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HIERARCHICAL ADAPTIVE-STEP ALGORITHM FOR FAST VISIBILITY WINDOW CALCULATION IN SPACE DEBRIS SURVEILLANCE

Abstract

The escalating collision risk from orbital debris underscores the need for enhanced space situational awareness. Space-based optical observation systems are essential due to their global coverage and ability to detect small, low-albedo targets. Pyramidal field of view (FOV) is widely adopted in space-based optical observation sensors. However, calculating visible windows for space debris using pyramidal FOV sensors imposes substantial computational burden due to complex geometric constraints, particularly with numerous observation satellites and debris objects. This paper proposes a hierarchical adaptive-step algorithm to address this challenge. The algorithm contains two stages: The first stage employs spherical approximations to represent pyramidal FOV boundaries, computing approximate visible windows using a signed distance field method. Incorporating an adaptive step-size control strategy significantly reduces computational time. The second stage reformulates precise visible window computation as root-finding problems, thereby reducing overall computational complexity. The proposed algorithm achieves over tenfold computational efficiency compared to conventional fixed step-size algorithms, while maintaining comparable accuracy. In a one-day simulation scenario with over 15,000 debris objects and 24 surveillance satellites, our algorithm computed all visible windows in under one minute, compared to over 30 minutes for traditional methods, with identical results. These results demonstrate the algorithm's superior efficiency while preserving computational accuracy.