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A PONTRYAGIN NEURAL NETWORK APPLICATION TO TRACKLETS CORRELATION OF OPTICAL OBSERVATIONS

Abstract

The increasing interest in the X-GEO region is leading towards a significant increment of its population of satellites and debris. Consequently, there will be a demand for techniques capable of accurately identifying, correlating, and cataloging X-GEO objects. Unfortunately, current methods available for two-body problems cannot be efficiently extended to the three-body dynamics governing the motion of objects in the Earth-Moon region. This paper introduces an innovative approach to solve tracklets correlation of optical observations via Pontryagin Neural Network (PoNN), which is a Physics-Informed Neural Network (PINN) trained to solve optimal control problems via indirect method and Pontryagin Minimum Principle. Nevertheless, its applications to tracklets correlation problems have not yet been investigated. Within PoNN, the PINN framework called Extreme Theory of Functional Connections (X-TFC) is employed. As a remark, X-TFC is an already proven method for orbit determination regardless the problem's dynamics, which showed fast and robust convergence to highly accurate results with respect to the state of the art. PoNN is a particular kind of single-layer feed-forward neural network used to estimate the object's state and costate, while solving an energy optimal control problem. Indeed, since no maneuvering objects are considered, the ballistic trajectory, solution of the successfully correlated tracklets, is assumed to be the one minimizing the control effort. The correlation is assessed through a criterion based on the Mahalanobis distance, involving the residuals on the observations and the DeltaV associated to the computed optimal trajectory. The loss function of PoNN takes into account the observations residuals as well as a regularization term which ensures that the orbital dynamics is respected. Therefore, the relation input/output is encouraged to be compliant with the physics, while fitting the observations. The proposed method is shown to work with angle-only observations of objects in Keplerian dynamics by testing it on both simulated and real data. The real topocentric right ascension and declination measurements are provided by the telescopes of the Space4 Center at the University of Arizona. The PoNN performances are assessed not only for correlation, but, as a secondary objective, also for Initial Orbit Determination

(IOD) purposes. Preliminary tests have been successfully carried out showing accurate results for tracklets correlation of simulated data, soon to be tested on the real data scenario.