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Event-triggered Finite-time Extended Dissipative Control for a Class of Switched Nonlinear Systems via the T-S Fuzzy Model

Hui Gao, Hongbin Zhang*, and Jianwei Xia

Abstract: This paper foucuses on the study of finite-time extended dissipative control for a class of switched nonlinear systems. An event-triggered communication scheme is proposed to reduce the transmitted data of the system state. Sufficient conditions for finite-time extended dissipative control for the switched nonlinear systems are addressed, based on extended dissipative, we can solve the H_∞, $L_2 - L_\infty$, Passivity and (Q, S, R)-dissipativity performance at the same time. T-S fuzzy models are applied to represent the nonlinear subsystems. Linear matrix inequality techniques are used for the design of the fuzzy controller. Finally, numerical examples are presented.

Keywords: Event-trigger, extended dissipative, finite-time, T-S fuzzy.

1. INTRODUCTION

Switched system has attracted much attention in the past decades, which can be modeled by a class of discrete or continuous-time subsystems and a logical rule that orchestrates the switching among the subsystems. It has many practical applications, such as aircraft, traffic control, automotive industry and many other fields. Thus, many results on switched systems have been researched in [1–5].

In many practical systems, the existence of nonlinearity is inevitable. The Takagi-Sugeno (T-S) fuzzy model, which is well known that can effectively represent complex nonlinear systems approximately by fuzzy sets and fuzzy reasoning, also can be used to approximate switched nonlinear systems. As we all know, considerable research attention for fuzzy nonlinear systems focuses on Lyapunov asymptotic stability. However, in practice, the system behavior over a finite time interval is also of great importance, such as robot control systems, chemical processes and so on. Up to now, only few results about finite-time analysis of fuzzy nonlinear systems reported [6–11].

In general, the transmission of the state to the controller is usually continuous in time. However, in some cases, when the control objective is acheived, it is unnecessary to transmit the state every time when the system performance is maintained, which leads to the redundant transmission. To reduce the redundant data transmission, a so-called event-triggered scheme was proposed, which can reduce the transmission resource efficiently. The event-triggered scheme has many advantages, it transmits the state data only when necessary. Recently, much work has been done to the event-triggered analysis and control [12–17]. Specially, distributed event-triggered estimation over sensor networks is surveyed in [12], distributed secondary control for active power sharing and frequency regulation in islanded microgrids using an event-triggered communication mechanism is studied in [13]. Event-triggered generalized dissipativity filtering for neural networks is investigated in [14]. The authors in [16] provided an important insight that a felicitous event-driven scheme dealing with asynchronous filtering could save network communication resources with a satisfactory finite-time stability performance. Significant results concerning event-triggered observer design are achieved in [17], and then a resilient controller is constructed in the meaning of finite-time stability. However, only few results of event-triggered control foucuses on switched nonlinear systems, which motivates our research interest.

Up to now, many significant results on the system performance such as H_∞ performance, $L_2 - L_\infty$ performance, Passivity performance and (Q, S, R)-dissipativity performance. Recently, the concept of extended dissipative was proposed by Zhang in [18], which is a generalization of these performances. Through adjusting weighting matrices of extended dissipative, we can obtain the above mentioned performance, which provide a efficient method for system performance analysis. This performance index has

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Hui Gao and Hongbin Zhang are with the School of Information and Communication Engineering, University of Electronic Science and Technology of China, Chengdu, Sichuan 611731, P. R. China (e-mails: gaohui194011@sina.com, zhanghb@uestc.edu.cn). Jianwei Xia is with the School of Mathematics Science, Liaocheng University, Liaocheng 252000, P. R. China (e-mail: njustxjw@126.com).
* Corresponding author.

been adopted to neural networks and linear switched systems [18–27]. To the best of our knowledge, the analysis and the synthesis of extended dissipative has not been extended to nonlinear switched systems, which inspired our current research.

Based on the above discussions, the contributions are listed as follows: 1) a novel event-triggered scheme with merged switching signal of the system is proposed; 2) finite-time extended dissipative performance is firstly studied for switched nonlinear systems; 3) detailed procedures for solving controller gains are given.

This paper is organized as follows. In Section 2, system descriptions and preliminaries are formulated. In Section 3, sufficient conditions of finite-time extended dissipative performance for switched nonlinear systems are established. Furthermore, the design of the state feedback controllers are proposed. All the results are given in terms of LMIs. In Section 4, numerical examples are present. In Section 5, conclusion is given.

Notation: In this paper. M^T represents the transpose of the matrix M; $X>0$ denotes a positive-definite matrix. $\lambda_{min}(P)$, $\lambda_{max}(P)$ denote the minimum and maximum eigenvalue of matrix P respectively.

2. SYSTEM DESCRIPTIONS AND PRELIMINARIES

Consider the switched nonlinear systems

$$\begin{cases}\dot{x}(t)=f_{\sigma(t)}(x(t),u(t),w(t)),\\ y(t)=s_{\sigma(t)}(x(t)),\end{cases} \tag{1}$$

where $x(t)\in\mathbb{R}^{n_x}$, $u(t)\in\mathbb{R}^{n_u}$ and $y(t)\in\mathbb{R}^{n_y}$ are the state vector, input vector and output vector, respectively; $w(t)\in\mathbb{R}^{n_w}$ is the disturbance input and belongs to $L_2[0,\infty)$; $f_{\sigma(t)}$ and $s_{\sigma(t)}$ are nonlinear functions; $\sigma(t)$ is switching signal and takes value in the finite set $\mathcal{I}=\{1,2,\cdots,N\}$. When $\sigma(t)=i$, we say the ith subsystem is activated.

The fuzzy model of ith subsystem is described as follows:

Rule m: IF $z_{i1}(t)$ is N_{i1m} and $\cdots$ and $z_{ig}(t)$ is N_{igm}, THEN

$$\begin{cases}\dot{x}(t)=A_{im}x(t)+B_{im}u(t)+E_{im}w(t),\\ y(t)=C_{im}x(t),\end{cases}$$

where $z_i(t)=(z_{i1}(t),\ z_{i2}(t),\ \cdots,\ z_{ig}(t))$ are some measurable premise variables and N_{ipm} $(p=1,\ 2,\cdots,g)$ are fuzzy sets. A_{im}, B_{im}, E_{im} and C_{im} are real matrices of the mth local model of the ith subsystem.

Through using "fuzzy blending", the final output of the ith subsystem is inferred as follows:

$$\begin{cases}\dot{x}(t)=\sum_{m=1}^{r_i}h_{im}(z(t))[A_{im}x(t)+B_{im}u(t)+E_{im}w(t)],\\ y(t)=\sum_{m=1}^{r_i}h_{im}(z(t))C_{im}x(t),\end{cases} \tag{2}$$

and $h_{im}(z(t))=l_{im}/\sum_{m=1}^{r_i}l_{im}$, $l_{im}=\prod_{p=1}^{g}N_{ipm}(z_{ip}(t))$, in which $N_{ipm}(z_{ip}(t))$ is the grade of the membership function of z_{ip} in N_{ipm}. It is assumed that $l_{im}\geq 0$ for all t and $m=1,2,\cdots,r_i$. Therefore, the normalized membership function $h_{im}(z(t))$ satisfies $h_{im}(z(t))\geq 0$, $\sum_{m=1}^{r_i}h_{im}(z(t))=1$, $\forall t\in\mathbb{N}$.

Proposition 1: The external disturbance satisfies

$$\int_0^t w^T(s)w(s)ds\leq d,\ \ d\geq 0.$$

3. MAIN RESULTS

Given the event-triggered scheme:

$$t_{k+1}=min\{t'_{k+1},t_k+\tau_d\},\ \ t_0=0, \tag{3}$$

where $t'_{k+1}=min_{t>t_k}\{t\mid[x(t)-x(t_k)]^T\Phi_{\sigma(t_k)}[x(t)-x(t_k)]\geq x(t_k)^T\Psi_{\sigma(t_k)}x(t_k)\}$, t_k denotes the sampling instants for any integer $k\geq 0$. τ_d is the dwell time of the switched system.

We denote $e(t)=x(t)-x(t_k)$ and $\Omega_s=[t_k,t_{k+1})$, positive definite matrices $\Phi_{\sigma(t_k)}$ and $\Psi_{\sigma(t_k)}$ are event-triggered parameters. It should be noted that $\Phi_{\sigma(t_k)}$ and $\Psi_{\sigma(t_k)}$ could not be different too much and $t_{k+1}-t_k>0$.

