Optik - International Journal for Light and Electron Optics 176 (2019) 482–490

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

Vibration measurement method based on point tracking for irregular structures

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ARTICLE INFO

Keywords:
Point tracking
Vibration measurement
Binocular photogrammetry
Irregular structures
Wind turbine blade

ABSTRACT

A novel vibration measurement method through binocular photogrammetry is proposed to solve the problem of vibration sensing for 3D structures with irregular surfaces. Radial and tangential distortions in the image modeling process are considered for camera calibration through non-linear optimization with Levenberg-Marquardt algorithm. Precise positioning, tracking and matching techniques are analyzed and developed in image processing. As an example, a wind turbine blade's vibration is photographed and calculated, and the measured vibration displacement is consistent with that of the hammer method. The result shows that the relative errors of the first and second order natural vibration frequencies are below 4%. The proposed photogrammetry method is simple, efficient, feasible and reliable, and can be applied to the field of dynamic testing of large irregular structures.

1. Introduction

Three-dimensional structures with irregular surfaces have been widely applied in engineering fields such as the wind turbine blade, aircraft wing and container shell of the aerospace spacecraft and so on. Vibration measurement and modal analysis should be done for the installation, design and modification of such structures before service [1]. Vibration monitoring is also an essential job of the fault diagnosis and prediction when the structures are working in the onsite environment [2,3].

Digital photogrammetry has the advantages of non-contact, high-accuracy, full-field measurement. It is a combined technique of the optical measurement, computer vision, and digital image processing analysis. We can carry out accurate measurement and positioning of the spatial points of geometrical quantities [4]. This method is particularly suitable for detection of light, flexible objects. It has no additional mass and no impact on the structural properties of the measured object. For example, Jurjo used photogrammetry to analyze the deformation of the film structure under different stress by marking the film surface [5]. Kim captured and processed the video using a portable digital video camera to achieve the dynamic measurement of the suspension tension of Gwangan Bridge [6]. The measured deformation can be used to analyze the structural stress, but it is hard to obtain dynamic performance, and lacks high-frequency testing capability. With the improvement of the camera resolution and sampling rate, scholars have conducted researches on photogrammetry technology in the field of dynamic measurement. For example, a monocular camera was used to measure the vibration of an object and analyze the forced vibration of a uniform cantilever beam [7,8]. They have not considered the influence of the complex and curved structure; Xu studied the modal parameter identification for large-scale flexible structures in orbit using digital photogrammetry measurement technology [9]. Tang realized non-contact measurement of disk

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https://doi.org/10.1016/j.ijleo.2018.09.100
Received 18 July 2018; Accepted 18 September 2018

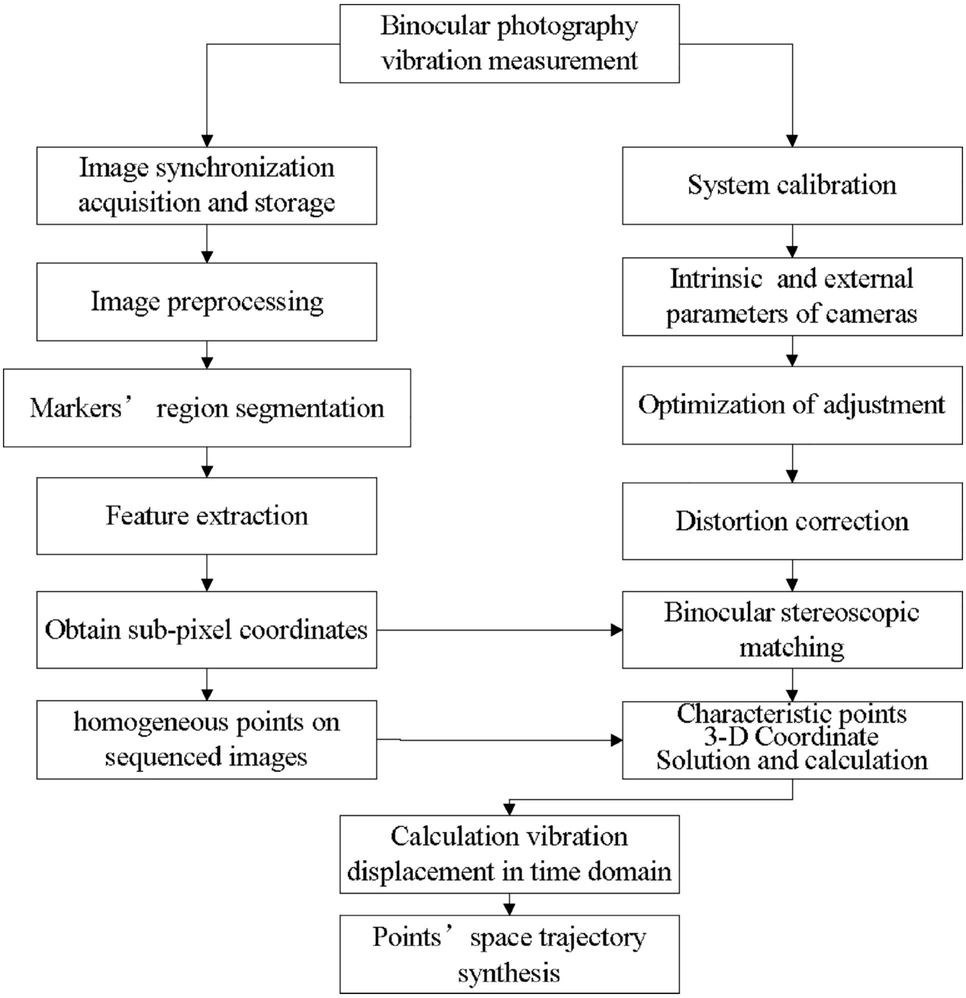

Fig. 1. Flow chart of binocular photogrammetry vibration measurement.

vibration based on machine vision technique [10]. Wang adopted the target point tracking method to achieve geometric modeling of lightweight fan blades, leaves based on video measurements [11].

High-accuracy camera calibration, sub-pixel image coordinates positioning and matching between two cameras are the key techniques in accurate vibration measurement. So a high-accuracy vibration measurement method using binocular photogrammetry based on point tracking is proposed through binocular stereo imaging, target point positioning and feature extraction in this paper. The outline of this paper is arranged as follows. In Section 2, the binocular photogrammetry vibration measurement theory is described. In Section 3, the experiment setup is presented. In Section 4, the results are analyzed and discussed. The conclusions are elucidated in Section 5.

2. Method of binocular photogrammetry vibration measurement

A non-contact binocular photogrammetry vibration measurement method is proposed. It includes through binocular stereo imaging, image feature extraction and target point tracking. The technical route is shown in Fig. 1, which is achieved in three steps. First, the measurement system is calibrated to obtain intrinsic and external parameters of the two cameras. The intrinsic parameters are focal length, principal point coordinates and distortion coefficients. The external parameters are the relative positions of the two cameras. Then the vibration images were captured by two cameras and image features were extracted to position and track certain mark points on the object. At last, the 3D vibration displacement curves were plotted and modal frequencies were analyzed to justify the running status of the measured object.

2.1. Principle of binocular stereo imaging

Fig. 2 shows the stereo imaging model with two cameras, each camera model is a basic pinhole projection model. The subscripts 1