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DESIGN AND VERIFICATION OF A ROBUST DRAG-FREE ATTITUDE CONTROL SYSTEM FOR THE LISA MISSION

Abstract

In this paper, we address the design and verification of a drag-free attitude control system (DFACS) for the laser interferometer space antenna (LISA) mission, one of the European Space Agency's (ESA's) most challenging Space endeavours ever undertaken, aiming to realize a gravitational wave observatory (GWO).

The GWO is based on laser interferometry between test masses (TMs) that follow their geodesic trajectories by free flying within three identical heliocentric spacecraft flying in a triangular formation with a mean inter satellite distance of about 2.5 million km.

Each of the three spacecraft is a 19 Degree-of-Freedom (DoF) system, which requires a drag-free attitude control system (DFACS) actuating micro-newton thrusters, an electrostatic suspension system and an inter-telescope angular actuator to control a total of 16 DoFs with a high degree of couplings and with unprecedented precision.

The aim of this paper is to present how several challenges related to the control can be overcome using state-of-the-art design and analysis techniques based on H_∞-synthesis algorithms, the structured singular value (μ) approach, and the integral quadratic constraint (IQC) framework.

First, we will zoom into the design of the TM release controller, which is subject to exceptionally large release conditions relative to the available actuation capabilities. This leads to severe actuator saturation issues that cannot be properly resolved using linear control techniques. It will be demonstrated that this problem has an effective solution that includes an anti-windup compensator scheme that was designed using a state-of-the-art IQC-based synthesis algorithm.

Next, we will present the design of the DFACS science sub-mode controller. It will be demonstrated how the 16DoF design problem can be systematically tackled using structured H_∞-synthesis and μ-robustness analysis techniques guaranteeing that the key DFACS science performance requirements are satisfied in the presence of all the modelled uncertainties.

Finally, we will address the design of a micro-meteorite add-on algorithm to cope with micro-meteorite impacts. Indeed, due to the sensitivity of the system, even tiny meteorites could severely disrupt the science observations. It will be demonstrated that this can be effectively prevented using a dedicated detection algorithm in combination with feedforward and anti-windup compensators that can quickly restore nominal operations.

The DFACS was tested through an extensive V&V campaign consisting of several Monte Carlo tests and robustness analyses. The paper will conclude with a overview of simulation results demonstrating that the DFACS can establish the drag-free control while achieving the key performance requirements.