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Research on displacement measurement of disk vibration based on machine vision technique

Wusheng Tang[a], Lihong Tian[b], Xilu Zhao[c,*]

[a] School of Mechanical and Vehicle Engineer, Changchun University, Changchun, China
[b] School of Continuing Education, Changchun University, Changchun, China
[c] Saitama Institute of Technology of Japan, Fukaya, Japan

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ABSTRACT

The paper proposes a new measurement of displacement based on machine vision technique. It ingeniously makes good use of principle of camera calibration and realizes non-contact measurement of disk vibration. There are mainly two parts during the whole process: first, the intrinsic parameters of the camera used are measured by means of highly precise calibration target, and then the extrinsic parameters of disk are obtained by camera. The displacement variation of the feature points on Z axis will be calculated by extrinsic parameters and the vibration displacement can be acquired by conversion of world coordinates with camera coordinates. Compared with previous methods, it can simultaneously obtain vibration displacement of many feature points on the disk, increase the efficiency and precision of measurement with simple and economic apparatus and wide range of application, thus a convenient, feasible and non-contact displacement measurement.

1. Introduction

With the development of micro mechanical system and elaborate processing technology, vibration has drawn people's attention in production and scientific research. Vibration displacement, as the primary parameters in mechanical vibration, plays a prominent role in troubleshooting, supervision of construction; reliability analysis of key mechanical components, etc. Therefore, the measurement of displacement is of great significance.

It is inevitable to have disk vibration when it rotates, which will be the most influential parameter in production. The displacement vibration can reflect amplitude which has immediate impact on practical application. For instance, the vibration displacement of saw blade for logging on the normal direction will reflect the size of log and have immediate impact on wastage of sawing and the pinching of log [1]; the vibration displacement of disk with high-speed revolution will determine working reliability and service life of the disk [2].

At present, vibration measurement has been broadly researched and there are mainly three types: contact measurement based on mechanics; non-contact measurement based on electronic sensor; non-contact measurement based on optical sensor. The measurement based on mechanics has been adopted relatively earlier. Pure mechanical method is used to perceive the displacement vibration of objects to be measured and the signals are magnified and recorded by mechanical structure. It is characterized with advantages of simple structure and easy operation and shortcomings of low sensitivity and impact on the surface of the object [3]. In order to improve the impact of touching with the object during measurement, non-contact measurement method based on electronic sensor has been researched. For instance, in 1974, Stoll R. L. in Oxford University proposed the measurement of axis vibration displacement by means of sensor-measuring disk vibration by eddy current sensor, which created relatively good result. However, its major shortcoming consisted in poor linearity of and greater drifting of temperature of axis displacement [4]. Others adopt magneto electric sensor and sound sensor for measurement. Though the vibration measurement in certain circumstance can be realized, the accuracy of measurement will be impaired since the sensor will be subject to environment and the sensor itself will create noise [5].

In 1989, Vikhagen raised Using Phase-shifting TV-holography and Digital Image-processing for Vibration Measurement [6]. In 1996, Wang put forward The Time-Averaged Electronic Speckle Pattern for vibration measurement [7]. In 2009, Perrone came up with A Low-Cost Optical Sensor Technology for vibration measurement [8].

Since it is broadly acknowledged that laser sensor can provide fewer feature points, and no vibration data of other points on the

* Corresponding author. Tel.: +86 13804310281.
E-mail address: tws@ccu.edu.cn (X. Zhao).

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disk surface, Yan Gao proposed semiconductor laser using self-mixing interferometer for measurement in 2014 [9]. At present, machine vision technology has still not been adopted for vibration measurement. The paper first proposes the new measurement for disk vibration displacement based on machine vision technique, which is featured with easy operation, simple apparatus, low cost, high accuracy and possibility of non-contact simultaneous optical measurement for multiple points [10]. The paper will be presented in several parts including principle of measurement, intrinsic parameter calibrating of camera, procedure of disk vibration measurement, experiments measurement and conclusion.

2. Principle of measurement

The paper studies vibration of any point on the disk along the $O-Z_w$ direction by establishing world coordinate system $X_wY_wZ_w-O$ according to camera calibrating method of Zhengyou Zhang [11], i.e. displacement variation of the disk surface on the normal direction, as schematically presented in Fig. 1 measurement of disk vibration by camera calibration method [12].

First of all, intrinsic parameters of camera will be obtained through calibration target of high precision; the disk at idle state will be shot by the camera and extrinsic parameters of the disk will be calculated by the information of angular point stuck on the disk (the equation of plate under the coordinate of camera will be reflected). Four feature points on the disk image will be randomly selected, as is shown in Fig. 4. The equation of radial which passes through the four feature points and is vertical to the disk plane will be obtained. The vibrating image of the disk will be snapped and the corresponding extrinsic parameters at different moments calculated, thus getting the intersected point of the disk plane and the radial. Therefore, the vibration displacement of the four feature points along the direction of radial will be finally obtained [13,14].

