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X-RAY PULSAR NAVIGATION: DATA ASSOCIATION AND ATTITUDE DETERMINATION

Abstract

Navigation using x-ray pulsars, commonly referred to as XNav, has been proposed as a method which would allow spacecraft to determine their position independently, without communication to Earth. In November of 2017, the NICER/SEXTANT experiment demonstrated that millisecond x-ray pulsars could be used to autonomously determine the position of the spacecraft. While SEXTANT demonstrated that XNav is possible, much work remains in order for it to become a viable technology. In this work, we address two related parts of the XNav: attitude estimation and data association.

Implicit in any XNav scheme is the assumption that the detector "knows" what pulsar it is looking at. This assumption implies that the spacecraft can measure its attitude to an accuracy greater than the field-of-view of the x-ray detector. While this is not an unreasonable assumption, it does place added hardware requirements on the system.

Alternatively, if an x-ray detector could measure both the time and angle of arrival of the photons in question, then that detector could be used to determine not only position but also the orientation of the spacecraft, using the photon arrival vectors as measurements of the unit vector to the pulsar. In this work, we present an estimation scheme designed to estimate a full 6 degree of freedom position and orientation solution using measurements of x-ray pulsars.

In order to implement such a joint position and attitude estimation scheme, the spacecraft must be able to correctly associate the incoming photons with the correct signal source. This is the problem of data association. We use a variant of the Joint Probability Data Association Filter (JPDAF) to meet this requirement. Furthermore, we show that by using the JPDAF to perform the data association operation, the required area of the detector needed to achieve a given position accuracy is reduced. This is because by correctly associating photons with their true signal sources, we can effectively eliminate a large number of background photons, effectively lowering the background noise. The end result is that a smaller detector with the ability to measure both time and angle of arrival may achieve the same signal-to-noise ratio as a larger detector with time of arrival measurements alone.

The efficacy of the estimation scheme presented in this work is demonstrated using both simulated data and real pulsar observation data from the observatory Chandra.