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Detection of Surface Breaking Cracks Using Flying Line Laser Thermography: A Canny-Based Algorithm †

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Abstract: In this work, we introduce a new algorithm for effectual crack detection using flying line laser thermography, based on the well-known Canny approach. The algorithm transforms the input thermographic sequence into an edge map. Experimental measurements are performed on a metallic component that contains surface breaking cracks due to industrial use. The specimen is tested using flying line thermography at different scanning speeds and laser input powers. Results obtained with the proposed algorithm are additionally compared with a previously established algorithm for flying spot thermography. The proposed Canny-based algorithm can be used in automated systems for thermographic non-destructive testing.

Keywords: flying line thermography; flying spot thermography; canny approach; automated thermographic non-destructive testing; crack detection

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1. Introduction

Flying spot thermography has been known since last century [1–3]; however, novel aspects of it are currently under further development [4–9]. The main reasons are its versatility for scanning large components looking for defects, the thermal property characterization of large components, its predisposition for automation and its variety of possible configurations. The basic idea behind this technique is to move a heating source over the specimen surface while recording the temperature of this scanned surface. Even though this technique can be fast enough for many cases, one way to speed it up is using a line heating source instead of a spot. This gives rise to what is also known as flying line thermography. Particularly, when a laser is used as a heating source, one refers to the above configurations as flying spot laser thermography and flying line laser thermography if the laser beam is shaped as a spot or as a line, respectively.

Nevertheless, one drawback of this technique is that a long thermographic film demands a high computational cost for postprocessing, which is always required to extract the relevant information from the scanned specimen. Therefore, efficient postprocessing techniques are needed. In the case of crack detection, a clever approach was developed a decade ago. It consists of: Computing the first derivatives along the horizontal and vertical directions of the thermal images; The two derivative films are stacked in the time direction and each pixel is sorted ascending in intensity; The best image with crack indications is chosen from the first thermograms in the last step [7]. In this work, we introduce a new algorithm for semi-automatic detection of surface breaking defects based on the Canny approach [10]. In contrast to the algorithm described above, the proposed algorithm requires the processing of less thermograms and outputs an edge map of the automatically detected defects. The proposed algorithm is applied to find surface breaking cracks in a metallic component. The detected defects are due to the industrial use of the tested component.

2. Materials and Methods

2.1. Algorithm for Surface Breaking Crack Detection

Let us consider a recorded thermographic film consisting of a sequence of N thermograms (infrared images or frames). Each thermogram is an image of $V \times H$ pixels. It is assumed that, due to the experimental conditions on which this film was obtained, the number of frames required by the laser to scan the imaged surface is $N_{scan} < N$. In the case of a line laser scanning the surface, the direction of the scan is assumed to be just one way for the whole film. In summary, a sequence of N thermograms and the value of N_{scan} are required as inputs for the following algorithm.

First, each pixel on the thermogram is sorted from its lowest to its largest temperature value in the film. That is, N thermograms are processed in this operation. Next, the sorted film is reduced in length, by keeping the last N_{scan} thermograms and dropping the rest. Each thermogram in the reduced film is normalized in the gray-level. Accordingly, only N_{scan} images are processed in this operation. After this, a Gaussian blur filter of kernel 5×5 is applied to the normalized sequence. That is, an operation on N_{scan} thermograms. Now, the Canny filter is applied to the blurred film. Again, this only requires an operation on N_{scan} thermograms. Each pixel on the thermogram is averaged along the length of the filtered film. At this stage, the processed N_{scan} "edge maps" are reduced to one, the "edge map". On the other hand, each pixel on the thermogram of the initial input film is averaged along the length of the film, that is, the N frames are reduced to one, with the same number of pixels. This average thermogram is now normalized according to the gray-level. Finally, this normalized thermogram is merged with the edge map to produce the "detected edges" image. Figure 1 shows a block-diagram of the described algorithm for surface breaking crack detection.

