Paper ID: 83073
student

IAF ASTRODYNAMICS SYMPOSIUM (C1)
Interactive Presentations - IAF ASTRODYNAMICS SYMPOSIUM (IP)

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ORBIT DETERMINATION FOR X-RAY PULSAR NAVIGATION WITH THE AID OF ARTIFICIAL NEURAL NETWORKS

Abstract

Recent technological advancement and the commercialisation of the space sector have led to a significant surge in the development of space exploration missions. Currently, space missions mainly rely on Earth ground-based Guidance, Navigation and Control (GNC) operations involving human-in-the-loop processes. Although reliable, the ground-based navigation approach is prone to prolonged periods of communication delay, lacking real-time capabilities and autonomy. In addition, the booming growth of users in space will inevitably lead to saturation of ground slots, hindering the progression of space exploration. Reducing the dependence on ground operation by developing on-board autonomous navigation methods represents a potential solution for future space missions.

X-ray pulsar navigation represents an innovative concept for achieving autonomous spacecraft navigation. This technique, which utilises the pulsar's signal time-of-arrival to determine a spacecraft's position, has been shown to have superior accuracy. In this work, an orbit determination algorithm for X-ray pulsar navigation is explored. Artificial neural networks (ANNs) are applied to estimate the environmental disturbances present in space, given their inherent capability of approximating unknown functions.

Three pulsars B0531+21, B1937+21 and B1821-24 are used as the candidate signal sources to generate timing measurements. An extended Kalman filter (EKF) is used within the orbit determination algorithm for spacecraft state estimation. The dynamics of the EKF is augmented by an ANN that captures the unmodelled disturbances. The ANN is trained by feeding it with large datasets of high-fidelity perturbations, such as a high-fidelity non-spherical gravity model, atmospheric drag with a high-fidelity atmosphere model, third-body perturbations from all relevant solar system bodies, solar radiation pressure with a high-fidelity solar activity model. The performance of the proposed orbit determination algorithm is also compared with a traditional EKF navigation solution. Simulation results highlight the superior efficacy of ANNs in aiding space GNC applications. This study is also anticipated to instill greater confidence in the implementation of X-ray pulsar navigation, marking a fundamental step towards achieving fully autonomous navigation for space missions in the future.