SPACE EXPLORATION SYMPOSIUM (A3)
Solar System Exploration (5)

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AUTONOMOUS DEEP SPACE NAVIGATION WITH X-RAY PULSARS

Abstract

In the last decade there has been some research about space navigation using celestial X-ray sources. Under ESA contract, the GMV and University of Helsinki has preliminary designed an autonomous navigation system based on X-ray pulsars observation that can be applied to different exploration missions. The complete navigation chain, from X-ray instrument to navigation filter is analysed in detail. A critical requirement is that the X-ray sensor shall consider autonomous navigation constraints, e.g. low mass (few kilograms) and size. Initially different X-ray pulsars and navigation strategies were assessed based on the needs and constraints of different exploration missions. The most promising X-ray sources and navigation strategies are compared. Detailed simulations of the detection times of photons from each X-ray pulsar are performed, considering the pulse shape and period, the integration time, and the instrument characteristics (e.g. timing errors). The resulting event detection times are processed to compute two navigation measurements, the pulse arrival time (PAT), aka time-of-arrival, and the pulse arrival time drift (PATD). These observables are later processed by the navigation filter to estimate the spacecraft state. Three different algorithms to compute the navigation observables are traded, namely least squares, maximum correlation, and maximum likelihood. The quality of the observables (statistics) is the main trade-off criteria. The CPU time is also considered for comparison of the algorithms in case of similar estimation performances. The navigation algorithms are validated via Monte Carlo simulation campaigns. The combination of X-ray pulsars providing the best navigation performances are obtained (all combinations are tested). Parametric analyses for the driving error sources are performed to derive an error budget. Considering the integration time and the location in the sky vault, simulations of the most interesting exploration missions are performed. An Unscented Kalman Filter processes the X-ray observables (when available) and provides the navigation solution. The navigation performances are used to define the missions in which X-ray navigation is applicable. The last validation step is to process real data from XMM-Newton space telescope to validate the navigation performances. At the end of the study, the feasibility of an autonomous X-ray pulsar based navigation system is demonstrated. The design of the X-ray instrument considers the state-of-the-art technologies that can produce an operational system within 10 years.