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Consensus Control of the Multi-Agent Systems under both Disturbances and Noises*

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Abstract Consensus tracking control problem of the multi-agent systems with both noise and disturbances is studied in this paper. A robust adaptive control scheme is designed according to Lyapunov stability theory. The main contribution of this paper is that the consensus is realized in multi-agent systems with both noise and external disturbances. Numerical simulations are carried out for the proposed scheme to demonstrate the effectiveness of the control strategy proposed in this paper.

Keywords Multi-agent systems, consensus, numerical simulations

MSC(2010) 26A33, 39A13.

1. Introduction

In the era of big data, how to realize consensus in multi-agent systems has caused wide concern due to wide applications of multi-agent systems in unmanned aerial vehicles, mobile robots, etc [1–4]. Adaptive consensus control of multi-agent systems with uncertainties is proposed in the paper [5]. Consensus problem of Brunovsky-type nonlinear multi-agent systems is studied in [6]. Neural network-based adaptive consensus control for a class of nonaffine nonlinear multi-agent systems is studied in [7]. Therefore, consensus problem in multi-agent systems is a very important research topic.

At the same time, event-triggered control is very important in control theory because it can balance limited bandwidth with control system performance compared to a periodic sampling control. The control signal is updated only at discrete

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time and the control input remains constant between events during event-triggered control [8–13].

Recently, event-triggered control of multi-agent systems has made good progress [14–20]. A particularly interesting topic is the leader-following consensus problem. Wang et al. [21] investigated the leader-following consensus problem in a class of multi-agent systems with directed communication topology. Liu and his collaborators [22] studied the leader-following attitude consensus problem of multiple rigid-body systems. In [23], the leader-following problem was investigated in the multi-agent system with unknown parameters and uncertain external disturbances. Garcia et al. [24] studied the consensus tracking control for uncertain multi-agent systems and proposed an adaptive event-triggered consensus control scheme.

However, the information exchange between multiple agents will be affected by noises from communication channels and external environment in the real world. So, it is important to study the multi-agent system with noises and switched topology [25–29].

Based on the above discussion, this paper generalizes the existing research results and further studies the consensus tracking of multi-agent systems with noises and external disturbances by means of event-triggered adaptive control.

The rest of this paper is organized as follows. Consensus tracking control problem of multi-agent system is described in Section 2. Main mathematical results are given in Section 3. Numerical simulations are performed in Section 4. Finally, conclusions are made in Section 5.

2. Problem description

The dynamical behavior of the leader is given by the equation

$$\dot{x}_1(t) = a_1 x_1(t) + r(t), \tag{2.1}$$

where $x_1 \in R$ is the leader agent with the initial value $x_1(0) = x_{10}$, $r(t) \in R$ is the input of leader agent, and $a_1 < 0$ is an unknown parameter. The input signal $r(t)$ is bounded, that is to say, there exists $\bar{r} > 0$, such that $|r(t)| \leq \bar{r}$ holds for all $t \geq 0$.

In the following, we will consider the $N-1$ follower agents. The ith follower can be described by the following equation:

$$\dot{x}_i(t) = a_i x_i(t) + u_i(t) + \sigma_i(t), \tag{2.2}$$

where $i = 2, \ldots, N, x_i \in R$ represents agent i with the initial value $x_i(0) = x_{i0}$, $u_i(t) \in R$ is the control input and $\sigma_i(t) \in R$ is an unknown disturbance factor. Let $\sigma(t) = [\sigma_2(t) \ldots \sigma_N(t)]^{\mathrm{T}}$ and it is assumed that there exists a constant $\bar{\sigma} > 0$ such that $\|\sigma(t)\|_\infty \leq \bar{\sigma}$. In this paper, the infinite norm is used, and the subscript ∞ will be omitted next to the norm operators unless it is necessary. It is assumed that parameters $a_i\,(i = 2, \ldots, N)$ are unknown. It is called non-identical or heterogeneous agent dynamics because each agent may have its own distinct dynamics.

In this paper, each agent i can only get its own states and it can transmit these states to agent j at some discrete time instants t_{ki} by using event-triggered strategies to schedule broadcasting instants and to reduce communication among agents. Fig. 1 gives a control block diagram of follower i.

Remark 2.1. It should be pointed out that the existing paper [24] considers the event-triggered consensus problem without noise and external disturbances, but

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we will consider event-triggered consensus problem with noise and external disturbances here. It is important to study event-triggered consensus problem with noise and external disturbances because noise and external disturbances are unavoidable in the real world.

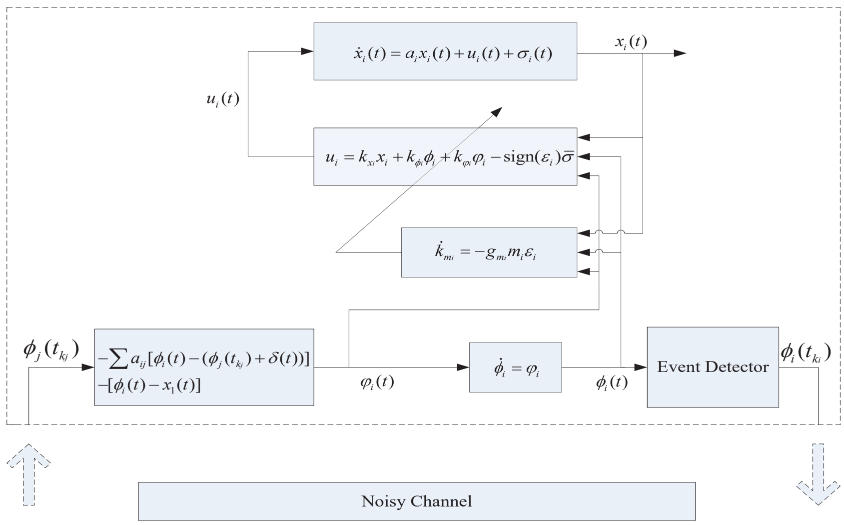

Figure 1. The control block diagram of follower.

