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Networked non-fragile H_∞ static output feedback control design for vehicle dynamics stability: A descriptor approach[☆]

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ABSTRACT

This paper deals with the problem of networked non-fragile H_∞ static output feedback controller design for continuous Takagi–Sugeno T–S fuzzy systems with uncertainties and measurement noise under unreliable communication links. The packet dropouts and network-induced delays, which are two typical network constraints of data transmission through network, are considered in control design. Due to the introduction of the noise measurement and in order to simplify the control design, the descriptor model is adopted. For the multiplicative case of controller gain variations, we suggest a new solution of the fragility problem by developing the non-fragile design schemes ensuring the robustly admissibility for the resulting network closed-loop systems. By considering an appropriate Lyapunov-Krasovskii functional (LKF), and using the deviation bounds of asynchronous normalized membership functions, we propose a new delay-dependent sufficient conditions formulated in LMI constraints which can be easily solved using convex optimization tools. To demonstrate the validity and the effectiveness of the proposed approach, the vehicle dynamics stability and the comparison with existing results are considered.

1. Introduction

Networked control systems (NCSs) are spatially distributed systems which use digital communication networks to connect the plant, sensors, actuators, and controllers and then exchange information between them. However, because of the limitation of the network resources, the network-induced delays and data packet dropouts caused by data transmission, will inevitably degrade the performance of the NCSs and may bring system instability. It is pointed out that the communication delay, which has time varying characteristics, is one of the important issues to be considered in NCS analysis and synthesis. Recently, much attention has been paid to stability analysis and controller design for dynamic systems by considering network-induced delay and packet dropout in the transmission network [12,34,43]. Although some interesting techniques and results have been proposed for linear NCSs in the literature [3,4,14,38,50,51], nonlinear NCSs have received little attention [25,52]. Those nonlinear NCSs have not been fully studied and still remain an open problem. The T–S fuzzy models play an important role due to their capacity to describe a large class of nonlinear systems and the existence of systematic and effective control design tools to complete other nonlinear control techniques [10,40,54].

Recently, the T–S fuzzy model has been extended to nonlinear descriptor systems with time delay and various problems of analysis and synthesis have been studied [16,18,29,46–48,55].

In reality, imprecision in controller implementation due to finite word length in digital systems or additional tuning of parameters in the final controller implementation is often unavoidable. In this case, the controllers are very sensitive, or fragile, with respect to errors in the controller coefficients [22]. Hence, it is necessary to design a controller that should be able to tolerate some level of controller parameter variations. This is known as resilient or non-fragile control problem [7,8,19,26,33].

In general, state feedback control is a simple and easy method to apply to control systems and many results have been achieved in existing literature [3,4,14,15]. It is known that state feedback systems require the measurement of every component of the state. However, in practical applications, it is not always possible to have access to all state variables, and only partial information is available via measured outputs. The static output feedback (SOF) control problem plays a central role in control theory and applications because designs of this controller are less expensive to implement and do not require full information on the state variables, and many problems involving synthesizing dynamic controllers can

☆ Fully documented templates are available in the elsarticle package on CTAN.

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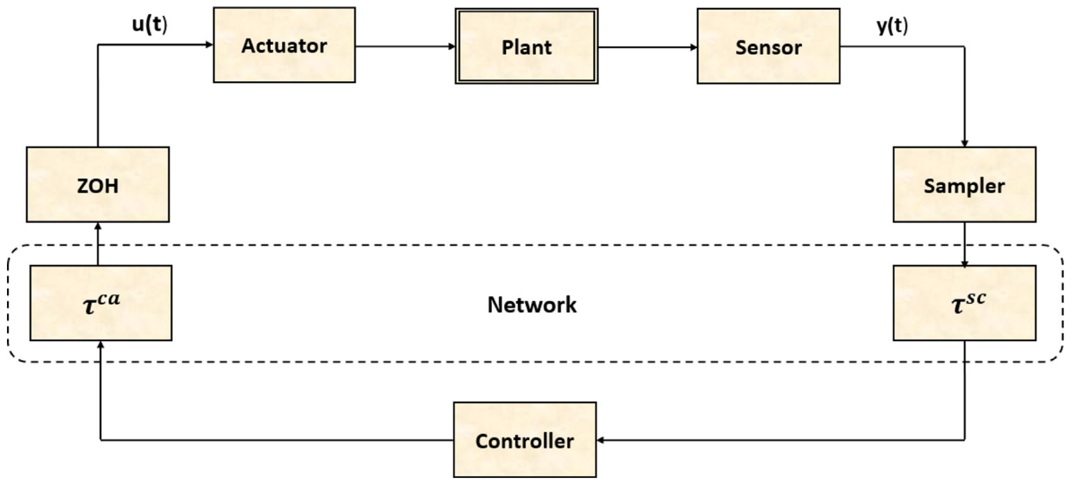

Fig. 1. Framework of networked control system.

be reformulated as an SOF control design using augmented plants [9,30]. In [45], the study is made on the single-step method based on non-fragile H_∞ control problem of active suspension systems with consideration of the finite frequency constraint. In [37], the authors proposed a new method for event-triggered controller design for networked control systems.

