Mathematics

Research article

Master-slave synchronization of Lurie systems with time-delay based on event-triggered control

Chao Ma, Tianbo Wang * **and Wenjie You**

School of Mathematics, Physics and Statistics, Shanghai University of Engineering Science, Shanghai 201620, China

* **Correspondence:** Email: tb_wang@163.com.

Abstract: This paper investigates the master-slave synchronization of Lurie systems with time delay via the event-triggered control. Different from some state feedback control methods with a fixed sampling period or impulsive control with random sampling moments, the event-triggered control means that the controller is updated only if some event-triggering conditions are satisfied. A predefined triggering condition is provided by using the Lyapunov stability theory. Moreover, this condition is proved not to be commonplace. Finally, a numerical example is given to show the correctness of the proposed method.

Keywords: Master-slave synchronization; event-triggered control; Lurie system; time delay
Mathematics Subject Classification: 34D20

1. Introduction

It is known to all that Lurie systems consist of a linear dynamical system and a nonlinear part with the sector bounded constrains, which can be used to model many nonlinear dynamical systems such as Chua's circuit [1], Hopfield neural networks [2], cellular neural networks [3] and hyperchaotic attractors [4], and so on. Thus, the Lurie systems have attracted much attention of researchers in the field of physical and natural science. For example, by using an extended integral inequality, the convex combination theorem and S-procedure, Tang et al. investigated the cluster synchronization of complex dynamical networks consisting of identical or nonidentical Lurie systems and designed some adaptive updating laws in [5]. Qin et al. investigated the problem of the global exponential stability of a class of uncertain neural networks with discontinuous Lurie-type activation and mixed delays and presented some stability conditions by using the Leray-Schauder alternative theorem in [6].

In recent years, master-slave synchronization has attracted some researchers attention for its broad applications and there exist lots of literatures such as [7–14]. Master-slave synchronization means that

the state of master system follows with the state of slave system along with the time development. In some practical plants, because the state of the master systems can not be measured directly for technical limitations or too cost, we can use its measurement output to design a slave system that the structure is same with the master system. So, one can use the state of slave system to replace the state of master system. Viewed from the used methods of solving this problem, there include adaptive control [7], PID control [9], output feedback control [10], impulsive control [11, 12], and so on. There exist many work to study the master-slave synchronization of the Lurie systems so far. For example, Chen et al. investigated the master-slave synchronization of chaotic Lurie systems with sampled-data control based on a novel construction of piecewise differentiable Lyapunov functionals in [15]. By using the Lyapunov stability theory, Ji et al. considered the synchronization problem for Lurie systems with sector and slope restricted nonlinearities in [16]. For the master-slave Lurie systems with constant time delay, Guo et al. presented some synchronization criteria and designed a PD controller by using the integral inequality method in [17].

In addition, event-triggered control, as one of the effective control methods, has been deeply studied. Event-triggered controller is updated only if some predefined triggering criteria are activated. Compared with the time-triggered controller, the event-triggered controller can reduce the number of the sampling and decrease the computation complexity. Some related works can be found in [18–26]. For instance, Su et al. studied the problem of sliding mode control for discrete-time switched systems via an event-triggered strategy by using a time-delay system design method in [18]. By using the multiple Lyapunov functional method, Xiao et al. considered the event-triggered control problem for continuous-time switched linear systems in [19]. Liu et al. discussed the event-triggered synchronization in fixed time for semi-Markov switching dynamical complex networks with multiple weights and discontinuous nonlinearity by applying Lyapunov functional method and inequality analysis technique in [21]. In [22], Wang et al. investigated the Lyapunov stability for general nonlinear systems by means of the event-triggered impulsive control by using the impulsive control theory.

Motivated by the above discussion, in this paper, we intend to investigate the master-slave synchronization of Lurie systems based on the event-triggered control. The main contributions are as follows: (1) The considered master-slave systems are the Lurie systems, and the related results by using the event-triggered control are less. (2) Provide a predefined event-triggering condition and prove that this condition is not commonplace. (3) Some synchronization control criteria are presented. Moreover, the control gains can be easily found in terms of linear matrix inequalities.

The rest of this paper is organized as follows. In section 2, model description and preliminary results are presented. In section 3, The event-triggered conditions and feasibility are derived. In section 4, a numerical example is provided to illustrate the effectiveness of the obtained method. Finally, this paper is ended with a conclusion in section 5.

