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PULSAR-BASED POSITIONING SYSTEM

Abstract

Millisecond pulsars are extremely stable, rapidly rotating, and highly magnetized neutron stars that emit electromagnetic radiation along their magnetic axes. Due to the misalignment between the rotational and the magnetic axes, the observed pulsar signals are analogous to the light beams of distant lighthouses. This predictable pulsing behavior is the fundamental mechanism that allows researchers to use pulsars as tools for science and engineering. This research focused on the problem analysis, estimator design, and experiment verification in order to show the feasibility of using multiple radio millisecond pulsars to estimate the observatory position and identify Solar System ephemeris bias. The experimental verification of this concept has never been done before and its success means that we are one step closer to the ultimate goal of self-localization within the solar system and beyond.

In contrast to traditional approach, this research analyzed the positioning accuracy and designed estimators using the statistics associated with the pulsar waveform measurements rather than that of the post-processed pulse time of arrivals. State space formulation and Kalman filtering technique were used to combine the pulsar waveform measurements with the dynamics of the states to more coherently estimate the position of the observatory. As a result, cross-correlation technique is not necessary, which simplifies the implementation.

Numerical simulations using the Unscented Kalman Filter were performed to process pulsar signals using a representative pulsar timing and Earth orientation model. Simulation results showed that sequential observation of five pulsars once a day with an interval of 7 days for 63 days can simultaneously reduce the root mean squared error bounds of the observatory position and the ephemeris bias from 52 km to 460 m and 173 m to 155 m, respectively.

Currently, we are in the experiment verification phase and are working towards integrating our algorithms with existing pulsar timing software to leverage the state-of-the-art pulsar timing model and to process actual pulsar measurements collected by NASA's Deep Space Network. In conclusion, this research provides an alternative approach to estimate observatory position that is more coherent than the traditional approach. The successful completion of the experiment verification phase is a proof of concept for pulsar-based navigation system and this goal is aligned with NASA's ongoing vision for space exploration.