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NONLINEAR MODELLING AND DRAG-FREE CONTROLLER DESIGN FOR SPACE-BASED GRAVITATIONAL WAVE DETECTOR

Abstract

The past few years have witnessed many discoveries of gravitational wave by ground-based detector which indicate the coming era of GW astronomy and GW cosmology. Compared to GWs in frequency range of $10-10^3$ Hz, GWs at low frequencies from 0.1 mHz to 1.0 Hz are expected to carry an enormous amount of information, which are expected to be detected by future space-based interferometers. In this background, many spaced-based detectors were proposed, like LISA of European Space Agency and Taiji program of Chinese Academy of Sciences. For most missionsthe detector consists of an equilateral triangle of three spacecrafts in orbit around the Sun while each spacecraft is drag-free and forced to follow two cubic test mass which are put into a pure gravitational free fall around the sensitive axis with an accuracy of about $3 \times 10^{-15} m/s^2/\sqrt{Hz}$ in the measurement bandwidth. Taking Taiji program as example, this paper explores the modelling and controller design method for space-based detector. Firstly, an overall non-linear dynamic model is proposed to describe the 19 degree of freedoms of the spacecraft. Further, the resulting highly coupled MIMO system is linearized and decoupled to pave the way for innovative drag-free and attitude control system design. After a summary of measurement noises and external and internal disturbances in power spectrum density, the various performance specifications are presented and transformed into a set of design criteria expressed as constraints for the controller sensitivity and complementary sensitivity transfer functions of each individual control axis. Then considering an extended state observer, a robust disturbance rejection algorithm is designed based on H_∞ theory. Finally, based on the designed controller, the stability margins of each control axis are analyzed and transfer function analyses are conducted to evaluate changes in the design and identify areas where improvements are most valuable. Both frequency-domain and time-domain simulation results are presented to prove the robustness and stability of the system in terms of inhibiting disturbance, and show that all the defined requirements are achieved.