During the experiment measurement, the disk to be measured will be fixed on the spindle, which is driven by the frequency conversion. CCD camera which is connected with computer through image capture card, will collect image data of the rotating disk at any moment and the data processing software will process the real-time image data. The coordinate of any point on the disk in the coordinate system of the camera will be determined according to Zhengyou Zhang's principle of extrinsic parameters calibration of camera. ΔZ—the variation of disk on the direction of Z_w will be obtained by converting measured data into coordinates, i.e. the displacement variation on the Z direction during the rotation of disk.

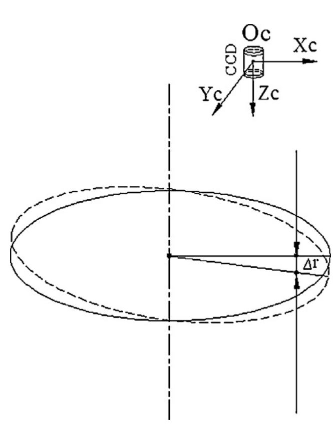

Fig. 1. Schematic figure of vibration measurement of disk.

3. Calibrating of intrinsic parameters of camera

The intrinsic parameters of camera should be calibrated before vision measurement. Zhang proposed a flexible new technique for camera calibration by viewing a planar target from different unknown orientations [15]. Accurate calibration points can be easily obtained using this method. Now, it is widely used in the camera calibration.

According to Mr. Zhang's method, when three-dimensional point is projected on the two dimensional plane, the process is regarded to follow the principle of aperture imaging, in which there are four conversions of coordinate system. The world coordinate (X_w, Y_w, Z_w) will be successively converted to camera coordinate (X_c, Y_c, Z_c), ideal coordinate (x_u, y_u), real coordinate (x_d, y_d) and pixel coordinate $\left(x_p, y_p\right)$. For general cases, Z coordinate of the world coordinate can be determined as 0, i.e. $Z_w = 0$. A plane-calibrating linear model of pixel coordinate (x_p, y_p) converted from $(X_w, Y_w, 0)$ will be obtained if non-linear distortion is neglected.

$$s\begin{bmatrix} x_p \\ y_p \\ 1 \end{bmatrix} = A\begin{bmatrix} r_1 & r_2 & t \end{bmatrix}\begin{bmatrix} X_w \\ Y_w \\ 1 \end{bmatrix} = H\begin{bmatrix} X_w \\ Y_w \\ 1 \end{bmatrix} \tag{1}$$

$r_i\,(i = 1, 2, 3)$ refers to No. i line of the rotation matrix R, t refers to translation vector. R and t are jointly extrinsic parameters of calibrating model. $A = \begin{bmatrix} \alpha & \gamma & u_0 \\ 0 & \beta & v_0 \\ 0 & 0 & 1 \end{bmatrix}$ is the matrix of intrinsic parameters. Under the ideal condition, the world coordinate and pixel coordinate will rigidly fit Eq. (1). While in reality, it is impossible to get the case mentioned above, for the image coordinate of the feature points will be subject to distortion.

On this account, the lens distortion should be taken in to consideration. In the paper, radial and tangent distortion will be taken into consideration.

$$s\begin{bmatrix} x_u \\ y_u \\ 1 \end{bmatrix} = \begin{bmatrix} r_1 & r_2 & t \end{bmatrix}\begin{bmatrix} X_w \\ Y_w \\ 1 \end{bmatrix}$$

$$\left(1 + k_1r^2 + k_2r^4\right)\begin{bmatrix} x_d \\ y_d \end{bmatrix} + \begin{bmatrix} 2p_1x_dy_d + p_2\left(r^2 + 2x_d^2\right) \\ p_1\left(r^2 + 2y_d^2\right) + 2p_2x_dy_d \end{bmatrix} = \begin{bmatrix} x_u \\ y_u \end{bmatrix}$$

where $r = \sqrt{x_u^2 + y_u^2}$, $\begin{bmatrix} x_p \\ y_p \\ 1 \end{bmatrix} = \begin{bmatrix} \alpha & \gamma & u_0 \\ 0 & \beta & v_0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} x_d \\ y_d \\ 1 \end{bmatrix}$.

The optimization function for the calibration is established by minimizing the metric distance error between the calculated point and the real point in 3D measurement coordinate,

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\left\|M_{ij} - \widehat{M}\left(A, k_1, k_2, p_1, p_2, R_i, t_i, m_{ij}\right)\right\|^2$$

where the subscript m denotes the number of patterns, the subscript n denotes the number of points in one pattern. By means of the L–M algorithm, the model of this paper can be solved accurately. Thus, the intrinsic parameters of camera, the intrinsic matrix $A = \begin{pmatrix} \alpha & \gamma & u_0 \\ 0 & \beta & v_0 \\ 0 & 0 & 1 \end{pmatrix}$ and the distortion coefficient $K = (k_1, k_2, p_1, p_2)$, can be determined first [11,15].