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PERFORMANCE AND SENSITIVITY ANALYSIS OF MACHINE LEARNING-BASED APPROACHES FOR RESIDENT SPACE OBJECT CHARACTERIZATION

Abstract

One of the main challenges for Space Situational Awareness (SSA) is the capability to characterize Resident Space Objects (RSO), thus supporting functions such as accurate orbit propagation and anomaly detection. While conservative forces, including the Earth gravity force and third body perturbations, can be modelled with good accuracy, non-conservative perturbations (i.e., atmospheric drag and solar radiation pressure) are not easy to compute. In fact, apart from the uncertainty in the modeling of atmosphere and solar activity, these forces strongly depend on the object's characteristics, usually known with limited accuracy for space debris. An important role is played by the area-to-mass ratio (AMR), i.e., the ratio between the cross-section area /area exposed to the Sun and the mass of the RSO for LEO/GEO objects. Current literature proposes several approaches for the estimation of the AMR, ranging from semi-analytical (Lacruz et al., 2020) and numerical (Badhwar and Anz-Meador, 1989) methods, to filtering (Linares et al., 2014) and Machine Learning (ML)-based (Peng and Bai, 2018) techniques. As regards ML-based techniques, recent studies have focused on classification algorithms or regression algorithms for specific types of orbits (e.g., sun-synchronous, geostationary). In this context, this paper proposes a ML-based regression approach for the estimation of the AMR in Low Earth Orbit, covering a wide set of orbital parameters. Using a synthetic space catalog generated through numerical simulations, the performance of different ML-techniques is evaluated. The sensitivity of the proposed algorithm to the amount of training data is analyzed with the goal of minimizing the computational cost during the training phase and avoiding underfitting and overfitting of the statistical model. Moreover, solar activity has a great impact on the atmospheric model, hence on the atmospheric drag and consequently on the RSO orbital decay. This could mislead the learning process if it is not adequately considered. Therefore, the effect of introducing information regarding the space weather in the training set is also analyzed. The applicability of the presented approach is tested and discussed using both real (i.e., based on publicly available catalogues of Two-Line Elements) and synthetic datasets: in both the cases, the error in the propagation of the orbital parameters obtained using the estimated AMR is adopted as performance metric. Finally, the presented approach is compared with traditional physics-based, semi-analytical approaches in terms of accuracy and computational cost.