Throughout this paper, the following notations are used. R^n and $R^{n \times m}$, respectively, denote the n-dimensional Euclidean space and the set of $n \times m$ real matrices. For a n-dimensional vector $x = (x_1, x_2, ..., x_n)^T \in R^n$, $\|x\| = \sqrt{\sum_{i=1}^{n} x_i^2}$ denotes its norms. The notation $X \geq Y$(respectively, $X > Y$), where X, Y are symmetric matrices, means that $X - Y$ is a symmetric semi-definite matrix(respectively, positive definite matrix). For a given matrix $A \in R^{n \times n}$, A^T denotes its transpose. $\lambda_{max}(A)$ and $\lambda_{min}(A)$ denote its maximum and minimum eigenvalues, respectively, whose norm is defined as $\|A\| = \sqrt{\lambda_{max}(A^T A)}$.

2. Problem formulation

In this paper, we consider the following master-slave systems composed of Lurie systems

$$Master : \begin{cases} \dot{x}(t) = Ax(t) + Bx(t - \tau) + C\sigma(Dx(t)) \\ x(t) = \varphi(t), t \in [0, \tau] \end{cases} \tag{2.1}$$

and

$$Slave : \begin{cases} \dot{\hat{x}}(t) = A\hat{x}(t) + B\hat{x}(t - \tau) + C\sigma(D\hat{x}(t)) + u(t) \\ \hat{x}(t) = \psi(t), t \in [0, \tau], \end{cases} \tag{2.2}$$

where $x(t) = (x_1(t), x_2(t), ..., x_n(t))^T$ and $\hat{x}(t) = (\hat{x}_1(t), \hat{x}_2(t), ..., \hat{x}_n(t))^T$ denote the state vectors, respectively. $A \in R^{n \times n}$, $B \in R^{n \times n}$, $C \in R^{n \times m}$, $D \in R^{m \times n}$ are some known constant real matrices. $\sigma(\cdot) = (\sigma_1(\cdot), \sigma_2(\cdot), ..., \sigma_m(\cdot))^T : R^m \to R^m$ is a nonlinear function. The initial conditions $\varphi(t) \in R^n$ and $\psi(t) \in R^n$ are continuous functions. $u(t) \in R^n$ is the control input to be designed. $\tau > 0$ is a known constant and denotes the transmission time delay.

Definition 1. Master system (2.1) and slave system (2.2) are said to be asymptotic synchronization if

$$lim_{t \to \infty} \|x(t) - \hat{x}(t)\| = 0$$

for any initial conditions.

In what follows, we intend to design the following state feedback controller

$$u(t) = K(x(t_k) - \hat{x}(t_k)), \ \forall t \in [t_k, t_{k+1}), \tag{2.3}$$

such that master system (2.1) synchronizes with slave system (2.2), where $K \in R^{n \times n}$ is the control gain to be determined, $t_0, t_1, \cdots, t_k, \cdots$ are the sampling time and $lim_{k \to +\infty} t_k = +\infty$. From which we know that the control signal holds constant by a zero-order hold (ZOH) until the next sampling time. This kind of control scheme is usually called event-triggered control. Different with some common state feedback controller, which needs not be updated at each sampling instant.

Remark 1. Event-triggered controller (2.3) is a ZOH and does not compute and transmit the control information at each sampling instant, which can reduce the computation complexity and decrease the burden of transmission data.

Let $z(t) = x(t) - \hat{x}(t)$ and $e(t) = z(t) - z(t_k)$, then one gets the error system

$$\begin{aligned} \dot{z}(t) &= Az(t) + Bz(t - \tau) + Ch(z(t)) - Kz(t_k) \\ &= (A - K)z(t) + Bz(t - \tau) + Ch(z(t)) + Ke(t), \ t \in [t_k, t_{k+1}), \end{aligned} \tag{2.4}$$

where $h(z(t)) = \sigma(Dx(t)) - \sigma(D\hat{x}(t))$ and $h_i(z(t)) = \sigma_i(d_i^T x(t)) - \sigma_i(d_i^T \hat{x}(t))$, d_i^T is the ith row of matrix D.

In order to establish our main results, the following assumptions and lemmas are necessary.

Assumption 1. Assume that each component of the nonlinear function $\sigma(\cdot)$ belongs to the sector bound $[0, \eta]$, i. e.,

$$0 \le \frac{\sigma_i(\xi_1) - \sigma_i(\xi_2)}{\xi_1 - \xi_2} \le \eta, \ \forall i = 1, 2, ..., m,$$

for any $\xi_1, \xi_2 \in R$, where $\eta > 0$ is a known positive constant. In fact, this condition is similar to literature [26].

