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Application of optical flow analysis for defect detection in composite plates based on high-speed camera recordings

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SUMMARY: The purpose of this study is to apply optical flow analysis to the detection of defects in composite plates based on high-speed camera recordings. The study used 500 mm x 500 mm x 3.5 mm CFRP (USN150B) composite plate specimens made of 12 layers of carbon fiber and Ottobock Orthocryl Lamination Resin 80:20 PRO 617H119 with curing agent 617P37. Artificial delaminations were introduced in some samples to simulate defects. The vibrations of the plates were induced by hitting them with a metal ball and then recorded with a high-speed camera. Optical flow analysis provided detailed data on the dynamics of plate motion, such as vibration frequency, velocity and the position of the plates over time. The results of the analysis showed that defects cause dissipation of vibration energy in the plate, leading to more damped responses at high frequencies.
KEY WORDS: optical flow, defect detection, composite boards, high-speed camera

1. Introduction

Detection of defects in composite plates is a key aspect in ensuring their reliability and safety in various industrial applications, including aerospace, automotive and construction [1]. In this paper, we present a novel approach using optical flow analysis to detect defects in composite plates based on high-speed camera footage [2].

Optical flow is an image analysis technique that tracks the motion of each pixel in a sequence of video frames. We use it to analyze recordings of composite plates, both with and without defects, recorded with a high-speed camera. From the optical flow analysis, we obtain data on vibration frequency, velocity and position of the plates over time. This data is then used to train machine learning models to automatically detect the presence of defects.
The study used CFRP composite plate samples (USN150B) with dimensions of 500 mm x 500 mm x 3.5 mm. These plates were made of 12 layers of carbon fiber (carbon fabric 160 g/m², style 447 Aero plain weave, Tenax® HTA 40 / 200 tex (3k)) and Ottobock Orthocryl Lamination Resin 80:20 PRO 617H119 with hardener 617P37.

In order to simulate defects, artificial delaminations of 60 mm x 20 mm were introduced in some samples, which were located at different depths of the plate. These defects were created by leaving dry zones or placing thin Teflon films as barriers.

2. Optical Flow

Optical flow is a technique used to analyze motion in image sequences. Optical flow is based on the assumption that the intensity of light reflected from objects in the scene remains constant as they move between video frames. Mathematically, this can be expressed by the intensity continuity equation [3]:

$$I\left(x,y,t\right)=I\left(x+\Delta x,y+\Delta y,t+\Delta t\right) \tag{1}$$

where $I(x, y, t)$ is the pixel intensity at point (x, y) at time t, and Δx, Δy are the pixel displacements int the x and y at time Δt.

There are many algorithms for calculating optical flow, including local and global methods. In this paper, two popular algorithms are used and compared: the Kanade-Lucas-Tomasi (KLT) method and the Farnebäck method [4], [5].

The Farnebäck algorithm is a dense optical flow method that estimates motion vectors for all pixels in the image. The Farnebäck method estimates motion vectors for all pixels in an image by:

- **Estimation of gradients**: Calculating spatial and temporal gradients of images.
- **Local polynomials**: Approximation of local areas of images as second-degree polynomials.
- **Motion vector estimation**: Minimization of intensity differences between frames for each pixel.
- **Refinement**: Iterative refinement of motion vectors by analyzing polynomials at different scales.

The KLT method estimates motion vectors for selected feature points in an image by:

- **Detection of feature points**: Identifying points with significant intensity difference.

- **Point tracking**: Calculating motion vectors for feature points by minimizing intensity differences between frames.

Optical flow, for both the KLT method and the Farnebäck, provides a powerful tool for analyzing motion in video images.

This paper compares the results of both methods in the context of vibration monitoring of composite panels. Analysis of the data from both methods yielded valuable information about the dynamics of motion and potential damage in the slabs. The results showed that both methods have their unique advantages and limitations, highlighting the importance of choosing the right optical flow method depending on the specific application.

3. Analysis results

As part of the study, vibrations of composite plates (Fig. 1) excited by a metal ball dropped on the edge of the plate were recorded using a high-speed camera for samples both with and without defects. Based on the recorded recordings, optical flow analysis was performed, which provided detailed data on the dynamics of plate motion (Fig. 2 and Fig. 3).

