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The research of wavefront sensor based on focal plane and pupil plane

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ABSTRACT

Large aperture telescope with its high concentrated capability and high resolution plays an important role in many fields. The demand for large aperture imaging telescope is increasingly urgent, there are a lot of challenges with the increase of telescope aperture during the optical processing and testing. In order to solve the above problems, this paper mainly studies wavefront sensing technology which is the key technology in the adaptive optics system, launches a comprehensive in-depth study on the pupil plane wavefront sensor and focal plane wavefront sensor, introduced the pupil wavefront detector and focal plane wavefront detector, and then compares both of them, this work has important implications for theoretical research and engineering applications, providing a favorable guidance for the practical application of adaptive optics system is also needed for the large-diameter telescope distortion and provides a reference wavefront aberration detector.

1. Introduction

In order to pursue higher resolution observations, whether ground or space-based telescopes [1], a common trend is the increasing diameter of the primary mirror of the telescope. To some extent, the aperture size becomes a reflecting telescope observing capabilities of indicators. However, when light-wave goes through the atmosphere, due to the dynamic perturbation of atmospheric turbulence, the beam quality will be severely damaged, which will cause the wavefront distortion. For large-aperture ground telescope imaging system, atmospheric turbulence makes the target image blur, light scatter, resolution in serious decline. On the other hand, increasing the size of the primary mirror to the telescope design, processing, manufacturing, testing and other technology has brought unprecedented challenges. Therefore, it needs adaptive optics (AO) [2] caused by atmospheric turbulence correction, which is an important prerequisite for achieving effectively detect wavefront distortion and correction [3]. Development of wavefront sensor (WFS) [4–7] becomes one of the key issues for AO system. To solve the above problem, this paper mainly studies WFS technology which is the key technology in the adaptive optics system, launches a comprehensive in-depth study on the pupil plane wavefront sensor (PP-WFS) and focal plane wavefront sensor (FP-WFS), first introduces PP-WFS and FP-WFS, and then compares both of them. This work has important implications for theoretical research and engineering applications, providing a favorable guidance for the practical application of AO system is also needed for the large-diameter telescope distortion and provides a reference wavefront aberration detector.

This paper is organized as follows: the introduction of WFS is presented in Section 2, the comparison of PP-WFS and FP-WFS in Section 3 and the summary in Section 4.

2. Wavefront sensor

According to the position in which the optical system, wavefront sensor can be divided into pupil plane wavefront sensor and focal plane wavefront sensor in the exit pupil position of the optical system.

2.1. Pupil plane wavefront sensor

The common PP-WFS has knife-edge instrument, Shack–Hartmann sensor and interferometers and so on.

2.1.1. Knife-edge instrument

The knife-edge instrument is a shadow method using the principle of a simple tool to check the wavefront error of optical components in the processing of the scene. The principle is that light emits from the light source via the first condenser lens converging planar light-wave, and then goes through the second condenser lens through an aggregation of small plane mirror steering, imaging in the vicinity of the light source edge. Shown in Fig. 1, put a pinhole in the image of the light source, and then get the

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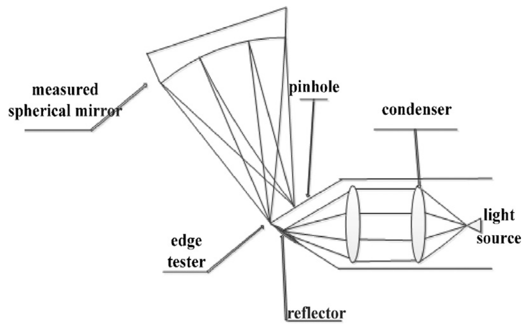

Fig. 1. Schematic of knife-edge instrument.

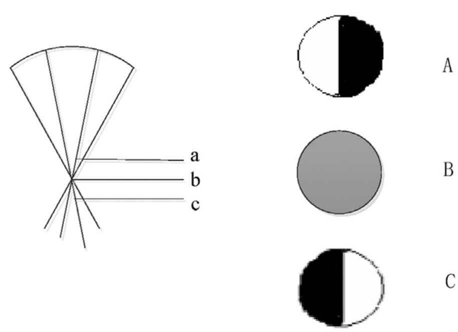

Fig. 2. The theory of knife-edge instrument measurement.

standard point source. The spherical wave outgoes from pinhole exposure to the detected spherical mirror, after spherical reflector, and then images onto the blade. With a knife cut a pinhole image, we can see the situation of the shadow which is not far from the measured spherical mirror after the edge; we will know the error of the measured spherical mirror.