From Assumption 1, one gets

$$
\begin{aligned}
\|\sigma(Dx(t)) - \sigma(D\hat{x}(t))\|^2 &= \sum_{i=1}^{m} |\sigma_i(d_i^T x(t)) - \sigma_i(d_i^T \hat{x}(t))|^2 \\
&\leq \sum_{i=1}^{m} \eta^2 |d_i^T x(t) - d_i^T \hat{x}(t)|^2 \\
&\leq \eta^2 \sum_{i=1}^{m} \|d_i\|^2 \cdot \|x(t) - \hat{x}(t)\|^2 \\
&= \eta^2 d^2 \cdot \|x(t) - \hat{x}(t)\|^2,
\end{aligned}
\tag{2.5}
$$

where $d = \sqrt{\sum_{i=1}^{m} \|d_i\|^2} = \sqrt{\sum_{i=1}^{m} \sum_{j=1}^{n} d_{ij}^2}$, d_{ij} are the element of matrix $D = (d_{ij})_{m \times n}$.

Lemma 1. [27] For any symmetric positive matrix $W \in R^{n \times n}$ and scalar $\tau > 0$, there is

$$
\int_{t-\tau}^{t} x^T(s)ds \, W \int_{t-\tau}^{t} x(s)ds \leq \tau \int_{t-\tau}^{t} x^T(s)Wx(s)ds.
$$

3. Main results

This section will present some event-triggered conditions under which master system (2.1) and slave system (2.2) achieve synchronization, and further shows that the length of triggered interval is bigger than zero.

Theorem 1. Under Assumption 1 and the action of event-triggered controller (2.3), if there exist symmetric positive matrices $P \in R^{n \times n}$, $Q \in R^{n \times n}$, $R \in R^{n \times n}$, matrix $K \in R^{n \times n}$ and positive constants $\beta > 0$, $\gamma > 0$ such that

$$
\Theta = \begin{bmatrix}
\Theta_{11} & \Theta_{12} & \Theta_{13} & P + \tau^2(A - K)^T R \\
* & -Q - R + \tau^2 B^T RB & \tau^2 B^T RC & \tau^2 B^T R \\
* & * & \tau^2 C^T RC - \gamma I & \tau^2 C^T R \\
* & * & * & -\beta I_n + \tau^2 R
\end{bmatrix} < 0,
\tag{3.1}
$$

where

$$
\Theta_{11} = P(A - K) + (A - K)^T P + \tau^2(A - K)^T R(A - K) + Q - R + \beta I_n,
$$

$$
\Theta_{12} = PB - R + \tau^2(A - K)^T RB,
$$

$$
\Theta_{13} = PC + \tau^2(A - K)^T RC + \frac{1}{2}\eta\gamma I,
$$

then master system (2.1) synchronizes with slave system (2.2). In addition, controller (2.3) is updated when

$$
\|Ke(t)\| = \sqrt{\alpha}\|z(t)\|
$$

with $\alpha \in [0, 1)$.

Proof. Choose the Lyapunov functional as

$$
V(t) = z^T(t)Pz(t) + \int_{t-\tau}^{t} z^T(s)Qz(s)ds + \tau \int_{-\tau}^{0} \int_{t+s}^{t} \dot{z}^T(v)R\dot{z}(v)dvds.
\tag{3.2}
$$

Then the derivative of $V(t)$ with respect to the trajectories of error system (2.4) is

$$
\begin{aligned}
\dot{V}(t) &= 2z^T(t)P[(A - K)z(t) + Bz(t - \tau) + Ch(z(t)) + Ke(t)] \\
&\quad + z^T(t)Qz(t) - z^T(t - \tau)Qz(t - \tau) + \tau^2 \dot{z}^T(t)R\dot{z}(t) - \tau \int_{t-\tau}^t \dot{z}^T(s)R\dot{z}(s)ds \\
&= z^T(t)[P(A - K) + (A - K)^T P + Q]z(t) + 2z^T(t)PBz(t - \tau) \\
&\quad + 2z^T(t)PCh(z(t)) + 2z^T(t)PKe(t) - z^T(t - \tau)Qz(t - \tau) \\
&\quad + \tau^2[(A - K)z(t) + Bz(t - \tau) + Ch(z(t)) + Ke(t)]^T R[(A - K)z(t) \\
&\quad + Bz(t - \tau) + Ch(z(t)) + Ke(t)] - \tau \int_{t-\tau}^t \dot{z}^T(s)R\dot{z}(s)ds.
\end{aligned}
\tag{3.3}
$$

