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LASER GENERATED LAMB WAVE AND CANNY EDGE TECHNIQUE FOR AUTOMATICALLY LOCATING DEFECTS OCCURRED IN PLATES

Peter W. Tse [1], Gaochao Wang, Jingming Chen
Smart Engineering Asset Management Laboratory and Croucher Optical Non-destructive Testing Laboratory,
Department of Systems Engineering and Engineering Management, City University of Hong Kong, Hong Kong, China.

ABSTRACT

Laser generated Lamb wave (LW) is a promising NDT tool for structural health monitoring because it is a non-contact inspection technique and capable of providing long-distance inspection manner. However, an experienced operator must be hired to analyze the reflected LW signals so that the location of each detected defect can be known. This paper reports a research method that can automatically determine the location of defect using laser generated LW. After the emission of LW to the inspected plate, a de-noising technique called continuous wavelet transform and canny edge detection were employed to automatically locate defect like images from the LW signals reflected from the plate. The whole spectrum of wavelet coefficients was processed as an image and the canny edge detector was applied to minimize interference and enhance the target for the first time. Then an ellipse algorithm was used to locate each defect occurred in the plate by only using three enhanced LW signals rather than scanning the entire surface of the plate done by conventional methods. To verify the effectiveness of the proposed method, experiments were conducted with promising results. Significant processing time and intensive human visual inspection can be reduced. Moreover, the method can be applied to production line for automatic plate integrity inspection.

Keywords: Lame wave; plate defect inspection; image processing; edge detection; automation.

1. INTRODUCTION

In aerospace industry, over 80% of aircraft fuselage (formed by different shapes of thin plates) inspection is depending on visual method. However, not all the plate surface areas can be access by human visual inspection [1]. The occurrence of cracks and the ignorance of its propagation may finally trigger a fatal accident because they may lead to serious fractures. Special attention must be paid to the plates that formed part of the aircraft or train body. Extensive research efforts have been continuously spent on non-destructive testing (NDT) for finding an effective solution to detect and locate anomalies, like cracks and corroded areas [2]. Lamb wave has low energy attenuation, propagating at high speed and is capable of long-length inspection. Its advantages are superior to that offered by conventional NDT methods such as eddy current [3], ultrasonics [4, 5], magnetic flux leakage etc. [6]. The success of using Lamb wave in inspection has been widely reported [7-11]. This paper reports the generation of Lamb wave (LW) by using laser as a non-contacted technique to detect crack occurred on plates. Laser generated LW has recently become popular as it can inspect plates that not hot or have too small a space to mount the required sensor. Moreover, laser can detect a crack size as small as its wavelength.

Recently, machine vision becomes a popular inspecting tool due to its portability and enable to detect large object remotely. Different kinds of signal processing, image processing via edge detection [12] and object pattern clustering [13, 14] have been developed to help identify targeted objects or images. In this research, a Nd:YAG pulsed laser was used to emit the desired LW to a plate. A laser Doppler vibrometer (LDV) was used to receive the reflected LW signals. The received LW signals were then converted to a time-frequency 2.5D plot by using continuous wavelet transform (CWT). The entire plot was then analyzed by Canny edge detector and the ellipse algorithm to determine the location of each defect occurred in such isotropic plate structure. A number of experiments were conducted on normal and defective plates to verify the effectiveness of this entirely non-contact and image processing based method. Moreover, the characteristics of LW signals reflected by the plates were revealed through this method. The experimental results show that the laser generated LW, the CWT, the Canny edge detector and the ellipse algorithm have successfully identify defects and their locations on the defective plate. In the full paper, the theory and the procedures of this new method will be explained in details. The experimental setup and the generated

[1] Contact author: meptse@cityu.edu.hk

results and ellipse algorithm will also be presented and discussed. Finally, concluding remarks and areas for future improvement will be highlighted in the full paper.