We can deduce from (3) that $t_{k+1}-t_k\leq\tau_d$. Obviously, for any $t\in[t_k,t_{k+1})$, we have $[x(t)-x(t_k)]^T\Phi_{\sigma(t_k)}[x(t)-x(t_k)]<x(t_k)^T\Psi_{\sigma(t_k)}x(t_k)$.

We assume $\tau(t)=t-t_k, t\in[t_k,t_{k+1})$, then $\sigma(t_k)=\hat{\sigma}(t)=\sigma(t-\tau(t))$. Merging the switching signal $\sigma(t)$ with $\hat{\sigma}(t)$, we have $\delta(t)=(\sigma(t),\hat{\sigma}(t))$. By $\tau(t)\in[0,\tau_d)$ and $\hat{\sigma}(t)\in S[\tau_a,N_0+\frac{\tau_d}{\tau_a}]$ we can obtain the following Lemmas.

Lemma 1 [28]**:** Considering $\sigma(t)\in S[\tau_a,N_0]$, then $\delta(t)\in S[\frac{\tau_a}{2},2N_0+\frac{\tau_d}{\tau_a}]$.

Lemma 2 [28]**:** Assume $T_s(\tau,t)$ be the total synchronous time in time interval $[\tau,t)$ of $\sigma(t)$ and $\hat{\sigma}(t)$, and denote $T_{as}(\tau,t)=t-\tau-T_s(\tau,t)$ as total asynchronous time in $[\tau,t)$. Then, for positive constants λ_s,λ_μ and $\lambda\in(0,\lambda_s)$, if $(\lambda_s+\lambda_\mu)\tau_d\leq(\lambda_s-\lambda)\tau_a$, then $-\lambda_sT_s(\tau,t)+\lambda_uT_{as}(\tau,t)\leq(\lambda_s+\lambda_\mu)N_0\tau_d-\lambda(t-\tau)$.

Denote

$$u(t)=\sum_{n=1}^{r_i}h_{jn}(z(t))K_{jn}x(t_k),\ \ t\in\Omega_s, \tag{4}$$

where K_{jn} is the controller gain.

The closed-loop fuzzy system could be obtained as follows:

$$\begin{cases}\dot{x}(t)=A_{\delta(t)}(t)x(t)-B_{\delta(t)}(t)e(t)+E_{\sigma(t)}(t)w(t),\\ y(t)=C_{\sigma(t)}(t)x(t),\end{cases} \tag{5}$$

where

$$A_{\delta(t)}(t)=\sum_{m=1}^{r_i}h_{im}(z(t))\sum_{n=1}^{r_i}h_{jn}(z(t))(A_{im}+B_{im}K_{jn}),$$

$$B_{\delta(t)}(t) = \sum_{m=1}^{r_i} h_{im}(z(t)) \sum_{n=1}^{r_i} h_{jn}(z(t)) B_{im} K_{jn},$$

$$E_{\sigma(t)}(t) = \sum_{m=1}^{r_i} h_{im}(z(t)) E_{im},$$

$$C_{\sigma(t)}(t) = \sum_{m=1}^{r_i} h_{im}(z(t)) C_{im}.$$

Proposition 2 [18]**:** Matrices ψ_1, ψ_2, ψ_3, ψ_4 satisfy the following conditions:

(1) $\psi_1 = \psi_1^T \le 0$, $\psi_3 = \psi_3^T > 0$, $\psi_4 = \psi_4^T \ge 0$;

(2) $(\|\psi_1\| + \|\psi_2\|)\psi_4 = 0$.

Definition 1 [18]**:** Given matrices ψ_1, ψ_2, ψ_3 and ψ_4 satisfying Assumption 2, and for any $T_f \ge 0$ and all $w(t) \in L_2[0,\infty)$, system (5) is said to be extended dissipative if:

$$\int_0^{T_f} J(t)dt - \sup_{0 \le t \le T_f} y^T(t)\psi_4 y(t) \ge 0, \tag{6}$$

where

$$J(t) = y^T(t)\psi_1 y(t) + 2y^T(t)\psi_2 w(t) + w^T(t)\psi_3 w(t). \tag{7}$$

Remark 1: By setting the weighting matrices, we have

(1) $L_2 - L_\infty$ performance: $\psi_1 = 0$, $\psi_2 = 0$, $\psi_3 = \gamma^2 I$, $\psi_4 = I$;

(2) H_∞ performance: $\psi_1 = -I$, $\psi_2 = 0$, $\psi_3 = \gamma^2 I$, $\psi_4 = 0$;

(3) Passivity performance: $\psi_1 = 0$, $\psi_2 = I$, $\psi_3 = \gamma I$, $\psi_4 = 0$;

(4) (Q, S, R)-dissipativity performance: $\psi_1 = Q$, $\psi_2 = S$, $\psi_3 = R - \beta I$, $\psi_4 = 0$.

Definition 2: [1] Given positive constants c_1, c_2, T_f with $c_1 < c_2$, a positive definite matrix R and a switching signal $\sigma(t)$, $\forall t \in [0, T_f]$, switched system (5) is said to be finite-time bounded with respect to $(c_1, c_2, R, T_f, \sigma)$, if $\forall t \in [0, T_f]$,

$$\sup_{-\tau \le \theta \le 0} \{ x^T(\theta)Rx(\theta), \dot{x}^T(\theta)R\dot{x}(\theta)\} \le c_1$$
$$\Rightarrow x^T(t)Rx(t) \le c_2. \tag{8}$$

Definition 3 [1]**:** For any $T_2 > T_1 \ge 0$, let $N_\sigma(T_1, T_2)$ denotes the switching number of $\sigma(t)$ over (T_1, T_2). If

$$N_\sigma(T_1, T_2) \le N_0 + \frac{T_2 - T_1}{\tau_a} \tag{9}$$

holds for $\tau_a > 0$ and an integer $N_0 \ge 0$, then τ_a is called an average dwell-time. We choose $N_0 = 0$.

3.1. Finite-time boundedness and extended dissipative performance analysis

Theorem 1: If there exist positive scalars b, λ_s, λ_u and $\mu \ge 1$, positive definite matrices R, P_{ij}, Q_{ij}, Ψ_j, Φ_j, such that the following matrix inequalities hold for all $i, j \in \mathcal{I}$.

$$\mu^{-1} P_{ii} \le P_{ij} \le \mu P_{jj}, \quad P_{ii} \le \mu P_{jj}, \quad \forall i \ne j, \tag{10}$$

$$\frac{1}{b} P_{ij} - C_i^T(t)\psi_4 C_i(t) > 0, \tag{11}$$

$$\begin{bmatrix} \Theta_{11} & -P_{ij}B_{ij}(t) & P_{ij}E_i(t) & \Psi_j \\ * & -\Phi_j & 0 & -\Psi_j \\ * & * & -Q_{ij} & 0 \\ * & * & * & -\Psi_j \end{bmatrix} < 0, \tag{12}$$

$$\Theta_{11} = 2\lambda_{ij}P_{ij} + P_{ij}A_{ij}(t) + A_{ij}^T(t)P_{ij},$$

$$\begin{bmatrix} \Sigma_{11} & -P_{ij}B_{ij}(t) & P_{ij}E_i(t) - C_i^T(t)\psi_2 & \Psi_j \\ * & -\Phi_j & 0 & -\Psi_j \\ * & * & -\psi_3 & 0 \\ * & * & * & -\Psi_j \end{bmatrix} < 0, \tag{13}$$

$$\Sigma_{11} = 2\lambda_{ij}P_{ij} + P_{ij}A_{ij}(t) + A_{ij}^T(t)P_{ij} - C_i^T(t)\psi_1 C_i(t)$$

hold, the average dwell-time satisfies

$$\tau_a \ge \frac{ln(\mu) + \tau_d(\lambda_s + \lambda_u)}{\lambda_s}, \tag{14}$$

and

$$\mu^{2N_0 + \frac{\tau_d}{\tau_a}} e^{2(\lambda_s + \lambda_u)N_0\tau_d}(\lambda_2 c_1 + \lambda_3 d) < \lambda_1 c_2, \tag{15}$$

$$\mu^{2N_0 + \frac{\tau_d}{\tau_a}} e^{2(\lambda_s + \lambda_u)N_0\tau_d} < b, \tag{16}$$

we define

$$\lambda_{min}(R^{-\frac{1}{2}}P_{ij}R^{-\frac{1}{2}}) = \lambda_1, \lambda_{max}(R^{-\frac{1}{2}}P_{ij}R^{-\frac{1}{2}}) = \lambda_2,$$
$$\lambda_{max}(R^{-\frac{1}{2}}Q_{ij}R^{-\frac{1}{2}}) = \lambda_3. \tag{17}$$

Then, the switched system (5) is finite-time boundedness with extended dissipative performance.

