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3D model assisted fully automated scanning laser Doppler vibrometer measurements

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ABSTRACT

In this paper, a new fully automated scanning laser Doppler vibrometer (LDV) measurement technique is presented. In contrast to existing scanning LDV techniques which use a 2D camera for the manual selection of sample points, we use a 3D Time-of-Flight camera in combination with a CAD file of the test object to automatically obtain measurements at pre-defined locations. The proposed procedure allows users to test prototypes in a shorter time because physical measurement locations are determined without user interaction. Another benefit from this methodology is that it incorporates automatic mapping between a CAD model and the vibration measurements. This mapping can be used to visualize measurements directly on a 3D CAD model. The proposed method is illustrated with vibration measurements of an unmanned aerial vehicle

1. Introduction

The increasing availability of low cost and industrial 3D cameras has increased the research on 3D object recognition and pose estimation. Today object recognition and pose estimation techniques are mainly used in robotics and 3D scanning techniques. In this paper 3D measurements and processing techniques are combined with an optical vibration measurement system: the scanning laser Doppler vibrometer (SLDV).

The laser Doppler vibrometer is frequently used in the design and testing of products and structures (e.g. automotive, machine or aircraft components) [1–4]. The scanning laser Doppler vibrometer (SLDV) is an accurate instrument based on laser interferometry that can measure high spatial resolution vibration data by sequentially positioning the measurement laser beam at discrete positions using two scanning mirrors (for the vertical and horizontal deflection of the beam). Commercial SLDV's also have an integrated 2D RGB camera in which the position of the laser can be detected.

Although the SLDV is an accurate vibration measurement instrument, the measurement procedure involves a lot of user interaction: the user has to manually draw a grid of measurement locations on a 2D camera image of the measurement scene. Furthermore, the user also has to perform a calibration between the 2D image of the test object and the two laser mirror angles to aim the laser beam to the object. This can be a time consuming and tedious task that has to be repeated every time that the instrument or the test object is moved. Moreover, the manual interaction can lead to uncertainties between different measurements on the same object [5].

Our proposed methodology uses an automated calibration procedure and a 3D Time-of-Flight camera to measure the location and orientation of the test-object. The 3D image of the Time-of-Flight camera is then matched with the 3D CAD-model of the object in which measurement locations are predefined.

Currently, 3D matching techniques exist and are implemented in open source libraries like PCL-C++ libraries [6]. In our work we mainly use viewpoint feature histograms [7] to detect an object in a point cloud and for finding an initial pose estimation. An implementation of the iterative closest point algorithm is used to refine the pose estimation [8,9]. The pose estimation procedure will be elaborated in the Section 3.3.

2. State of the art

2.1. SLDV systems

Fig. 1 is a picture of the Polytec psv 300 SLDV. The SLDV has 2 movable mirrors used to aim the laser beam and a RGB camera used to see the test object and laserspot. Currently the SLDV measurement procedure requires a lot of user input. When vibration shapes of an object are measured with a traditional system the user needs to go through the following steps:

1. *Calibration* of the scanning system: in the calibration step the transformation between the image coordinates (x,y) and laser

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Fig. 1. Standard scanning laser Doppler vibrometer (Polytec psv 300).

scanning angles (θ_{hor}, θ_{ver}) are determined. To do this the user points the laser at minimum three positions on the structure and manually identifies these positions [5,10]. (see Fig. 2a).

2. *Definition of grid points* on the object in the camera-image. In commercial software, polygon drawing tools are used for this purpose (see Fig. 2b).
3. *Measure* the selected grid points (with specified frequency range, sample rate, etc.) by scanning over the defined grid points by aiming the laser beam. Fig. 2c shows an example of the output of the measurements.

During these steps, aiming the laser on a location on a structure is done by changing the angle of two integrated scanning mirrors. In order to be able to point at arbitrary locations on the structure during the measurement a mapping between the position of the laser spot and the angles of the mirrors is needed. This mapping is calculated with a 2D calibration procedure.

When the measurements are ready, they need to be interpreted and/or validated. With the traditional scanning laser Doppler vibrometer, measurements are only visualized on a standard 2D image of the object (see Fig. 1c). Measurements are also difficult to compare with values from numerical simulations (e.g. finite element analysis) because no direct geometric relation between numerical and measurements nodes is available.