2. METHODOLOGY AND EXPERIMENTAL SETUP

Identification of possible defects occurred in a plate is depended on the sudden increase in the amplitude of LW reflected signal from its temporal plot. True defects are sometimes difficult to be distinguished from noise. It is necessary to take new method to separate signals generated from defects and noise. As aforementioned, the proposed method is a combination of several techniques, namely laser generated LW, CWT, Canny edge detector and the ellipse algorithm.

First, the reflected LW was captured from the tested plate at several receiving points marked on the plate. The desired LW mode was emitted in a non-contacted manner by the pulsed Nd: YAG laser with a wavelength of 532 nm as shown in Figure 1. The size of the aluminum plate used in this experiment is 2000 mm×1000 mm and its thickness is 2 mm. The emitted LW signals were then propagating along the entire aluminum plate. The propagating or reflected LW signals from the plate were received by the LDV at a number of designated receiving points marked on the plates as shown in Figure 2. The left and right diagrams of Figure 2 show the locations of receiving points of a normal plate and a plate that has an artificial defect respectively. Then the received signals from both plates were displayed on an oscilloscope and then finally stored in a computer for further analysis and processing.

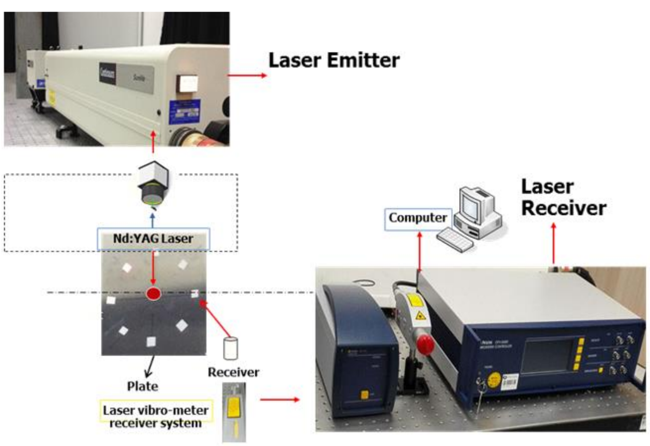

FIGURE 1: EXPERIMENTAL SETUP FOR EMITTING LASER-BASED LW (Nd:YAG PULSED LASER) AND RECEIVING THE LW SIGNALS (THE LDV).

Second, the received LW signals were then converted to a 2.5D time-frequency plot with the help of the CWT signal processing method. The CWT technique can decompose the LW signals into multiple scales of different time and frequency ranges and displayed in the 2.5D time-frequency plot. With the help of CWT, LW signals that had higher amplitudes would produce higher CWT coefficients or being highlighted in brighter color in the 2.5D plot embedded with time information. Given a velocity of LW signal and its temporal information when it was received by the LDV, the location of the artificial defect that had higher signal amplitude was highlighted in the plot. The coefficients of CWT applied to signal $f(t)$ with a mother wavelet $\psi(t)$ at a scale (a>0) $(a > 0, a \in R^{+})$ and translational value $b \in R$ can be defined as:

$$W(a,b) = \frac{1}{|a|^{\frac{1}{2}}} \int_{-\infty}^{\infty} f(t)\overline{\psi}\left(\frac{t-b}{a}\right)dt \qquad (1)$$

where $\overline{\psi}(t)$ denotes the complex conjugate of the mother wavelet ψ(t), a is the dilation parameter (scale) and b is the translation. The type of mother wavelet used in this study is Morlet wavelet.

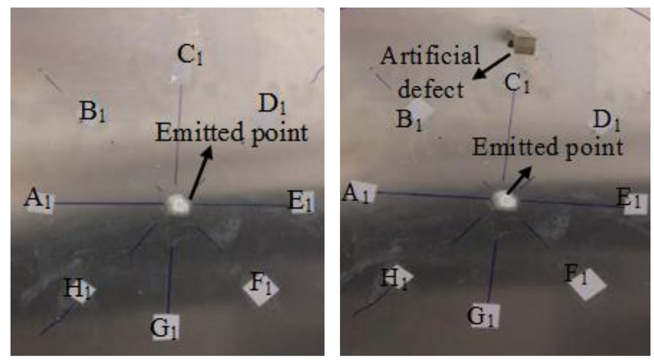

FIGURE 2: THE SIGNALS RECEIVING POINTS AS MARKED ON A NORMAL PLATE (THE LEFT DIAGRAM) AND A PLATE WITH AN ARTIFICIAL DEFECT (THE RIGHT DIAGRAM).

