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Interval Observers for Global Feedback Control of Nonlinear Systems with Robustness with respect to Disturbances[☆]

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Abstract

This paper develops criteria for designing interval observers to guarantee robustness with respect to disturbances for feedback control of nonlinear systems. Intervals in which components of the state vector are guaranteed to stay are estimated based on the information of the range of the initial state and the disturbances. For formulating desirable properties of boundedness and convergence of estimated intervals in the presence of disturbances, the notion of integral input-to-state stability is introduced to interval observer design. Guaranteed properties of the observer-based feedback designed in the formulation are not only global, but also address nonlinearities which are broader than those covered by previously existing approaches.

Keywords: Interval observers, Nonlinear systems, Output feedback control, Lyapunov functions, Guaranteed state estimation.

1. Introduction

The Luenberger observer and similar traditional observers estimate the state variables of a system from its input-output data. The estimation is undoubtedly useful for feedback control purposes. The Luenberger-type observers are stable mechanisms which give estimates of the state vectors as time tends to infinity. Due to the stable mechanisms, this asymptotic estimation remains valid in the presence of sufficiently small errors in system parameters. However, there is no guarantee during transient periods that the Luenberger-type observers give useful information of the unmeasured state. Indeed, they cannot provide us with any readily usable estimate when system parameters or disturbances are changing or large. In applications, another important demand in estimation is to monitor and detect faults of systems. Usefulness of the Luenberger-type observers is limited when some guarantees for monitoring and detection are needed in transient periods.

About two decades ago, the notion of interval observers was introduced as a new paradigm for monitoring unmeasured variables all times in the presence of large and fluctuating disturbances [11]. Interval observers produce component-wise upper and lower bounds of state vectors of considered systems at every instant. In the absence of disturbances, interval observers guarantee the difference between the upper and lower bounds to converge to zero. Such state estimators without the convergence are called framers. Framers and interval observers belong to a specific class of estimation methods called guaranteed state estimation methods. The capability of coping with large uncertainties has been useful for biological models, and framers and interval observers have been successfully applied to many real-life problems (see e.g., [5, 1, 10, 19] and references therein). Designing framers and interval observers has been studied for both continuous-time and discrete-time systems. Some works are devoted to various classes of finite or infinite-dimensional linear systems [17, 18, 22, 20, 8], and others concern some classes of nonlinear systems [23, 25, 26, 21].

Recently, in the context of systems with control input and output measurement, an interval observer has been proposed for a class of nonlinear systems which are affine in the unmeasured part of the state variables [7]. Compared with other approaches, it employs a simpler structure consisting of two modified Luenberger observers. A sufficient condition under which the constructed simple structure is guaranteed to function as an interval observer globally is presented there. Notably, the modified Luenberger-type construction enables us to use the interval observer for global feedback control as in the ordinary observer case. Thus, a single interval observer can play both roles of control and monitoring in a simple way. While continuous-time measurement is assumed in [7], an interval observer can be constructed with discrete-time measurement [6]. The technique employed for the discrete-time measurement is, however, basically effective only for strongly limited bilinearlities, and generalizing the result to nonlinearities covered by the continuous-time measurement case is not trivial. Although continuous-time measurement allows one to cover a larger class of nonlinear systems in feedback control, nonlinearities satisfying the sufficient condition proposed in [7] are not satisfactorily broad. The sufficient condition requires the feedback control input to be mild in accordance with the observer, which restricts the use of nonlinear damping. The necessity of global Lipschitzness assumed in [7] is not clear. Moreover, the convergence of the

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