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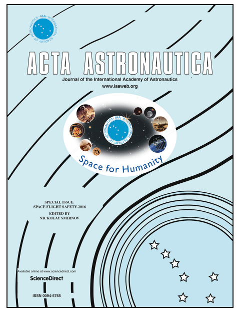

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Adaptive Relative Pose Control of Spacecraft with Model Couplings and Uncertainties

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Abstract

The spacecraft pose tracking control problem for an uncertain pursuer approaching to a space target is researched in this paper. After modeling the nonlinearly coupled dynamics for relative translational and rotational motions between two spacecraft, position tracking and attitude synchronization controllers are developed independently by using a robust adaptive control approach. The unknown kinematic couplings, parametric uncertainties, and bounded external disturbances are handled with adaptive updating laws. It is proved via Lyapunov method that the pose tracking errors converge to zero asymptotically. Spacecraft close-range rendezvous and proximity operations are introduced as an example to validate the effectiveness of the proposed control approach.

Keywords: spacecraft control, relative pose control, adaptive control, kinematic couplings, model uncertainties

1. Introduction

Spacecraft pose tracking control is considered as an enabling technology that can revolutionize future space operations. The ability to autonomously circumnavigate a target spacecraft or an asteroid and control its relative motion is a necessary ingredient to make tasks such as docking, servicing, health-monitoring, surveillance, and inspection in orbit or for deep space missions routine [1]. Autonomous rendezvous and docking missions require adequate accurate model and control algorithm of the relative motion between pursue spacecraft and target spacecraft. Generally, a typical rendezvous mission can be divided into a number of major phases, such as launch, phasing, far-range rendezvous, close-range rendezvous, final approach, capture and docking [2]. Especially, the phase of the proximity operations is very critical in view of mission safety, because it is required to drive a pursuer to a certain hovering position with respect to the target and align the pursuer's docking port with the target's docking port synchronically. After the autonomous accurate control for pursue spacecraft, the two spacecraft will eventually have no relative motion and the subsequent docking or capture mechanism can be safely performed. However, because of the complexity of the nonlinear relative motion model with modeling uncertainties and couplings, many nonlinear control methods are valued in community of control theory and practice.

Many representative researches in spacecraft control have been proposed in the past decades. A fault-tolerant attitude stabilization controller in [3] and a velocity-free feedback attitude stabilization controller in [4] were proposed for rigid satellites, a nonlinear estimator-based attitude controller was developed in [5] for a flexible satellite, and a robust attitude synchronization controller was proposed in [6] for satellite formation flying. A robust relative pose controller based on state dependent Riccati equation technology was designed in [7]. In [8], phase-plane control method was applied to the relative position motion and relative quaternion feedback method was applied to the relative attitude motion. In [9], an integrated pose controller was proposed for spacecraft proximity operations in the presence of parametric uncertainties, bounded disturbances, and measurement noises. A Lyapunov-based adaptive tracking control approach was proposed in [10] for satellite attitude tracking in docking operations, but the coupled relative translational motion was ignored as in [11]. An output feedback adaptive controller was developed in [12] to achieve the spacecraft autonomous rendezvous and docking missions under measurement uncertainties. A closed-form nonlinear optimal controller was addressed in [13] for flexible spacecraft proximity operations, but the parametric uncertainties and external disturbances were ignored. The problem in [13] was studied again in [14], and the optimal controller was redesigned with considering the modeling uncertainties. With considering constraints on thrust magnitude and on approach velocity in spacecraft proximity operations, the relative position control problem was converted into a model predictive optimization problem in [15], then the robust pose tracking controller was designed. An integrated translational and rotational finite-time controller was designed in [16] for a rigid spacecraft with thruster misalignment and bounded disturbances. For spacecraft rendezvous and proximity operations, two kinds of relative pose finite-time controllers were proposed in [17] based on geometric method. Adaptive pose tracking controllers were proposed in [18] and [19] based on certainty-equivalence principle to achieve spacecraft proximity operations, where relative translational and relative rotational controllers were developed separately. Then, based on the relative dynamics described in chaser's body-fixed frame,

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