Deep-Space Navigation Using Optical Communications Systems

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Since the first interplanetary spacecraft, radio frequency communications systems have been the main provider for the tracking data necessary to navigate in deep space to their intended destinations. Optical navigation, i.e. the use of images to track solar system bodies against the star background, can also be used when the positon of the target object has not been determined well enough to navigate just using radio-frequency data, but it requires carrying cameras that may not be needed otherwise. Up to now, active spacecraft have always been equipped with a radio system in order to transmit data to the ground and to receive commands from the ground, and this communications link has also been used to perform navigational tracking.

Optical communication links using lasers can potentially deliver data rates much higher than those possible using radio frequencies. A number of experiments have been performed in Earth orbit and in lunar orbit using optical data links, including the LADEE Lunar Laser Communication Demonstration.[1] Other missions have demonstrated optical links over interplanetary distances, such as the MESSEGER[2] mission. Laser ranging using corner cube retroreflectors is a very well established technique that has been used for precise orbit determination of Earth orbiting spacecraft, for geodesy, and for lunar research, achieving centimeter-level precisions, but it is not a practical method for deep-space distances. In order to perform interplanetary optical ranging, active systems are needed at both ends of the link. If optical communications equipment is going to be carried by future missions, this equipment, with some adaptations, could also be used to perform tracking for trajectory determination.

There are two main optical tracking types that are being considered. The first is optical astrometry of spacecraft: a telescope in the ground images the laser beam coming from a spacecraft against the star background, determining its plane-of-sky position as seen from the ground observatory. This type is going to greatly benefit from the release of the high-accuracy star catalog produced by the ESA's Gaia mission, allowing for the generation of plane-of-sky measurements with an accuracy similar to what it can be obtained today using VLBI tracking techniques. The second is optical ranging, i.e. the measurement of the time it takes for the signal to travel between the ground telescope and the spacecraft and back. This second type requires a two-way link, unless there are atomic clocks at both ends, and a more careful design of the spacecraft optical communications system. One of the advantages of using optical frequencies is that they are not affected by charge particles in the signal path the way that radio frequencies are, eliminating solar plasma and ionospheric effects from the light-time calculation. In the other hand, clouds would preclude any type of optical communication, and daytime light scattering precludes astrometric measurements.

We are in the process of analysing what would be the performance that could be achieved using optical data types in a range of deep-space scenarios, and the paper will present our results. One of the questions that we are trying to answer is whether spacecraft equipped with optical communications terminals would also need to carry radio-frequency equipment for navigational purposes. We also want to understand how accurately we will be able to navigate spacecraft in different mission types and phases, and what would be the constraints, advantages, and disadvantages of using optical communications systems for navigation.

References

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