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Simulation on the Measurement Method of Geometric Distortion of Telescopes[†] [⋆]

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Abstract The accurate measurement on the effect of telescope geometric distortion is conducive to improving the astrometric positioning accuracy of telescopes, which is of significant importance for many disciplines of astronomy, such as stellar clusters, natural satellites, asteroids, comets, and other celestial bodies in the solar system. For this reason, the predecessors have developed an iterative self-calibration method to measure the telescope geometric distortion by dithering observations in a dense star field, and achieved fine results. However, the previous work did not make constraints on the density of star field, and the dithering mode, but chose empirically some good conditions (for example, a denser star field and a larger dithering number) to observe, which took up much observing time, and caused a rather low efficiency. In order to explore the validity of the self-calibration method, and optimize its observational conditions, it is necessary to carry out the corresponding simulations. In this paper, we introduce first the self-calibration method in detail, then by the simulation method, we verify the effectiveness of the self-calibration method, and make further optimizations on the observational conditions, such as the density of star field and the dithering number, to achieve a higher accuracy of geometric distortion measurement. Finally, taking consideration of the practical application for correcting the geometric distortion effect, we have analyzed the relationship between the number of reference stars in the field of view and the astrometric accuracy by virtue of the simulation method.

Key words astrometry—techniques: image processing—methods: numerical

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1. INTRODUCTION

As the studies indicated, no matter in space or on ground, the telescope geometric distortion affects seriously the accuracy of astrometric position determination[1−2]. Hence, the accurate measurement on the effect of telescope geometric distortion will be conducive to improve the astrometric accuracy, and to promote the development of the kinematic research of celestial bodies, including the stellar clusters, the natural satellites, asteroids, and comets in the solar system[1−7]. Here, the geometric distortion indicates the deformation of the celestial area image actually observed by the telescope detector with respect to the real image, which can not be explained by a linear transformation, hence it is also called the optical distortion, and it is caused by the defects in the design and fabrication of the telescope optical system and the back-end detector.

Early in 1995, Holtzman et al. found the geometric distortion in the data processing of the Hubble Space Telescope (HST), for its Wide Field Planetary Camera 2 (WFPC2) the maximum error attained 0.17 arcsec[8]. This influenced gravely the development of the successive research subjects. Hence, using the self-calibration method, they made the data treatment on the multi-epoch dithering observations (with the F555W filter) of the stellar cluster NGC 5139, and derived the geometric distortion expressed by a cubic polynomial of plate coordinates (x, y). After the correction, the accuracy of position determination was approximate to 10 mas. Later, Gilmozzi, Trauger, and Casertano et al. improved respectively the method of Holtzman et al., for example, updating the expression of the geometric distortion, introducing a flat-field transmission coefficient to eliminate the effect of the observing wavelength on the measurement of geometric distortion, and observing a denser star field, etc., so that the accuracy of geometric distortion correction was raised to 0.05 pixel (for a planetary camera), and 0.02 pixel (for a wide angle camera) [9−11]. In 2003, Anderson and King made further improvements on the geometric distortion correction, by introducing a point spread function to increase the measuring accuracy of stellar image position, by eliminating the camera edge effect, increasing the observation number and density, and rotating the observing direction to derive the linear skew term of the geometric distortion, they raised the correction accuracy to 0.02 pixel (planetary camera) and 0.01 pixel (wide angle camera), respectively[12]. In 2009, the HST equipped with a new camera, namely the WFC3, by the multi-epoch dithering observations in a denser start field, Bellini and Bedin obtained the geometric distortion of the new camera, and its correction accuracy attained 0.008 pixel, corresponding to 0.3 mas[13−14].

Different from the space observation, the inferiority of the ground-based observation is not only the gravity bending effect of telescopes, but also the atmospheric effect to degrade the measuring accuracy of stellar image position; but it has an advantage over the space observation that because the data acquisition is not limited by the bandwidth, hence we can improve the measuring accuracy of stellar image position by means of data acquisition, besides, the ground-based telescopes generally have a rather large field of view, and therefore