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Non-linear dynamic compensation and re-sampling for tactile scanning measurement of curved surface topography based on GPS standards

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ABSTRACT

Tactile scanning method is widely used for curved surface topography measurement. Owing to the non-linear transformation process from the vertical translational displacement of the measured point (the coordinates of stylus tip) to the angular displacement of the stylus tip (measured by the cylindrical diffraction grating), the non-linear error exists within the horizontal and vertical coordinates of the obtained sampling data. And the non-linear error normally rises with the increasing of the measurement range.

To solve the non-linear problem, a tactile scanning measurement system based on cylindrical grating interference principle is constructed for curved surface topography; the originations of the non-linear error in this system are analyzed, the error compensation model is established, through which the non-linear error of the collected data is dynamically compensated. Subsequently, for the non-uniform distribution of the sampling points, data analysis method is investigated, in which non-uniform interpolation and re-sampling techniques are investigated to obtain accurate data with uniform interval, so that the analysis and evaluation of surface profile can be conducted based on GPS (Geometrical Product Specifications) standards. Experimental results prove the improvements.

1. Introduction

Despite a great development of optical and other techniques, a tactile profilometer is still the most widely used surface topography measuring device in mechanical industry [1,2]. With the development of large range tactile scanning transducer, measurement of curved surface topography in spherical and aspheric optical elements, gear surfaces, etc., becomes possible [3].

The tactile scanning measurement system based on cylindrical grating interference principle can be used for the measurement of curved surfaces topography. The rotational angle of stylus arm can be up to ±2°, and the vertical measurement range can be up to 10 mm. However, the error of measurement and evaluation normally exists owing to the non-linear transformation process from the vertical translational displacement of the sampling point to the angular displacement of the stylus tip, and it rises with the increasing of the measurement range.

To solve this problem, current methods are mainly based on modeling and least square fitting, in which the non-linear mechanism is not cared; only a model with many unknown coefficients relating sampling data to practical coordination of measurement points is given. Then by applying least square fitting model to a group of data extracted from a standard sphere, the coefficients are obtained, so that the sampling data can be compensated for practical measurement. A problem in this method is the incompleteness of the model, and the standard sphere is a specific standard sphere with given diameter, which does not necessarily include all possible cases with different surface curvatures [4–7].

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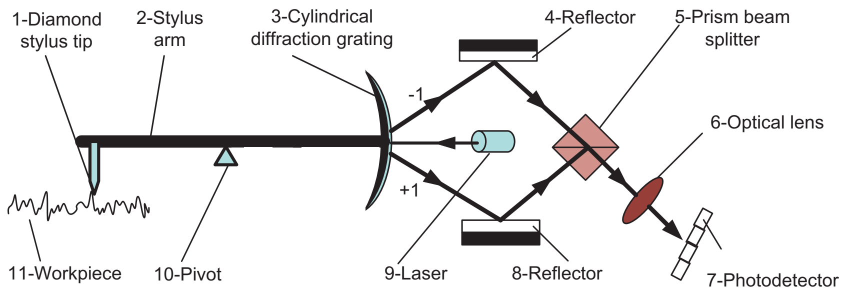

Fig. 1. Principle of the cylindrical grating interference transducer.

In this paper, the non-linear mechanism for large range tactile scanning measurement system is analyzed, a compensation model relating the horizontal and vertical coordinates of the sampling point (which are the collected data) to the horizontal and vertical coordinates of the practical measured point (the coordinates of stylus tip) has been built. Subsequently, non-uniform interpolation and re-sampling techniques are researched to obtain accurate data with uniform interval from the collected sampling point with non-uniform distribution, so that the analysis and evaluation of surface profile can be conducted based on ISO standards.

2. Principle of the cylindrical diffraction grating transducer

Principle of the cylindrical grating interference transducer is shown in Fig. 1 [8]. The center of the cylindrical diffraction grating coincides with rotation center of the stylus arm. The laser beam, of which the frequency is f_0 and the wavelength is λ, is incident onto the cylindrical grating and diffracted. The +1 order and −1 order diffraction lights gather in the prism beam splitter and interfere with each other. By the optical lens and the photodetector, the interference fringe information is detected and transformed to periodical electronic signal.

When the stylus arm rotates, the frequency shift phenomenon happens to the diffraction lights according to the Doppler Effect, as shown in expression (1).

$$f_m = f_0 + \frac{v}{d} m \tag{1}$$

where m is the order of the diffraction light, v is the tangential velocity of the incident point in grating, and d is the grating constant. The beat frequency of interference between +1 and −1 order diffraction lights is showed in expression (2) [8].

$$\Delta f = f_{+1} - f_{-1} = \frac{2v}{d} = \frac{2wr}{d} \tag{2}$$

where r is the rotation radius of grating, w is the angular velocity of grating. Intensity of the beat frequency signal received by the detector is represented as expression (3).

$$I(t) = I_1 + I_2 \cos\,(2\pi \int_0^t \Delta f dt) = I_1 + I_2 \cos\left(\frac{4\pi r\varphi}{d}\right) \tag{3}$$

where I_1 is the direct current component of light intensity, $I_2 \cos\left(\frac{4\pi r\varphi}{d}\right)$ is the alternating current component of light intensity, φ is the angular displacement of the grating and it will be measured precisely by detecting the phase changes of the beat frequency signal.

The transducer's measurement range depends on length of the cylindrical diffraction grating. Therefore by this transducer, surface topography could be measured in a large range.

3. Non-linear analysis and dynamic compensation model

The axial section of the stylus is shown in Fig. 2, where L is the horizontal distance from the stylus tip to the pivot of stylus arm, φ is the angular displacement of the stylus tip, dx is the difference of horizontal position between the actual measured point and the supposed measured point, dz

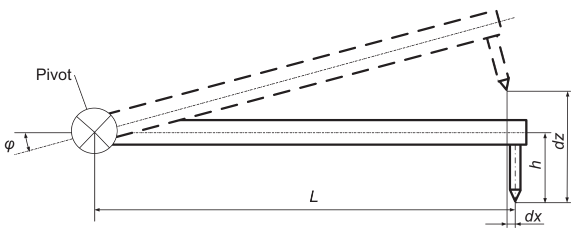

Fig. 2. Schematic diagram of tactile scanning model with large range.

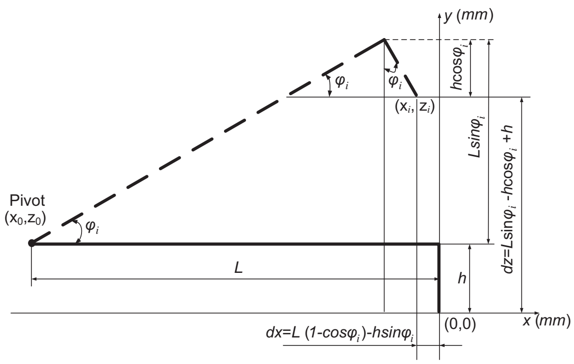

Fig. 3. Geometrical relationships of the non-linear conversion process.