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Finite-time H_∞ control of uncertain networked control systems with randomly varying communication delays

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ABSTRACT

This paper is concerned with the problem of finite-time H_∞ stability analysis of uncertain discrete-time Networked Control Systems (NCSs) with varying communication delays in a random fashion. Both measurement and actuation delays are modeled by two independent Bernoulli distributed white sequences. A dynamic output feedback controller is designed to realize finite time control for this class of NCSs with prescribed H_∞ performance level. An iterative algorithm is developed to compute the controller's parameters by means of the Cone Complementarity Linearization Method (CCLM). The validity and feasibility of the proposed stability criterion are confirmed via numerical simulation examples.

1. Introduction

Networked control systems (NCSs) as a kind of distributed control systems are comprised of the system to be controlled (plant), actuator, sensor, and controller, which are interconnected through a communication network. Fig. 1 illustrates the structure of NCSs adopted in this paper.

Due to the low cost, flexibility and less wiring, stability analysis and control synthesis problems of the NCSs have drawn considerable attention over the past decades [1–7]. However, incor poration of the communication network in the control loop leads to some inherent phenomena, which cause the analysis and design of NCSs more complicated. Network delay and data packet dropout are the most significant phenomena that degrade the system performance or even make system instability. The focus of the research work is to develop a control strategy for stabilizing NCSs in order to suppress the detrimental effects of network delays.

Referring to Fig. 1, network delays in the NCSs are exposed when the data exchange from the sensor to controller and controller to actuator, called measurement and actuation delays, respectively. Regardless of the type of network, the performance of NCSs is always affected by the delays, which can be constant, or random and time-varying [8–10]. Lately, researchers have started to model the random delays in different probabilistic manners. Bernoulli distributed white sequence and Markov chains are generally two kinds of modeling for the network delays [11–18]. Different studies have been carried out in modeling, stability analysis, and control design of NCSs [19–28]. Several control algorithms have been extensively investigated in the literature to deal with the stability analysis of NCSs using Lyapunov theory. The Lyapunov theory focuses mainly on the state convergence property of the system in infinite time interval. However, a key topic in practice is the behavior of the dynamic systems over a specified time interval; for example, large values of the states are not satisfactory in the presence of saturation. Finite-time stability (FTS) or short-time stability is a different stability concept which concerns the boundedness of the system states over a finite time interval for arbitrary initial conditions. Since the systems with finite-time convergence typically reveal some specific attributes such as faster convergence and better robustness, the FTS technique was successfully applied to the stabilization of different systems [29–36], particularly in the NCSs [37–45]. Compared with the existing works, the problems of finite-time stability and stabilization of uncertain NCSs with randomly varying delays have not fully investigated and still remain challenging. Tables 1 and 2 are provided to show this gap.

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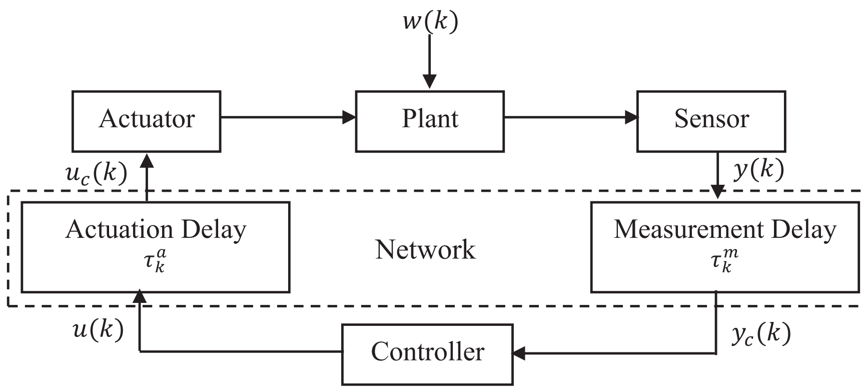

Fig. 1. Structure of the considered NCS.

Table 1
Finite-time stability and stabilization of continuous and discrete NCSs.

Works Reported	Plant model						Delay model				Controller type	
	Linear	Nonlinear	Certain	Uncertain	Discrete	Continues	Constant		Time varying	Random	State feedback	Output feedback
							known	unknown				
[37]		■	■		■						■	
[38]	■		■			■			■		■	
[39]		■	■		■						■	
[40]	■		■			■	■				■	
[41]	■		■			■	■				■	
[42]	■		■		■						■	
[43]	■		■			■			■		■	
[44]	■		■			■		■			■	
[45]	■		■		■						■	
Current Work	■			■	■				■	■		■

Table 1 represents some appealing results about FTS developed for both continuous and discrete NCSs with respect to several aspects including linearity/nonlinearity or being certain and uncertain for the model of plant, constant, time varying or randomly for the delay, and the type of the designed controller. In [42], an iterative approach for modelling of discrete NCSs was introduced. Then, the finite-time boundedness and stabilization problems was realized by designing the state feedback control without considering the effects of uncertainties and time delays in the NCSs. In [43], the finite-time boundedness problem for a class of linear NCSs with short time-varying delays and sampling jitter using state feedback controller was studied. The closed-loop NCS was described as a discrete-time linear system model, where the uncertain parts reflect the effect of the network-induced delays and short sampling jitter of the system dynamics. In [44], the finite-time boundedness and dissipativity analysis for a class of networked cascade control systems in presence of time delays and packet dropouts was discussed. State feedback controller for the NCSs without uncertainty was designed. In [45], the finite-time stability of a class of discrete-time linear NCSs with bounded Markovian packet dropout using state feedback controller was analyzed without considering time delay and uncertainties.

From control point of view, Table 2 lists the recent networked control techniques by considering communication delays [46–49] into different categories. In [47], a dynamic output feedback controller was designed to stabilize the linear discrete-time NCSs with both random measurement and actuation delays. In [46], the H_∞ control for discrete-time linear NCSs was designed in presence of the random communication delays modeled by the Bernoulli binary distributed white sequence. Nevertheless, the method presented in [46,47] intensively depends on the sampling period and is only applicable for the NCSs with small random delays. To solve this problem, in [48], the NCS design for continuous-time systems with randomly-varying delay was developed. However, the observer-based feedback control algorithm given in [48] was derived based on the assumption that the delay occurs only in the measurement channel. This clearly does not accord with the practical situation in the NCSs, where another typical kind of network-induced delay (i.e. actuation delay) often happens in the channel from the controller to the actuator. Compared with [48], in [49], an observer-based controller was designed by involving both randomly varying measurement and actuation delays. Therefore, the main challenging of this work is to compensate for the effects of the randomly varying network delays in order to preserve robust stability and performance of the uncertain NCSs.

Referring to Tables 1 and 2, the main contribution of the paper can be itemized as follows. (1) when external signals and model uncertainties are exposed in the NCS, it is required to design appropriate controllers to guarantee the robust stability and performance simultaneously by minimizing certain appropriate norms, such as $\|.\|_\infty$. In light of this issue, here, robustness properties of the uncertain NCS is characterized in terms of H_∞ performance criterion, (2) the use of the network may give rise to probabilistic signal delays, which is fairly realistic. In this paper, the NCS with randomly varying delay are studied, which are occurred both in the sensor to controller and controller to actuator channels, (3) most of the works associated to the stability of NCSs are focused on Lyapunov asymptotic stability, which is defined over an infinite time interval. However, in real world, the main focus is on the behavior of the dynamical systems over a fixed finite-time interval, which is another motivation of the current work, (4) existing literature on NCS stabilization mainly consider the state feedback controller, which highly depends on the states. Nevertheless, there are some typical conditions where the system states are not fully available that motivates the use of output feedback control technique.