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AI-DRIVEN DETECTION OF RESIDENT SPACE OBJECTS (RSOS) USING MONOCHROMATIC WIDE-FIELD IMAGING FOR SPACE SITUATIONAL AWARENESS (SSA)

Abstract

The rapid proliferation of Resident Space Objects (RSOs) presents growing risks to space missions, driven by the potential cascade of collisions described by the Kessler Syndrome. This paper focuses on advancing Space Situational Awareness (SSA) through the development of an AI-based RSO detection algorithm called R3D. Building on earlier work in proximity-based filtering and tracking (PFT) methods, this study uses real-world datasets collected via a stratospheric mission, with the R3D algorithm demonstrating an incremental increase of 25% in the F1-score compared to PFT.

The methodology integrates video-based 3D convolution to enhance RSO detection, addressing challenges posed by platform movement, varying illumination conditions, and the differentiation of stars and RSOs (as they appear identical within the dataset). A dataset of 1,400 images containing constellations such as Pegasus, Equuleus, and Aquarius were manually annotated to train and validate the models. Data augmentation techniques, including Gaussian blur and rotation, were employed to simulate space-based imaging conditions and improve algorithm robustness.

The R3D algorithm achieved a precision of 97%, recall of 85%, and an F1-score of 90% for RSO detection across 8,494 test samples containing both stars and RSOs. In comparison, the PFT method achieved a precision of 93.6%, recall of 49.09%, and an F1-score of 65.1% using the same set of images. These results demonstrate the algorithm's capability to detect RSOs accurately while minimizing false positives, providing a robust solution for enhancing SSA.

This research highlights the potential of using AI-based detection methods for space and sub-orbital platforms to contribute to SSA and support sustainable space operations. Future work will focus on deploying the developed algorithm on hardware platforms like Raspberry Pi, facilitating in-mission RSO monitoring and enhancing Canada's contribution to global SSA efforts.