Since the system is controlled via a network, a noise can affect the system output. Thus it is compulsory to consider the fragility and the noise phenomenon in the control analysis. This paper concerns the design problem of non-fragile fuzzy static output-feedback control for nonlinear NCSs converted into uncertain T–S fuzzy descriptor systems. Bounded network-induced delays and data loss are taken into consideration in the transmission. The main contributions of this paper are summarized as below:

1. Taking $u(t)$ as a state component, we construct a descriptor dynamic system with a new state matrix showing a decoupling between matrix input B_i and controller gain K_i. This allows us to synthesize the gains controller even the noise occurs in the measurement. We note that the descriptor model approach is widely used in control engineering and many research topics have been reported in the literature [1,17,28].
2. Without resorting of any system transformation or any recursive algorithm, a non-fragile fuzzy static output feedback controller is designed by solving a certain set of linear matrix inequalities to ensure the H_∞ performance of the controlled system in presence of network-induced delays and data packet dropouts, in comparison with the approach of [19] and [31] which did not consider communication networks.

The rest of the paper is organized as follows: Section 2 presents the description of the system and some preliminaries. The main results, which consist in the robustness and non-fragility analysis and synthesis of the considered system, are developed in Section 3. In Section 4, Networked controlled vehicle dynamics stability is analyzed to demonstrate the application of the proposed approach. A comparison with existing methods is also given. Finally, a conclusion and future works are evoked in Section 5.

Notations: $sym(W)$ stands for $W+W^T$. Symbol $(*)$ within a matrix represents the symmetric entries. L_2 is the space of square integrable functions over $[0, \infty)$, and $||.||_2$ denotes the L_2-norm.

2. System description and preliminaries

A typical NCS model with network-induced delays is shown in Fig. 1, where τ^{sc} is the sensor-to-controller delay and τ^{ca} is the controller-to-actuator delay. It is assumed that the controller computational delay can be absorbed into either τ^{sc} or τ^{ca}. We consider a nonlinear plant in Fig. 1, which can be described by the following T–S fuzzy model:

Plant rule i:
IF $\theta_1(t)$ is F_{i1} and $\cdots$ $\theta_s(t)$ is F_{is} THEN

$$\begin{cases} \dot{x}(t) = A_i(t)x(t) + B_i(t)u(t) + B_{1i}w(t) \\ z(t) = C_{1i}x(t) + D_{1i}w(t) \\ y(t) = C_{2i}x(t) + D_{2i}\nu(t) \end{cases}$$

where $\theta_j(t) = [\theta_1(t), \theta_2(t), \ldots, \theta_s(t)]$ and $F_{ij}(i = 1, \ldots, r, j = 1, \ldots, s)$ denote, respectively, the premise variables and the fuzzy sets. $x(t) \in \mathbb{R}^n$ is the state vector; $u(t) \in \mathbb{R}^m$ is the control input vector, $y(t) \in \mathbb{R}^p$ is the measured output, $z(t) \in \mathbb{R}^q$ is the controlled output, $w(t) \in \mathbb{R}^w$ and $\nu(t) \in \mathbb{R}^\nu$ are, respectively, the disturbance and noise inputs vectors belonging to $L_2[0, \infty)$, and r is the number of IF-THEN rules. $A_i(t) = A_i + \Delta A_i(t)$, and $B_i(t) = B_i + \Delta B_i(t)$ are the ith time-varying system matrices. A_i, B_i, B_{1i}, C_{1i}, C_{2i}, D_{1i} and D_{2i} are constant matrices with appropriate dimensions. We assume that matrix C_{2i} is row full rank and matrices $\Delta A_i(t)$ and $\Delta B_i(t)$ are norm-bounded uncertainties with the following form:

$$\Delta A_i(t) = D_{Ai}F(t)E_{Ai}, \quad \Delta B_i(t) = D_{Bi}F(t)E_{Bi},$$

where D_{Ai}, D_{Bi}, E_{Ai}, and E_{Bi} are constant known matrices of appropriate dimensions, and $F(t)$ is an unknown and possibly time-varying matrix satisfying $F^T(t)F(t) \leq I$ for any given t.

The resulting fuzzy system model is inferred as the weighted average of the local models of the form

$$\begin{cases} \dot{x}(t) = \sum_{i=1}^{r} h_i(\theta(t))\{A_i(t)x(t) + B_i(t)u(t) + B_{1i}w(t)\} \\ z(t) = \sum_{i=1}^{r} h_i(\theta(t))\{C_{1i}x(t) + D_{1i}w(t)\} \\ y(t) = \sum_{i=1}^{r} h_i(\theta(t))\{C_{2i}x(t) + D_{2i}\nu(t)\} \end{cases} \tag{1}$$

where

$$h_i(\theta(t)) = \frac{\upsilon_i(\theta(t))}{\sum_{i=1}^{r} \upsilon_i(\theta(t))}, \quad \upsilon_i(\theta(t)) = \prod_{j=1}^{s} F_{ij}(\theta_j) \tag{2}$$

$h_i(\theta(t))$ is the weighted average for each rule, representing the normalized membership grade, and satisfies

$$h_i(\theta(t)) \geq 0, \ \sum_{i=1}^{r} h_i(\theta(t)) = 1, \ t >= 0 \tag{3}$$

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