Comparison of three image processing algorithms for analysis of in-plane vibrating structures

N. Kasyanenka, A. Kraft, E. Reithmeier

Institute for Measurement and Control, University of Hannover

mailto:kasyanenko@imr.uni-hannover.de

Image processing algorithms were compared and applied to a high-speed image sequence of an in-plane vibrating one-end-clamped beam. This is a closed system, mathematically easy to describe and therefore employed as ideal reference system in the discussed case. The following algorithms were used: optical flow, Kanade-Lucas-Tomasi-Tracker (KLT-Tracker) and correlation-based. In order to generate the afore-mentioned image sequence a system composed of high-speed camera and image derotator was used.

1 Motivation

Knowledge of the vibrational behaviour of mechanically exposed rotating devices is essential. Natural frequencies of such devices arise during high strain processes. These lead to the development of noise or damage to the device. Therefore, observing the modes of vibration or natural frequencies in the rotational process is an important step towards their understanding.

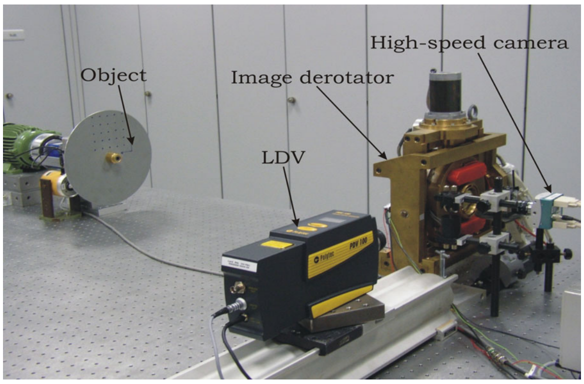

Fig.1 *Set-up for 3-D measurement of the parameters of vibrations of a rotating disc.*

The combination of Laser Doppler Vibrometry (LDV), image derotator and high-speed camera in combination with digital image processing (DIP) opens up new possibilities for simultaneous 3-D measurement of the various parameters of the vibration (fig. 1).

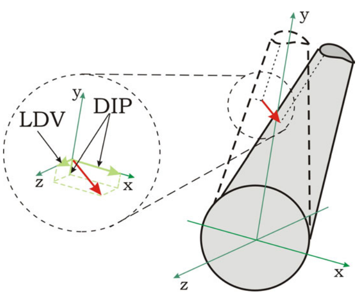

Fig.2 *In-plane, out-of-plane vibration-component*

This system allows continuous vibration analysis. Vibrations differ according to their direction: in-plane vibration and out-of plane vibration. To detect the former image processing in high-speed image sequences was used, for the latter–Laser Doppler Vibrometry (LDV) (fig.2). In the presented investigation we deal with the image processing algorithms for vibration-detection.

2 Experimental set-up

The experimental set-up for the vibration-measurement is shown in Fig.3. As vibrating object, the clamped-free beam was used, as it is mathematically easy to describe and the natural frequency and mode shape are known [4].

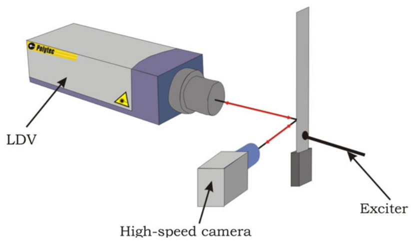

Fig.3 *Set-up for in-plane measurement of vibration.*

The beam was excited with natural frequencies; the image was captured with a Mikrotron high-speed camera (fig 4). A one-point Polytec LDV was used for verification of the results from image processing.

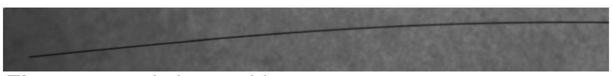

Fig.4 *one-end clamped beam*

3 Image processing algorithm

For detection of the beam vibration-frequency a selection of three tracking algorithms was used. The same image sequences (fig. 4) were processed by all three algorithms: optical flow, KLT-tracking, correlation-based. They were firstly characterised and then compared.

