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Restoration of Space Object Images by Using A Maximum Entropy Method† ⋆

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Abstract Due to the various factors of image degradation in the optical observation of space objects, the imaging process is affected, it reduces the detection accuracy and brings difficulty to the high-precision positioning calculation. In order to improve the positioning accuracy of space objects, the maximum entropy method is adopted for image restoration, with an a priori PSF (Point Spread Function) model. The measuring errors of object positions before and after restoration are compared to investigate the effectiveness of the image restoration. The experimental results indicate that the influences of image degradation are reduced, and the positioning accuracy of degraded images is obviously improved by using the maximum entropy method.

Key words astrometry, techniques: image processing, space vehicles

1. INTRODUCTION

The ground-based optical observation is an effective measure for probing space objects. To make high-precision monitoring of space objects by using ground-based optical telescopes is of great significance for the recognition of spatial attitude, the computation of collision forewarning, and the safety insurance of orbiting space vehicles[1]. In observations, the telescope follows the motion of an object according to the corresponding observation strategy[2], because of the rather high angular velocity of the object relative the observational station, the tracking errors increase because of the mechanical instability of the telescope in its rapid motion; meanwhile, the image profiles on the observed CCD images are undersaturated,

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even undersampled because of the relatively short exposure time[3]; moreover, in order to adapt to the observation of space objects, the multi-channel readout and the stripped front mechanical shutter that generally adopted by the CCD cameras cause also extra image contaminations[4−5], it is, therefore, difficult to detect and precisely locate the object images, when they are positioned on the edges of image blocks of different readout channels or near the smears of bright stars. So, it is necessary to consider all these factors, which will degrade the observed images, reduce the imaging quality, affect the data processing, and lower the observing accuracy of space objects.

Along with the development of computer techniques, the digital image processing technique has got more and more applications. An important branch of the image processing is the image restoration, which constructs an image degradation model according to the image degradation process or phenomenon, and restores the images by choosing a proper restoration algorithm on the basis of this model, so that the original images may be restored and the image quality can be improved[6−7]. The image restoration has been widely applied to various astronomical fields[8], such as the reconstruction of the images observed by IRAS (Infrared Astronomical Satellite)[9], the mid-infrared image processing for revealing the interior structure of the active galactic nucleus NGC 1068[10], and the elimination of telescope's tracking errors[11], and so on. In this paper, an image restoration method is adopted on the basis of the maximum entropy estimation to treat the observed images of space objects in order to reduce the influences of image degradation on the data processing, and to raise the observing accuracy.

In this paper, firstly, the basic theory about the image degradation and the basic principle and procedures of the maximum entropy method for restoration are briefly presented, and then multiple frames of seriously degraded GPS satellite images are treated, and the observing accuracy of the satellite is obtained by a comparison between the measured satellite positions on the images and the interpolated values of the precise ephemeris. Finally, the result of image restoration is analyzed and discussed by means of a comparison between the observing accuracies of the satellite before and after the image restoration.

2. BASIC PRINCIPLE AND METHOD

For two-dimensional images, let $O(x, y)$ be the non-degraded true value, and $I(x, y)$, the collected degraded image. We assume that the imaging process is linear in the space domain, and satisfies the requirement of translational invariability. Then it can be expressed as

$$\begin{aligned} I(x,y) &= \int_{x_1=-\infty}^{+\infty}\int_{y_1=-\infty}^{+\infty} P(x-x_1, y-y_1)O(x_1,y_1)\mathrm{d}x_1\mathrm{d}y_1 + N(x,y) \\ &= O(x,y)\otimes P(x,y) + N(x,y)\,, \end{aligned} \tag{1}$$

in which $P(x, y)$ is the general imaging function, $N(x, y)$, noise in the imaging process, $\otimes$ indicates a convolution operation. It must be pointed out that $P(x, y)$ represents the