It is known that there exists a positive scalar $\gamma > 0$ such that

$$
\gamma h^T(z(t))(h(z(t)) - \eta z(t)) \le 0. \tag{3.4}
$$

By Lemma 1 and (3.1), one gets

$$
\begin{aligned}
\dot{V}(t) &\le \xi^T(t)\Theta\xi(t) - \beta z^T(t)z(t) + \beta e^T(t)K^T Ke(t) \\
&\le (\alpha - 1)\beta z^T(t)z(t),
\end{aligned}
\tag{3.5}
$$

where $\xi(t) = [z^T(t), z^T(t - \tau), h^T(z(t)), e^T(t)K^T]^T$ and $\|Ke(t)\| \le \sqrt{\alpha}\|z(t)\|$. From the Lyapunov stability theory, we know that $lim_{t\to\infty}z(t) = 0$. Thus, master system (2.1) and slave system (2.2) are synchronized.

Remark 2. In fact, system (2.4) asymptotically converges to zero only if condition (3.1) holds when $t \in [t_k, t_{k+1})$. If inequality (3.1) does not hold, then we will control it by using the information of next sampling instant. So we can take the triggering event as

$$
\|Ke(t)\| = \sqrt{\alpha}\|z(t)\|. \tag{3.6}
$$

It is noticed that (3.1) is a nonlinear inequality on the variables, and we can obtain the following linear matrix inequality by variable transformation.

Theorem 2. Under Assumption 1 and the action of event-triggered controller (2.3), if there exist symmetric positive matrices $Q \in R^{n\times n}$, $R \in R^{n\times n}$, matrix $W \in R^{n\times n}$ and positive constants $\beta > 0$, γ such that

$$
\tilde{\Theta} = \begin{bmatrix}
\tilde{\Theta}_{11} & \tilde{\Theta}_{12} & \tilde{\Theta}_{13} & R + \tau^2(AR - W^T) & \tau(A^T R - W^T) \\
* & -Q - R + \tau^2 B^T RB & \tau^2 B^T RC & \tau^2 B^T R & 0 \\
* & * & \tau^2 C^T RC - \gamma I & \tau^2 C^T R & 0 \\
* & * & * & -\beta I_n + \tau^2 R & 0 \\
* & * & * & * & -R
\end{bmatrix} < 0, \tag{3.7}
$$

where

$$
\tilde{\Theta}_{11} = RA + A^T R - W - W^T + Q - R + \beta I_n,
$$

$$
\tilde{\Theta}_{12} = RB - R + \tau^2(A^T RB - W^T B),
$$

$$
\tilde{\Theta}_{13} = RC + \tau^2(A^T RC - W^T C) + \frac{1}{2}\eta\gamma I,
$$

then master system (2.1) synchronizes with slave system (2.2). In addition, controller (2.3) is updated when

$$
\|Ke(t)\| = \sqrt{\alpha}\|z(t)\|
$$

with $\alpha \in [0, 1)$, $K = R^{-1}W$.

Proof. From (3.1) and letting $P = R$, one gets

$$\Theta = \hat{\Theta} + \begin{bmatrix} \tau(A - K)^T R \\ 0 \\ 0 \\ 0 \end{bmatrix} R^{-1} \begin{bmatrix} \tau R(A - K) & 0 & 0 & 0 \end{bmatrix} < 0, \tag{3.8}$$

where $\hat{\Theta}$ is the same with Θ except $\hat{\Theta}_{11} = P(A - K) + (A - K)^T P + Q - R + \beta I_n$. Letting $RK = W$ and applying the Schur complement lemma, we know that (3.8) is equivalent with (3.7). The proof is completed.

Remark 3. In Theorem 1, because PK and RK all include variable K, it is difficult to depart them away. Thus we take $P = R$, which increases the conservatism of the results.

Theorem 3. For $\alpha \in [0, 1)$, the length of triggered control interval $[t_k, t_{k+1})$ is not commonplace for any $k = 0, 1, \cdots$. That is, there must exist a positive scalar $\delta > 0$ such that $min_{k \geq 0}\{t_{k+1} - t_k\} \geq \delta$.