Proof: Considering

$$V(t) = V_{\delta(t)}(t) = x^T(t)P_{\delta(t)}x(t). \tag{18}$$

Denote τ_k as the switching time of $\delta(t)$. Then from (10) we have

$$V_{\delta(\tau_k)}(\tau_k) \le \mu V_{\delta(\tau_k^-)}(\tau_k^-). \tag{19}$$

for $\forall t \in \Omega_s$, we have

$$\begin{aligned} &\dot{V}_{\delta(t)}(t) + 2\lambda_{\delta(t)}V_{\delta(t)}(t) - w^T(t)Q_{\delta(t)}w(t) \\ &= 2x^T(t)P_{\delta(t)}\dot{x}(t) + 2\lambda_{\delta(t)}x^T(t)P_{\delta(t)}x(t) \\ &\quad - w^T(t)Q_{\delta(t)}w(t) \le 2x^T(t)P_{\delta(t)}(A_{\delta(t)}(t)x(t) \\ &\quad - B_{\delta(t)}(t)e(t) + E_{\sigma(t)}(t)w(t)) + 2\lambda_{\delta(t)}x^T(t)P_{\delta(t)}x(t) \\ &\quad - w^T(t)Q_{\delta(t)}w(t) + [x(t) - e(t)]^T\Psi_{\hat{\sigma}(t)}[x(t) - e(t)] \end{aligned}$$

$$-e(t)^T\Phi_{\hat{\sigma}(t)}e(t) \le X^T(t)\Omega_{\delta(t)}X(t), \tag{20}$$

where

$$\lambda_{\delta(t)} = \begin{cases} \lambda_s, & t \in T_s(\Omega_s); \\ -\lambda_u, & t \in T_{as}(\Omega_s), \end{cases}$$
$$X(t) = \begin{bmatrix} x^T(t) & e^T(t) & w^T(t) \end{bmatrix}^T,$$

and

$$\Omega_{\delta(t)} = \begin{bmatrix} \Psi_{11} & -P_{\delta(t)}B_{\delta(t)}(t) & P_{\delta(t)}E_{\sigma(t)}(t) \\ * & -\Phi_{\hat{\sigma}(t)} & 0 \\ * & * & -Q_{\delta(t)} \end{bmatrix} + E^T\Psi_{\hat{\sigma}(t)}E,$$
$$\Psi_{11} = 2\lambda_{\delta(t)}P_{\delta(t)} + P_{\delta(t)}A_{\delta(t)}(t) + A^T_{\delta(t)}(t)P_{\delta(t)},$$
$$E = \begin{bmatrix} I & -I \end{bmatrix}.$$

Assume one switching in $[t_k, t_{k+1})$ for $\delta(t)$. And let $\sigma(\tau_k) = i$. When $t \in [t_k, \tau_k)$, we have $\delta(t) = (j, j)$, $\Omega_{\delta(t)} = \Omega_{jj}$; and if $t \in [\tau_k, t_{k+1})$, then $\delta(t) = (i, j)$, $\Omega_{\delta(t)} = \Omega_{ij}$.

Assume no switching in $[t_k, t_{k+1})$ for $\delta(t)$, then $\delta(t) = (j, j)$ in $t \in [t_k, t_{k+1})$ and $\Omega_{\delta(t)} = \Omega_{jj}$.

By Schur complement of (12), we have $\Omega_{\delta(t)} < 0$.

Thus, $\dot{V}_{\delta(t)}(t) + 2\lambda_{\delta(t)}V_{\delta(t)}(t) - w^T(t)Q_{\delta(t)}w(t) < 0$ holds.

Denote $\tau_1, \ldots, \tau_{N_\delta(0,t)}$ as the switching instants of $\delta(t)$ in $(0, t)$. We assume $\tau_1 > 0$ and $\tau_{N_\delta(0,t)} < t$. Then, from (19) and $\dot{V}_{\delta(t)}(t) + 2\lambda_{\delta(t)}V_{\delta(t)}(t) - w^T(t)Q_{\delta(t)}w(t) < 0$, we have

$$\begin{aligned}
V_{\delta(t)}(t) \le\; & e^{-2\lambda_{\delta(\tau_{N_\delta(0,t)})}(t-\tau_{N_\delta(0,t)})}V_{\delta(\tau_{N_\delta(0,t)})}(\tau_{N_\delta(0,t)}) \\
& + \int_{\tau_{N_\delta(0,t)}}^{t} e^{-2\lambda_{\delta(s)}(t-s)}w^T(s)Q_{\delta(s)}w(s)ds, \\
& \mu e^{-2\lambda_{\delta(\tau_{N_\delta(0,t)})}(t-\tau_{N_\delta(0,t)})} \\
& \times \Big[e^{-2\lambda_{\delta(\tau_{N_\delta(0,t)-1})}(\tau_{N_\delta(0,t)}-\tau_{N_\delta(0,t)-1})}V_{\delta(\tau_{N_\delta(0,t)-1})}(\tau_{N_\delta(0,t)-1}) \\
& + \int_{\tau_{N_\delta(0,t)-1}}^{\tau_{N_\delta(0,t)}} e^{-2\lambda_{\delta(s)}(\tau_{N_\delta(0,t)}-s)}w^T(s)Q_{\delta(s)}w(s)ds \Big] \\
& + \int_{\tau_{N_\delta(0,t)}}^{t} e^{-2\lambda_{\delta(s)}(t-s)}w^T(s)Q_{\delta(s)}w(s)ds \\
=\; & \mu e^{-2\lambda_{\delta(\tau_{N_\delta(0,t)})}(t-\tau_{N_\delta(0,t)})-2\lambda_{\delta(\tau_{N_\delta(0,t)-1})}(\tau_{N_\delta(0,t)}-\tau_{N_\delta(0,t)-1})} \\
& \times V_{\delta(\tau_{N_\delta(0,t)-1})}(\tau_{N_\delta(0,t)-1}) \\
& - \mu \int_{\tau_{N_\delta(0,t)-1}}^{\tau_{N_\delta(0,t)}} e^{-2\lambda_{\delta(\tau_{N_\delta(0,t)})}(t-\tau_{N_\delta(0,t)})-2\lambda_{\delta(s)}(\tau_{N_\delta(0,t)}-s)} \\
& \times w^T(s)Q_{\delta(s)}w(s)ds \\
& + \int_{\tau_{N_\delta(0,t)}}^{t} e^{-2\lambda_{\delta(s)}(t-s)}w^T(s)Q_{\delta(s)}w(s)ds.
\end{aligned}$$

We can obtain from the above calculation that

$$\begin{aligned}
V_{\delta(t)}(t) \le\; & \mu^{N_\delta(0,t)}e^{\varphi(0,t)}V_{\delta(0)}(0) \\
& + \int_0^t \mu^{N_\delta(s,t)}e^{\varphi(s,t)}w^T(s)Q_{\delta(s)}w(s)ds,
\end{aligned}$$

where $\varphi(s,t) = -2\lambda_s T_s(s,t) + 2\lambda_u T_{as}(s,t)$, $\tau_0 = 0$ and $\tau_{N_\delta(0,t)+1} = t$.

By Lemma 1, we have $N_\delta(0,t) \le 2N_0 + \frac{\tau_d}{\tau_a} + \frac{2t}{\tau_a}$.

For all $\lambda \in (\frac{ln\mu}{\tau_a}, \lambda_s - \frac{\tau_d}{\tau_a}(\lambda_s + \lambda_u)]$, $\lambda - \frac{ln\mu}{\tau_a} > 0$ and $(\lambda_s + \lambda_u)\tau_d \le (\lambda_s - \lambda)\tau_a$, by Lemma 2 we have $\varphi(s,t) \le 2(\lambda_s + \lambda_u)N_0\tau_d - 2\lambda(t-s)$.

