Streak detection and analysis pipeline for optical images

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

We focus on the low signal-to-noise (SNR) detection of objects with high angular velocities, resulting in long and faint object trails, or streaks, in the optical images. The currently available, mature image processing algorithms for detection and astrometric reduction of optical data cover objects that cross the sensor field-of-view comparably slowly, and, particularly for satellites, within a rather narrow, predefined range of angular velocities. By applying specific tracking techniques, the objects appear point-like or as short trails in the exposures. However, the general survey scenario is always a 'track-before-detect' problem, resulting in streaks of arbitrary lengths. Although some considerations for low-SNR processing of streak-like features are available in the current image processing and computer vision literature, algorithms are not readily available yet.

In the ESA-funded StreakDet (Streak detection and astrometric reduction) project, we develop and evaluate an automated processing pipeline applicable to single images (as compared to consecutive frames of the same field) obtained with any observing scenario, including space-based surveys and both low- and high-altitude populations. The algorithmic flow starts from the segmentation of the acquired image (i.e., the extraction of all sources), followed by the astrometric and photometric characterization of the candidate streaks, and ends with orbital validation of the detected streaks. For the low-SNR extraction of objects, we put forward an approach which does not rely on a priori information, such as the object velocities, a typical assumption in earlier implementations. Our algorithm is based on local grayscale mean difference evaluation, followed by a threshold operation and spatial filtering of black-and-white (1-bit) data to remove stars and other non-streak features.

For long streaks, the challenge is to extract position information and related registered epochs with sufficient precision. Moreover, satellite streaks can show up in complex morphologies because of their fast, and often irregular lightcurve variations. A central concept of the pipeline is streak classification which guides the actual characterization process by aiming to identify the interesting sources and to filter out the uninteresting ones, as well as by allowing the tailoring of algorithms for specific streak classes (e.g. PSF fitting for point-like vs. long, disintegrated streaks).

Finally, to validate the single-image detections, the processing is finalized by orbital analysis using our statistical inverse methods (see, Muinonen et al., this conference), resulting in preliminary orbital classification (e.g., Earth-bound vs. non-Earth-bound orbits) for the detected streaks.

Acknowledgements: The work has been conducted in the StreakDet (Streak detection and astrometric reduction) project funded by the European Space Agency, Contract No 4000108373/13/D/SR.