Proof. In order to show this result, we calculate

$$\begin{aligned}
\frac{d}{dt}\left(\frac{\|Ke(t)\|}{\|z(t)\|}\right) &= \frac{(Ke(t))^T K\dot{e}(t)}{\|Ke(t)\| \cdot \|z(t)\|} - \frac{\|Ke(t)\| \cdot z^T(t)\dot{z}(t)}{\|z(t)\|^3} \\
&\leq \frac{\|K\dot{e}(t)\|}{\|z(t)\|} + \frac{\|Ke(t)\| \cdot \|\dot{z}(t)\|}{\|z(t)\|^2} \\
&= (\|K\| + \frac{\|Ke(t)\|}{\|z(t)\|})\frac{\|\dot{z}(t)\|}{\|z(t)\|} \\
&= (\|K\| + \frac{\|Ke(t)\|}{\|z(t)\|})\frac{\|(A-K)z(t)+Bz(t-\tau)+Ch(z(t))+Ke(t)\|}{\|z(t)\|}.
\end{aligned} \tag{3.9}$$

Noting that error system (2.4) is convergence, so its state is bounded for $t > 0$. Without loss of generality, we suppose that there exists a nonnegative constant $\gamma \geq 0$ such that $sup_{t \geq 0}\{\frac{\|z(t-\tau)\|}{\|z(t)\|}\} \leq \gamma$. Thus,

$$\begin{aligned}
\frac{d}{dt}\left(\frac{\|Ke(t)\|}{\|z(t)\|}\right) &\leq (\|K\| + \frac{\|Ke(t)\|}{\|z(t)\|})(\|A - K\| + \gamma\|B\| + d\eta\|C\| + \frac{\|Ke(t)\|}{\|z(t)\|}) \\
&= (\frac{\|Ke(t)\|}{\|z(t)\|})^2 + (\|K\| + \mu)\frac{\|Ke(t)\|}{\|z(t)\|} + \mu\|K\| \\
&= (\frac{\|Ke(t)\|}{\|z(t)\|} + \frac{\mu+\|K\|}{2})^2 - \frac{(\mu+\|K\|)^2}{4} + \mu\|K\|,
\end{aligned} \tag{3.10}$$

where $\mu = \|A - K\| + \gamma\|B\| + d\eta\|C\|$. Letting $y(t) = \frac{\|Ke(t)\|}{\|z(t)\|} + \frac{\mu+\|K\|}{2}$, and in view of

$$\frac{(\mu + \|K\|)^2}{4} - \mu\|K\| = \frac{(\mu - \|K\|)^2}{4},$$

there is

$$\dot{y}(t) \leq y^2(t).$$

It follows from the compare theory of the differential equation that

$$y(t) \leq \frac{\mu + \|K\|}{2 - (\mu + \|K\|)(t - t_k)},$$

where we use the fact $e(t_k) = 0$ and $y(t_k) = \frac{\mu+\|K\|}{2}$. As

$$\|Ke(t)\| = \sqrt{\alpha}\|z(t)\|,$$

there is

$$t - t_k = \frac{4\sqrt{\alpha}}{2\sqrt{\alpha}(\mu+\|K\|)+(\mu+\|K\|)^2}. \tag{3.11}$$

Since $\alpha \in [0, 1)$, one gets $t > t_k$. Which shows that the length of the sampling interval $[t_k, t_{k+1})$ is bigger than zero for $k = 0, 1, 2, \ldots$.

4. A numerical example

Example 1. Take the following Chua circuits [28] as master system

$$
\begin{cases}
\dot{x}_1(t) = a(x_2(t) - m_1 x_1(t) + \sigma(x_1(t))) - c x_1(t - \tau), \\
\dot{x}_2(t) = x_1(t) - x_2(t) + x_3(t) - c x_1(t - \tau), \\
\dot{x}_3(t) = -b x_2(t) + c(2 x_1(t - \tau) - x_3(t - \tau)),
\end{cases}
\tag{4.1}
$$

where $\sigma(x_1(t)) = \frac{1}{2}(m_1 - m_0)(|x_1(t) + 1| - |x_1(t) - 1|)$, $m_0 = -\frac{1}{7}$, $m_1 = \frac{2}{7}$, $a = 9$, $b = 14.286$, $c = 0.1$, $\tau = 2$. Writing

$$
A = \begin{bmatrix} -am_1 & a & 0 \\ 1 & -1 & 1 \\ 0 & -b & 0 \end{bmatrix}, B = \begin{bmatrix} -c & 0 & 0 \\ -c & 0 & 0 \\ 2c & 0 & -c \end{bmatrix}, C = \begin{bmatrix} a(m_1 - m_0) & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}, D = I_3,
$$