Then we have

$$\begin{aligned}
V_{\delta(t)}(t) \le\; & \mu^{2N_0+\frac{\tau_d}{\tau_a}}e^{2(\lambda_s+\lambda_u)N_0\tau_d}e^{-2t(\lambda-\frac{ln\mu}{\tau_a})} \\
& \times (V_{\delta(0)}(0) + \int_0^t w^T(s)Q_{\delta(s)}w(s)ds) \\
\le\; & \mu^{2N_0+\frac{\tau_d}{\tau_a}}e^{2(\lambda_s+\lambda_u)N_0\tau_d}\Big(V_{\delta(0)}(0) \\
& + \int_0^t w^T(s)Q_{\delta(s)}w(s)ds\Big).
\end{aligned} \tag{21}$$

On the other hand,

$$\begin{aligned}
V_{\delta(0)}(0) =\; & x^T(0)P_{\delta(0)}x(0) \\
=\; & x^T(0)R^{\frac{1}{2}}(R^{-\frac{1}{2}}P_{\delta(0)}R^{-\frac{1}{2}})R^{\frac{1}{2}}x(0) \le \lambda_2 c_1.
\end{aligned} \tag{22}$$

For $\forall t \in \Omega_s$, we have

$$\begin{aligned}
V_{\delta(t)}(t) =\; & x^T(t)P_{\delta(t)}x(t) = x^T(t)R^{\frac{1}{2}}(R^{-\frac{1}{2}}P_{\delta(t)}R^{-\frac{1}{2}})R^{\frac{1}{2}}x(t) \\
\ge\; & \lambda_1 x^T(t)Rx(t).
\end{aligned} \tag{23}$$

From (21) (22) and (23) we have that

$$x^T(t)Rx(t) < \frac{\mu^{2N_0+\frac{\tau_d}{\tau_a}}e^{2(\lambda_s+\lambda_u)N_0\tau_d}(\lambda_2 c_1 + \lambda_3 d)}{\lambda_1}.$$

Using (15), one obtains

$$x^T(t)Rx(t) < c_2.$$

The proof is completed.

Next we prove extended dissipative performance. Similar to the above proof, we have

$$\dot{V}_{\delta(t)}(t) + 2\lambda_{\delta(t)}V_{\delta(t)}(t) - J(t) \le X^T(t)\Phi_{\delta(t)}X(t),$$

where

$$X(t) = \begin{bmatrix} x^T(t) & e^T(t) & w^T(t) \end{bmatrix}^T,$$

by virtue of (13) we have that

$$\dot{V}_{\delta(t)}(t) + 2\lambda_{\delta(t)}V_{\delta(t)}(t) - J(t) < 0.$$

Similar to above proof, we have

$$\begin{aligned}
V_{\delta(t)}(t) \le\; & \mu^{N_\delta(0,t)}e^{\varphi(0,t)}V_{\delta(0)}(0) \\
& + \int_0^t \mu^{N_\delta(s,t)}e^{\varphi(s,t)}J(s)ds,
\end{aligned}$$

under zero initial condition $V_{\delta(0)}(0)$, we have

$$V_{\delta(t)}(t) < \mu^{2N_0+\frac{\tau_d}{\tau_a}} e^{2(\lambda_s+\lambda_u)N_0\tau_d} \int_0^t J(s)ds,$$

and it is equivalent to

$$\frac{V_{\delta(t)}(t)}{\mu^{2N_0+\frac{\tau_d}{\tau_a}} e^{2(\lambda_s+\lambda_u)N_0\tau_d}} < \int_0^t J(s)ds,$$

by (16), we have

$$\frac{V_{\delta(t)}(t)}{b} < \int_0^t J(s)ds,$$

so we have

$$\int_0^t J(s)ds > \frac{V_{\delta(t)}(t)}{b} > \frac{1}{b}x^T(t)P_{\delta(t)}x(t) > 0,$$

considering inequality

$$\int_0^{T_f} J(t)dt - \sup_{0\le t\le T_f} y^T(t)\psi_4 y(t) \ge 0,$$

when $\psi_4 = 0$, one obtains

$$\int_0^{T_f} J(t)dt \ge 0,$$

when $\psi_4 > 0$, by Proposition 2 we have $\psi_1 = 0$, $\psi_2 = 0$, $\psi_3 > 0$, then we have

$$\int_0^t J(s)ds = \int_0^t w^T(s)\psi_3 w(s)ds,$$

thus, for $\forall t \in [0, T_f]$, we have

$$\int_0^{T_f} J(s)ds > \int_0^t J(s)ds \ge \frac{1}{b}x^T(t)P_{\delta(t)}x(t) > 0,$$

it follows from (11) that

$$\begin{aligned}\int_0^{T_f} J(s)ds &\ge \frac{1}{b}x^T(t)P_{\delta(t)}x(t)\\ &\ge x^T(t)C^T_{\sigma(t)}(t)\psi_4 C_{\sigma(t)}(t)x(t)\\ &= y^T(t)\psi_4 y(t),\end{aligned}$$

so we get

$$\int_0^{T_f} J(t)dt - \sup_{0\le t\le T_f} y^T(t)\psi_4 y(t) \ge 0.$$

The proof is completed. □

Remark 2: Through adopting the novel event-triggered method, we successfully address the extended dissipative analysis to switched nonlinear systems, which is the main contribution of this paper. Then we discussed finite-time boundedness, it should be noted that the extended dissipative performance and finite-time boundedness are satisfied simultaneously.

Theorem 2: If there exist positive scalars b, λ_s, λ_u and $\mu \ge 1$, positive definite matrices R, R_{ij}, Q_{ij}, Ψ_j, Φ_j, such that the following matrix inequalities hold for all $i, j \in \mathcal{I}$.

$$\begin{aligned}&\mu^{-1}R_{ii}^{-1} \le R_{ij}^{-1} \le \mu R_{jj}^{-1},\ \ R_{ii}^{-1} \le \mu R_{jj}^{-1},\ \ \forall i \ne j,\\ &\frac{1}{b}R_{ij}^{-1} - C_i^T(t)\psi_4 C_i(t) > 0,\\ &\begin{bmatrix} \Sigma_{11} & -B_{ij}(t)R_{ij} & E_i(t) & \hat{\Psi}_j\\ * & -\hat{\Phi}_j & 0 & -\hat{\Psi}_j\\ * & * & -Q_{ij} & 0\\ * & * & * & -\hat{\Psi}_j \end{bmatrix} < 0, \qquad (24)\\ &\Sigma_{11} = 2\lambda_{ij}R_{ij} + A_{ij}(t)R_{ij} + R_{ij}A_{ij}^T(t),\\ &\begin{bmatrix} \Omega_{11} & -B_{ij}(t)R_{ij} & \Omega_{13} & \hat{\Psi}_j & R_{ij}C_i^T(t)\\ * & -\hat{\Phi}_j & 0 & -\hat{\Psi}_j & 0\\ * & * & -\psi_3 & 0 & 0\\ * & * & * & -\hat{\Psi}_j & 0\\ * & * & * & * & \psi_1^{-1} \end{bmatrix} < 0, \qquad (25)\end{aligned}$$

$$\begin{aligned}&\Omega_{11} = 2\lambda_{ij}R_{ij} + A_{ij}(t)R_{ij} + R_{ij}A_{ij}^T(t),\\ &\Omega_{13} = E_i(t) - R_{ij}C_i^T(t)\psi_2\end{aligned}$$

hold, the average dwell-time satisfies

$$\tau_a \ge \frac{ln(\mu) + \tau_d(\lambda_s + \lambda_u)}{\lambda_s},$$

and

$$\mu^{2N_0+\frac{\tau_d}{\tau_a}} e^{2(\lambda_s+\lambda_u)N_0\tau_d}(\lambda_2 c_1 + \lambda_3 d) < \lambda_1 c_2,$$

we define

$$\begin{aligned}&P_{ij}^{-1} = R_{ij},\ \ \hat{\Phi}_j = R_{ij}\Phi_j R_{ij},\ \ \hat{\Psi}_j = R_{ij}\Psi_j R_{ij},\\ &K_{jn}R_{ij} = Y_{jn},\\ &\lambda_{min}(R^{-\frac{1}{2}}R_{ij}^{-1}R^{-\frac{1}{2}}) = \lambda_1, \lambda_{max}(R^{-\frac{1}{2}}R_{ij}^{-1}R^{-\frac{1}{2}}) = \lambda_2,\\ &\lambda_{max}(R^{-\frac{1}{2}}Q_{ij}R^{-\frac{1}{2}}) = \lambda_3.\end{aligned}$$

Then, the switched system (5) is finite-time boundedness with extended dissipative performance. The controller gains can be given by $K_{jn} = Y_{jn}R_{ij}^{-1}$.