Currently 3D and 2D localization techniques in combination with laser Doppler vibrometry are mainly used for measurements on moving objects. 2D techniques are used to track landmarks of a moving or rotating object and automatically aim the laser beam to a landmark position [11]. Although these methods are fast, the land-mark (white spot, reflective sticker) still needs to be applied manually. With these techniques 3D movements of the target where the landmark is distorted or only partially visible can cause inaccurate results. 3D techniques like photogrammetry are also used to track objects and aim the laser beam [12]. For accurate tracking manually applied or selected landmarks are still needed. None of the methods reported in literature provides a system that can automatically match measurements on a CAD-model and none of them can automatically select (visible) measurement points.

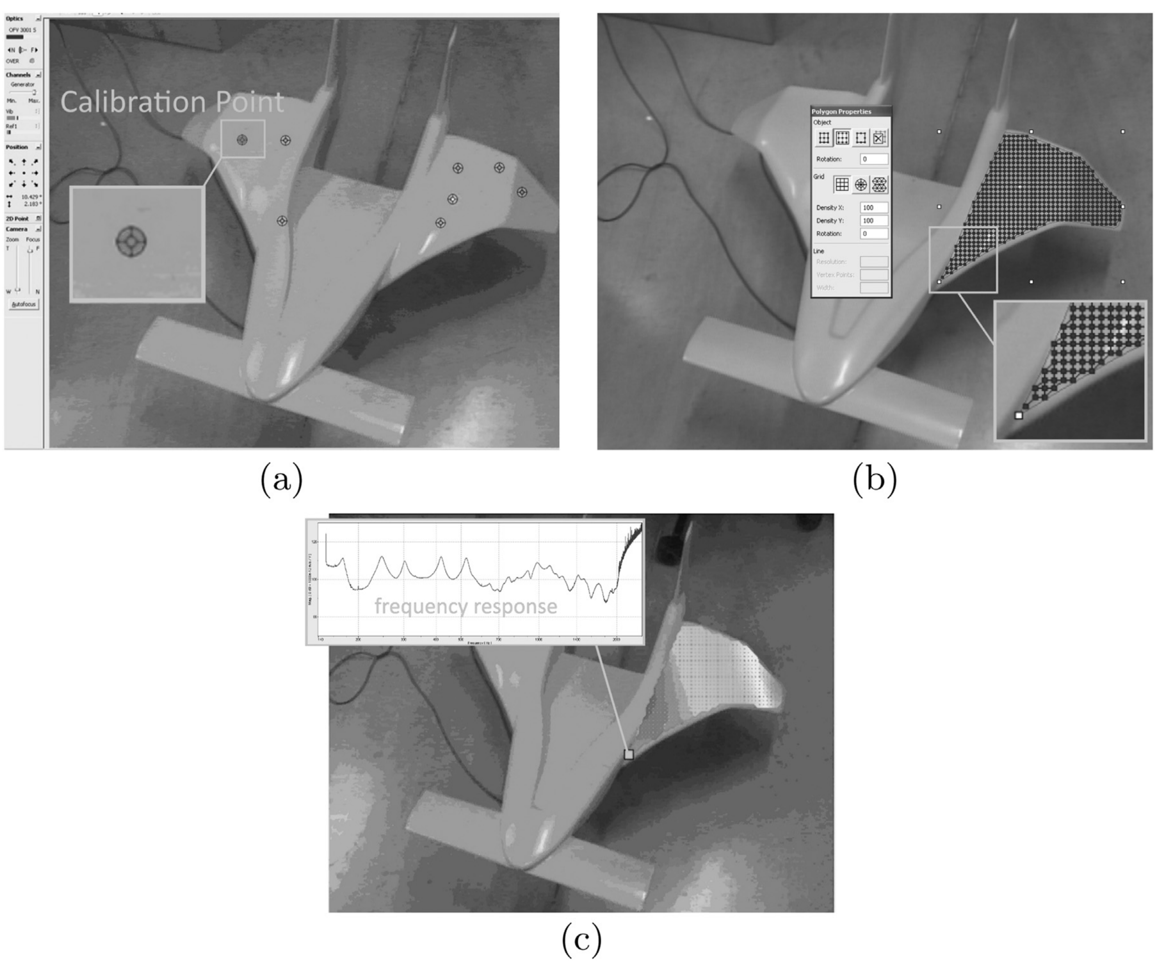

Fig. 2. (a) Manual selection of calibration points. The 8 targets on the structure show the locations where the laser spot was placed and where the user clicked. (b) Manual selection of grid points superimposed on an RGB camera image in the Polytec scanning LDV system using a polygon selection tool. (c) Graphical representation of the second operating deflection shape measured at the selected grid points and a frequency response at a selected grid point.

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