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A SENSITIVITY ANALYSIS APPROACH IN THE DESIGN OF THE ATTITUDE CONTROL SYSTEM OF SMALL SATELLITES

Abstract

The purpose of this work is to develop and implement a sensitivity analysis methodology useful for the design of the Attitude Control System (ACS) of small satellites.

The dynamic model under consideration for a small satellite has six degrees of freedom and uses Cartesian coordinates. The dynamic mathematical model is nonlinear. The sloshing effect due to the moving liquid propellant in two vertical-aligned spherical tanks is also nonlinear and is added to the dynamic model of the satellite by an equivalent mechanical model. This complete model is used as the starting point for the design of the ACS. The satellite's ACS uses pairs of micro-jet motors so that their command sequence necessary for applying control moments requires the use of nonlinear type trigger Schmidt element.

The dynamic mathematical model includes some parameters whose actual values are uncertain or could vary around some reference values (i.e., the mass and the second order inertia moments, the parameters of the sloshing model). The objective of the sensitivity analysis is to determine quantitatively the behavior of a response of the system locally around a chosen point of the trajectory in the phase-space of parameters and dependent variables. In this work the focus is first on the sensitivities of the eigenvalues of the linearized homogeneous system, which are the partial derivatives of the eigenvalues of the state-space system with respect the parameters. These are obtained using a modal approach based on the eigenvectors of the state-space direct and adjoint systems. Second, we are calculating the sensitivities of a (linear quadratic performance) cost function that is used in the design process of an optimal controller by using the same adjoint approach. The sensitivities, i.e. the derivatives of this functional type response with respect to all the parameters the system depends on, are useful in the controller design as well as for optimization purposes. In this paper we present the theoretical developments necessary for the application of the adjoint sensitivity analysis method for the fully coupled governing equations of the dynamic system.

The sensitivity analysis procedure is done on a typical small satellite configuration. The numerical results show that the sensitivities of the stability eigenvalues and of the cost function are reliable and can be used as a design tool.