IAF ASTRODYNAMICS SYMPOSIUM (C1)
Guidance, Navigation and Control (1) (3)

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NEURAL NETWORKS FOR ONBOARD MANEUVER DESIGN

Abstract

This paper presents a general neural network framework for spacecraft autonomous onboard maneuver design and its application to several astrodynamics regimes. A previous version of this work applied a neural network (NN) model to making a single low-thrust trajectory correction in cislunar space. This paper extends the prior work to allow any number of low-thrust trajectory corrections in cislunar space and implements it in a general framework. The NN framework is implemented in prototype flight software as a coreFlight System (cFS) app with minimal external dependencies. This framework is extended further to apply to interplanetary low-thrust trajectory correction, GEO station keeping, station keeping in Gateway's near-rectilinear halo orbit (NRHO), low-thrust spiral transfer corrections, and eclipse modeling.

One of the key challenges for electric propulsion (EP) spacecraft is the impact of inaccurate thrust due to a delay between navigation state estimation and updated maneuver designs turned into spacecraft instructions. The framework described here is intended to complement onboard navigation capabilities, such as GPS, optical navigation, or Advanced Space's CAPS system. When onboard orbit determination is implemented, the NN models described in this paper can be executed in flight software nearly-instantaneously. As a result, navigation updates can be translated immediately to maneuver design updates, avoiding days or weeks of lag time while ground teams manually process data and re-optimize trajectories. The framework is robust to small and large deviations from the nominal because of the powerful function approximation capabilities of NNs.

This framework allows space missions to offload the computational "heavy lifting" to ground-based computers. Ground systems generate training data (consisting of tens of thousands of off-nominal maneuver designs) and train a series of NNs, where each NN is applicable to a predefined range of states and/or epochs. NN output is fully deterministic and testable before flight. The computational burden for the spacecraft is minimal and easily fits within most current flight computers. Simulation results show accuracy and propellant use comparable to or better than the best human-in-the-loop ConOps.