We can see from Fig. 2, the convergence of the light from the mirror, the blade moves to a (former Focus) at the cut, this time to see the light on the right side of the first mirror is blocked. See the mirror from Fig. 2A. If c (back focus) is at the cut with a knife, then the mirror to the left of the first light is blocked, you can see the mirror as shown in Fig. 2C. If b (focus on) at the cut, then all the light on the mirror surface are obscured edge, mirror should suddenly dimmed, but there is always a certain size pinhole instead of infinitely small, due to the volatility of the principle of light (needle infinitesimally small hole), the smallest image of the pinhole is a diffraction spot, so we see the mirror is darkening, then cut into the most sensitive area, as shown in Fig. 2B.

2.1.2. *Shack–Hartmann WFS*

Shack–Hartmann (S-H) WFS [8–9] is an instrument that can be used to detect the wavefront in the processing site of the reign of detection, which is based on the slope of the wavefront measurement. In the detection time, using compensation glass and the microlens array, which is difficult to manufacture, needs high precision, and due to restrictions by the lens array, it has a lower lateral resolution.

The principle of S-H WFS is to use a microlens array at the aperture plane of the incident wavefront spatially sampled, the corresponding target image formed at the focal plane of each sub-lens, as shown in Fig. 3, the pore size and the focal length of the same set of micro-lens make the main microlens aperture of the detector divide into several sub-aperture, the distortion of the wave are imaged at the focal plane of each micro-lens, use an area array detector member (such as a CCD camera) measure the offset (wavefront slope) of each sub-aperture point and the calibration position,

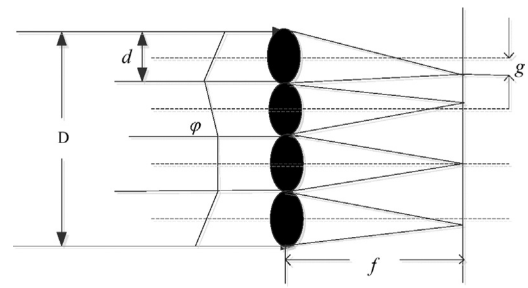

Fig. 3. Schematic of the theory of S-HWFS.

and then use wavefront restoration algorithm indirectly measure the size of the distortion of the wavefront.

2.1.3. *Interferometer*

Interferometer has high measurement accuracy, a high sampling rate; the order of the wavelength detection sensitivity can be achieved to the order of wavelength. First, we compare with interferometer and the former standard wavefront, and then obtain the measured data of the wavefront aberration by comparing, due to higher requirements of the environmental factors, the vibration and air turbulence is sensitive, and so in general, it needs work at a constant temperature of indoor environment. According to the reference wave generation method is divided into: point diffraction interferometer and shearing interferometer [10,11].

R.N. Smartt first proposed point diffraction interferometer in 1972, the principle is to focus the beam to be detected in a translucent panel with a pinhole mask; we can get the phase contour map of the detected wavefront with the spherical reference wave produced by the pinhole diffracted and the interference pattern detected by the mask resulting wavefront.

Shearing interferometer splits the wavefront through the detected device into two plane waves by using a suitable optical system, and make them mutually staggered (shearing) from each other, they have a two-wave interference pattern in the overlap portion surface, get wavefront information by analyzing interference striped. The advantage is relatively simple and stable structure, strong anti-jamming capability and eliminates the need for a standard reference optical surface; the disadvantage is more difficult to interpret the interference pattern formed after the cut, lower solar energy utilization. Thus, it is replaced by a subsequent interferometer.

Wave-plane interferometer is a precision instrument that detects surface shape of the optical element, the wavefront aberration of the optical lens, the optical uniformity of the material and so on. It has high detection accuracy, measurement accuracy is generally 1/10 wavelength to 1/100 wavelength, but difficult to detect the surface shape in the processing scene.

2.2. *Focal plane wavefront sensor*

FP-WFS is in the image plane of the imaging optical system position, often do not need to add the auxiliary optical components, which capture the multi-frame short-exposure image by given the defocus aberration, the solver to get the wavefront phase information of the optical system and can use Zernike polynomials fitting the individual aberrations. The most common application FP-WFS is phase retrieval (PR) WS, phase diversity (PD) WS, phase-diversity phase retrieval (PDPR) WS, extend Nijboer–Zernike (ENZ) WS.

2.2.1. *1PR-WFS*

PR technique [12–16] uses light field diffraction model, diffracted calculate the assumed input light field and obtain the intensity distribution of the output surface of the light field.