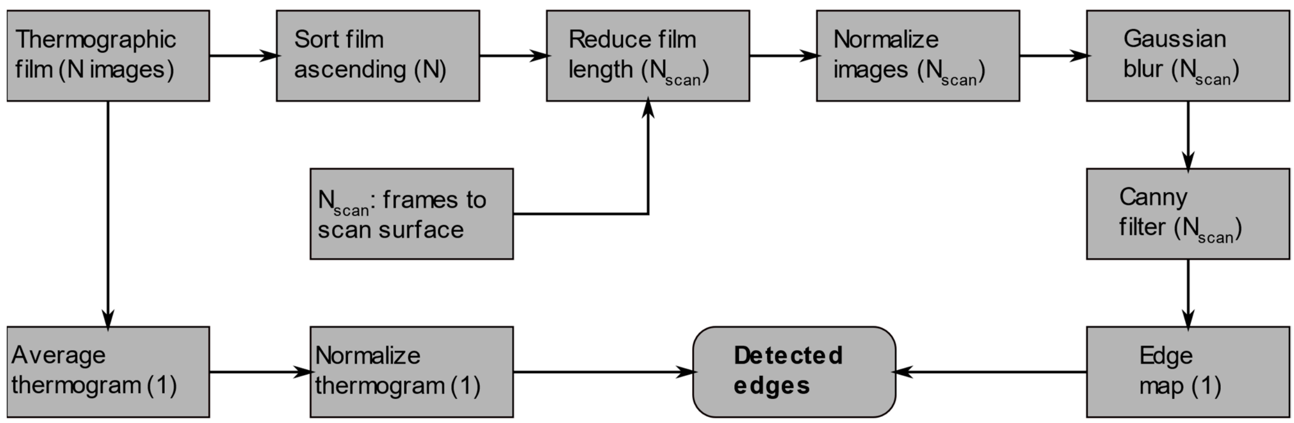

Figure 1. Block-diagram of the proposed algorithm for crack detection using flying spot/line thermography. In parenthesis, the number of frames involved in the computation is shown at each stage of the algorithm.

One can think of the presented algorithm as taking an input tensor of size $V \times H \times N$ and "squeeze" it through the appropriate transformations until extracting the most relevant information regarding edges present in this tensor. Therefore, the output is a simple sparse tensor of size $V \times H \times 1$, in other words, a 2-dimensional edge map.

The sample analyzed in this work is the base plate of a turbine blade, $33 \times 24 \times 10$ cm^3, 12 kg weight, density of 8602 kg m^{-3}, heat capacity of 411 J kg^{-1} K^{-1} and thermal conductivity of 8.4 W m^{-1} K^{-1}. It contains several surface breaking cracks. From visual and penetrant testing, the length of the cracks at the surface has been determined. One crack of 5 mm length has been chosen for demonstration in this work.

2.2. Experimental Setup

Figure 2 shows a diagram of the experimental setup. A continuous-wave diode laser (940 nm central wavelength and 500 W maximum output power) is coupled with an optical fiber into the appropriate laser optics to reshape the beam coming out of the fiber into a line of 34 mm × 0.75 mm. An infrared (IR) camera (InSb-based, 640 × 512 pixel, 3–5 µm spectral range) is aligned with a dichroic mirror and the test sample. The dichroic mirror is tilted, such that the line laser is directed perpendicular to the sample surface. The three components are fixed on a linear stage, which moves in a defined direction (or the opposite), so that the line laser scans the surface imaged by the IR camera.

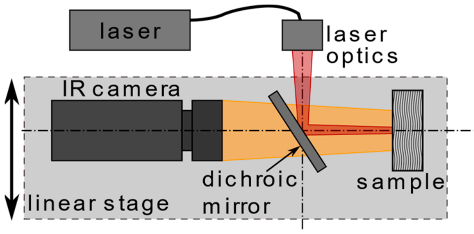

Figure 2. Diagram of the experimental setup used for the flying line laser thermography tests.

3. Results and Discussion

We performed thermographic tests for the automatic detection of surface breaking cracks on the turbine blade, using three different configurations: (a) scanning speed of 10 mm s^{-1} and laser power of 50 W, (b) scanning speed of 30 mm s^{-1} and laser power of 60 W and (c) scanning speed of 60 mm s^{-1} and 120 W. In all cases, the frame rate of the IR camera was set to 200 Hz. The camera's spatial resolution is about 55 µm/px. As an example, Video S1 (see Supplementary Materials) shows the thermographic film recorded using 120 W laser input power, 60 mms^{-1} scanning speed and 200 Hz camera frame rate.

Figure 3 shows the detected edges (edge map (in red) + average film (gray scale)) obtained with the proposed algorithm. Figure 3b,c show a better detection of the crack morphology. However, Figure 3c presents also more "artifacts" from the Canny filter processing. That is, fictitious (tiny) edges, which are mainly related to the thresholding levels in the Canny filter. On the other hand, Figure 3a is almost free of these artifacts, which is understandable due to the higher signal-to-noise ratio obtained by processing more images than in the other two cases.

