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Orbital objects detection algorithm using faint streaks

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Abstract

This study proposes an algorithm to detect orbital objects that are small or moving at high apparent velocities from optical images by utilizing their faint streaks. In the conventional object-detection algorithm, a high signal-to-noise-ratio (e.g., 3 or more) is required, whereas in our proposed algorithm, the signals are summed along the streak direction to improve object-detection sensitivity. Lower signal-to-noise ratio objects were detected by applying the algorithm to a time series of images. The algorithm comprises the following steps: (1) image skewing, (2) image compression along the vertical axis, (3) detection and determination of streak position, (4) searching for object candidates using the time-series streak-position data, and (5) selecting the candidate with the best linearity and reliability. Our algorithm's ability to detect streaks with signals weaker than the background noise was confirmed using images from the Australia Remote Observatory.

Keywords: Space debris; Observation; Image-processing

1. Introduction

Sustainable space development and utilization requires proper understanding of the present situation within the orbital environment. Optical observations contribute to this understanding, providing advantages in long-range detection sensitivity and installation cost mitigation. The Innovative Technology Research Center of the Japan Aerospace eXploration Agency (ITRC/JAXA) has conducted optical surveys and analysis of geostationary orbit (GEO) objects (Yanagisawa et al., 2010). In optical surveys, even the GEO objects that appear as almost-point sources within the captured images can be detected. As shown in Fig. 1, however, the ESA's program for radar and optical observation forecasting (PROOF) model (Krag et al., 2000) version 2009 identifies a significant number of objects moving at high apparent velocity, which may in fact be objects orbiting at lower altitude, appearing in the field of view. A flux from such an object leaves a streak that spreads over several pixels in the image. Consequently, the per-pixel signal-to-noise-ratio (SNR) from a streak is low compared with that of a point source. Therefore, such objects are difficult to detect. This decrease in the SNR reduces the effectiveness of object detection.

Objects of considerable brightness can be detected using the conventional detection method, even though their apparent velocities are high (Oda et al., 2014). However, the discrepancy between the PROOF model and the observational results indicates that the GEO surveys failed to detect faint objects of high apparent velocity (e.g., objects in a medium-Earth orbit (MEO) or lower). The efficiency

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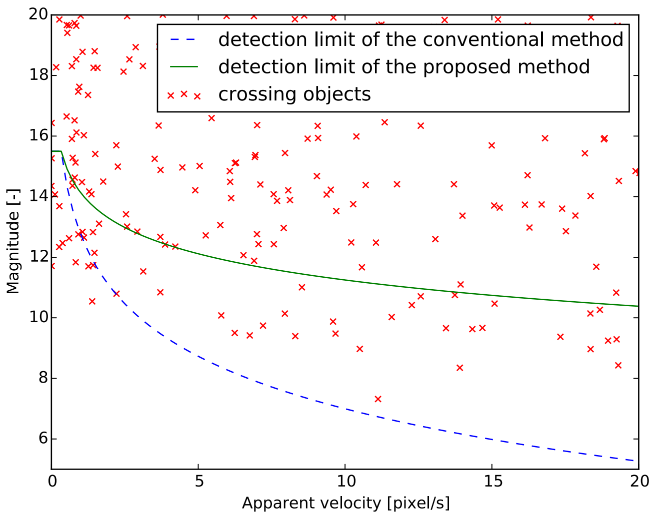

Fig. 1. Crossing-objects distribution as a function of apparent velocity and magnitude over 10 days of observations from 2015/Jan./1. The dashed line and the solid line represent the theoretical detection limit magnitude as a function of apparent velocity. This analysis assumes the use of 18-cm aperture telescope and a cooled CCD camera. The site was located at a latitude of 0° and a longitude of 135°E, and points toward the local zenith.

of the debris detection can be improved using an algorithm that detects if an object is moving at high apparent velocity.

Fig. 1 shows the magnitude vs. apparent velocity distribution of objects crossing a $3.17 \times 3.17°$ field of view during a 10 day-period. Assume that the dashed line represents the limiting magnitude of detection for the conventional method. The drop in the dashed line represents a linear decrease in the per-pixel signal intensity. This signal intensity is used to detect objects via the conventional method. The sensitivity degradation dm_c is calculated by $dm_c = m_0 - 2.5 \log l_p$, where m_0 is a nominal sensitivity limit by magnitude and l_p is the length of a streak in pixels. Our new detection algorithm, utilizing the streaks of moving objects, can improve the limiting magnitude to the level represented by the solid line. The drop in the solid line is gradual because the proposed method recovers the SNR of a streak proportionately to the square root of the streak length. Therefore, the SNR of a streak in our method decreases proportionally with the square root of the streak length. The sensitivity degradation dm is calculated by $dm = dm_c + 2.5 \log \sqrt{l_p}$. In this study, we propose an algorithm for the detection of objects in the region between the dashed and solid lines.

Previous studies by Virtanen et al. (2014) and Zimmer et al. (2013) mainly focus on longer streaks that consist of hundreds or thousands of pixels. This study aims to detect objects appearing in images as streaks consisting of tens of pixels, because such objects' orbital elements are relatively close to those from a primary observation target. This similarity is useful for understanding the orbital environment around a primary target. Therefore, this study presents a new algorithm to detect objects moving at high apparent velocity.

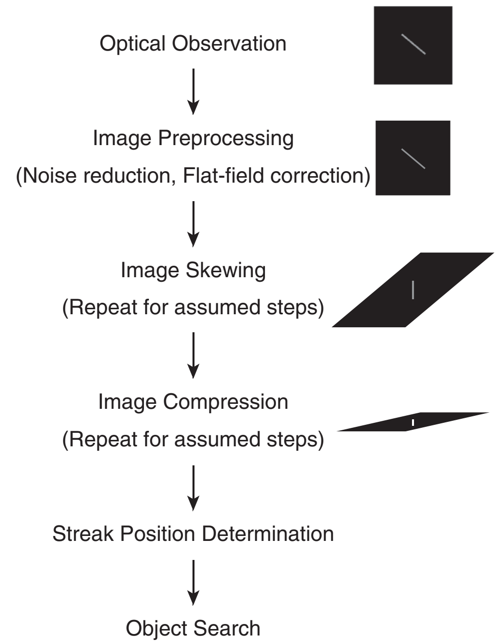

Fig. 2. The flow of the algorithm.

In this study, we introduce an algorithm and report its capability for object detection from faint streaks. The main purpose is to detect objects moving at high apparent velocity so as to improve debris-detection efficiency. The detection method is described in Section 2. In Section 3, we present the results of the detection capability assessment using theoretical images and observational data from object detection using faint streaks. For the capability assessment, the method is implemented using Python. Section 4 is devoted to conclusions and discussion.

2. Detection algorithm

This section introduces a new image-processing algorithm to detect objects moving at high apparent velocity. Fig. 2 shows the flow of the proposed algorithm. The fundamental idea of the algorithm is to improve the SNR of streaks by applying skewing and compression sequences to the images. The proposed algorithm applies a streak position determination sequence to reject false alarms in the object search sequence. The algorithm is intended to survey unknown or unintended objects during primary operations.

2.1. Pre-processing

We eliminate background star-streaks and reduce noises prior to applying the proposed detection algorithm. Innovative Technology Research Center (ITRC)/JAXA developed a software to conduct these pre-processing functions (Oda et. al., 2014). The software eliminates star-streaks by using time-series images and accounting for the expected diurnal motion between images. First,