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Brief papers

Extended dissipative analysis and synthesis for network control systems with an event-triggered scheme

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A B S T R A C T

This paper considers the problem of extended dissipativity analysis and synthesis for network control systems under an event-triggered scheme, where the extended dissipativity analysis unifies the H_∞, passivity, dissipativity, and $L_2 - L_\infty$ performance in one framework. Firstly, the proposed system is modeled as a network control system with an suitable event-triggered scheme. Then, by using the improved integral inequality and reciprocally convex inequality technique, sufficient condition to guarantee the extended dissipativity of the network control systems is given in terms of linear matrix inequalities (*LMIs*). Furthermore, the design of the state feedback controller is also proposed. Finally, numerical examples are given to illustrate the efficiency of the addressed method.

1. Introduction

In recent years, network control systems(NCSs) have received extensive attention due to its pervasive applications in many practical systems such as the car automation [1], transportation networks [2], and offshore platforms [3] etc. Network control systems(NCSs) are generally composed of sensors, controllers and plants connected over a common network communication channel, and some phenomena such as the communication delays, data dropouts, packet disorder and congestions may occur due to the use of communication channel [4]. Due to the existence of time delay is often one of the main sources to cause undesirable system performance or even instability [5–10]. Therefore, the stability is one of the most important issues for NCSs, and a lots of researchers have shown great interest toward stability analysis and stabilization synthesis for lots of delayed NCSs in literatures [11–15], respectively.

It should be pointed out that, most of above mentioned results, just time-triggered control scheme for system modeling and analysis were used. In this triggering method, a fixed sampling interval should be selected to guarantee the desired performance under the worst conditions such as external disturbances, uncertainties, time-delays and so on [14,16]. However, in practical systems, the worst cases are seldom encountered, which frequently lead to the sending of many unnecessary sampling signals through the network, and further cause high utilization of the communication bandwidth. To solve this problem, one named event-triggered techniques has been reported and have been got much attention for different systems [17–23], where a useful way of determining when the sampling action is carried out to ensure that only really need state signal will be sent out to the controller. For example, the problem of dissipavity control using event-triggered schemes were studied for neural networks and systems with multiple sensors in recent research [22,23], respectively.

On the other hand, it is well known that the external disturbances can also affect the performance of system. The influence of external disturbances on the system can be reduced by introducing some famous performances, such that H_∞ performance in [24], $L_2 - L_\infty$ performance analysis in [25], passivity analysis in [26], and dissipativity analysis in [22,23], etc. Recently, some researchers have tried to unify some different performances in one unifies framework, in which can provide a more flexible robust control design in practical engineering, such as chemical process control and power converters. For example, the extended dissipativity analysis was introduced in [27], where H_∞ and passivity performance could be analyzed together. In [28], (Q, S, R)-dissipativity analysis was proposed, where H_∞ performance, passivity and dissipativity analysis could be solved in one time. Zhang et el. addressed a general performance called extended dissipativity in [29], which unified the above mentioned four performances. More recently, and the

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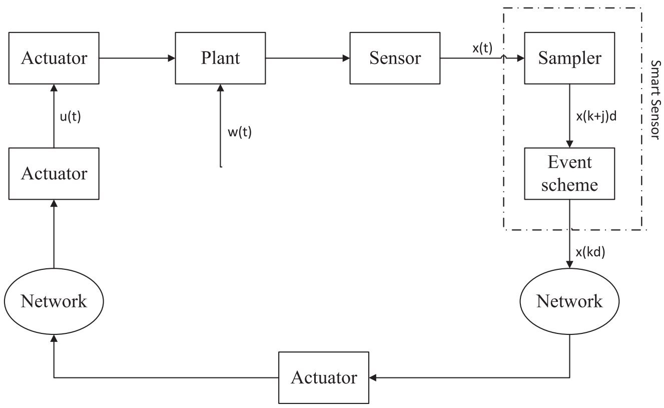

Fig. 1. Structure of an event-trigger network control system.

improved extended dissipativity has been used in many systems [30–37]. Unfortunately, as far as the authors' known, no one has been focused on the study of extended dissipativity for the network control systems. This motivates our research on this issue.

The structure of this paper is as follows. In Section 2, preliminaries and problem statement are formulated and some necessary lemmas are given. In Section 3, by using a parameter-dependent Lyapunov–Krasovskii functional and convex combination technique, the extended dissipative analysis for network control systems is investigated. Furthermore, existence and the design method of the state feedback controllers are proposed. All of the results are in terms of a set of linear matrix inequalities which can be easily resolved using the LMIs toolbox. In Section 4, numerical examples are given to show the effectiveness of the proposed approach.

Notation. Throughout this paper, the notations are quite standard. R^n denotes the n dimensional Euclidean space, $R^{m\times n}$ is the set of $m\times n$ real matrices. Given $X, Y \in R^{n\times m}$, the notations $X>0$ $(x<0)$ is used to denote a symmetric positive definite (negative definite) matrix, and the expression $X>Y(X<Y)$means $X-Y>0(X-Y<0)$. M^T represents the transpose of the matrix $M;I_n$ denotes the $n\times n$ identity matrix $e_i(i=1,2,\dots,12)\in R^{12n\times n}$ are elementary matrices. For a real matrix B and two real symmetric matrices A and C of appropriate dimensions, $\begin{bmatrix} A & B \\ * & C \end{bmatrix} \geq 0$, denotes a real symmetric matrix, where * denotes the entries implied by symmetry. The space of square-integrable vector functions over[0, ∞] is denoted by $L_2[0,\infty]$.

