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NUMERICAL MODELING OF CHARGED PARTICLE DYNAMICS IN SPACE: APPLICATION TO ORBITAL DEBRIS MITIGATION

Abstract

Boris particle pusher algorithm is an essential computational method for modeling charged particle dynamics in electromagnetic fields, particularly in space conditions when satellites are subjected to complex electromagnetic interactions. This algorithm has been applied and tested in twelve various electromagnetic field configurations, ranging from uniform to randomly varying fields, to model space conditions and evaluate its applicability as trajectory prediction for orbital collision debris prevention.

The simulation's objectives were twofold: testing the Boris algorithm against electrodynamic theory from Lorentz and Maxwell's equations, and determining whether the algorithm can be used for the modeling of satellite shielding and trajectory mapping in high-energy applications. The algorithm was implemented as a Python algorithm with the NumPy library in Google Colab. This study investigated six main types of fields most commonly found in charged particle-dense regions: uniform, increasing, oscillating, rotating, random, inhomogeneous fields.

Results confirm that the algorithm effectively simulates gyroscopic motion in static magnetic fields and effectively simulates charged particle behavior in dynamic environments, with minimal deviations when compared to analytical solutions. For highly variable electromagnetic fields, such as those caused by solar flares, the algorithm correctly predicts space debris orbital perturbations. These results confirm its suitability for Space Situational Awareness (SSA) and potential for improving early warning systems for collision hazards and Space Traffic Management (STM). Future research will focus on refining these models for SSA operational integration, enabling further orbital safety as space operations continue to grow. Optimization of computational performance and inclusion of real-time space weather information will be done in the future to advance SSA operational schemes for improved orbital debris removal as space operations increase.