$\sigma(x(t)) = (0.5(|x_1(t) + 1| - |x_1(t) - 1|), 0, 0)^T$, then system (4.1) can be rewritten as the form of system (2.1). Then its phase diagram is shown in Figure 1 and appears the scroll attractors.
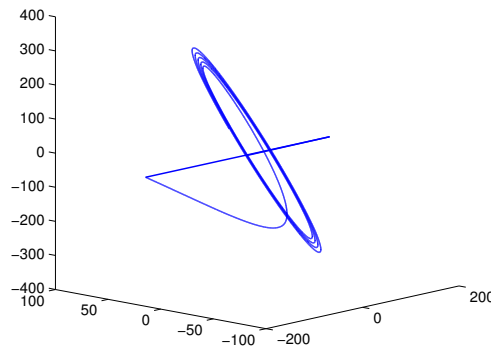

Figure 1. State trajectories of the Chua's system with the given initial condition $s(0)$.

After computation, one gets the feasible solutions of inequality (3.7) as

$$
R = \begin{bmatrix} 1.0466 & 0.0282 & 0.0764 \\ 0.0282 & 0.9084 & 0.0139 \\ 0.0764 & 0.0139 & 0.9525 \end{bmatrix}, Q = \begin{bmatrix} 1.6685 & 0.1062 & 0.5525 \\ 0.1062 & 0.4364 & 0.0597 \\ 0.5525 & 0.0597 & 0.7254 \end{bmatrix},
$$

$$
W = \begin{bmatrix} 2.5543 & 8.1001 & -0.3405 \\ 1.4454 & 4.4173 & 0.1505 \\ -1.0214 & -11.9481 & 5.0374 \end{bmatrix}, K = \begin{bmatrix} 2.4939 & 8.5814 & -0.7184 \\ 1.5336 & 4.8004 & 0.1060 \\ -1.2948 & -13.3027 & 5.3448 \end{bmatrix},
$$

$$
\alpha = 0.5, \beta = 2.4024, \gamma = 0.3741, \eta = 2, \tau = 2.
$$

From Theorem 2, we know that master-slave systems (2.1) and (2.2) with the given parameters can synchronize with each other. Taking the initial conditions $x(0) = (-41.5, 34, -44.5)^T$ and $\hat{x}(0) =$

$(-6, 10.5, -8)^T$ respectively, then the state trajectories of master-slave systems (2.1) and (2.2), update laws (2.3) and error system (2.4) are shown in Figures 2–5. In particular, Figure 4 shows that master-slave systems (2.1) and (2.2) synchronizes well.
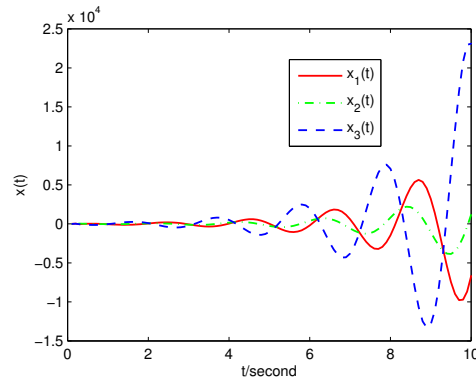

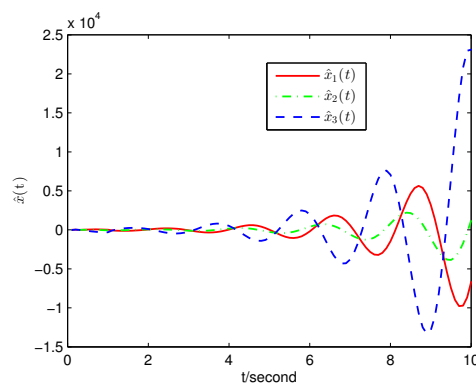**Figure 2.** The state trajectories of master system with the initial value $x(0)$.

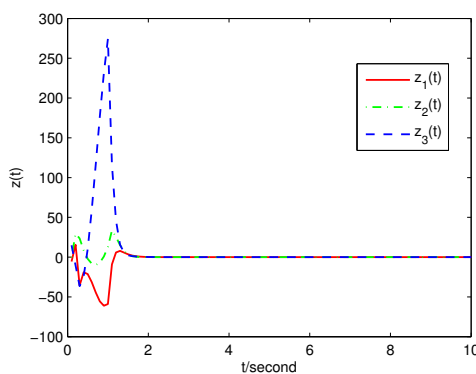**Figure 3.** The state trajectories of slave system with the initial value $\hat{x}(0)$.