Proof: Similar to the proof of Theorem 1, we have

$$\begin{aligned}&\dot{V}_{\delta(t)}(t) + 2\lambda_{\delta(t)}V_{\delta(t)}(t) - w^T(t)Q_{\delta(t)}w(t)\\ &\ \le X^T(t)\Omega_{\delta(t)}X(t).\end{aligned}$$

Pre- and post-multiplying (24) by $diag\{R_{ij}^{-1}, R_{ij}^{-1}, 0, R_{ij}^{-1}\}$, by Schur complement, we have $\Omega_{\delta(t)} < 0$, we can conclude that

$$\dot{V}_{\delta(t)}(t) + 2\lambda_{\delta(t)}V_{\delta(t)}(t) - w^T(t)Q_{\delta(t)}w(t) < 0.$$

Similarly,

$$\dot{V}_{\delta(t)}(t) + 2\lambda_{\delta(t)}V_{\delta(t)}(t) - J(t) \le X^T(t)\Phi_{\delta(t)}X(t).$$

Pre- and post-multiplying (25) by $diag\{R_{ij}^{-1}, R_{ij}^{-1}, 0, R_{ij}^{-1}\}$, by Schur complement, we have $\Phi_{\delta(t)} < 0$, we can conclude that

$$\dot{V}_{\delta(t)}(t) + 2\lambda_{\delta(t)} V_{\delta(t)}(t) - J(t) < 0.$$

The following proof is similar to that of Theorem 1, it is omitted here. □

Remark 3: By applying schur complement and some matrix transformation method. The desired controllers can be constructed by solving certain linear matrix inequalities (LMIs).

4. NUMERICAL EXAMPLE

Example: Consider the following switched nonlinear system with two subsystems.

Subsystem 1:

$$\begin{aligned}\dot{x}_1(t) &= 0.2x_1(t) + 0.1\sin(x_1(t))x_1(t) + 0.1x_2(t)\\ &\quad + 0.2\sin(x_1(t))x_2(t) + 0.1u_1(t) + 0.4u_2(t)\\ &\quad - 0.2\sin(x_1(t))u_2(t) + 0.3w_1(t)\\ &\quad - 0.4\sin(x_1(t))w_1(t) + 0.8\sin(x_1(t))w_2(t);\\ \dot{x}_2(t) &= 0.1x_1(t) + 0.3x_2(t) - 0.3\sin(x_1(t))x_2(t)\\ &\quad + 0.1u_1(t) - 0.1\sin(x_1(t))u_1(t) + 0.1u_2(t)\\ &\quad + 0.2\sin(x_1(t))u_2(t) + 0.2w_1(t)\\ &\quad - 0.2\sin(x_1(t))w_1(t) + 0.2w_2(t)\\ &\quad - 0.1\sin(x_1(t))w_2(t);\end{aligned}$$

Subsystem 2:

$$\begin{aligned}\dot{x}_1(t) &= 0.3x_1(t) - 0.1\cos(x_2(t))x_1(t) + 0.2x_2(t)\\ &\quad - 0.1\cos(x_2(t))x_2(t) + 0.1u_1(t) + 0.6u_2(t)\\ &\quad - 0.5\cos(x_2(t))u_2(t) + 0.2w_1(t)\\ &\quad - 0.3\cos(x_2(t))w_1(t) + 0.7\cos(x_2(t))w_2(t);\\ \dot{x}_2(t) &= 0.1x_1(t) + 0.1\cos(x_2(t))x_1(t) + 0.2x_2(t)\\ &\quad - 0.2\cos(x_2(t))x_2(t) + 0.8\cos(x_2(t))u_1(t)\\ &\quad + 0.2u_2(t) + 0.9w_1(t) - 0.9\cos(x_2(t))w_1(t)\\ &\quad + 0.2w_2(t);\end{aligned}$$

Let $x(t) = [x_1^T(t)x_2^T(t)]^T$, $u(t) = [u_1^T(t)u_2^T(t)]^T$, the T-S fuzzy model of switched nonlinear system (5) consisting of four local rules are formulated:

Subsystem 1:

Fuzzy Rule 1.

IF $\sin(x_1(t)) = 0$, THEN $\dot{x}(t) = A_{11}x(t) + B_{11}u(t) + E_{11}w(t)$;

Fuzzy Rule 2.

IF $\sin(x_1(t)) = 1$, THEN $\dot{x}(t) = A_{12}x(t) + B_{12}u(t) + E_{12}w(t)$;

Subsystem 2:

Fuzzy Rule 1.

IF $\cos(x_2(t)) = 0$, THEN $\dot{x}(t) = A_{21}x(t) + B_{21}u(t) + E_{21}w(t)$;

Fuzzy Rule 2.

IF $\cos(x_2(t)) = 1$, THEN $\dot{x}(t) = A_{22}x(t) + B_{22}u(t) + E_{22}w(t)$;

where

$$A_{11} = \begin{bmatrix} 0.2 & 0.1 \\ 0.1 & 0.3 \end{bmatrix}, \ B_{11} = \begin{bmatrix} 0.1 & 0.4 \\ 0.1 & 0.1 \end{bmatrix},$$
$$C_{11} = \begin{bmatrix} 0.3 & 0.1 \\ 0 & -0.1 \end{bmatrix}, \ E_{11} = \begin{bmatrix} 0.3 & 0 \\ 0.2 & 0.2 \end{bmatrix},$$
$$A_{12} = \begin{bmatrix} 0.3 & 0.3 \\ 0.1 & 0 \end{bmatrix}, \ B_{12} = \begin{bmatrix} 0.1 & 0.2 \\ 0 & 0.3 \end{bmatrix},$$
$$C_{12} = \begin{bmatrix} 0.4 & 0 \\ 0.6 & -0.2 \end{bmatrix}, \ E_{12} = \begin{bmatrix} -0.1 & 0.8 \\ 0 & 0.1 \end{bmatrix};$$
$$A_{21} = \begin{bmatrix} 0.3 & 0.2 \\ 0.1 & 0.2 \end{bmatrix}, \ B_{21} = \begin{bmatrix} 0.1 & 0.6 \\ 0 & 0.2 \end{bmatrix},$$
$$C_{21} = \begin{bmatrix} 0.2 & 0.5 \\ 0 & -0.2 \end{bmatrix}, \ E_{21} = \begin{bmatrix} 0.2 & 0 \\ 0.9 & 0.2 \end{bmatrix},$$
$$A_{22} = \begin{bmatrix} 0.2 & 0.1 \\ 0.2 & 0 \end{bmatrix}, \ B_{22} = \begin{bmatrix} 0.1 & 1 \\ 0.8 & 0.2 \end{bmatrix},$$
$$C_{22} = \begin{bmatrix} 0.4 & 0 \\ 0.2 & -0.1 \end{bmatrix}, \ E_{22} = \begin{bmatrix} -0.1 & 0.7 \\ 0 & 0.2 \end{bmatrix}.$$

The fuzzy membership functions are taken as

$$h_{11} = 1 - \sin(x_1(t)), \ \ h_{12} = \sin(x_1(t)),$$
$$h_{21} = 1 - \cos(x_2(t)), \ \ h_{22} = \cos(x_2(t)).$$

The initial condition is $x(0) = \begin{bmatrix} -0.2 & 0.2 \end{bmatrix}^T$, and $w(t) = \begin{bmatrix} e^{-t} * \sin^T(t) & e^{-t} * \cos^T(t) \end{bmatrix}^T$.

We choose $c_1 = 0.08$, $c_2 = 0.4$, $T_f = 8$, $\gamma = 0.6$, $R = I_{2\times 2}$, $\lambda_s = 0.1$, $\lambda_u = 0.1$.

H_∞ performance: As discussed in Remark 3, we set matrices $\psi_1 = -I$, $\psi_2 = 0$, $\psi_3 = \gamma^2 I$, $\psi_4 = 0$.

