods use fixed pulses when scanning their target, lock-in methods are taking several sets of measures and use different pulse

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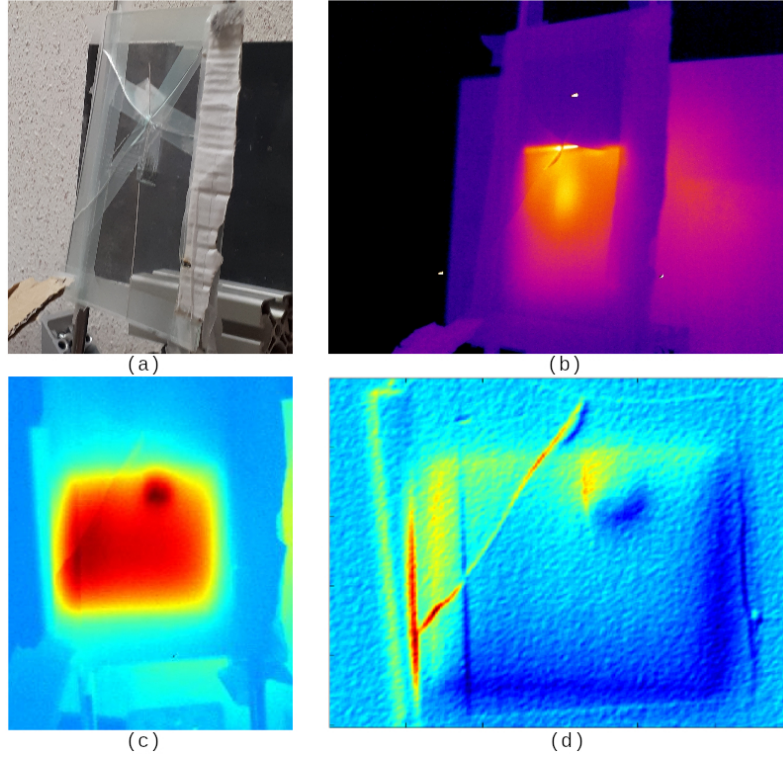


Figure 1. Piece of glass with cracks (a). Image acquired by the thermal camera (b) where the oblique crack and some others are visible. Average of all thermal images in the sequence (c) where the oblique crack is still visible. In (d) the average image was cropped and rescaled in quantization to highlight the crack.

frequency each time. Those methods can provide very accurate results and also detect deep, hidden broken parts but they are required lot of time to be processed and are also not very easy to use because of the use of very specials lasers. Unlike the previous ones, the continuous methods do not use any pulse. The heat produced by the laser is stronger and can penetrate deep under the target's surface. These methods provide lower accuracy but only require a traditional laser and a thermal camera. As the emissivity is omnidirectional for most materials, the model of infrared radiation tends to approach the model of the diffuse reflection of visible light for diffuse surfaces and, thus, addresses the issue of specular reflection or transparency in the visible spectrum. SFH is traditionally used in the case of high conductive materials (metals for example).⁵⁻⁷ In this paper we are interested by glass material which presents low thermal conductivity, specular reflection and transparency. The experiments have been done using a broken glass material sample (Figure 1.a). The surface of this sample has been scanned by the laser and an IR image snapped for each position of the laser (Figure 1.b). The thermal distribution of the hot point is analyzed and the defects are detected (Figure 1.d). A post-treatment is then applied on the result image to highlight the defects.

In this paper, the goal is to minimize the processing time for a correct accuracy. Thus continuous laser is chosen (is the fastest and the simplest to apply) and simple edge detection algorithms like Sobel, Logarithmic, Roberts and Canny filters are applied.

The paper is organized as follows. Section 2 describes the scanning setup and the active thermographic acquisition and the post-processing for the defects detection. Section 3 summarizes the results and finally section 4 highlights the outcomes of this research and proposes an outlook on future work.

2. THERMAL MAP ESTIMATION

2.1 Scanning setup

For the acquisition, the target is heated by a powerful laser. As presented in⁸ the laser source a 1.07 μm laser diode and the power ranges from 0 to 50 W. A LWIR camera performs the thermal measurement. The scanning process is done by a galvanometer scan head is made up of two mirrors controlled by piezoelectric motors that can deflect the laser beam with 150 μrad step, in X and Y directions. A compromise had to be found between speed and accuracy. Indeed decreasing the distance between two successive lines increases the accuracy. However the orientation of the scanning line does not impact the results: a correct alignment between the scanning lines and the cracks magnifies the effects but the orientation of the cracks is not controlled. In this paper we used horizontal lines. The laser intensity should enable a sharp transition between crack and glass. The speed of the scan should be selected so as to cause a sufficient elevation of temperature without damaging the target. This process scans a large surface in a short time from a predictable scanning path. It provides a sequence constructed from the non-compressed images taken by the thermal camera. Each sequence contains from ten to hundred of images. The processing time decreases if a reduced part of the target is scanned.

2.2 Mapping computation

For cracks detection, the sequence is compressed into a single image by a pixel by pixel averaging. The local elevation of temperature induced by the laser is the same regardless of the local composition of the material. The highest value of temperature for a position is also not discriminative. But the intensity of the hot spot created by the laser decreases more slowly when it is placed on a crack. The average value of the temperature during the scanning process is also higher for the cracks.

An example of such an average image is shown in Figure 1. Three cracks are visible: the transversal crack provides a high value easily detected, the horizontal crack (in the top) has a lower intensity, the vertical crack is more difficult to isolate (it corresponds to an internal crack nearly invisible from rgb image). This IR image, snapped for each position of the laser, provides a significant cue that have to be filtered in a post processing step to isolate the cracks.

