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DISTRIBUTED AUTONOMOUS NAVIGATION FOR MULTI-SPACECRAFT MISSIONS USING X-RAY PULSARS AND INTER-SATELLITE LINKS

Abstract

Most of the reported X-ray pulsars navigation (XNAV) schemes are designed for single-spacecraft tasks. When simultaneous observations from multiple pulsar sources are needed, it requires that these observations to be conducted contemporaneously by the spacecraft or to be adjusted to the same epoch with specific algorithms.

Inspired by the increasing spacecraft formation flying or constellation missions, a novel distributed autonomous navigation scheme based on XNAV methods and inter-satellite links is proposed for timing, relative and absolute positioning of multiple-spacecraft missions. The novel scheme is able to overcome the multiple pulsar sources observation difficulty and to extend the application of XNAV and inter-satellite links to multiple-spacecraft missions.

For tasks involving three or more spacecrafts, the member spacecrafts are designed to use their onboard X-ray pulsar detectors to fixedly observe and record the time of arrivals (TOA) of pulsar signals. Two observing modes are designed and compared here. For missions with relatively short inter-satellite distance (e.g. formation flying missions), each spacecraft is designed to fixedly observe one pulsar, while different pulsar is required for different spacecraft. Relative navigation results are obtained by inter-satellite links, and then used to transfer and synchronize TOA observations made by other spacecrafts to the chief spacecraft, which determine the absolute navigation results by incorporating all the TOA observations and astrodynamical characteristics of the spacecrafts. For missions with longer inter-satellite distance (e.g. most constellation missions), each spacecraft is required to observe two pulsars, and the observing scheme is designed so that the time difference of arrival (TDOA) measurements of spacecraft pairs could be applied to solve their relative navigation results, which are then employed with all TOA observations by the chief spacecraft for absolute navigation solution in a similar manner.

With the extended Kalman filter (EKF) being adopted as navigation filter, feasibility and expected navigation performances are analyzed by Cramer-Rao lower bound (CRLB) calculation for both modes. As example missions, numerical simulations of a deep space formation flying and a lunar constellation are carried respectively. High-order TOA transfer equations, observe noise, timing errors and inter-satellite link accessibility are considered in the simulations. Simulated absolute position error estimates are on the order of 1 km for formation flying and 10's km for the constellation. The simulating results validate the effectiveness of the proposed scheme.