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Brief Papers

Two channel event-triggering communication schemes for networked control systems

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ABSTRACT

This paper is concerned with event-triggered controller design for networked control systems. At first, novel model-based event-triggered transmission strategies for both the sensor-to-controller and the controller to actuator channels are proposed, which are capable of reducing the communication bandwidth utilization, while preserving the desired control performance. Second, considering the effect of the network transmission delay, a newly delay system model for the analysis is firstly constructed. Third, based on our newly proposed model, criteria for stability and criteria for co-designing both the feedback gain and the trigger parameters are derived. Finally, a numerical example is given to demonstrate the effectiveness of the proposed method.

1. Introduction

Due to the popularization and advantages of using network in control systems, networked control systems (NCSs) have received considerable attention in recent years [1–7]. In many practical systems, the insertion of the network can also bring about several challenging issues including network-induced delays, packet dropouts and the constrained bandwidth of the communication network. With these concerns, some effective methods have been proposed to improve these problems [8–12]. For example, in [9], the authors propose an existence theorem of the maximum packet dropout rate and show that the NCS is stabilizable if the network-induced delay and the packet dropout rate satisfy some simple algebraic inequalities. The authors in [10] and [12] propose new event triggered mechanisms to reduce the utilization rate of communication bandwidth.

More recently, in order to save the limited communication resource for NCSs, much attention has also been paid to design the reasonable communication scheme [13–16,18,19]. In the context of NCSs, the bandwidth of the communication network and the power in sensor nodes are inevitably constrained. Therefore, one needs to design a reasonable communication scheme to save the limited resources of communication capacity and energy supply while guaranteeing the control performance. A widely used method is time-triggered communication scheme, which is believed to be beneficial for resource saving. Although there have been publications about nonlinear NCSs in the literature [18,24], it should be pointed out that time-triggered communication scheme leads to inefficient utilization of the limited network resources. Especially when there is little new information in the transmission, such as when no disturbances are acting on the system and the system is operating desirably, inefficient or redundant communications have inevitably transmitted through communication networks. Therefore, it is necessary to find an alternative control paradigm to mitigate the unnecessary waste of communication resources.

Recently, event-triggered method has received considerable attention [20–23], which can reduce the burden of the network communication and the occupation of the sensor, while retaining a satisfactory closed-loop performance. Compared to time-triggered communication scheme, event-triggered method is a control strategy in which the control task is executed after the occurrence of an event. "Event" will be triggered by some well-designed event-triggering condition, rather than the elapse of a certain fixed period of time [25]. In this way, event-triggered method is capable of increase the energy efficiency and reduce the cost of sensor network. For example, in [2], a novel distributed event-triggered sampled-data transmission strategy is proposed and a sufficient condition on the consensus of the multi-agent system is derived. The authors in [13] proposed a novel event-triggering scheme and developed an event-triggered H_∞ control design method for networked control systems with network-induced delay. In [16], the authors proposed a discrete event-triggered communication scheme for a class of networked T–S

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fuzzy systems. In the aforementioned studies, different communication schemes are established mostly between the sensor and the controller, which can decide whether or not the sampled sensor measurements are to be transmitted. Only when the current sampled sensor measurements violate a special condition, they can be transmitted. However, the network resource between the controller and the actuator are also limited, only little attention has been paid to deal with this problem. Especially when the control signal is sent to plant over a lossy communication channel, where network-induced delay and packet dropout occur simultaneously, it is essential to design a transmission scheme to save the capacity of the network. The control output transmitted in practical NCSs should be event-based before they are sent to the actuator in order to achieve better performance. However, to the best of the authors' knowledge, little attention has been paid to this problem, which is another motivation of the current study.

In this paper, we will propose model-based event-based mechanisms for both the sensor-to-controller and the controller to actuator channels. The communication traffic will be significantly reduced while preserving the desired performance and without resorting to extra hardware. We only measure the state and compute the error at a constant sampling period. Notice that not all of the measured states are transmitted through the communication network, that is, only the error violates the prescribed threshold, then the measured state is transmitted to the controller. Moreover, not all of the output of controller can be sent to the actuator. Only when the error of the output of controller violate a special condition, they can be transmitted. The main contributions of this paper are as follows: (1) the event-based mechanisms for both the sensor-to-controller and the controller to actuator channels are firstly proposed. (2) Considering the effect of the network transmission delay and the properties of the event-triggering schemes, a novel model is firstly proposed for the use of system analysis and control design, which has not been considered in the existing references. (3) Based on the model, sufficient conditions for the stability and controller design are derived in terms of linear matrix inequalities.

The paper is organized as follows. Firstly, a novel two-channel event-triggered transmission strategy will be proposed in Section 2. Then, sufficient conditions for the stability of the addressed model are established in terms of linear matrix inequalities in Section 3. Finally, in Section 4, a numerical example is employed in the final part to demonstrate the effectiveness and applicability of our method.

