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Co-design of dynamic scheduling and quantized control for networked control systems

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Abstract

A novel co-design scheme of dynamic scheduling strategy and quantized control for a class of time-delay networked control system with communication constraints is presented in this paper. Sufficient condition of bit rate is given to guarantee the convergence of quantization error by Lyapunov stability theory. The networked control system is modeled as a discrete-time switched system under the effect of Try-once-Discard (TOD) dynamic scheduling strategy and time-varying quantization, and a state feedback controller design method is given to guarantee asymptotic stability of the closed-loop system by using LMI techniques. Finally, two simulation results demonstrate the effectiveness of the proposed method.

1. Introduction

In recent years, considerable attention has been paid to the study of networked control systems (NCSs), in which control loops are closed via digital communication channels. However, the introduction of the network in the feedback control loops makes the analysis and synthesis of NCSs much more complex [1–3]. In NCSs, certain control loops contain network channels with limited bandwidth in which only a finite amount of nodes can access the shared channel, and this leads to communication constraints that cannot be ignored in the controller design procedure. Currently, there are two representative methods to describe communication constraints. The first is media access constraints [4–7], which means only a subset of sensors and controllers is

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allowed to transmit their data over the shared channel at each transmission instant. The second is rate constraints [8–15], which means only a finite number of bits can be transmitted over the digital communication channel at any transmission instant due to the bandwidth limitation. For media access constraints, many results focus on determining nodes scheduling sequence, such as Round Robin (RR), Try-once-Discard (TOD), and EDF (Earliest Deadline First) protocol. For bit rate constraints, the network introduces quantization error in digital signals from quantizer; therefore quantizer design and quantized control for NCSs have received increasing attention in recent years.

Some work on quantizer design and quantized control has been investigated for digital control systems, which aim at analyzing the quantized feedback effects and guaranteeing the stability and performance of the system. Brockett considers the feedback stabilization problems for linear time-invariant control systems with saturating quantized measurements [8]. Elia and Mitter consider a stabilization problem via quantized input signals and the coarsest memoryless quantizer for stabilization of signal-input discrete-time linear time-invariant systems is derived [9]. A problem of finding an optimal dynamic quantizer for nonlinear control subject to discrete valued signal constraints is considered in [10]. The problem of achieving input-to-state stability (ISS) with respect to external disturbances for control systems with quantized measurements was considered by [11] using quantizers which have an adjustable center and zoom parameters. Tatikonda and Mitter provide lower bounds on the rates required to achieve asymptotic observability and asymptotic stability based on quantization of the feedback signals [12]. In [13], a sector bound method is presented for the stability analysis of quantized feedback control system by using a simple sector bound to model the quantization error. In [14], a dynamic scaling method for quantized output feedback control is presented to achieve stabilization by using a finite-level quantizer, and a suboptimal approach to the optimization of the number of quantization levels is also given. In [15], a quantization dependent approach to the problems of analysis and synthesis for quantized feedback control system with logarithmic quantizers is presented. You investigated the attainability of the minimum average data rate for stabilization of linear systems via logarithmic quantization [16]. In [17], You also investigated the minimum data rate for mean square stabilization of discrete linear time-invariant systems over a lossy channel. Recently, the quantized control system with networked and shared communication channel has gradually become an attractive research area [18–25]. In [18], sufficient and necessary condition of lower bounds on the rates is given for network channel with packet dropout. In [19] and [20], the problem of state quantized feedback control and output quantized feedback control for networked control system by using logarithmic quantizer with random packet dropouts was studied and the characteristics of random packet dropout are modeled as Bernoulli process, and sufficient conditions are given to guarantee the closed-loop system asymptotically stable. In [21], H-infinity quantized control for networked control system is considered by zooming a quantized factor and solving Riccati equation, and sufficient conditions are given to ensure the robust stability of the system. In [22], an approach for state feedback assignment of control inputs' quantization precision and update rate is proposed. A quantized system with finite-level quantized input computed from quantized measurements was considered in [23] and the stability analysis of the system is transferred into the one of an equivalent system depending on a multiplier which is nonnegative and bounded. A new control strategy with on-line updating the quantizer's parameter is proposed in [24], which can ensure the controlled system to attain the same dynamic performance. A quantized control problem for stabilizing uncertain linear systems in the sense of quadratic stability is considered in [25], which the coarsest quantizer for achieving quadratic stabilization is of logarithmic type.

For nodes scheduling approach, Donkers consider the NCS with time-varying transmission intervals as a discrete-time switched linear uncertain system under TOD or