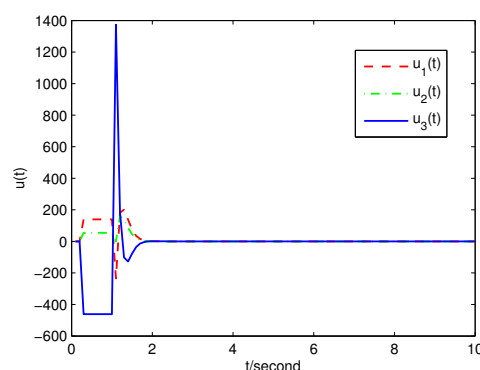**Figure 4.** The error state trajectories of master system and slave system.

Figure 5. The event-triggering controller $u(t)$.

5. Conclusions

This paper has investigated the master-slave synchronization of Lurie systems with time delay via event-triggered control scheme. We have obtained the synchronization conditions and the computation method of the control gain. Moreover, we have proved that the presented event-trigged controller is not commonplace. A numerical example has shown that the proposed method is right.

Conflict of interest

The authors declare that they have no conflicts of interest.

References

1. H. Mkaouar, O. Boubaker, Chaos synchronization for master slave piecewise linear systems: application to Chua's circuit, *Commun. Nonlinear Sci.*, **17** (2012), 1292–1302. https://doi.org/10.1016/j.cnsns.2011.07.027

2. T. P. Chen, S. Amari, Stability of asymmetric Hopfield networks, *IEEE T. Neural Networ.*, **12** (2001), 159–163. https://doi.org/10.1109/72.896806

3. C. Guzelis, L. Chua, Stability analysis of generalized celluar neural networks, *Int. J. Circ. Theor. App.*, **21** (1993), 1–33. https://doi.org/10.1002/cta.4490210102

4. M. E. Yalcin, J. A. K. Suykens, J. Vandewalle, Master-slave synchronization of Lur'e systems with time-delay, *Int. J. Bifurcat. Chaos*, **11** (2001), 1707–1722. https://doi.org/10.1142/S021812740100295X

5. Z. Tang, J. H. Park, J. W. Feng, Novel approaches to pin cluster synchronization on complex dynamical networks in Lur'e forms, *Commun. Nonlinear Sci.*, **57** (2018), 422–438. https://doi.org/10.1016/j.cnsns.2017.10.010

6. S. T. Qin, Q. Cheng, G. F. Chen, Global exponential stability o funcertain neural networks with discontinuous Lurie-type activation and mixed delays, *Neurocomputing*, **198** (2016), 12–19.

7. X. Wang, X. Z. Liu, K. She, S. M. Zhong, Finite-time lag synchronization of master-slave complex dynamical networks with unknown signal propagation delays, *J. Franklin I.*, **354** (2017), 4913–4929. https://doi.org/10.1016/j.jfranklin.2017.05.004

8. K. B. Shi, Y. Y. Tang, X. Z. Liu, S. M. Zhong, Non-fragile sampled-data robust synchronization of uncertain delayed chaotic Lurie systems with randomly occurring controller gain fluctuation, *ISA T.*, **66** (2017), 185–199. https://doi.org/10.1016/j.isatra.2016.11.002

9. C. Yin, S. M. Zhong, W. F. Chen, Design PD controller for master-slave synchronization of chaotic Lur'e systems with sector and slope restricted nonlinearities, *Commun. Nonlinear Sci.*, **16** (2011), 1632–1639. https://doi.org/10.1016/j.cnsns.2010.05.031

10. A. Loria, Master-slave synchronization of fourth-order Lü chaotic oscillators via linear output feedback, *IEEE T. Circuits-II*, **57** (2010), 213–217. https://doi.org/10.1109/TCSII.2010.2040303

11. Y. Q. Wang, J. Q. Lu, J. L. Liang, J. D. Cao, M. Perc, Pinning synchronization of nonlinear coupled Lur'e networks under hybrid impulses, *IEEE T. Circuits-II*, **66** (2019), 432–436. https://doi.org/10.1109/TCSII.2018.2844883

12. Y. B. Yu, F. L. Zhang, Q. S. Zhong, X. F. Liao, J. B. Yu, Impulsive control of Lurie systems, *Comput. Math. Appl.*, **56** (2008), 2806–2813. https://doi.org/10.1016/j.camwa.2008.09.015

