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ON THE DYNAMICS AND CONTROL OF A SPACECRAFT OBSERVING EXOPLANETS VIA THE SOLAR GRAVITATIONAL LENS

Abstract

The work is devoted to the investigation of the dynamics and control of a spacecraft in the Solar Gravitational Lens Focus (SGLF). The SGLF is a region where light rays from a distant source converge after being bent by the Sun's gravity, a phenomenon called gravitational lensing. This region is located along a line passing through the Sun and the light source and begins at 550 AU away from the Sun. Because of interference, the light rays' intensity increases there by several orders of magnitude making the SGLF a promising location for a telescope to directly observe exoplanets or other objects. Studies have shown that a telescope placed in the SGLF can theoretically take a photo of an extended object located 100 light-years away with a resolution of 10 km per pixel. This provides a remarkable potential for planetary physics as well as for the search for extraterrestrial life. However, since the SGLF begins quite far from the Sun, placing a telescope there becomes a challenge. Furthermore, to build a high-resolution image, the telescope must be positioned in the SGLF with a meter-class precision, which is complicated by the fact that the SGLF is constantly moving in a complex way. Moreover, control and navigation in the SGLF must be fully autonomous due to the remoteness of the region. So far, studies have shown a mission to the SGLF to be feasible with cutting-edge technologies. However, many aspects of the mission, in particular the autonomous control and navigation in the SGLF, remain to be thoroughly examined.

This research focuses on the problem of controlling a spacecraft in the SGLF autonomously and precisely. To describe the motion of the spacecraft in the SGLF, a non-inertial reference frame is introduced, the equations of motion in this frame are derived, and solar gravity is shown to be reasonably neglected. Several control algorithms for spacecraft positioning in the SGLF are proposed: the proportional derivative regulator, the time-optimal control, and the model predictive control. The algorithms are tested via numerical simulations in the presence of model and navigational errors. Based on simulation results, conclusions are drawn on the applicability of the algorithms and the navigation precision required. Relevant navigation methods are also briefly overviewed. The research advances studies on the mission to the SGLF by providing insights into dynamical and control aspects and might be also of interest for other missions to Solar system's outer regions.