Notation: $\mathbb{R}^n$ and $\mathbb{R}^{n\times m}$ denote the n-dimensional Eculidean space, and the set of $n\times m$ real matrices, respectively; the superscript "T" stands for matrix transposition; I is the identity matrix of appropriate dimension; $\|\cdot\|$ stands for the Euclidean vector norm or the induced matrix 2-norm as appropriate; the notation $X>0$ ($X\ge 0$), for $X\in\mathbb{R}^{n\times n}$, means that the matrix X is real symmetric positive definite (positive semi-definite). When x is a stochastic variable. For a matrix B and two symmetric matrices A and C, $\begin{bmatrix} A & * \\ B & C \end{bmatrix}$ denotes a symmetric matrix, where $*$ denotes the entries implied by symmetry.

2. System description

In this section, we will study the networked control configuration as shown in Fig. 1, in which the system is described by

$$\dot{x}(t)=Ax(t)+Bu(t) \tag{1}$$

where $x(t)\in\mathbb{R}^n$, $u(t)\in\mathbb{R}^m$ denote the state vector, control vector, respectively; A and B are parameter matrices with appropriate dimensions.

As is well known, all the sampled data are transmitted to the controller via the communication channel in network control systems, all the controller output can be transmitted to the actuator in

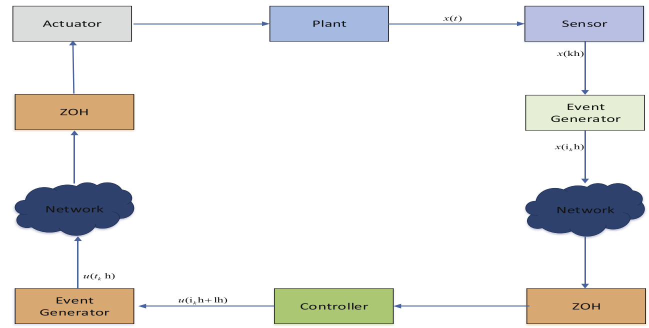

Fig. 1. The structure of an event-triggered networked control system.

the same way. Indeed, if the current data vary slightly compared with the previous one, we can still use the previous one. In this case, part of sampled signal need not be transmitted over network, thus, the transmission frequency can be reduced and the network bandwidth can be saved. Then, how to filter out those unuseful signal before transmitting to the controller and actuator through the network? In recent years, there are some interesting results as to how to choose those useful sampled data to be transmitted, see, e.g. [13,16,17]. Different from these studies, in this paper, we propose a two channel event triggered schemes to decide whether the current signal should be transmitted or not.

Throughout this paper, we assume the system (1) is controlled by a network and possibly wireless network, for which communication resources and energy sources, e.g., the batteries for the wireless devices, are limited. For this reason, it is desirable to propose new event-triggered communication schemes to reduce the number of transmitted packets over the sensor to controller and controller to actuator channels as much as possible, while preserving the stability and desired control performance.

In solving this problem, two mechanisms are proposed based on the event-triggered control for the configuration in Fig. 1. In order to save the limited resources in the sensor to controller channel, an event generator is constructed between the sensor and the controller to determine when information should be transmitted to the controller system. Similarly, the other event generator constructed between the controller and actuator is used to determine whether information should be transmitted to the actuator side, which can reduce the transmissions in the controller to actuator.

For ease of exposition, we make the following assumptions:

(i) The system states are sampled at a constant period h. The sampled instants is lh, $l\in\{0,1,2,\dots\}$.
(ii) The logic ZOH (zero-order-hold) before the controller (or actuator) is used to hold the control input (or actuator input), when there is no latest control packet arrived at the controller (actuator).
(iii) The transmitted instant i_{kh} from the sensor to controller is determined by the sampled state $x(lh)$. The set of transmission instants is represented by i_{kh}, $i_k\in N$. The transmitted instant t_{kh} from the controller to actuator is determined by the state that arrived at the controller, which can be represented by t_{kh}, $t_k\in N$.
(iv) $\tau^{sc}_{t_k}$ and $\tau^{ca}_{t_k}$ are network-induced delays from the sensor to the controller and from the controller to the actuator, representatively. $\tau^{sc}_{t_k}$ and $\tau^{ca}_{t_k}$ and the computational and waiting delays are lumped together as τ_{t_k}, where $\tau_{t_k}\in(0,\overline{\tau}]$, $\overline{\tau}$ is the upper bound of τ_{t_k}.

The purpose of this paper is to design a linear controller $u(t)=Kx(t)$; where K is a gain matrix to be determined later, such that the resulting closed-loop system satisfies the required performance.