High-precision non-contact profile measurement for spherical surfaces and aspherical surfaces

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Abstract: Using the advantage of white-light interferometric technique, a new method for the optical non-contact profile measurements of spherical surface and aspherical surface based on image orientation technology is presented in this paper. In this method, a new system uses the grating sensors and piezoelectric transducer to control the motion of the objects, and utilizes the vertical scanning interferometric techniques to achieve the large-range profile measurement for spherical surface and aspherical surfaces.

1. Introduction
The non-contact profile measurement of the spherical surfaces and aspherical surfaces is quite hard because of the reflectivity and surface characteristics. Contact methods, such as stylus profilometer, have some advantages to measure curved surface profiles, but it only can be used to measure mechanical surfaces. With the development of white-light interferometric technique, the white-light interferometry is employed in the measurement of spherical surfaces and aspherical surfaces.

Recently, because of its theoretically unlimited unambiguous height range and high-precision, white–light interferometric non-contact measurement method has been applied in many facets of research and manufacturing[1]. Many instrument companies have developed precise, non-contact three-dimensional profiler, such as Talysurf CCI 3000, ZYGO NewView 5000, Wyko optical 3D profiling systems etc. These interferometers use piezo-based transducers to change the optical path difference (OPD) and to achieve the scan of surfaces, so they have high resolution and have unparalleled performance on the measurement of surface roughness. But one measurement area is not large enough to assess the form of spherical surfaces and aspherical surfaces; one solution to enlarge the measurement area is to use small magnification objectives, but this decreases the optical resolution. Another way to measure larger surfaces is to stitch those small view fields, but that will increase the measurement time.

We used a displacement stage to achieve the larger surface measurements based on image orientation techniques, without decreasing any resolution. In this paper, a new system based on this new method is described.

2. Approach and measurement instrument
The main characteristic of white light interference is that the maximum intensity is at the only place where the OPD is zero. If the fringe exists and can be discerned in the image, computer will detect this place through comparing the intensity, so the place of the maximum intensity is considered as the
observed place and it is located at a fixed place of the view field, such as the center of view field. During the scanning process, every horizontal displacement of the measured object makes the observed place move from the fixed place, but it is moved back to the fixed place through the vertical step motion of the measured object. Then a larger area could be measured with one scan.

To achieve the purpose of this measurement method, a system is developed based on Linnik interferometry in Figure 1. This system consists of an optical set-up of Linnik interferometry, a set of stages and image acquisition system. These stages are the key to achieve the measurement of the spherical surfaces and aspherical surfaces. They include a horizontal displacement stage driven by a stepping motor with grating sensor, a coarse displacement stage driven by a stepping motor and a fine stage driven by a closed-loop piezoelectric transducer with grating sensor.

Before the measurement of the spherical and aspherical surfaces, a measurement range is predetermined. It depends on the resolution of the CCD. The measurement process is performed by the adjustments of the stages. Because the slopes of the measured curved surfaces by non-contact measurement method could not be large to have sufficient light reflected to the objective, every horizontal displacement is equi-spaced. Then the fine vertical displacement makes sure that the observed place of the fringe returns the fixed place after every horizontal displacement. Considering the range limitation of PZT and the vertical displacement of the measured spherical surface and aspherical surfaces far beyond the working distance of PZT, so when the cumulative vertical displacement is beyond the working distance of PZT, the PZT is initialized and the coarse vertical displacement stage is adjusted to make the observed place move to the fixed place. The motion of PZT shows the vertical displacement of the measured object and the coarse vertical stage just enlarges the vertical working distance of this system.

The measurement precision of this measurement system depends on the scanning process, mainly depends on the scan steps [2]. To solve this error, a closed-loop system with grating sensor monitors the motion of PZT. The grating adopts 1200 grids/mm, so one counter pulse is expressed as $1/(1200*16)\text{mm} \approx 52\text{nm}$. The subdivision of signal is up to 100, and then the vertical resolution of PZT is about $0.5\text{nm}$. In these experiments, the practical signal is subdivided by 10, the vertical resolution is about $5.2\text{nm}$. The coarse vertical stage provides the large scanning range though the iterative scanning of PZT and is not involved in scanning precision but the precision of location precision, so its resolution is enough to up to the resolution of CCD.

There are still some problems that affect the scanning process, such as the reference mirror, and the flatness of the horizontal displacement. If the reference mirror does not parallel the axis of horizontal displacement, the radius of the fringe will change and some points at the observed place will change
their relative places when horizontal displacement moves. Such errors also introduced by the skid of horizontal displacement stage.

3. Experiments and results
Experiments are performed by a WIVS measurement system with the 6JA interferometer, ARONIX MBC6060 CCD camera and industrial computer in Figure 2. The numerical aperture of the interferometer is 0.65 and the magnification is 40X. The effective picture elements of CCD is 752(horizontal) × 582(vertical).

![WIVS measurement system](image)

Figure 2. WIVS measurement system

![Profile curve and error curve of spheric lens](image)

Figure 3. Profile curve and error curve of spheric lens

Figure 3 presents the measured profile curve and error curve of the spherical lens with a 19.011mm radius. A fitted circle is obtained by the least-squares fitting technique[3] and the fit radius of measured spherical data is 19.012mm. The error is 1µm. The error curve shows the errors increase from the crown to the lower, because the resolution decreases with the decreasing of the fringes space.

Figure 4 is the surface profile curves of a cylinder lens with 48mm radius. The radius of fitting sphere is 48.308mm. The axis of cylinder lens is not perpendicular to the motion direction of the horizontal displacement stage, so that causes the large error in the radius.

![Profile curve and error curve of cylinder lens](image)

Figure 4. Profile curve and error curve of cylinder lens.
Figure 5 is the surface profile of a stainless steel ball of 3/4 inch diameter. The diameter of fitting sphere is 19.043mm and the error is 7µm.

![Profile curve and error curve of stainless steel ball](image)

4. Conclusions
The discussion of this measurements system for the spherical surfaces and aspherical surfaces shows that the roughness and form of spherical surfaces and aspherical surfaces are measured with one scan. This process can measure larger spherical and aspherical surface profiles rapidly. But there are still many factors, such as ambient chatter, uneven light etc, that affect the accuracy and performance of this measurement system.

References
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[3] J. W. McBRIDE and K. J. CROSS 1996 *Int. J. Mach. Tools Manufact* 36 597