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Improved delay-dependent stabilization for a class of networked control systems with nonlinear perturbations and two delay components

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ABSTRACT

This paper focuses on the problem of delay-dependent state feedback control for a class of networked control systems (NCSs) with nonlinear perturbations and two delay components. Based on the dynamic delay interval (DDI) method and the Wirtinger integral inequality, some improved delay-dependent stability analysis are obtained. Furthermore, the results are extended to the conditions of NCSs with one time delay, and the corresponding stability analysis results and state feedback controller are obtained. Finally, some numerical examples and simulations are given to show the effectiveness of the proposed methods.

1. Introduction

In the past years, systems with time delays have received widely consideration due to time delays inevitably exist in various practical systems, such as neural networks, stochastic Markovian jumping system, engineering systems, NCSs [1–5,19]. Specially, in NCSs, sampled data are transmitted to the controller via communication networks, so there often exist time delays in measurements [6–9]. The inevitable encountered time delays usually are the main reason resulting in some complex dynamic behaviors such as oscillation, divergence and instability. Generally, the technique to proof the delay-dependent stability and stabilization criteria can be classified into two types: one is LKF method, for example, Discretized LKF method [10], augmented LKF method [11] , delay-partition-dependent LKF method [12], discontinuous LKF method [13] etc. The other one is estimation of bounding the integral term approach, for example, Jensen inequality approach, free-weighting matrix approach [14], convex optimization approach [7,15], Wirtinger inequality approach [7,16], free-matrix- based integral inequality approach [17], relaxed conditions for stability of time-varying delay systems [18] etc.

On the other hand, networked control systems (NCSs) have a relatively new structure where sensors, controllers and plants are often connected over a common networked medium [19] and many results has been reported recently based on this modeling idea. Such as, improved stability and stabilization design for networked control systems using new quadruple-integral functionals [20], output tracking control of networked control systems via delay compensation controllers [21], event-triggered control for networked control systems using passivity [22]. Due to variable networked transmission conditions, there do exists in the transmission delay and the data packet dropout. The transmission delay generally includes the sensor-to-control delay and the control-to-actuator delay. So the networked control system can take a form with two time delays: $\dot{x}(t) = Ax(t) + Bx(t - \tau_1(t) - \tau_2(t))$. Based on this model, many results have addressed in some articles [23–27]. In

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this articles, the stability of networked control system with additive time-varying delays was discussed and got some delay dependent results. The results of this articles is got by constructing different LKF and the linear inequalities. With the different of [23–26], [27] constructed new LKF by separating the whole delay interval into subintervals. The LKF as a whole to examine its positive definite, rather than restrict each term of it to positive definite as usual. So getting the less conservatism of stability results and new state feedback controller. But there is a problem that we have to addressing, as variable network transmission conditions in different properties, it may be not rational to lump them into one input state delay in some articles. Recently, [28] proposed a new method: dynamic delay interval method (DDI). A novel feature of the DDI is that the new bounds of the time-varying delay are the convex combinations of $\tau_1(t)$ and $\tau_2(t)$, and their fixed bounds. In [28], the stability analysis of neural networks with two delay components based on DDI was discussed. Motivated by our observations, we make a try to apply this method to get the results of the state feedback stabilization controller for NCSs with two delay components.

The problem of delay-dependent feedback stabilization for a class of networked control systems (NCSs) with nonlinear perturbations and two delay components is considered in this paper. Firstly, by constructing a new augmented Lyapunov functional based on the DDI method and using the reciprocally convex combination technique and Wirtinger integral inequality, some some improved delay-dependent stability analysis are obtained for for a class of NCSs with two additive input delays and the nonlinearity. Secondly, the state feedback controller is designed by adjusting different parameters with the DDI parameters. Then, the obtained results are extended to the case of NCSs with one time delay. Finally, numerical examples and illustrations are given to show the effectiveness and the significant improvement of the proposed methods. The main contributions of this paper include: 1. A new augmented Lyapunov functional is constructed based on the DDI method. 2. The reciprocally convex combination technique and Wirtinger integral inequality are applied to estimate the derivative of the Lyapunov functional to reduce conservatism of the obtained results.

Notation. Throughout this paper, I is the identity matrix with appropriate dimension; M^T represents the transpose of the matrix M; R^n denotes the $n-$dimensional Euclidean space; $0_{m\times n}$ represents a zero matrix with $m\times n$ dimensions; The notations$X>0(\geq 0)$ is used to denote a symmetric positive-definite (positive-semidefinite) matrix. In symmetric block matrices or complex matrix expressions, we use an asterisk * to represent a term that is induced by symmetry, and $diag\{\cdot\}$ stands for a block-diagonal matrix. Matrices, if their dimensions are not explicitly stated, are assumed to be compatible for algebraic operations .

2. System description and preliminaries

Consider the following nonlinear networked control model

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

where $x(t)\in R^n$ is the state vector; A, B are the known real constant matrices of appropriate dimensions. $f(x(t))$ is the nonlinear perturbations and satisfy the following:

$$\frac{df(x(t))}{dx(t)} = h(x(t)) = DF(x(t))E. \tag{2}$$

Here C, D are the known real constant matrices of appropriate dimensions and $F(x(t))$ is the norm-bounded matrix satisfying $F^T(x(t))F(x(t))\leq I$.

In the following we focus on the nonlinear networked control model with a controller gain K and two delay components described by

$$\dot{x}(t) = Ax(t) + f(x(t)) + BKx(t-\tau_1(t)-\tau_2(t)), \tag{3}$$

$\tau_1(t)$ and $\tau_2(t)$ are two time-varying delays satisfying

$$\begin{aligned} &0 \leq \tau_1(t) \leq \tau_1, 0 \leq \tau_2(t) \leq \tau_2 \\ &\dot{\tau}_1(t) = d_1(t) \leq d_1, \dot{\tau}_2(t) = d_2(t) \leq d_2, \end{aligned} \tag{4}$$

where τ_1, τ_2, d_1, d_2 are constants and $\tau_1>0$, $\tau_2>0$. We denote

$$\begin{aligned} &\tau(t) = \tau_1(t) + \tau_2(t), \tau = \tau_1 + \tau_2. \\ &d(t) = d_1(t) + d_2(t), d_m = d_1 + d_2. \end{aligned} \tag{5}$$

For each delay components, the dynamic delay interval (DDI) of $\tau_1(t)$ is denoted by $[\alpha\tau_1(t), \tau_1-\alpha\tau_1(t)]$, and the DDI of $\tau_2(t)$ is denoted by $[\beta\tau_2(t), \tau_2-\beta\tau_2(t)]$, respectively. Therefore, the internal of $\tau(t)$ is $[a(t), b(t)]$, where

$$\begin{aligned} &a(t) = \alpha\tau_1(t) + \beta\tau_2(t), \\ &b(t) = \tau - \alpha(\tau_1-\tau_1(t)) - \beta(\tau_2-\tau_2(t)), \end{aligned} \tag{6}$$

$$(\alpha,\beta) \in \begin{cases} \aleph \triangleq \{[0,1]\times[0,1]-(0,0)\cup(1,1)\}, d_1+d_2<1 \\ \quad\{(\alpha,\beta)|\alpha d_1+\beta d_2<1\}\cap\aleph, d_1+d_2\geq 1 \end{cases} \tag{7}$$