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Sampled-data sliding mode observer for robust fault reconstruction: A time-delay approach

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Abstract

A sliding mode observer in the presence of sampled output information and its application to robust fault reconstruction is studied. The observer is designed by using the delayed continuous-time representation of the sampled-data system, for which sufficient conditions are given in the form of linear matrix inequalities (LMIs) to guarantee the ultimate boundedness of the error dynamics. Though an ideal sliding motion cannot be achieved in the observer when the outputs are sampled, ultimately bounded solutions can be obtained provided the sampling frequency is fast enough. The bound on the solution is proportional to the sampling interval and the magnitude of the switching gain. The proposed observer design is applied to the problem of fault reconstruction under sampled outputs and system uncertainties. It is shown that actuator or sensor faults can be reconstructed reliably from the output error dynamics. An example of observer design for an inverted pendulum system is used to demonstrate the merit of the proposed methodology compared to existing sliding mode observer design approaches.

1. Introduction

A sliding mode observer is a category of robust observer which facilitates the complete rejection of a class of uncertainty between the system and observer [27]. In most cases, the sliding surface is set to be the difference between the observer outputs and system outputs, which is therefore forced to zero [3,28]. A discontinuous injection term is designed and applied to drive

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the observer so that the error between the outputs of the observer and the outputs of the plant will move onto this surface within the error space and then remain there. In terms of implementation, delays exist in many applications, for example those caused by transmission delay and computational delay. If performance levels are to be optimized in the presence of such delays it is necessary to consider the development of methodologies which incorporate knowledge of the delay in the design framework. There have been many results that investigate the effect of state delay on observer design [1,2]. However very little work has considered the effect of delays in the output measurement on observer performance. In terms of work that considers the effect of time-delay in sliding mode observers, the literature is very sparse [15] and is strongly aligned to observer based control rather than fault detection and estimation with an emphasis on state delay rather than measurement delay [23,24]. Since the switching term in a sliding mode observer depends on the output measurement, which may be subject to delay in practice, the resulting discontinuous injection applied to the observer has the potential to cause chattering of large amplitude. This behaviour may limit the magnitude of the discontinuous signal that it is possible to apply with the observer.

There has been a great deal of interest in the application of sliding mode observers to the problem of model based fault detection and isolation [5,12,29]. The merit of the approach lies in the application of the so-called *equivalent output injection* to explicitly reconstruct fault signals. The results obtained to date mostly require that an ideal sliding motion is attained in finite time before the appearance of faults, and that no delay is present on the output measurement used to drive the observer. It is clear that in the presence of sampled outputs, the ideal sliding mode cannot be achieved. Indeed the error dynamics in the observer can become unstable as the sampling interval is increased. It is important to note that uncertain sampled-data systems have received significant interest in recent years [20,22,25]. Sampled-data models, in which the conventional continuous states and discrete observations interact, have proved useful for capturing many real world engineering phenomena [7,17,26,31]. Motivated by recent results in the area of relay delay control in [9,11], this paper will consider the effects of sampled output measurements when designing sliding mode observers for fault reconstruction.

It has been shown in [10,21] that a sampled-data output can be represented as a continuous one with fast varying delay. From this representation, the aim in this paper is to develop a general framework for sliding mode observer design and fault reconstruction under multiple sampled outputs. The error dynamics is forced to exhibit a bound proportional to the sampling period of the outputs and the magnitude of the discontinuous switching gain employed in the observer. The observer, which is designed using a singular perturbation approach, possesses a sufficiently small perturbation parameter μ such that faults are reliably constructed despite the presence of the sampled output. The observer synthesis is formulated in terms of LMIs, the feasibility of which is guaranteed for small enough μ. The effect of uncertainties on the fault reconstruction is minimized by incorporating H_∞ concepts within the observer design framework. In Section 2, the problem of sliding mode observer design with sampled outputs is formulated in terms of a system representation with known fast varying delay. Section 3 develops a constructive observer design approach which ensures the ultimate boundedness of the error dynamics. By using the singular perturbation method, Section 4 shows that approximate fault reconstruction can be achieved. The sensor fault reconstruction is demonstrated in Section 5, where new measurable states are augmented to the original faulty system so that the results developed in the previous sections can be applied as the sensor fault is now transformed to be an input fault. In Section 6 the effectiveness of the result is demonstrated using a linearized model of the inverted pendulum. Some preliminary results from this paper in the context of the input delay problem were presented in [13].

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