A Focal Plane Metrology System and PSF Centroiding Experiment

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ABSTRACT

In this paper, we present an overview of a detector array equipment metrology testbed and a micro-pixel centroiding experiment currently under development at the National Space Science Center, Chinese Academy of Sciences. We discuss on-going development efforts aimed at calibrating the intra-/inter-pixel quantum efficiency and pixel positions for scientific grade CMOS detector, and review significant progress in achieving higher precision differential centroiding for pseudo star images in large area back-illuminated CMOS detector. Without calibration of pixel positions and intra-pixel response, we have demonstrated that the standard deviation of differential centroiding is below 2.0e-3 pixels.

KEYWORDS: STEP, exoplanets, centroiding, photon weighted means, Gauss fitting, Fourier resampling

1. INTRODUCTION

In 1992, planets around a pulsar are discovered by means of pulsar timing technique in radio wave band[4]. The discovery of the first exoplanet surrounding a main-sequence star was announced in 1995 by radial velocity measurement[5]. The exoplanet-star systems have many observation characteristics. Several detection methods have been developed based on the observation characteristics of exoplanets: radial velocity measurements, transit observations, microlensing, astrometry, direct imaging and so on. Current detection methods have obvious selection effects and most of the planets detected are gas giants. Astrometry is the one of the most efficient technique for the detection of low-mass, solid and small planets. The launch of the Gaia satellite paves the way for future space astrometry missions aiming at the detection of the Earth-like planets around nearby stars[6].

The Search for Terrestrial Exo-Planet (STEP) mission aims at the nearby earth-alike planets detection, and it was originally proposed in 2013 by the National Space Science Center, Chinese Academy of Sciences, which is currently being under background engineering study phase in China[1]. The STEP mission is a space astrometry telescope working at visible light wavelengths and it has a compact TMA design comparing with the NEAT mission[5-9]. The STEP mission aims at the nearby terrestrial planets detection through micro-arcsecond-level astrometry. The requirement of centroiding accuracy for STEP is 1e-5 pixel. A centroiding experiment have been carried out on a metrology testbed in open laboratory. In this paper, we present the preliminary results of determining the separations between star images.

In this paper, we will present the design of the metrology testbed and the preliminary results of a centroiding experiment. The paper is organized as follows. The design of the testbed is presented in Sec. 2. In Sec. 3, the data reduction method and the results are presented. The summary are given in Sec.4.

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The focal plane metrology system is based on the heterodyne laser interferometry. The heterodyne laser interference system is used to calibrate the detector array equipment. It consists of a HeNe laser source, a splitter, several AOMs, a synthesizer & RF driver, a polarization controller, an optical switch and several optical fibers. Due to frequency offset, the two coherent laser beams will generate the moving fringes on the detector. It can be used to calibrate the geometrical characteristics and the intra-/inter-pixel QE of the detector array. The centroiding testbed consists of a LED source, a fiber bundle, a spherical mirror. The LED source and a single mode fiber bundle is used to generate the pseudo star source. The schematic of the focal plane metrology testbed and centroiding testbed is shown in Figure 1. The parameters of the testbed is listed in Table 1. A similar optical design appeared in the NEAT centroiding testbed[10-13].

Table 1. The main technical parameters of testbed.

<table>
<thead>
<tr>
<th>Laser wavelength (nm)</th>
<th>Pupils of spherical mirror (mm)</th>
<th>Focal length (mm)</th>
<th>CMOS array</th>
<th>Pixel size (μm)</th>
<th>No. of fiber cores</th>
<th>Wavelength of white source (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>632.8</td>
<td>5</td>
<td>600</td>
<td>2048×2048</td>
<td>11×11</td>
<td>5</td>
<td>440-800</td>
</tr>
</tbody>
</table>

3. DATA ACQUISITION, REDUCTION AND RESULTS

In order to demonstrate the detector array equipment calibration and the centroiding, a CMOS camera is designed. The array of the camera is 2k×2k. The dynamic fringes and the star images are recorded in this data acquisition systems.

3.1 The pre-processing

In order to acquire a higher precision of calibration and the centroiding, the fringes and the star images are dark subtracted and flattened before fringe analysis and star centroiding calculation.

3.2 The metrology fringes

In the detector calibration experiment, a set of dynamic fringes are obtained. In order to reduce the photon noise, many frames are obtained. We can see a sinusoidal wave in one pixel output signal. The pixel position can be determined from the phase difference for any two pixels. The inter-/intra-pixel quantum efficiency can be determined from the Fourier transformation of the pixel response function reconstructed by several fringe combinations.
3.3 The pseudo star field

In our experiment, the star field is consisted by five star images. The images are put on twenty places in order to obtain the centroiding precision. The star images and the motions is displayed in Figure 2.

![Five star images and the motions](image)

Figure 2. The star field and their motion in the centroiding experiment.

3.4 The centroid calculation

In order to compare the precision of different centroiding methods. The centroiding results for three kinds of centroiding method are shown in Figure 3. It is shown that The Fourier resampling method has the highest precision. For different methods, obvious systematic errors exist.

![Differential centroid for 20 displacements](image)

Figure 3. The differential centroid between star A and star B estimated through three algorithms (photon weighted mean(PWM), Gauss fitting and Fourier resampling) for 20 measurements. The standard deviations are 2.362e-3 pixels, 1.857e-3 pixels and 1.816e-3 pixels respectively.
4. SUMMARY

We have designed a testbed for the focal plane metrology and carried out centroiding experiment on a CMOS detector. Without calibration of pixel positions and intra-pixel response, we have demonstrated that the standard deviation of differential centroiding is below 2.0e-3 pixels by the algorithm Fourier resampling. For comparison, the photon weighted means (PWM) and Gauss fitting are also used in the data reduction.

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