Streak detection challenges for telescope observations of satellites

Alexis Petit[1,2], Thierry Antoun[2], Jérémie Vaubaillon[1], Romain Lucken[2,3], Florent Delefie[1], and Damien Giolito[2]

⋆alexis.petit@sharemyspace.global
[1]Observatoire de Paris, Institut de Mécanique Céleste et de Calcul des Éphémérides (IMCCE), UMR CNRS 8028, 77 Av Denfert Rochereau, 75014 Paris, France
[2]Share My Space, 32 Boulevard du Port, 95032 Cergy-Pontoise, France
[3]Laboratoire de Physique des Plasmas (LPP), UMR CNRS 7648, Ecole Polytechnique, Route de Saclay, 91128 Palaiseau, France

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Abstract

The identification and characterization of space debris is becoming essential today: over the next few years, more and more satellites will be launched, increasing the population of objects in Earth's orbit and the risk of collision. Whether GEO (Geostationary Earth orbit), MEO (Medium Earth orbit) or LEO (Low-Earth orbit), it is mandatory to develop tools for the observation and analysis of these orbiting objects. A recurring problem is the difficulty to detect objects with very small Signal-to-Noise Ratios (SNR).

To investigate this challenge we decided build and operate two observatories located in France with an 8-inch and a 14-inch Rowe-Ackermann Astrograph Schmidt telescope (RASA). First observation and image analysis results are presented in this paper.

1 Introduction

The RASA-8 has an effective focal length of 400 mm and an aperture of 203 mm, while the RASA-14 has an effective focal length of 790 mm and an

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aperture of 357 mm. These two telescopes allow us to perform observations of resident space objects (RSO) in all types of orbits.

In order to detect faint streaks, we use the Streakdet (Streak detection and astrometric reduction) software provided by ESA and developed by the University of Helsinki Virtanen et al. [2016]. Streakdet is designed to detect objects trails using astrometric and photometric processes. It is divided into three main phases: segmentation, classification, astrometric and photometric reduction as described in [Virtanen et al., 2016]. The segmentation consists of a robust low-SNR extraction of all necessary information (features) from one image. The classification is the characterization and efficient reduction of the extracted data. The astrometric and photometric reduction package provides tools for coordinate and magnitude measurements.

Considering the setup currently at work, we want to extract the most of the datasets obtained. To that end, we use the Streakdet software, an ESA tool developed by the University of Helsinki Virtanen et al. [2016].

Tests are carried out for various objects and orbits, such that the streaks obtained can be either faint or bright, short or long. Overall, we are seeking the best tools to detect streaks with from our observations and analyse the data in a robust and computationally efficient manner.

2 Automated chain for object detection

In order to support SSA and STM services, robotic telescopes are installed in Normandy and Provence (France). A priority list of targets for observations is sent from the central Share My Space (SMS) database to the observatory which schedules an observation plan of visible RSOs in LEO, MEO and GEO, and priority targets. Series of images are produced during the night and are processed in real time by StreakDet to obtain angular position of streaks and to store them in the Share My Space database.

We developed a program called observation scheduler that controls the telescope mount and camera during the night. For now, observations are planned from an object catalogue that aggregates orbital information from multiple sources, primarily the TLE catalog, but also orbital data from operators, and Share My Space observations. Orbits are computed in Caertesian coordinates and converted into equatorial coordinates. We implemented an observation strategy with different modes:

- An object can be observed at it maximal elevation – the object is then closer and is moving faster in the sky so the streak longer for the same exposure time;

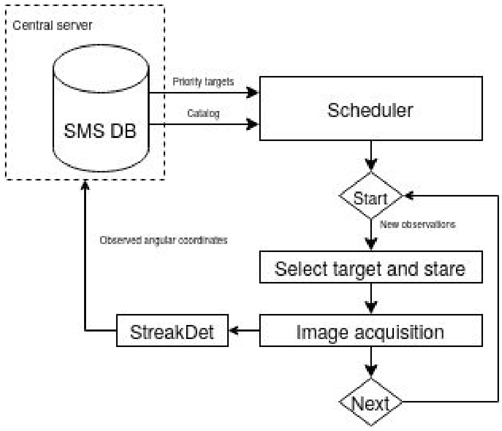


Figure 1: Workflow of automated observations at Share My Space.

- An object can be observed in during its ascending and descending phases – which potentially allows for better orbit determination from one single passage.
- An object priority list can be established based on various criteria, such as a high collision risk against a satellite.
- The observations can be organized during the night to maximize the number of observed objects through the night. This operational mode is particularly interesting to build a catalogue of objects.

The observation schedule is sent to the PRISM software[1] that controls the mount, the dome, the focalisation system and the camera. PRISM enables a fully automated operation of the telescope from a script.