2.3 Filtering

Cracks provide higher value on the average IR image. But, as seen in Figure 1, the variation is not the same on the whole target. As the heat distribution is disrupted for the cracks, edge detection filtering is applied on the average image. To reduce the processing time only simple filters are used: Logarithm, Canny, Sobel and Roberts.

3. EXPERIMENTS AND RESULTS

A FLIR A655sc was employed in the performed inspections as infrared detecting device and a laser SIC TSH8310D have been used as heat source. The parameters of the method are experimentally fixed as following : the scanning lines are separated by 2 mm and the laser is set at 2.5 W with a displacement of 10 mm/s. The whole target is scanned in less than 3 minutes.

The experiments we will present in the paper, have been done using a broken glass material sample (Figure 1.a). The thermal distribution obtained by averaging of the IR images acquired for each position of the laser is shown in Figure 1b. To correctly analyze and detect the defects, various simple filters are applied on the thermal map (Figure 1.d). The criterion selected to evaluate the efficiency of our method are: the processing time, the accuracy of the detection and the separability. Logarithm filter is used in Figure 2.a. It provides a great recall but a poor precision. Cracks are correctly detected but many false positives appear. The result is too noisy for a correct automatic detection. With the three other filters, precision increases but the sample of false positives on the right side of the image can be interpreted as a crack considering its shape. Sobel filter is used in Figure 2.b. Two vertical lines incorrectly appear. The real crack is between the two lines. Canny filter is used in Figure 2.c. Precision increases but the cracks are not fully detected (for example the middle of the vertical crack is missing). The presence of cracks is detected but not precisely localized. Finally Roberts filter is used in Figure 2.d. False positives are enough sparse not to be classified as a crack. The crack is fully detected and refined (just a part of the cracks is represented by two edges).

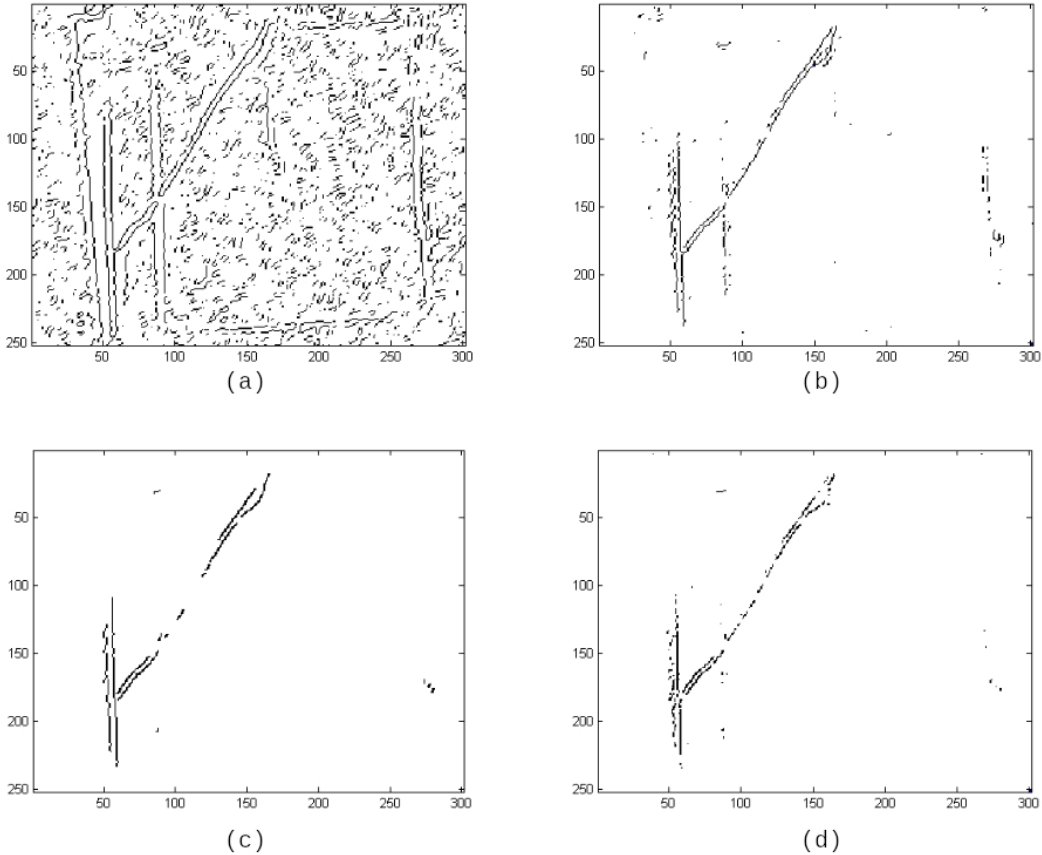


Figure 2. Edge estimation obtained by the Logarithm (a), Sobel (b), Canny (c) and Roberts (d) filters to detect the oblique crack.

4. CONCLUSION

Continuous lasers are right now not generally used in industry because of the more accurate pulse-based (pulse laser and lock-in) detection methods. However we have experimentally show in this work that a continuous method provides competitive results. Moreover continuous methods are faster on a large target. More power can be used for scanning low conductive material. Hence the hot spot is larger and the scan is widely spaced that reduces the scanning time. Then the propagation of the heat is deeper on the target. Finally no component required to be calibrated.

Future work is to compare all of the laser detection methods on the same target. We consider the possibility to associate continuous and pulse-based methods. Continuous method would provide a fast localization of the regions of interest whose the estimation would be refined by the pulse-based method. Using less-sensitive components, these association could be used on mobile supports such as small robots.

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