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Multi-objective output feedback control for autonomous spacecraft rendezvous

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Abstract

In this paper, the problem of robust output feedback control for a class of spacecraft rendezvous systems is investigated, which contains parameter uncertainty, external disturbance, poles assignment, $H_\infty -$norm, variance and input constraints. The aim of this problem is to design a dynamic output feedback controller such that the closed-loop poles are placed within a specified disc, the H_∞ norm of the transfer function from disturbance to output is ensured to be less than a prespecified disturbance attenuation level, the steady-state variance for each state of spacecraft rendezvous system is guaranteed to be less than the prespecified individual upper bound, and the actual control input is confined into a certain range simultaneously. Based on the Lyapunov theory, the existence conditions of such controller are derived in terms of linear matrix inequalities (LMIs). An illustrative example is given to demonstrate the effectiveness of the proposed control design method.

1. Introduction

Many astronautic missions, such as space transporting, repairing, saving, docking, large-scale structure assembling, and satellite networking, rely heavily on successful rendezvous. During the last few decades, the spacecraft rendezvous control problem has attracted considerable attention

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in the literature and many design methods have been developed, see [2–18] and references therein.

The C–W equations, derived by Clohessey and Wiltshire in 1960 [2], have been widely used to describe the linear relative motion between two neighboring spacecraft if the target orbit is approximately circular and the distance between them is much smaller than the orbit radius. For example, based on C–W equations, the optimal impulsive rendezvous problem was studied in [3,7]; the new switch control laws for active collision avoidance manoeuvre were proposed in [8]. For this kind of models, there are some parameters which are difficult to determine due to the detection errors and the complex external perturbations in space, and these uncertainties have much to do with the stability and accuracy of rendezvous, see, for instance [11–17]. Besides the uncertainties, it is necessary to simultaneously consider that the orbital control input force is limited due to the constraints of the thrust equipment and the limited quantity of fuel, for example [5,8,11], so the rendezvous controller design based on the above situation is a multi-objective problem. In order to cope with the multiple objectives, a robust H_∞ control algorithm for spacecraft rendezvous was investigated in [11]; a non-fragile robust H_∞ control algorithm for uncertain spacecraft rendezvous system with pole and input constraints was studied in [14]; a mixed H_2/H_∞ reliable control scheme for trajectory-tracking of rendezvous via parameter-dependent Lyapunov functions was proposed in [16]. However, in [11,14,16], they all assumed that the relative position states and velocity states between the target and the chaser spacecraft are available for feedback purposes, actually in some real case, the relative velocity states may not be measured, so it is necessary to design the output feedback scheme for spacecraft rendezvous such that only the relative position states are used. The robust output feedback control has been widely studied for many practical systems in engineering applications, such as networked control systems [19], pneumatic actuator systems [20], highway vehicle systems [21], and hypersonic vehicle systems [22].

The spacecraft flights in space will be inevitably influenced by random factors, so the stochastic external perturbations should be considered. Although the H_2 performance was used in [16] to ensure the controller's immunity to white noise disturbances, it cannot guarantee the states satisfying the prespecified steady-state variance constraint. In order to cope with the stochastic disturbances, variance control is an effective method, which can guarantee the steady-state variance to be less than the prespecified individual upper bounds. During the last few years, variance control has been widely used and developed [28–31,37,38]. For example, the controller design for continuous systems with variance and circular pole constraints was studied in [30]; the robust control of linear uncertain systems with regional pole and variance constraints was proposed in [31]. However, there are no studies focusing on the variance constraint problem in spacecraft rendezvous engineering.

Motivated by the above discussions, in this paper, we propose a multi-objective robust output feedback controller design method for the rendezvous problem of two neighboring spacecraft subject to parameter uncertainty, external perturbation, poles constraint, $H_\infty-$norm constraint, variance constraint and control input constraint. First, for fast response, it is achievable by poles placement, where the closed-loop poles are placed in a specified region such as a disc [35]. Secondly, for disturbance attenuation, it is achievable by H_∞ control, where the $H_\infty-$norm is guaranteed to be less than a prespecified disturbance attenuation level. Thirdly, for steady-state performance, it is achievable by variance constraint. At last, it is also necessary to consider the constraint on the control input. For this multi-objective problem, a new robust output feedback controller design method is developed by a Lyapunov approach. The existence conditions for admissible controllers are formulated in terms of liner matrix inequalities (LMIs). An illustrative example is provided to show the effectiveness of the proposed control design method.