Third, the Canny edge detector was then applied to the 2.5D plot generated by CTW. By comparing a few threshold values, then a proper image pixel value, which was selected as the threshold value, could be used to distinguish the difference between an image area that has healthy signals and an image area that has defective signals. The threshold T used for the edge detector can be automatically selected when the difference between that generated by healthy signal and defect signal is at its maximal in terms of the number of pixels marked as an edge.

$$T = \text{argmax} \sum\sum |E_t^{*}[a,b] - E_t[a,b]| \qquad (2)$$

where E_t^{*}means defect signal.

Forth, the binary edges of the image belonged to the defect were generated after selecting the most suitable threshold T. Then the difference of edges formed the healthy image and defect image was calculated and transformed the residual by averaging the CWT scales into a 1D signal plot.

Fifth, the ellipse algorithm was then applied to each residual 1D signal and then summed all the results into a single image. The maximal point in the single image was the location of defect.

3. RESULTS AND DISCUSSION

The experimental result of the single image, is shown in Figure 3, were generated by using only three pairs of signals received from receiving points A1, B1, and F1 as illustrated in Figure 2. The location of real defect (a star point in blue color) and the estimated location of defect (a square in black color) are marked in this figure. The actual coordinate of the center of artificial defect was located at [210,115]. Whilst, the coordinate for detected defect was estimated to be [213,114]. The measurement error is around 3 mm with an error of 1.42%.

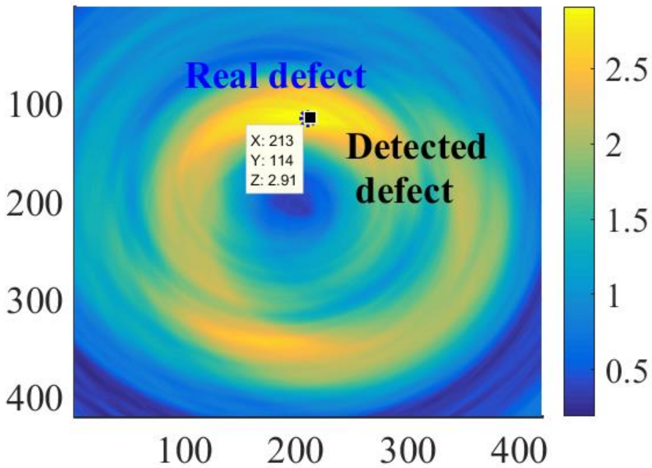

FIGURE 3: THE COMPARISON OF REAL AND ESTIMATED DEFECT LOCATIONS HIGHLIGHTED IN THE IMAGE PLOT.

4. CONCLUSION

In this paper, a new method is presented to automatically determine the location of a defect occurred in an aluminum plate. The method combined the techniques of LW and signal processing and image processing. The LW is emitted and received by laser equipment, which provides a non-contact sensing method. The received signals can then be converted by using CWT to a 2.5D time-frequency plot which also acts as an image. Since the 2.5D plot is treated as an image, the contrast between belongs to a healthy signal and a defect signal can be shown in the image. Canny edge detector and ellipse algorithm are then applied to this 2.5D plot's image. By finding the maximum difference of the pixel values generated between the healthy and defect images, a proper threshold value can be found and used it to distinguish the areas of healthy plate and areas with defects. The experimental results prove the effectiveness of this new and combined method. Besides, this method provides an automatic selection of the most suitable threshold value for the Canny edge detector. Hence, the entire process of locating a defect can be fully automatic rather than using human visual inspection. This automatic and non-contact inspection method is especially suitable for inspecting the integrity of plates when they are manufacturing in a factory.

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