The workflow implemented at Share My Space is presented in Figure 1. For now, the image processing with Streakdet is performed ater all the execution of the execution script is complete. In the future, the image processing should be performed for each image right after the file is created.

3 Image processing with Streakdet

3.1 State-of-the art

Multiple tools and software exist to detect features in an astronomical image and extract the RA-DEC (right ascension – declination) coordinates. One of them is Sextractor (Bertin [2011]). It is a very powerful and general purpose

[1] http://www.prism-astro.com

feature detection software for astronomical images. It can be combined with astronomical reduction software such as Scamp Bertin [2006]. The Streakdet software provides the user with potentially less control over the various parameters, but it is easier to setup and to use (although the installation of the various dependencies is sometimes not straightforward). It represents a good trade-off between user control, and user experience for our purpose. Furthermore, the computation time is only a few seconds (up to 30 seconds depending on the parameters and the size of the image) per image for both the feature extraction and the astronomical reduction, which represents a good level of performance. Detecting features with a low SNR on images is always a challenge for research Vananti et al. [2020],Hickson [2018],Do et al. [2019],Šára et al. [2013].

3.2 Overview of Streakdet

The feature detection relies on the OpenCV library, a well-known software in the field of image processing. The latest version of Streakdet uses the GAIA star catalogue to perform the astrometrical reduction. This final step yields the RA-DEC coordinates of the beginning, the middle, and the end of each streak, together with multiple indicators of the SNR, the aspect and the porosity. A result of the feature detection or extraction of Streakdet is shown in Figure 3.

3.3 Strategies to optimize the parameters

The critical parameter to optimize the segmentation in Streakdet is the *density* paramter. This parameter controls one of the first steps of the algorithm that consists in converting the image in black and white with the right thresholds. A target density and a density inverval are provided by the user in the configuration file. If the density parameter is too small, the segmentation time becomes very large (up to 1 min 30 s). A density parameter around 0.2 seems to be a good trade-off in a large range of observation conditions (bright or dark backgound, faint or bright streak).

The main parameter for the astronomical reduction is the number of stars taken into account. The computation time increases with the number of stars and so does the accuracy. Streakdet provides the user with a parameter that assesses the quality of the astronomical reduction. If this parameter is higher than 1, the astronomical reduction is probably wrong. We found that for the images made with our RASA 8 telescope the good trade-off was around 70 stars to be used in the astronomical reduction.

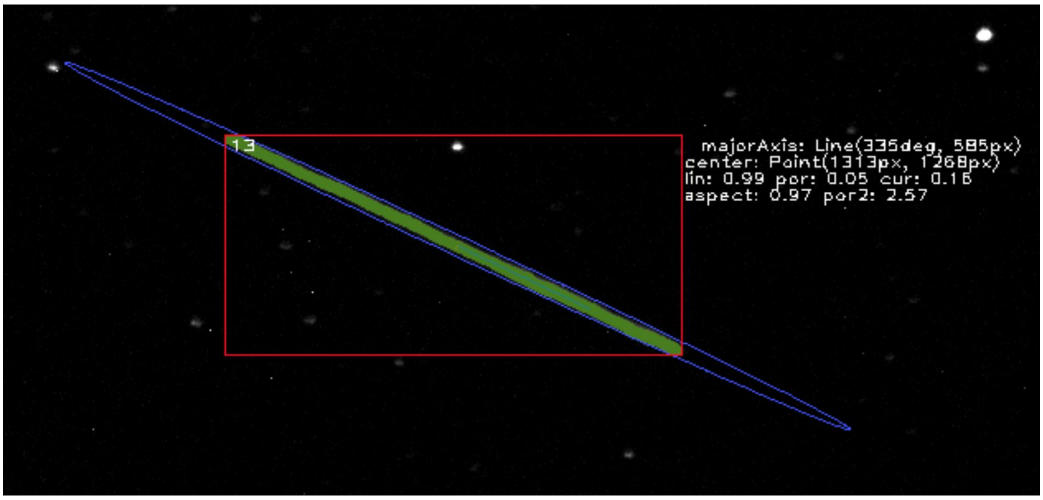


Figure 2: Streak detected with the software. The streak features are displayed directly on the image.

(a)  (b)  (c) 

Figure 3: Series of streaks detected for a LEO satellite for a single passage.

The optimal set of input configuration depends on the instrument, the type of object, the orbit and the observation conditions.

4 Observation results

4.1 LEO observations

As illustrated in Figure 3, for LEO objects, multiple acquisition can be performed for one single passage. The telescope mount is in sideral tracking (it compensates for the Earth rotation) but it is not tracking the object.

