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AN EXTENSIVE AND AUTONOMOUS DEEP SPACE NAVIGATION SYSTEM USING RADIO PULSARS

Abstract

Interstellar navigation poses significant challenges in all aspects of a spacecraft. One of them is reliable, low-cost, real-time navigation, especially when there is a considerable distance between Earth and the spacecraft in question. In this paper, a complete system for navigation using pulsar radio emissions is described and analysed.

The system uses a pulsar's emissions in the radio spectrum to create a novel system capable of fully autonomous navigation. The system is roughly divided into two parts, the front - end and the back - end, as well as their subdivisions. The front - end performs initial signal reception and pre-processing. It applies time-based coherent de-dispersion to allow for low-power on-board processing, and uses a very wide bandwidth to limit the required antenna size. As a result, the electronics required performing the processing is complex, but the system is well limited in both size and power consumption.

The back-end, in turn, performs advanced nonlinear Kalman filtering and supplies the final navigational product - the systems complete (position and velocity) state vector, as well as the involved uncertainties. Rather uniquely, it uses two inherent signal properties, the Doppler shift and the inherent pulse period slowdown, simultaneously, to obtain both a relative and an absolute estimate of the spacecraft's position. Combined, in the nonlinear Kalman filter, they result in the complete state vector of the system.

Performance of the system was analysed and validated using actual telescope data from the LOFAR array. The results show that the front-end can indeed receive and process even a very weak signal from an actual pulsar, while the back-end can output a navigational product despite significant random noise in the signal data received from the front-end.