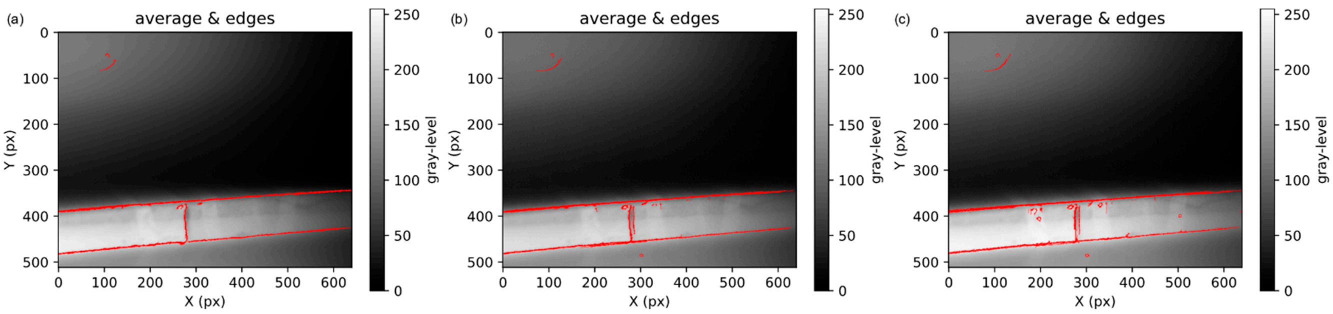

Figure 3. Detected edges obtained for (**a**) 10 mm s^{-1}, (**b**) 30 mm s^{-1} and (**c**) 60 mm s^{-1} scanning speeds of the laser line. The edges (in red color) are obtained automatically from the algorithm proposed in this work.

4. Conclusions

We have proposed a new algorithm for semi-automatic detection of surface breaking cracks using flying line thermography based on the Canny approach. The proposed algorithm was tested to detect a crack in an industrial component. The three different configurations of scanning speed and laser power tested were successful for crack detection. The algorithm is fast enough for industrial applications and is suitable to be implemented for automatic thermographic non-destructive testing. Minor issues related to the artifacts in the edge map might be addressed with the use of more advanced edge-detection methods, based on machine learning and deep learning.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/engproc2021008022/s1, Video S1: 8000HTB1_SSLFLINN_60mms_120W_200Hz.mp4.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kubiak, E.J. Infrared detection of fatigue cracks and other near-surface defects. *Appl. Opt.* **1968**, *7*, 1743–1748. [CrossRef] [PubMed]
2. Krapez, J.-C. Résolution spatiale de la caméra thermique à source volante. *Int. J. Therm. Sci.* **1999**, *38*, 769–779. [CrossRef]
3. Wang, Y.Q.; Kuo, P.K.; Favro, L.D.; Thomas, R.L. Flying Laser Spot thermal Wave IR Imaging of Horizontal and Vertical Cracks. In *Review of Progress in Quantitative Nondestructive Evaluation*; Thompson, D.O., Chimenti, D.E., Eds.; Springer: Boston, MA, USA, 1990.
4. González, J.; Mendioroz, A.; Sommier, A.; Batsale, J.C.; Pradere, C.; Salazar, A. Fast sizing of the width of infinite vertical cracks using constant velocity Flying-Spot thermography. *NDT E Int.* **2019**, *103*, 166–172. [CrossRef]
5. Ahmadi, S.; Burgholzer, P.; Jung, P.; Caire, G.; Ziegler, M. Super resolution laser line scanning thermography. *Opt. Lasers Eng.* **2020**, *134*, 106279. [CrossRef]
6. Salazar, A.; Colom, M.; Mendioroz, A. Determining the thermal diffusivity and the principal directions on anisotropic moving samples with laser-spot thermography. *Int. J. Heat Mass Transf.* **2021**, *176*, 121447. [CrossRef]
7. Schlichting, J.; Ziegler, M.; Dey, A.; Maierhofer, C.; Kreutzbruck, M. Efficient data evaluation for thermographic crack detection. *Quant. InfraRed Thermogr. J.* **2011**, *8*, 119–123. [CrossRef]
8. Sommier, A.; Malvaut, J.; Delos, V.; Romano, M.; Bazire, T.; Batsale, J.C.; Salazar, A.; Mendioroz, A.; Oleaga, A.; Pradere, C. Coupling Pulsed Flying Spot technique with robot automation for industrial thermal characterization of complex shape composite materials. *NDT E Int.* **2019**, *102*, 175–179. [CrossRef]
9. Burrows, S.E.; Dixon, S.; Pickering, S.G.; Li, T.; Almond, D.P. Thermographic detection of surface breaking defects using a scanning laser source. *NDT E Int.* **2011**, *44*, 589–596. [CrossRef]
10. Canny, J. A Computational Approach to Edge Detection. *IEEE Trans. Pattern Anal. Mach. Intell.* **1986**, *PAMI-8*, 679–698. [CrossRef]