IAF ASTRODYNAMICS SYMPOSIUM (C1)
Interactive Presentations - IAF ASTRODYNAMICS SYMPOSIUM (IP)

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DYNAMIC MODELLING AND DRAG-FREE CONTROL SYSTEM DESIGN FOR THE SPACE-BORNE GRAVITATIONAL WAVE DETECTOR IN THE PORT-HAMILTONIAN FRAMEWORK

Abstract

Since the first detection of gravitational waves by the ground-based detector LIGO in 2016, the space gravitational wave detection missions have gained more and more attention. Due to the Earth's seismic activity and limited arm length of the interferometer, ground-based detectors can only detect gravitational wave in the high-frequency bandwidth. Therefore, the detection of gravitational wave signals in the frequency band between 0.1 mHz and 1 Hz can be achieved only in the space environment, which is believed to have great astronomical significance and open a new window to explore the universe.

A drag-free control system is one of the crucial technologies for space-borne gravitational wave observations. In general, such a detector will enclose two free-floating test masses inside the spacecraft. The surrounding satellite and cages can prevent the environment disturbance from acting on the test masses. Thus, they can be regarded as ideal inertial references. In addition, the drag-free satellite is a multiple degree-of-freedom system that consists of the following rigid bodies: (i) a rigid spacecraft body (6 DoFs); (ii) two rigid test massed (6 DoFs each); and (iii) two movable optical sub-assemblies (1 DoF each). Each components is strongly coupled with the others, which results in a quite complex and nonlinear dynamic system.

These factors introduce challenges in the modelling and control of the spacecraft. Currently, there is little open research on the mathematical modelling and control of the nonlinear system. Amongst the modelling approaches for mechanical system, we find that the port-Hamiltonian framework provides clear insights into the roles that the interconnection, dissipation, and energy play in the physical behavior. Furthermore, control system design in the port-Hamiltonian formalism has cleaner physical interpretations and tuning opportunities. Since the motion of the detector follows the physical law of energy, we propose to model and control the spacecraft in the PH framework using the well-established interconnection and damping assignment passivity-based control.

This provided approach has the advantage of the lack of linearization strategies and robustness to parametric uncertainty and model structure change in the open loop system. Besides, through coordinate transformation, it is proved that that the achieved nonlinear integral action ensures asymptotic stability under unknown constant disturbance. Finally, by taking Taiji program of the Chinese Academy of Sciences as an example, numerical simulation is carried out to evaluate the performance of the proposed method.