By solving the LMIs presented in Theorem 2, we can obtain the controller gains and event-triggered parameters listed in Tables 1 and 2, respectively.

$L_2 - L_\infty$ performance: As discussed in Remark 3, we set matrices $\psi_1 = 0$, $\psi_2 = 0$, $\psi_3 = \gamma^2 I$, $\psi_4 = I$.

By solving the LMIs presented in Theorem 2, we can obtain the controller gains and event-triggered parameters listed in Tables 1 and 2, respectively.

Passivity performance: As discussed in Remark 3, we set matrices $\psi_1 = 0$, $\psi_2 = I$, $\psi_3 = \gamma I$, $\psi_4 = 0$.

By solving the LMIs presented in Theorem 2, we can obtain the controller gains and event-triggered parameters listed in Tables 1 and 2, respectively.

(Q,S,R)-dissipativity performance: As discussed in Remark 3, we set matrices $\psi_1 = I$, $\psi_2 = I$, $\psi_3 = I - 0.4 * I$, $\psi_4 = 0$.

Table 1. Controller gains for each subsystem.

Subsystem 1
$K_{11} = \begin{bmatrix} -5.1898 & -9.5658 \\ -3.1638 & -4.5708 \end{bmatrix}$
$K_{12} = \begin{bmatrix} -5.1898 & -9.5658 \\ -3.1638 & -4.5708 \end{bmatrix}$
Subsystem 2
$K_{21} = \begin{bmatrix} -6.9115 & -21.7918 \\ -1.7344 & -4.6505 \end{bmatrix}$
$K_{22} = \begin{bmatrix} -6.9115 & -21.7918 \\ -1.7344 & -4.6505 \end{bmatrix}$

Table 2. Event-triggered parameters for each subsystem.

Subsystem 1
$\Phi_1 = \begin{bmatrix} 20.3190 & -3.4779 \\ -3.4779 & 14.9973 \end{bmatrix}$
$\Psi_1 = \begin{bmatrix} 0.1119 & 0.1854 \\ 0.1854 & 0.3088 \end{bmatrix}$
Subsystem 2
$\Phi_2 = \begin{bmatrix} 31.7157 & -38.7129 \\ -38.7129 & 47.2604 \end{bmatrix}$
$\Psi_2 = \begin{bmatrix} 0.8378 & -1.0075 \\ -1.0075 & 1.2116 \end{bmatrix}$

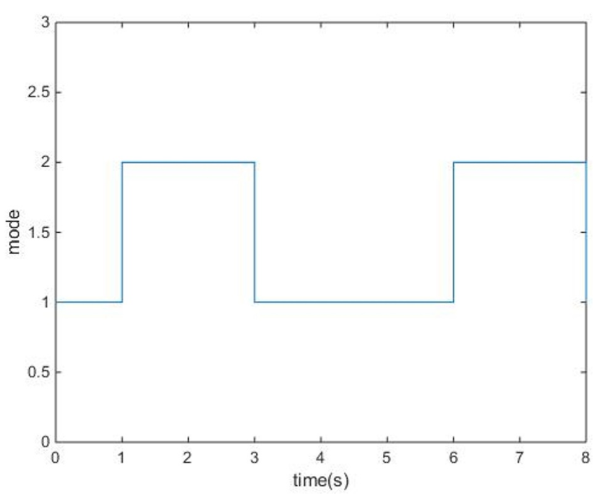


Fig. 1. The switching signal of the system.

From Fig. 1, we can see that the switching signal of the system is time dependent and without Zeno behavior.

By solving the LMIs presented in Theorem 2, we can obtain the controller gains and event-triggered parameters listed in Tables 1 and 2, respectively.

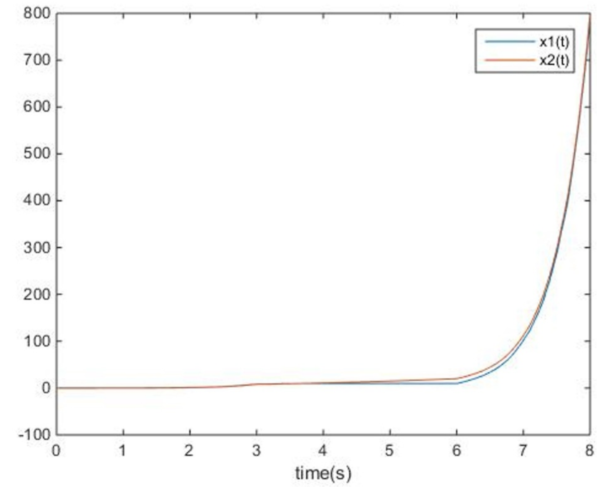


Fig. 2. The state trajectory without control.

Table 3. Controller gains for each subsystem.

Subsystem 1	$K_{11} = \begin{bmatrix} -5.3847 & -9.9341 \\ -3.2021 & -4.6720 \end{bmatrix}$, $K_{12} = \begin{bmatrix} -5.3847 & -9.9341 \\ -3.2021 & -4.6720 \end{bmatrix}$
Subsystem 2	$K_{21} = \begin{bmatrix} -6.9856 & -22.1511 \\ -1.7286 & -4.6554 \end{bmatrix}$, $K_{22} = \begin{bmatrix} -6.9856 & -22.1511 \\ -1.7286 & -4.6554 \end{bmatrix}$

Table 4. Event-triggered parameters for each subsystem.

Subsystem 1	$\Phi_1 = \begin{bmatrix} 0.6022 & 1.0650 \\ 1.0650 & 1.9605 \end{bmatrix}$, $\Psi_1 = \begin{bmatrix} 0.1224 & 0.2045 \\ 0.2045 & 0.3433 \end{bmatrix}$
Subsystem 2	$\Phi_2 = \begin{bmatrix} 0.5566 & 1.7997 \\ 1.7997 & 5.8850 \end{bmatrix}$, $\Psi_2 = \begin{bmatrix} 0.0380 & 0.1162 \\ 0.1162 & 0.3556 \end{bmatrix}$

From Fig. 2, we can see that the state trajectory without control is diverge, it is not asymptotically stability.

Tables 3-8 shows the controller gains and event-triggered parameters for each subsystem.

From Fig. 3, one can see that when the initial condition $x^T(0)Rx(0) \le 0.08$, the trajectory satisfies $x^T(t)Rx(t) \le 0.4$ during the time interval, then system is finite time bounded. Fig. 4 shows that the transmission of the state information is reduced effectively. Take H_∞ performance for example, Fig. 5 shows the relation of $z(t)$ and $w(t)$.

Table 5. Controller gains for each subsystem.

Subsystem 1	$K_{11} = \begin{bmatrix} -5.3847 & -9.9341 \\ -3.2021 & -4.6720 \end{bmatrix}$, $K_{12} = \begin{bmatrix} -5.3847 & -9.9341 \\ -3.2021 & -4.6720 \end{bmatrix}$
Subsystem 2	$K_{21} = \begin{bmatrix} -6.9856 & -22.1511 \\ -1.7286 & -4.6554 \end{bmatrix}$, $K_{22} = \begin{bmatrix} -6.9856 & -22.1511 \\ -1.7286 & -4.6554 \end{bmatrix}$

Table 6. Event-triggered parameters for each subsystem.

Subsystem 1	$\Phi_1 = \begin{bmatrix} 0.6022 & 1.0650 \\ 1.0650 & 1.9605 \end{bmatrix}$, $\Psi_1 = \begin{bmatrix} 0.1224 & 0.2045 \\ 0.2045 & 0.3433 \end{bmatrix}$
Subsystem 2	$\Phi_2 = \begin{bmatrix} 0.5566 & 1.7997 \\ 1.7997 & 5.8850 \end{bmatrix}$, $\Psi_2 = \begin{bmatrix} 0.0380 & 0.1162 \\ 0.1162 & 0.3556 \end{bmatrix}$

Table 7. Controller gains for each subsystem.

Subsystem 1	$K_{11} = \begin{bmatrix} -5.1898 & -9.5658 \\ -3.1638 & -4.5708 \end{bmatrix}$, $K_{12} = \begin{bmatrix} -5.1898 & -9.5658 \\ -3.1638 & -4.5708 \end{bmatrix}$
Subsystem 2	$K_{21} = \begin{bmatrix} -6.9115 & -21.7918 \\ -1.7344 & -4.6505 \end{bmatrix}$, $K_{22} = \begin{bmatrix} -6.9115 & -21.7918 \\ -1.7344 & -4.6505 \end{bmatrix}$

Table 8. Event-triggered parameters for each subsystem.

