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Space Debris Detection, Tracking and Characterization - SST (2) (11)

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SPACE OBJECT OPTICAL DETECTION WITH REAL-TIME, HIGH-RESOLUTION VIDEO

Abstract

Increased space activity in recent years has led to a rapid rise in the numbers of active satellites and orbital debris – more satellites were launched into Earth orbit from 2019-2024 than all time prior to 2019. There are estimated to be over one million pieces of debris large enough to cause potentially mission-ending harm but small enough to remain untrackable by current systems. Larger pieces can be tracked by both optical and radar systems, but operational cost and complexity limit the number of observing sites and thus the frequency at which these debris pieces can be detected, tracked, and characterized. Past work on optical processing algorithms can be broadly categorized as either streak detection or shift-and-stack algorithms (either with a brute-force search or a dynamic programming approach). Streak detection approaches typically benefit from reduced computational demands (slower frame rates, less data to sift through) but are limited by sky noise from long exposures. Shift-and-stack approaches can theoretically achieve ideal SNR (signal to noise ratio) gain from frame stacking but are limited by computational burden and typically assume straight-line motion of objects across the instrument field of view. We propose a novel approach to optical image processing based on machine learning (ML) algorithms. We describe an image simulation framework, model training procedure, ML model, and postprocessing procedure to achieve state-of-the-art sensitivity with a computational burden comparable to a current high-end laptop. The image processing model is inspired by the well-known Vision Transformer (ViT) architecture, in which an image is divided into a sequence of small patches, patches are embedded as vectors, the set of patches is processed as a sequence, and, finally, an image shape is reconstructed. We modify the ViT architecture to work with a sequence of images and modify to reduce the memory requirements when processing high resolution video. Results from our approach, including both computational requirements and SNR limits, are compared to other state of the art algorithms, for both simulated and real imagery. We demonstrate the application of our algorithm to real-time processing of full resolution video (24 megapixel at 13 frames per second) from a ZWO ASI2400 MC camera with a 23-degree field of view lens. Known Low Earth orbit (LEO) objects are detected with single-frame SNR less than 1.0, translating to object size of 20-40 cm, depending on viewing geometry, lighting conditions, and surface properties.