13. Q. Xiao, T. G. Huang, Z. G. Zeng, Synchronization of timescale-type nonautonomous neural networks with proportional delays, *IEEE T. Syst. Man Cy.*, **52** (2022), 2167–2173. https://doi.org/10.1109/TSMC.2021.3049363

14. J. Q. Lu, J. D. Cao, D. W. C. Ho, Adaptive stabilization and synchronization for chaotic Lur'e systems with time-varying delay, *IEEE T. Circuits-I*, **55** (2008), 1347–1356. https://doi.org/10.1109/TCSI.2008.916462

15. W. H. Chen, Z. P. Wang, X. M. Lu, On sampled-data control for master-slave synchronization of chaotic Lur'e systems, *IEEE T. Circuits-II*, **59** (2012), 515–519. https://doi.org/10.1109/TCSII.2012.2204114

16. D. H. Ji, J. H. Park, S. C. Won, Master-slave synchronization of Lur'e systems with sector and slope restricted nonlinearities, *Phys. Lett. A*, **373** (2009), 1044–1050. https://doi.org/10.1016/j.physleta.2009.01.038

17. H. M. Guo, S. M. Zhong, F. Y. Gao, Design of PD controller for master-slave synchronization of Lur'e systems with time-delay, *Appl. Math. Comput.*, **212** (2009), 86–93. https://doi.org/10.1016/j.amc.2009.01.080

18. X. J. Su, X. X. Liu, P. Shi, Y. D. Song, Sliding mode control of hybrid switched systems via an event-triggered mechanism, *Automatica*, **90** (2018), 294–303. https://doi.org/10.1016/j.automatica.2017.12.033

19. X. Q. Xiao, L. Zhou, D. W. C. Ho, G. P. Lu, Event-triggered control of continuous-time switched linear systems, *IEEE T. Automat. Contr.*, **64** (2019), 1710–1717. https://doi.org/10.1109/TAC.2018.2853569

20. D. X. Peng, X. D. Li, Leader-following synchronization of complex dynamic networks via event-triggered impulsive control, *Neurocomputing*, **412** (2020), 1–10. https://doi.org/10.1016/j.neucom.2020.05.071

21. J. Liu, H. Q. Wu, J. D. Cao, Event-triggered synchronization in fixed time for semi-Markov switching dynamical complex networks with multiple weights and discontinuous nonlinearity, *Commun. Nonlinear Sci.*, **90** (2020), 105400. https://doi.org/10.1016/j.cnsns.2020.105400

22. M. Z. Wang, S. C. Wu, X. D. Li, Event-triggered delayed impulsive control for nonlinear systems with applications, *J. Franklin I.*, **358** (2021), 4277–4291. https://doi.org/10.1016/j.jfranklin.2021.03.021

23. X. F. Fan, Z. S. Wang, Event-triggered sliding mode control for singular systems with disturbance, *Nonlinear Anal.-Hybri.*, **40** (2021), 101011. https://doi.org/10.1016/j.nahs.2021.101011

24. Y. Sun, P. Shi, C. C. Lim, Event-triggered sliding mode scaled consensus control for multi-agent systems, *J. Franklin I.*, **359** (2022), 981–998. https://doi.org/10.1016/j.jfranklin.2021.12.007

25. W. Zhao, W. W. Yu, H. P. Zhang, Event-triggered optimal consensus tracking control for multi-agent systems with unknown internal states and disturbances, *Nonlinear Anal.-Hybri.*, **33** (2019), 227–248. https://doi.org/10.1016/j.nahs.2019.03.003

26. W. H. Wu, L. He, J. P. Zhou, Z. X. Xuan, A. Sabri, Disturbance-term-based switching event-triggered synchronization control of chaotic Lurie systems subject to a joint performance guarantee, *Commun. Nonlinear Sci.*, **115** (2022), 106774. https://doi.org/10.1016/j.cnsns.2022.106774

27. J. K. Tian, W. J. Xiong, F. Xu, Improved delay-partitioning method to stability analysis for neural networks with discrete and distributed time-varying delays, *Appl. Math. Comput.*, **233** (2014), 152–164. https://doi.org/10.1016/j.amc.2014.01.129

28. W. L. He, F. Qian, Q. L. Han, J. D. Cao, Synchronization error estimation and controller design for delayed Lur'e systems with parameter mismatches, *IEEE T. Neur. Net. Lear.*, **23** (2012), 1551–1562. https://doi.org/10.1109/TNNLS.2012.2205941