Title

Autonomous Orbit Determination for Spacecrafts based on the Time-of-Arrival of Solar Radiation

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Highlight

We show that it is possible to use the time differences of arrival of solar radiation to autonomously determine the orbits of the spacecrafts and the performance of such autonomous orbit determination strategy is discussed.

Abstract (500-1000 words)

Autonomous orbit determination (AOD) has a great advantage for spacecrafts either orbiting around Earth or transferring in deep space. It enables spacecrafts to autonomously determine its own orbit without depending on support from ground stations and thus allows better reliability for space missions especially when time delay is a major concern.

The periodic x-ray pulsar is theoretically promising to serve for that purpose in terms that it can be used as a space beacon. A spacecraft can continuously record the times of arrival of the x-ray photons and reconstruct its radiation profile. After proper corrections, the received profile can be compared with the standard profile modeled at the solar system barycenter (SSB), which can be converted the distance between the spacecraft and SSB along the pulsar's direction. This idea was initially proposed in the 1970s and has been extensively studied over the decades; however, actual implementation of such AOD or autonomous navigation system is seriously limited by the fact that the radiation of the candidate pulsars is so weak around Earth and in our solar system that current onboard equipment cannot meet the requirements in size or accuracy. It requires quite a long time of exposure and proper numerical technique to reconstruct usable profile in one period that can be compared with the standard profile, yet the accuracy (signal-to-noise ratio) is still compromised.

In this paper, we revise the approach by replacing the pulsars with the Sun, preferably

still in the x band. The solar radiation received by Earth satellites can be much stronger than that of the strongest x-ray pulsars and is therefore easier to be detected and utilized. The AOD approach needs revising accordingly. Since the radiation emitted by the Sun no longer bears the periodicity as for the pulsars, the radiation profile cannot be modeled but has to be measured on site. We include multiple spacecrafts in the scheme so the differenced observations can be obtained between the spacecrafts, instead of the between the spacecraft and SSB. Thanks to the stronger radiation, we do not need to do the epoch folding to accumulate a long time of observations to get the profile with reasonable quality, nor can we do this due to its aperiodicity.

We first discuss the possibility to correlate the profiles at different spacecrafts to obtain the time difference of arrival (TDOA). We simulate with a piece of actual solar radiation to show whether the different profiles received by the spacecrafts can be correlated to determine the actual TDOA of the same wavefront, despite their respective locations and movements. This analysis is to provide a basis for the following AOD discussion and to understand certain requirements if such system is to be implemented for application.

Then we assess the performance of AOD with such differenced observation. We would simulate with some spacecrafts in medium Earth orbit (MEO), which is a common option for current navigation satellites. Besides using only the TDOA measurements, we also include the satellite-to-satellite tracking (SST) measurements in the simulation. We note that using only SST for Earth-orbiting satellites is singular and cannot converge to reasonable results in AOD, while using only TDOA is subject to some “weak direction” as the time differences are measured in the direction of the Sun. We expect that combining both SST and TDOA measurements can reduce the limitation and increase the accuracy, reliability and feasibility of this AOD scheme.