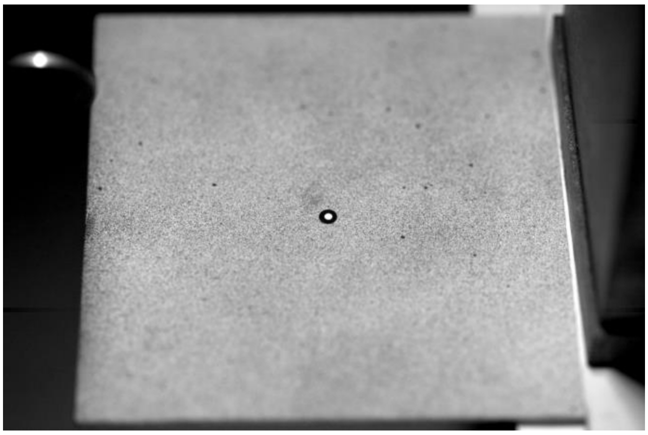

Fig. 1 View of the plate with the marker applied

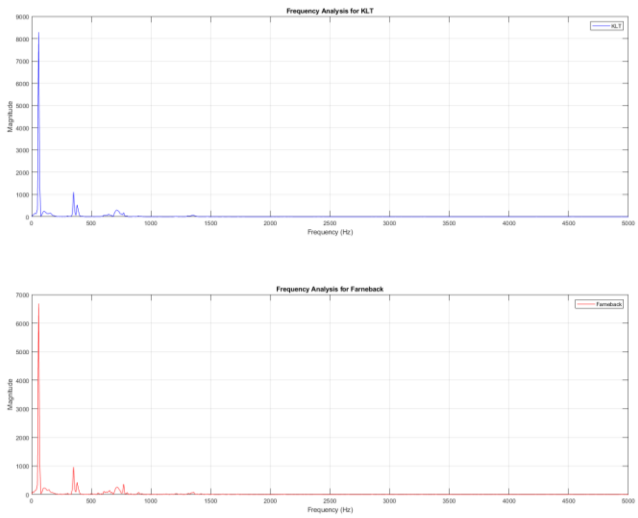

Fig. 2. Analysis results for a plate with a defect

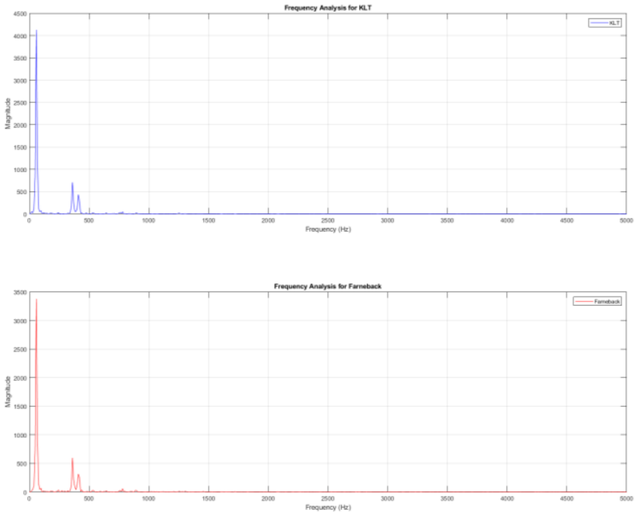

Fig. 3. Analysis results for the plate without defect

By analyzing the results shown in Fig. 2 and Fig. 3, it can be concluded that the healthy plate exhibits higher and more regular vibration amplitudes at low frequencies and more stable vibration energy distribution. In contrast, a plate with a defect shows unstable and more damped vibrations, with dissipated energy, which is characteristic of materials with internal defects. These differences confirm the effectiveness of using optical flow analysis in identifying defects in composite plates.

4. Summary

The presented optical flow analysis method has the potential to become an effective tool for defect detection in composite plates. The use of high-speed camera recordings and advanced image analysis has provided valuable information on the vibration dynamics of the plates. Using optical flow, information on vibration frequency, velocity and position of the plates over time was obtained. A comparison of the results of the two methods showed that defects in the composite plates cause dissipation of vibration energy, leading to more attenuated responses at high frequencies. Analysis of the data indicated that healthy plates exhibit higher and more regular vibration amplitudes at low frequencies and a more stable distribution of vibration energy. In contrast, plates with defects showed unstable and more damped vibrations with dissipated energy, which is characteristic of materials with internal defects.

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