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Output feedback gain scheduled control of actuator saturated linear systems with applications to the spacecraft rendezvous ☆

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Abstract

The problem of stabilization of a linear system that is asymptotic null controllable with bounded control is studied in this paper. By combining the parametric Lyapunov equation approach and the gain scheduling technique, a new observer-based output feedback gain scheduling controller is proposed to solve the semi-global stabilization problem for a linear system subject to actuator saturation. By scheduling the design parameters online the convergence rate of the state can be improved. Numerical simulations for a spacecraft rendezvous system show the effectiveness of the proposed approaches.

1. Introduction

Saturation nonlinearity exists in every practical control system and makes the overall system inherently nonlinear (see, for example, [1,2]). Ignoring saturation nonlinearity in the controller

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design may lead to performance degradation and even instability of the closed-loop system. Controller design that takes into account input saturation has been recognized to be a difficult problem and has received increasing attention from the research community and industry [3–5]. The methods to solve the stabilization problem of linear systems with actuator saturation can be divided into two categories, that is, state feedback control [6–10] and output feedback control [11–14]. State feedback control is very powerful for the control system whose full information of the state vectors is assumed to be accessible for feedback. Thus, if the state of the system is measurable, state feedback is the best choice. However, in practice, only the measured output information rather than the full state information is available for feedback. Consequently, output feedback control is more reasonable. In view of the fact that the ability of static output feedback is generally limited, it is more realistic to use an observer-based output feedback controller, which is a dynamic output feedback controller that estimates the system states on-line. Therefore, from the practical point of view, observer-based output feedback design is important. However, the observer-based output feedback control has not attracted enough attentions in the existing studies for control of linear systems with input saturation.

The gain-scheduling approach is perhaps one of the most popular nonlinear control design approaches which has been widely applied in fields ranging from aerospace to process control [15,16]. There are basically three kinds of scheduling approaches, namely, the continuous static scheduling approach [6,12,17,18], the continuous dynamic scheduling approach [19–21], and the discrete scheduling approach [7,22,23].

In this paper, we consider the problem of stabilizing a linear system which is asymptotic null controllable with bounded controls (ANCBC) subject to actuator saturation by observer-based output feedback. By using the parametric Lyapunov equation approach and the gain scheduling technique, a new observer-based output feedback gain scheduling controller is proposed to solve the semi-global stabilization problem for a linear system subject to actuator saturation. The main advantage of the designed controller is that the convergence rate of the state can be improved by scheduling the design parameters online.

As one of the applications of the proposed gain scheduling approach, the spacecraft rendezvous problem is revisited in this paper. Spacecraft rendezvous is an important technology for present and future space missions [24]. Considering a target spacecraft in a circular orbit and another chaser spacecraft in its neighborhood, the relative motion between two neighboring spacecraft can be described by autonomous nonlinear differential equations. If the distance between them is much smaller than the orbit radius, the model is given by C–W equation, derived by Clohessey and Wiltshire in 1960 [25]. During the last few decades, the spacecraft rendezvous has been actively studied and many results in control theory and technologies have been developed (see [8,26–28] and the references cited there). In this paper, with the three independent continuous control accelerations being as the control signals to the C–W equation, the proposed observer-based output feedback discrete gain scheduling control method is applied to the design of stabilizing controllers by recognizing that the C–W equation is ANCBC. Numerical simulations show that the proposed gain scheduling approach can significantly reduce the time required for accomplishing the rendezvous mission.

The rest of this paper is organized as follows. Section 2 formulates the stabilization problem. In Section 3, the observer-based output feedback gain scheduled controller is proposed to solve the problem. Then application of the proposed gain scheduled approaches to the spacecraft rendezvous problem is explored and established in Section 4, in which simulation results are also given. Finally, Section 5 concludes the paper.

Notation: Throughout the paper, the notation used is fairly standard. We use A^{T}, $\mathrm{tr}\,A$, and $\lambda_{\min}(A)$ to denote the transpose, the trace and the minimal eigenvalue of matrix A, respectively.