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Title

Intelligent guidance method for Galilean moon cycling with online error fitting via reinforcement learning

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Abstract

Galilean moon tour exploration is recently one of the hot topics for deep space mission [1,2]. A cycler orbit periodically fly-bys the Galilean moons, which provides higher detection efficiency than general multi-fly-by orbits [3,4]. Due to the strong non-linearity and uncertain error on the gravitations, actual trajectory drifts from desired orbit. Guidance method is required to modify the position error. However, current researches on guidance methods only provide offline error fitting techniques. The delay on dynamic correction affects the fuel consumption and trajectory accuracy [5].

In this paper, an intelligent guidance method for Galilean moon cycling with online error fitting is developed. Firstly, an error model is provided. Perturbing potentials including non-spherical gravities of Jupiter, Galilean moons and the Sun are considered to build a basic high fidelity model. Errors on the gravities of Jupiter, Galilean moons are taken into account as the uncertainties. Secondly, an intelligent dynamic model is built. The model combines the high fidelity model and a correction on the acceleration. This acceleration correction which indirectly represents the error of dynamic parameter is introduced by a neural network. By training the network, accurate acceleration correction is outputted to compensate the dynamical error. Thirdly, a double-loop intelligent guidance framework is constructed. In the inner loop, the acceleration correction network in intelligent model is trained online to fit the dynamical error. The trajectory is propagated under the high fidelity model in a short term. The difference between the predicted trajectory and actual trajectory is taken as a gain for reinforcement learning to train the neural network [6]. During the iteration, the neural network outputs a more accurate acceleration correction, which achieves an online error fitting behavior. In the outer loop, based on a classic differential correction method, an online predictor-corrector method is developed. The trajectory of the probe is propagated in a long term under the intelligent dynamical model. The difference between desired final position and predicted final position is obtained to evaluate the trajectory accuracy. A trajectory maneuver is introduced to correct the final position error. Then the trajectory is propagated repeatedly to predict the final position error and to optimize the trajectory correction maneuver. In this situation, the outer-loop achieves an accurate performance for Galilean moon guidance.

Numerical simulation is run to validate the proposed intelligent guidance framework. A cycler orbit with respect to Io, Europa and Ganymede is considered. Magnitudes of 0.1% of random errors on the gravity parameters of Jupiter and Galilean moons are considered. The intelligent guidance framework is employed to fit the error and increase the trajectory accuracy. Simulation result shows that compared to high fidelity model, the intelligent dynamic model

propagates a trajectory with smaller final position error, which generates more accurate trajectory correction maneuvers during the tour guidance. Besides, less trajectory correction maneuver and smaller velocity increments are required as the final position error is increasingly smaller during the online training.

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