STREAK DETECTION AND ANALYSIS PIPELINE FOR SPACE-DEBRIS OPTICAL IMAGES

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ABSTRACT

We describe a novel data-processing and analysis pipeline for optical observations of moving objects (Virtanen et al. 2016), either of natural (asteroids, meteors) or artificial origin (satellites, space debris).

Key words: space debris; asteroids; optical observations; automatic detection; image processing.

1. INTRODUCTION

The monitoring of the space object populations requires reliable acquisition of observational data, to support the development and validation of population models and to build and maintain catalogues of orbital elements. The orbital catalogues are, in turn, needed for the assessment of close approaches (for asteroids, with the Earth; for satellites, with each other) and for the support of contingency situations or launches. For both types of populations, there is also increasing interest to detect fainter objects corresponding to the small end of the size distribution.

The ESA-funded StreakDet (Streak detection and astrometric reduction) activity has aimed at formulating and discussing suitable approaches for the detection and astrometric reduction of object trails, or streaks, in optical observations. Our two main focuses are objects in lower altitudes and space-based observations (i.e., high angular velocities), resulting in long (potentially curved) and faint streaks in the optical images. In particular, we concentrate on single-image (as compared to consecutive frames of the same field) and low-SNR detection of objects. Particular attention has been paid to the process of extraction of all necessary information from one image (segmentation), and subsequently, to efficient reduction of the extracted data (classification).

2. RESULTS AND DISCUSSION

We have developed an automated streak detection and processing pipeline for optical images from both ground-based and space-based observing platforms. The pipeline consists of three main modules (see Fig.1): segmentation, classification, and astrometric and photometric reduction. In addition, we have implemented two independent modules that can be used optionally: MCMC orbital analysis for orbital validation of the detected streaks, and StreakPCA for classification analysis using training data.

We have demonstrated its performance with an extensive database of semisynthetic images simulating streak observations. In Figure 2, we show an example of the processing results after the modules segmentation and astrometric reduction for an image obtained from ground-based, sidereal tracking observing scenario.

To understand the performance of the prototype, we have adopted several metrics, such as time consumption (average time per image and CPU core is measured as the wall-clock time) and sensitivity (the fraction of all streaks that are correctly identified as such, optimum 100%). The average processing time per image is about 13 seconds for a typical 2k-by-2k image. We have shown that the prototype pipeline is capable of detecting at least 50% of the streaks with $0.5 < \mathrm{SNR} < 10$. For long streaks (length>100 pixels), the primary targets of the pipeline, the detection sensitivity (true positives) is about 90% for both ground- and space-based scenarios for the bright streaks (SNR>1), while in the low-SNR regime, the sensitivity is still 50% at SNR=0.5 (see Fig.3). For short streaks, the performance of the pipeline is considerably weaker (sensitivity 63%).

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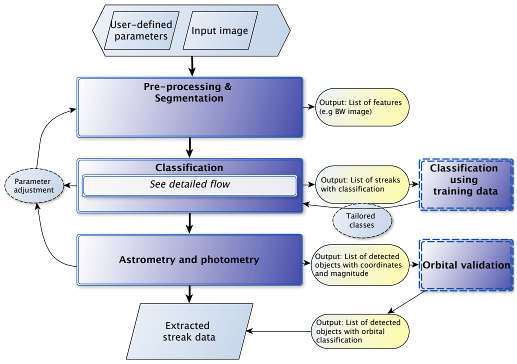

Figure 1. Algorithmic flow chart for the prototype developed in the StreakDet project. From Virtanen et al. 2016.

3. CONCLUSIONS

We have discussed the implementation of a prototype pipeline for streak detection and astrometric reduction. We have developed algorithms for single-image detections of streaks, where particular attention needs to be paid to the process of extraction of all necessary information from one image (segmentation), and subsequently, to efficient reduction of the extracted data (classification).