2. Problem formulation and preliminaries

Consider the following system:

$$\begin{aligned} \dot{x}(t) &= Ax(t) + Bu(t) + E\omega(t), \\ z(t) &= Cx(t), \end{aligned} \tag{1}$$

where $x(t)\in R^n$ is the system state vector, $u(t)\in R^m$ is the control input; $\omega(t)\in R^l$ is the external disturbance which belongs to $L_2[0,\infty)$; $z(t)\in R^p$ is the output. A, B, E and C are the parameter matrices with appropriate dimensions. Throughout this paper, we assume that the system (1) is controlled through a network.

The event-triggered networked control system as shown in Fig. 1 is considered in this paper. The network-induced delay is assumed to within a given interval $[0,\tau]$. A smart sensor carries out an event-triggered sampling strategy, namely the sensor updates its output only when the designed event-triggered condition is satisfied. This event-triggered sampling strategy is based on periodically sampled data $\{x(jd)|j\in N\}$ where d is a fixed sampling interval. The sampled stated $x((k+j)d)$ is released by the event generator when the current sampled $x((k+j)d)$ and the previously transmitted one $x(kd)$ satisfy the following event condition:

$$[x((k+j)d)-x(kd)]^T\Omega[x((k+j)d)-x(kd)]\geq\sigma x^T(kd)\Omega x(kd),\ j\in N_+, \tag{2}$$

where Ω is a symmetric positive definite matrix and $\sigma\in[0,1)$. Under the event condition (2), assume that the release times are $t_0d, t_1d, t_2d, \dots,$ where $t_0=0$ is the initial time. $\mu_i d = t_{i+1}d - t_i d$ denotes the release period which corresponds to the sampling period given by the event generator in (2).

Using a state feedback law and considering the network-induced delay , we have

$$u(t) = Kx(t),\ t\in[t_m d+\tau_m, t_{m+1}d+\tau_{m+1}, \tag{3}$$

where $\tau_m\in[0,\tau]$ is the network-induced delay. Following analysis transforms the system (1) into a time-delay model. Firstly, we divide the time interval $[t_m d+\tau_{t_m}, t_{m+1}d+\tau_{t_{m+1}})$ into $t_{m+1}-t_m$ subintervals.

$$\begin{aligned} &[t_m d+\tau_m, t_{m+1}d+\tau_{m+1}) \\ &\quad = \bigcup_{n=0}^{h}[t_m d+nd+\tau_{i_m+n}, t_m d+(n+1)d+\tau_{i_m+n+1}). \end{aligned} \tag{4}$$

For convenience, the $h=t_{m+1}-t_m-1$ and τ_{i_m+n} is an introduced scalar variable. Then define piecewise $\tau(t)$, $e(t)$ as follows:

$$\tau(t) = \begin{cases} t-t_m d, & t\in[t_m d+\tau_m, t_m d+d+\tau_{i_m+1}) \\ t-t_m d-d, & t\in[t_m d+d+\tau_{i_m+1}, t_m d+2d+\tau_{i_m+2}) \\ \quad\vdots\ , & \quad\vdots \\ t-t_m d-hd, & t\in[t_m d+hd+\tau_{i_m+h}, t_{m+1}d+\tau_{m+1}) \end{cases}$$

$$e(t) = \begin{cases} 0, & t\in[t_m d+\tau_m, t_m d+d+\tau_{im+1}) \\ x(t_m d)-x(t_m d+d), & t\in[t_m d+d+\tau_{im+1}, t_m d+2d+\tau_{im+2}) \\ \quad\vdots\ , & \quad\vdots \\ x(t_m d)-x(t_m d+hd), & t\in[t_m d+hd+\tau_{im+h}, t_{m+1}d+\tau_{m+1}) \end{cases}$$

Using these definitions, one can rewrite (1) as

$$\begin{aligned} \dot{x}(t) &= Ax(t) + BKx(t-\tau(t)) + BKe(t) + E\omega(t), \\ z(t) &= Cx(t), \end{aligned} \tag{5}$$

where $t\in[t_m d+\tau_m, t_{m+1}d+\tau_{m+1})$.

Remark 1. From the definition of $\tau(t)$ we have $0\leq\tau_m\leq\tau(t)\leq d+\tau$, $\dot{\tau}(t)=1$ and define $\tau_M = d+\tau$. Thus the time-varying delay $\tau(t)$ satisfying $0\leq\tau_m\leq\tau(t)\leq\tau_M$. Consider the definition of $e(t)$ and the event triggering condition (2) we have the following inequality

$$e^T(t)\Omega e(t)\leq\sigma x^T(t-\tau(t))\Omega x(t-\tau(t)). \tag{6}$$

For system (5), we denote the initial condition of state $x(t)$ as $x(t)=\phi(t), t\in[-\tau_M,0]$ where $\phi(t)$ is a continuous function on $[-\tau_M,0]$.

Assumption 1 [29]**.** Matrices ψ_1, ψ_2, ψ_3, ψ_4 satisfy the following conditions:

(1) $\psi_1=\psi_1^T\leq0, \psi_3=\psi_3^T>0, \psi_4=\psi_4^T\geq0,$
(2) $(\|\psi_1\|+\|\psi_2\|)\psi_4=0.$

Definition 1 [29]**.** For given matrices ψ_1, ψ_2, ψ_3 and ψ_4 satisfying Assumption 1, system (5) is said to be extended dissipative if the following inequality holds for any $T_f\geq0$ and all $w(t)\in L_2[0,\infty)$:

$$\int_0^{T_f} J(t)dt - \sup_{0\leq t\leq t_f} z^T(t)\psi_4 z(t)\geq0,$$

where

$$J(t) = z^T(t)\psi_1 z(t) + 2z^T(t)\psi_2 w(t) + w^T(t)\psi_3 w(t).$$