Subsystem 1	$\Phi_1 = \begin{bmatrix} 0.5721 & 0.9998 \\ 0.9998 & 1.8150 \end{bmatrix}$, $\Psi_1 = \begin{bmatrix} 0.1119 & 0.1854 \\ 0.1854 & 0.3088 \end{bmatrix}$
Subsystem 2	$\Phi_2 = \begin{bmatrix} 0.6169 & 1.9838 \\ 1.9838 & 6.4557 \end{bmatrix}$, $\Psi_2 = \begin{bmatrix} 0.0427 & 0.1295 \\ 0.1295 & 0.3937 \end{bmatrix}$

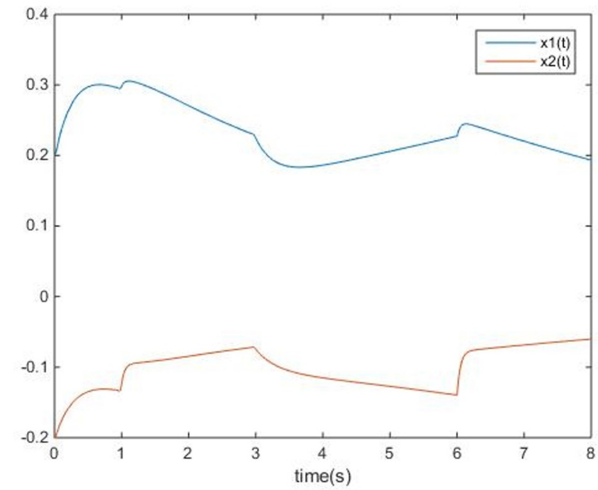


Fig. 3. The state trajectory under event triggered H_∞ control.

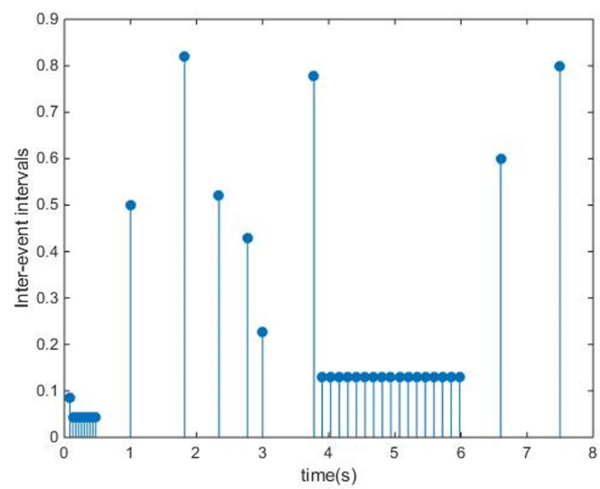


Fig. 4. Event triggered transmission interval.

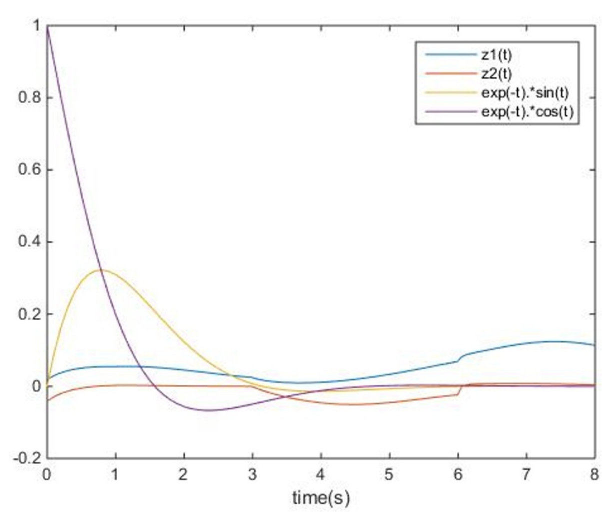


Fig. 5. Simulation of z(t) and w(t).

5. CONCLUSION

In this paper, the problem of finite time extended dissipative control for switched nonlinear system is investigated . An event triggered scheme is introduced to save the transmission resource. We can solve the H_∞, $L_2 - L_\infty$, Passivity and (Q, S, R)-dissipativity performance in a unified framework based on extended dissipative. LMIs are used to obtain the results, we give numerical examples to show the effectiveness of the method. This paper considers switched nonlinear systems, the proposed method could extended to repetitive control systems in the future research.

REFERENCES

[1] S. Wang, T. G. Shi, L. X. Zhang, A. Jasra, and M. Zeng, "Extended finite-time H_∞ control for uncertain switched linear neutral systems with time-varying delays," *Neurocomputing*, vol. 152, pp. 377-387, 2015.

[2] X. D. Zhao, P. Shi, and L. X. Zhang, "Asynchronously switched control of a class of slowly switched linear systems," *System and Control Letters*, vol. 61, pp. 1151-1156, 2012.

[3] L. X. Zhang, S. Zhuang, and R. D. Braatz, "Switched model predictive control of switched linear systems: Feasibility, stability and robustness," *Automatica*, vol. 67, pp. 8-21, 2016.

[4] X. D. Zhao, X. W. Liu, S. Yin, and H. Y. Li, "Improved results on stability of continuous-time switched positive linear systems," *Automatica*, vol. 50, pp. 614-621, 2014.

[5] Y. Wang, J. Zhao, and B. Jiang, "Stabilization of a class of switched linear neutral systems under asynchronous switching," *IEEE Trans. on Automatic Control*, vol. 58, no. 8, pp. 2114-2119, 2013.

[6] X. Q. Huang, W. Lin, and B. Yang, "Global finite-time stabilization of a class of uncertain nonlinear systems," *Automatica*, vol. 41, pp. 881-888, 2005.

[7] Y. J. Shen and Y. H. Huang, "Global finite-time stabilisation for a class of nonlinear systems," *Int. J. Syst. Sci*, vol. 43, pp. 73-78, 2012.

[8] Y. G. Hong and Z. P. Jiang, "Finite-time stabilization of nonlinear systems with parametric and dynamic uncertainty," *IEEE Trans. Autom. Control*, vol. 12, pp. 1950-1956, 2006.

[9] J. Wu, W. S. Chen, and J. Li, "Global finite-time adaptive stabilization for nonlinear systems with multiple unknown control directions," *Automatica*, vol. 69, pp. 298-307, 2016.

[10] Y. M. Sun, B. Chen, C. Lin, and H. H. Wang, "Finite-time adaptive control for a class of nonlinear systems with nonstrict feedback structure," *IEEE Trans. Cybern*, vol. 48, no. 10, pp. 2774-2782, 2017.

[11] J. Cheng, J. H. Park, Y. J. Liu, Z. J. Liu, and L. M. Tang, "Finite-time H_∞ fuzzy control of nonlinear Markovian jump delayed systems with partly uncertain transition descriptions," *Fuzzy Sets and Systems*, vol. 314, pp. 99-115, 2017.

[12] X. H. Ge, Q. L. Han, X. M. Zhang, L. Ding, and F. W. Yang, "Distributed event-triggered estimation over sensor networks: a survey," *IEEE Trans. Cybern.*, vol. 50, no. 3, pp. 1306-1320, 2020.

[13] L. Ding, Q. L. Han, and X. M. Zhang, "Distributed secondary control for active power sharing and frequency regulation in islanded microgrids using an event-triggered communication mechanism," *IEEE Trans. Ind. Informat*, vol. 15, no. 7, July 2019.

[14] J. Wang, X. M. Zhang, and Q. L. Han, "Event-triggered generalized dissipativity filtering for neural networks with time-varying delays," *IEEE Trans. Neural Netw. Learning SystI*, vol. 27, no. 1, January 2016.

[15] H. L. Ren, G. D. Zong, and T. S. Li, "Event-triggered finite-time control for networked switched linear systems with asynchronous switching," *IEEE Trans. Syst., Man, Cybern*, vol. 48, no. 11, pp. 1874-1884, 2018.

[16] H. L. Ren, G. D. Zong, and H. R. Karimi, "Asynchronous finite-time filtering of networked switched systems and its application: an event-driven method," *IEEE Trans. Circuits Syst. I Reg. Pap.*, vol. 66, no. 1, pp. 391-402, 2019.