We consider that the most important aspect of the prototype pipeline is the possibility for tuning the algorithms, such as the filtering scheme for different observing scenarios and optical setups. While the performance of the processing pipeline can and should be further improved with comprehensive testing using more varied and extensive real-life test image data, we provide the user with several configuration parameters and default thresholds for ground-based and space-based scenarios

We have shown that the prototype pipeline is capable of detecting at least 50% of the streaks with 0.5< SNR <10. For long streaks detection sensitivity is about 90% for the bright streaks, for short streaks, the performance of the pipeline is considerably weaker (sensitivity 63%). However, as the tailoring of the prototype was carried out for long streaks, there is room for improvement in the algorithms for short streaks.

As a first-aid tool for verifying the single-image detec-

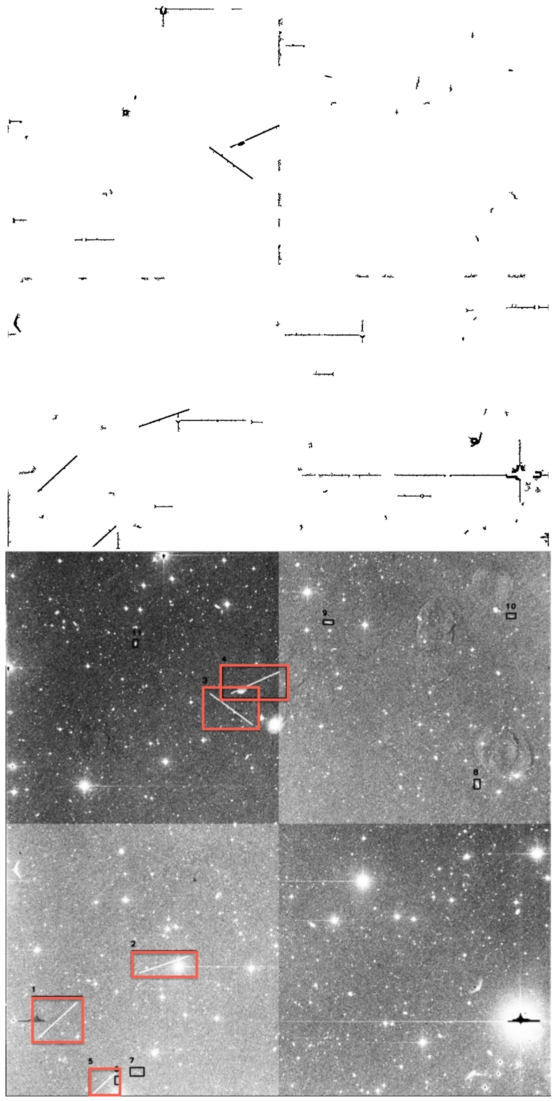

Figure 2. An example for ground-based, sidereal tracking observing scenario: low star density (0.2), long ($L = 200$ px) and high (SNR~ 3) streaks. Above: segmented image, below: original image with the detected GS streaks (black boxes) and segmented synthetic streaks (red boxes). From Virtanen et al. 2016.

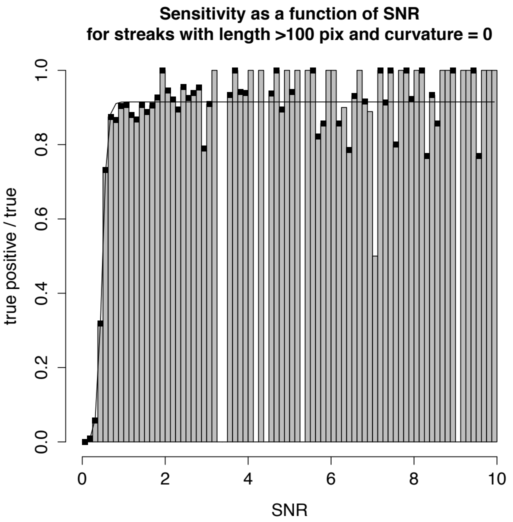

Figure 3. Sensitivity for linear, continuous streaks with effective lengths greater than 100 pixels. The black squares refer to data points that contain a statistically meaningful amount of data and are included in the 3-parameter fits described by the thin black line. From Virtanen et al. 2016.

tions, we offer the orbital validation module, which may be used to distinguish between Earth-bound and non-Earth-bound objects.

Although here, we have only considered space-debris observations, the developed algorithms and the pipeline can naturally be applied to asteroid detection, and we foresee possibilities for detection of any kind of extended objects in astronomical images

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