A streak detection for SL-14 rocket upper stage is shown in Figure 4. For this object that is several meter large, the streak is very clearly visible with a high SNR. The streak features fluctuations that allow us to characterize the rotation rate of the object (the computation of the rotation rate is presented

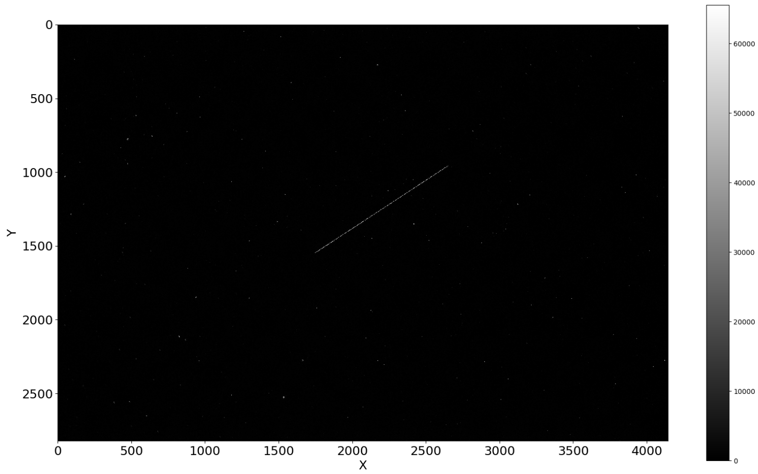


Figure 4: Light streak obtained for SL-14 (norad 20511) at 630 km of altitude observed from our Normandy observatory with a RASA-8 telescope. Exposure time is 1 s. The x and y axis represent the camera pixels.

in a separate sudy).

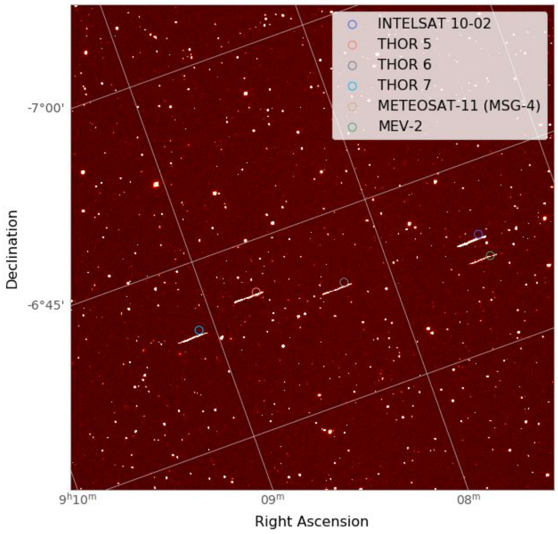
4.2 GEO observations

Streak detection also works for GEO objects when using sideral tracking and larger exposure times should be employed. While the typical exposure time for LEO objects is 1 s, for GEO objects, the exposure time is typically 20 s, because of the smaller rotation rate at higher altitudes.

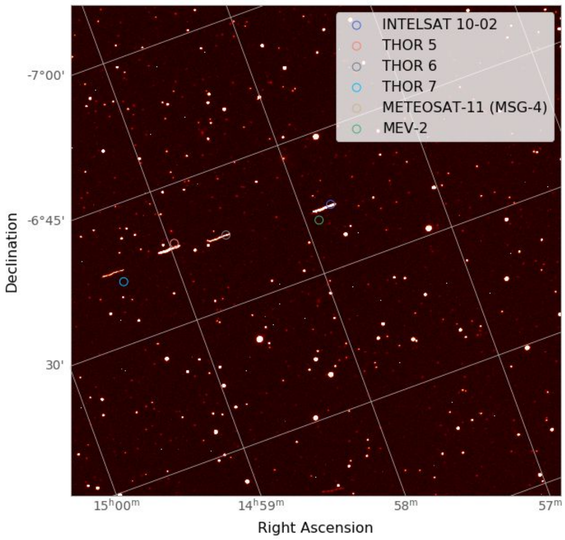
We recently performed observations of the docking of MEV-2 on Intelsat 10-02 satellite. Figure 5 shows pictures of MEV-2 and other nearby satellites before (a) and after (b) the docking. The image were acquired with our RASA-14 telescope and we could verify that the docking was successful.

5 Conclusion

An automated workflow has been implemented to produce continuous observations of RSO populations. The ESA's software StreakDet is a key software to perform the streak detections and astrometric and photometric reduction. This allows Share My Space to provide advanced SSA services to the



(a)



(b)

Figure 5: On the left, observation of Intelsat 10-12 and MEV-2 during the close approach (on 2021/04/05) and on the right, one object is visible after the docking (on 2021/04/12). Circles provide the positions computed from last TLE.

space community and ultimately build its own catalogue after the network of observation station has been upgraded.

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