第56卷 第1期 天 文 学 报 Vol.56 No.1
2015年1月 ACTA ASTRONOMICA SINICA Jan, 2015

doi: 10.15940/j.cnki.0001-5245 博士学位论文摘要选登

空间碎片光学观测中若干问题研究

孙荣煜†

(中国科学院紫金山天文台 南京 210008)

地基光学观测是探测空间碎片的重要手段. 本文从目标搜索方案的制定、目标质心提取、目标精密定位以及目标关联4方面入手, 研究提升设备探测能力、提高目标观测精度的方法.

首先, 为了满足对GEO (Geosynchronous Orbit, 地球同步轨道)空间碎片探测的要求, 克服长时间曝光CCD像元饱和溢出的问题, 使用多帧连续曝光图像叠加的方法, 增加图像的宽容度, 同时保证系统的探测能力. 实验表明, 叠加10帧连续图像, 有效消除了像元饱和的情况, 提升目标信噪比约3.2倍, 提升探测能力约2.5 mag, 使用底片常数的均值计算目标位置, 精度符合要求. 使用星像几何形态检测与线性关联的方法, 处理了IADC (Inter-Agency Space Debris Coordination Committee) AI23.4的光学联测数据, 关联139个目标弧段, 其中116个弧段对应星表中99个目标, 并得到这些目标的实测星等、初轨半长径、轨道升交点经度、轨道倾角分布.

其次, 提出了一种基于先验信息的探测方法. 该方法通过先验信息, 在图像中碎片星像的邻域设置波门, 计算波门内的局部背景阈值, 辅以相关的判据检测目标, 随后使用矩方法及线性平移计算碎片质心在整幅图像中的位置. 实验表明: 该方法复杂度低, 计算精度优于0.5 pixel, 计算时间短于0.5 s, 可以高效地探测空间碎片. 为了解决空间碎片光学观测图像中的拖尾与星像重叠问题, 使用数学形态学算子处理了星像. 结果表明, 该方法较好地去除了图像中的拖尾、分离了图像中的恒星星像与目标星像, 提高了目标的检测效率与定位精度.

再次, 基于数学形态学算子, 结合全局阈值分割图像、矩方法计算星像质心, 实现了一套星像信息提取算法. 大量实测数据的实验结果表明, 该方法对于1 K×1 K图像处理时间约为0.2 s, 处理低轨与高轨目标的精度分别为$\frac{1}{2}$ pixel与$\frac{1}{6}$ pixel, 适合于空间碎片观测数据的实时处理. 为了减小图像退化对处理精度的影响, 使用数学形态学算子, 沿图像多个方向卷积, 最后叠加所有处理过的图像得到最终结果. 实验表明, 该方法提高了图像中目标与恒星的信噪比及定位精度.

最后, 由于 GEO 空间目标视运动速度较慢, 给目标快速自动关联带来难度. 基于Lucas-Kanade算法, 在星像邻域开窗, 统计星像的移动速度, 给定阈值判别, 实现了相邻帧短曝光图像间GEO目标的自动关联. 实验表明: 该算法稳健可靠, 星像位移计算精度为10^{-3}, 计算时间快于0.1 s.

Research on Optical Observation for Space Debris

SUN Rong-yu

(*Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008*)

Space debris has been recognized as a serious danger for operational spacecraft and manned spaceflights. Discussions are made in the methods of high order position precision and high detecting efficiency for space debris, including the design of surveying strategy, the

†2013-07-07获得博士学位, 导师: 紫金山天文台赵长印研究员; rysun@pmo.ac.cn

extraction of object centroid, the precise measurement of object positions, the correlation and catalogue technique.

To meet the needs of detecting space objects in GEO (Geosynchronous Orbit), and prevent the saturation of CCD pixels with a long exposure time, a method of stacking a series of short exposure time images is presented. The results demonstrate that the saturation of pixels is eliminated effectively, and the SNR (Signal Noise Ratio) is increased by about 3.2 times, the detection ability is improved by about 2.5 magnitude when 10 seriate images are stacked, and the accuracy is reliable to satisfy the requirement by using the mean plate parameters for the astronomical orientation. A method combined with the geometrical morphology identification and linear correlation is adopted for the data calibration of IADC (Inter-Agency Space Debris Coordination Committee) AI23.4. After calibration, 139 tracklets are acquired, in which 116 tracklets are correlated with the catalogue. The distributions of magnitude, semi-major axis, inclination, and longitude of ascending node are obtained as well.

A new method for detecting space debris in images is presented. The algorithm sets the gate around the image of objects, then several criterions are introduced for the object detection, at last the object position in the frame is obtained by the barycenter method and a simple linear transformation. The tests demonstrate that this technique is convenient for application, and the objects in image can be detected with high centroid precision. In observations of space objects, the shutter of camera is often removed, and the smear noise is ineluctable. Based on the differences of the geometry between the stars and the smear noise, two operators of mathematic morphology are presented to resolve this problem. Tests carried out indicate that the smear noise can be removed effectively, and the detection rates of the objects and stars are improved distinctly. Due to the relative movement between space debris and background stars, the blending of objects and stars is ineluctable. In view of the geometric differences between the stars and the objects, a technique for separating the blended objects based on mathematical morphology is presented. It's sufficiently flexible to be applied, and the blended images can be separated effectively with a high degree of centroid precision.

Here we present an automatic technique which optimally detects and measures the sources from the images of optical space debris observations. Tests demonstrate that the technique performs well from the point of view of the fast and accurate detection. An automatic image reconstruction method is also presented, the variable structural elements along multiple directions are adopted for the image convolution, and then all the corresponding convolved images are stacked. With this method, the position accuracies of background stars are improved distinctly.

A technique based on Lucas-Kanade algorithm is presented to detect GEO objects between two short exposure time frames automatically. The experiments demonstrate that this method works effectively and robustly, the displacement precision of object images is about 10^{-3}, and the computing time is less than 0.1 s.