[17] H. L. Ren, G. D. Zong, and C. K. Ahn, "Event-triggered finite-time resilient control for networked switched systems: an observer-based approach and its applications in a boost converter circuit system model," *Nonlinear Dynamics*, vol. 94, no. 4, pp. 2409-2421, 2018.

[18] B. Y. Zhang, W. X. Zheng, and S. Y. Xu, "Filtering of Markovian jump delay systems based on a new performance index," *IEEE Trans.Circuits Syst.I Reg.Pap*, vol. 60, pp. 1250-1263, 2013.

[19] J. Y. Xiao, Y. T. Li, S. M. Zhong, and F. Xu, "Extended dissipative state estimation for memristive neural networks with time-varying delay," *ISA Transactions*, vol. 64, pp. 113-128, 2016.

[20] H. L. Yang, L. Shu, S. M. Zhong, and X. Wang, "Extended dissipative exponential synchronization of complex dynamical systems with coupling delay and sampled-data control," *Journal of the Franklin Institute*, vol. 353, pp. 1829-1847, 2016.

[21] H. Z. Wei, R. X. Li, C. R. Chen, and Z. W. Tu, "Extended dissipative analysis for memristive neural networks with two additive time-varying delay components," *Neurocomputing*, vol. 216, pp. 429-438, 2016.

[22] H. Shen, Y. Z. Zhu, L. X. Zhang, and J. H. Park, "Extended dissipative state estimation for Markov jump neural networks with unreliable links," *IEEE Trans. Neural Netw. Learning Syst*, vol. 28, pp. 346-358, 2017.

[23] T. H. Lee, M. J. Park, J. H. Park, and O. M. Kwon, "Extended dissipative analysis for neural networks with time-varying delays," *IEEE Trans. Neural Netw. Learn. Syst.*, vol. 25, no. 10, pp. 1936-1941, 2014.

[24] H. Gao, J. W. Xia, G. M. Zhuang, Z. Wang, and Q. Sun, "Nonfragile finite-time extended dissipative control for a class of uncertain switched neutral systems," *Complexity*, Article ID 6581308, 22 pages. 2018.

[25] J. W. Xia, H. Gao, M. X. Liu, G. M. Zhuang, and B. Y. Zhang, "Non-fragile finite-time extended dissipative control for a class of uncertain discrete time switched linear systems," *Journal of the Franklin Institute*, vol. 355, pp. 3031-3049, 2018.

[26] H. Gao, J. W. Xia, and G. M. Zhuang, "Robust finite-time extended dissipative control for a class of uncertain switched delay systems," *International Journal of Control, Automation and Systems*, vol. 16, pp. 1459-1468, 2018.

[27] H. Gao, H. B. Zhang, D. H. Zheng, L. L. Zhang, and Y. Li, "Finite-time event-triggered extended dissipative control for discrete time switched linear systems," *International Journal of General Systems*, vol. 48, no. 5, pp. 476-491, 2019.

[28] X. Xiao, L. Zhou, and G. Lu, "Event-triggered H_∞ filtering of continuous time switched linear systems," *Signal Processing*, vol. 141, pp. 343-349, 2017.

[29] X. Q. Xiao, J. H. Park, and L. Zhou, "Event-triggered H_∞ filtering of discrete-time switched linear systems," *ISA Transactions*, vol. 77, pp. 112-121, 2018.

[30] Z. Xiang, Y. Sun, and M. S. Mahmoud, "Robust finite-time H_∞ control for a class of uncertain switched neutral systems," *Commun. Nonlinear Sci. Numer. Simul.*, vol. 17, no. 4, pp. 1766-1778, 2012.

[31] D. Yang, G. D. Zong, and H. R. Karimi, "H_∞ refined anti-disturbance control of switched LPV systems with application to aero-engine," *IEEE Trans. Ind. Electron*, vol. 67, no. 4, pp. 3180-3190, 2020.

[32] D. Yang, G. D. Zong, and S. K. Nguang, "H_∞ bumpless transfer reliable control of Markovian switching LPV systems subject to actuator failures," *Information Sciences*, vol. 512, pp. 431-445, 2020.

[33] X. H. Chang and G. H. Yang, "Nonfragile H_∞ filtering of continuous-time fuzzy systems," *IEEE Trans. Signal Process*, vol. 59, no. 4, pp. 1528-1538, 2011.

[34] X. H. Chang, "Robust nonfragile H_∞ filtering of fuzzy systems with linear fractional parametric uncertainties," *IEEE Trans. Fuzzy Syst*, vol. 20, no. 6, pp. 1001-1011, 2012.

[35] X. H. Chang and G. H. Yang, "Nonfragile H_∞ filter design for T-S fuzzy systems in standard form," *IEEE Trans. Ind. Electron*, vol. 61, no. 7, pp. 3448-3458, 2014.

[36] X. Li, B. Zhang, P. Li, Q. Zhou, and R. Lu, "Finite-horizon H_∞ state estimation for periodic neural networks over fading channels," *IEEE Trans. Neural Netw. Learning Syst*, vol. 31, no. 5, pp. 1450-1460, 2020.

[37] X. Li, Q. Zhou, P. Li, H. Li, and R. Lu, "Event-triggered consensus control for multi-agent systems against false data injection attacks," *IEEE Trans. on Cybernetics*, vol. 50, no. 5, pp. 1856-1866, 2020.

[38] L. Cao, H. Li, G. Dong, and R. Lu, "Event-triggered control for multi-agent systems with sensor faults and input saturation," *IEEE Trans. Syst., Man, Cybern*, 2019. DOI: 10.1109/TSMC.2019.2938216

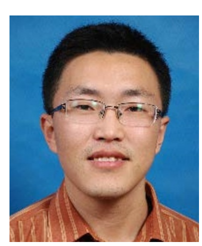
[39] L. Zhou, J. H She, and S. W. Zhou, "Robust H_∞ control of an observer-based repetitive-control system," *Journal of the Franklin Institute*, vol. 355, pp. 4952-4969, 2018.

[40] J. W. Xia, J. Zhang, W. Sun, B. Y. Zhang, and Z. Wang, "Finite-time adaptive fuzzy control for nonlinear systems with full state constraints," *IEEE Trans. Syst., Man, Cybern*, vol. 49, no. 7, pp. 1541-1548, 2019.

[41] J. W. Xia, J. Zhang, J. E. Feng, Z. Wang, and G. M. Zhuang, "Command filter-based adaptive fuzzy control for nonlinear systems with unknown control directions," *IEEE Trans. Syst., Man, Cybern*, 2019. DOI: 10.1109/TSMC.2019.2911115

Hui Gao received his B.E. degree from the University of Jinan, Jinan, China, in 2015, and an M.S. degree in system science from Liaocheng University, Liaocheng, China, in 2018. He is currently working towards a Ph.D. degree in circuits and systems at the University of Electronic Science and Technology of China, Chengdu. His current research interests include switched systems, robust control and event-triggered control.

Hongbin Zhang received his B.Eng. degree in aerocraft design from Northwestern Polytechnical University, Xian, China, in 1999, and his M.Eng. and Ph.D. degrees in circuits and systems from the University of Electronic Science and Technology of China, Chengdu, in 2002 and 2006, respectively. He has been with the School of Electrical Engineering, University of Electronic Science and Technology of China, since 2002, where he is currently a professor. From August 2008 to August 2010, he has served as a research fellow with the Department of Manufacturing Engineering and Engineering Management, City University of Hong Kong, Kowloon, Hong Kong. His current research interests include intelligent control, autonomous cooperative control and integrated navigation.



Jianwei Xia received his M.S. degree in automatic engineering from Qufu Normal University, Qufu, China, in 2004, and a Ph.D. degree in automatic control from the Nanjing University of Science and Technology, Nanjing, China, in 2007. He is a Professor with the School of Mathematics Science, Liaocheng University, Liaocheng, China. From 2010 to 2012, he was a Postdoctoral Research Associate with the School of Automation, Southeast University, Nanjing. From 2013 to 2014, he was a Postdoctoral Research Associate with the Department of Electrical Engineering, Yeungnam University, Gyeongsan, South Korea. His current research interests include nonlinear system control, robust control, stochastic systems, and neural networks.etc.