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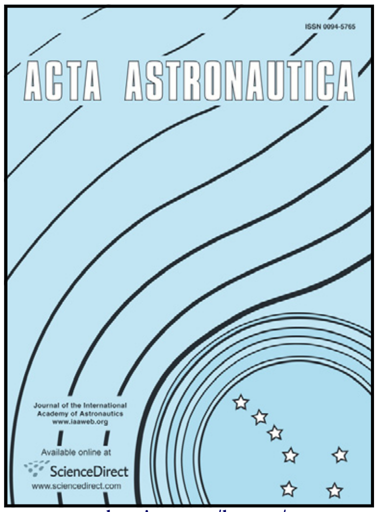

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A Six-degree-of-freedom Hardware-in-the-loop Simulator for Small Spacecraft

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Abstract

This paper presents a novel six degree of freedom, ground-based experimental testbed, designed for testing new guidance, navigation, and control algorithms for the relative motion of nano-satellites. The development of innovative guidance, navigation and control methodologies is a necessary step in the advance of autonomous spacecraft. The testbed allows for testing these algorithms in a one-g laboratory environment. The system stands out among the existing experimental platforms because all degrees of freedom of motion are controlled via real thrusters, as it would occur on orbit, with no use of simulated dynamics and servo actuators. The hardware and software components of the testbed are detailed in the paper, as is the motion tracking system used to perform its navigation. A Lyapunov-based strategy for closed loop control is used in hardware-in-the loop experiments to successfully demonstrate the full six-degree-of-freedom system's capabilities. In particular, the test case shows a two-phase regulation experiment, commanding both position and attitude to reach specified final state vectors.

Keywords: Small Spacecraft, hardware-in-the-loop verification, Guidance, Navigation, and Control

Nomenclature

$\mathbf{A}$	=	error system matrix
$\mathbf{B}(\boldsymbol{\theta})$	=	error input matrix
$(\hat{\mathbf{b}}_x, \hat{\mathbf{b}}_y, \hat{\mathbf{b}}_z)$	=	body principal axis reference frame components
$\mathbf{C}(\boldsymbol{\theta})$	=	mapping from relative angular velocity to Euler angles
$\mathbf{e}$	=	combined rotation and translation error
$\mathbf{F}$	=	force vector
$\mathbf{G}(\boldsymbol{\theta})$	=	rotational input matrix
$\mathbf{H}$	=	thruster mapping matrix
$\mathbf{J}$	=	moment of inertia matrix
$\mathbf{K}$	=	reference model gain matrix
$\mathbf{M}$	=	moment vector
O	=	orbiting reference point
$\mathbf{P}$	=	Lyapunov matrix
$\mathbf{Q}$	=	positive definite matrix in Lyapunov equation
$\mathbf{R}(\boldsymbol{\theta})$	=	direction cosine matrix
$\mathbf{u}$	=	vector of thruster forces [N]
V	=	Lyapunov function
$(\hat{\mathbf{x}}, \hat{\mathbf{y}}, \hat{\mathbf{z}})$	=	LVLH frame components [mm]
$\boldsymbol{\epsilon}$	=	error vector between $\boldsymbol{\xi}$ and linear reference model
$\boldsymbol{\eta}$	=	collection of nonlinear terms

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