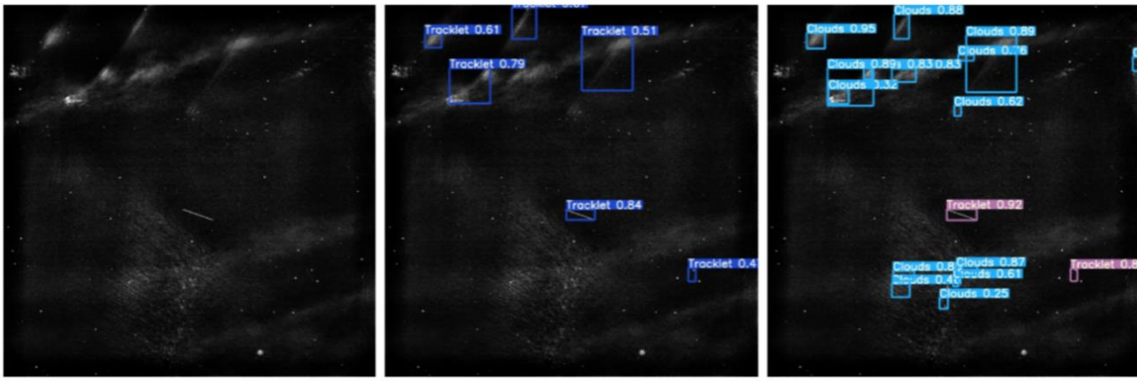
Machine Learning Techniques for Detection and Tracking of Space Objects in Optical Telescope Images

Jason Calvi
Pierluigi Di Lizia
Riccardo Cipollone
Andrea De Vittori

Abstract:

Performing real time and robust space object detection from optical acquisitions is a challenging task in space surveillance, especially when the tracking involves uncatalogued objects. Conventionally, this engineering problem is addressed by means of traditional detection or computer vision-based segmentation methods, aimed at identifying tracklets and extracting their coordinates through sensor pointing and stars position in its field of view. Nevertheless, the relatively high computational demand of these methods is their main limitation in real time applications. This work proposes two innovative tools based on machine learning techniques, respectively to automatically detect and track space objects in real-time through telescope images. The tracklet detection and localization tool relies on a Convolutional Neural Network (CNN) based on YOLOv5 architecture. The development of a machine learning model involves several steps, including dataset creation, pre-processing, training, and testing. To optimise the network accuracy and execution time, the whole process has been repeated for different datasets, based on synthetic and real telescope acquisitions, and for different combinations of the neural network hyper-parameters.

In a real case scenario, it is fundamental not only to detect tracklets from optical images, but also to classify and distinguish them from other sources. To tackle this issue, two classes are introduced as labels for the network training phase: ‘Tracklet’ and ‘Clouds’. Figure 1 (b) shows how a one-class network is not able to discern tracklets from clouds despite detecting both. In figure 1(c) instead, the two-class network correctly classifies both categories, avoiding false positives. From the validation dataset, the accuracy turns out to be 98%, with a computational time of 0.5 seconds for the inference phase. Faster configurations have been investigated as well, showing a limited degradation in terms of detection accuracy. As regards the real case application, a more elaborate pre-processing must be included in the computational burden: the entire process takes about 7 seconds to be executed, resulting still suitable with respect to characteristic telescope acquisition timings.



(a) (b) (c)

Figure 1 (a) is the original telescope acquisition containing two tracklets, (b) is the one-class network output, while (c) shows the two-class network improvement.

The tracker estimates the object angular path with a linear regression performed on multiple detections in consecutive images. When a space object is identified in two consecutive images, the script compares the new bounding box with the previous one by a statistical assessment of the possible straight-line trajectories and centroids position. More specifically, the method computes the slope and intercept standard deviations through Jacobians and covariance matrix computation on the bounding boxes. Therefore, by updating the telescope pointing according to the predicted path approximation, the number of target acquisitions is maximized, especially for uncatalogued space objects (see Fig. 2).

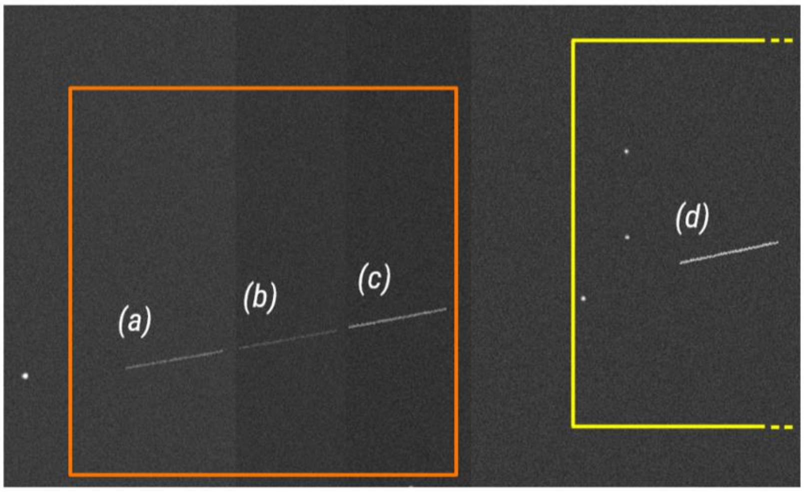


Figure 2 Satellite passage example composed by consecutive tracklets, where the rectangles represent 3 deg FoV, the orange ones show the first position of the telescope, while the yellow one is after the satellite has left the FoV and thus the position of the sensor has been moved

Since the angular path estimation relies on the predicted bounding boxes, the accuracy of the network plays a crucial role in object identification. To be compliant with the typical requirements of a real-time application, this technique adopts a faster image processing, followed by detection and finally a tracking script. The accuracy for this specific case drops to 91% and the total time required by the tracker is about 1.5 seconds. The algorithms are based on Python codes executed on a 2017 machine with an i7-7700HQ CPU, 16Gb of RAM and a GTX 1050 graphics card with 4Gb of VRAM. The proposed tools seem to be a valid alternative to traditional tracklet identification techniques. Conventional telescope surveys may take advantage of more efficient approaches that include artificial intelligence, real-time object detection, and tracking.