Optical flow is a representation of the instantaneous motion of intensity points between two frames of a sequence of images. Computing of optical flow was done by gradient methods [3].
The basic assumptions of the algorithm are: the brightness of the image pixels remains constant between successive video frames, the motion can be described by a pure translation in the image plane. This can be summarized as:

$$I(x,y,t) = I(x+\delta x, y+\delta y, t+\delta t) \quad (1)$$

I(x, t) is the image intensity function returning the pixel grey value at location x of the image at time t, δx , δy is a pixel shift. Expanding the right-hand side about the point (x, y, t) we get:

$$I(x,y,t) = I(x,y,t) + \delta x \frac{\partial I}{\partial x} + \delta y \frac{\partial I}{\partial y} + \delta t \frac{\partial I}{\partial t} + \varepsilon \quad (2)$$

We have a linear equation with two unknowns $\frac{dx}{dt} = u$ und $\frac{dy}{dt} = v$, where I_x, I_y, I_t represent the partial derivatives of image brightness with respect to x, y and t, respectively:

$$I_x u + I_y v + I_t = 0 \quad (3)$$

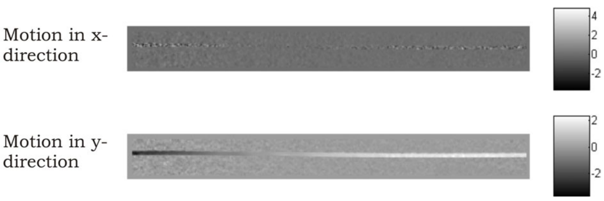

Fig.4 *optical flow tracker-results*

After solving Eq. (3) according to [3], a direction vectors u and v have been detected (fig. 4). Although the beam was excited only in y-direction, calculation has revealed motion in x –direction too. It shows, that optical flow is sensitive to fluctuation in the brightness (of the image).

The feature-based techniques extract local regions of interest (features) from the images and identify the corresponding features in each image of the sequence. The tracking process can be divided into two major subtasks: feature extraction and feature tracking.

KLT Tracker [1] is a dynamic feature extraction algorithm [2].This algorithm selects features which are optimal for tracking and keeps track of these features. The basic principle of the KLT is that a good feature is one that can be tracked well, so tracking should not be separated from feature extraction. If a feature is lost in a subsequent frame, the user can optionally ask the procedure to find another one to keep the number of features constant. This is the main disadvantage of KLT-tracker for our case of detection, since we always need the same region to track.

In the **correlation-based** algorithm some features (in this case 7) are extracted initially in the first image I_n; then the same features in the subsequent images in motion direction are searched for (Fig. 5) by means of correlation.

By this way of tracking we find the trajectories of the extracted features along the beam (fig. 6). Curves 1 and 2 in fig. 6 show the decreasing amplitude of a vibration-antinode; curve 3 represents the corresponding node and curves 4-7 show the following re-increase in amplitude of the following vibration-antinode.

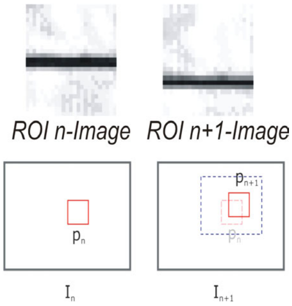

Fig.5 *p_n-region of interest in the first image I_n. In the second image (I_{n+1}) of the image sequence by mean of correlation we detect the shifted region p_{n+1}.*

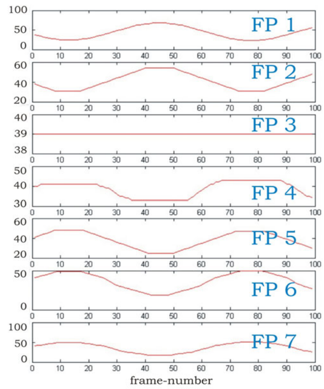

Fig.6 *Vibration trajectories of the region of interest.*

The frequency calculated from FP-1 (the first feature-point) by an FFT was 25 Hz. It was the exciter-vibration-frequency. The vibration-frequency of the FP-1 was verified by LDV.

4 Conclusion

The vibrating-beam-sequence was processed by optical flow, the KLT-tracking algorithm and the correlation-based method. By means only of the last one of these it was possible to trace the same feature-points on the vibrating beam. The frequency applied to the beam was verified via FFT and LDV.

References:

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[3] B.Jähne „Digitale Bildverarbeitung“ (2005)

[4] R.D.Blevins “Formulas for natural frequency and Mode Shape” (1979).