3. Main results

In this section, we will consider the modified MAS system according to [24],

$$\dot{\phi}_i(t) = -\sum_{j=2}^{N} a_{ij}[\phi_i(t) - (\phi_j(t_{kj}) + \delta(t))] - a_{i1}[\phi_i(t) - x_1(t)], \tag{3.1}$$

where $\phi_i \in R$ is the state variable of the MAS controller of follower $i, i = 2, \ldots, N$. $\phi_i(0) = \phi_{i0}$ is the initial value and $\delta(t) \in R$ is channel noises. LetΔ=$[\delta(\mathrm{t}) \ldots \delta(\mathrm{t})]^{\mathrm{T}} \in R^{N-1}, \|\Delta\| \leq \bar{\Delta}$. When an event is triggered at node i, the state $\phi_i(t_{ki})$ is transmitted to its neighbor agents. The index t_{ki} is the sequence of time instant at which agent i generates its own events. Thus, the information that is exchanged by the followers is $\phi_i(t_{ki})$. Fig.1 shows that each follower has the MAS controller, adaptive controller and event detector. The discontinuous arrows outside the large block represent the agents capabilities of receiving $\phi_j(t_{kj})$ for j such that $a_{ij} > 0$ and transmitting $\phi_i(t_{ki})$ which are generated by events. Let $\xi_i(t) = \phi_i(t) - x_1(t)$ be the error that will be used to detect events and to decide when to broadcast the MAS controller state ϕ_i. Let $z(t) = [z_2(t) \ldots z_N(t)]^{\mathrm{T}}$. Let $\xi_i(t) = \phi_i(t) - x_1(t)$ be the error between the state of the MAS controller of agent i and the leaders state. Let $\xi(t)$=$[\xi_2(t) \ldots \xi_N(t)]^{\mathrm{T}}, \bar{\xi} = \|\xi(0)\|$. The tracking error is $\varsigma_i(t) = x_i(t) - x_1(t), \varsigma(t)$=$[\varsigma_2(t) \ldots \varsigma_N(t)]^{\mathrm{T}}$. There exist positive numbers $\hat{\beta}$ and $\hat{\lambda}$, such that $\left\|\mathrm{e}^{-\hat{L}t}\right\| \leq \hat{\beta}\mathrm{e}^{-\hat{\lambda}t}$ according to Lemma 1 in the paper [30,31]. The adaptive

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controller is designed as

$$u_i(t) = k_{xi}x_i(t) + k_{\phi i}\phi_i(t) + k_{\varphi i}\varphi_i(t) - \text{sign}(\varepsilon_i(t))\bar{\sigma}, \tag{3.2}$$

with the adaptive tuning laws

$$\begin{aligned} \dot{k}_{xi}(t) &= -g_{xi}x_i(t)\varepsilon_i(t), \\ \dot{k}_{\phi i}(t) &= -g_{\phi i}\phi_i(t)\varepsilon_i(t), \\ \dot{k}_{\varphi i}(t) &= -g_{\varphi i}\varphi_i(t)\varepsilon_i(t), \end{aligned} \tag{3.3}$$

where sign() denotes the signal function, $g_{xi}, g_{\phi i}$ and $g_{\varphi i}$ are three designed positive parameters, and $\varepsilon_i(t) = x_i(t) - \phi_i(t)$.

The event-triggered instant is defined as

$$t_{ki+1} = \min\{t > t_{ki} | \, |z_i(t)| \geq \beta \mathrm{e}^{-\lambda t} + \gamma, \beta > 0, \lambda > 0, \gamma > 0\}. \tag{3.4}$$

Theorem 3.1. *The tracking error of the MAS system (2.2) under conditions (3.2)-(3.4) is defined as follows*

$$\lim_{t\to+\infty} \|\varsigma(t)\| \leq \frac{\hat{\beta}}{\hat{\lambda}}[\bar{d}_i(\gamma + \bar{\Delta}) + 2\bar{r}].$$

Proof. The error z_i is reset to zero when an event is triggered by agent i. That is to say, $z_i(t_{ki}) = 0$ when an event is triggered by agent i. Thus, z_i satisfies $|z_i(t)| \leq \beta \mathrm{e}^{-\lambda t} + \gamma$ according to (3.4), for $i = 2, \ldots, N$. So, we have $\|z(t)\| \leq \beta \mathrm{e}^{-\lambda t} + \gamma$. The derivative of $\xi_i(t)$ is

$$\begin{aligned} \dot{\xi}_i(t) &= -\sum_{j=2}^{N} a_{ij}[\phi_i(t) - (\phi_j(t_{kj}) + \delta(t))] - a_{i1}[\phi_i(t) - x_1(t)] - \dot{x}_1(t) \\ &= -\sum_{j=2}^{N} a_{ij}[x_1(t) + \xi_i(t) - \phi_j(t) - z_j(t) - \delta(t)] - a_{i1}\xi_i(t) - \dot{x}_1(t) \\ &= -\sum_{j=2}^{N} a_{ij}[\xi_i(t) - \xi_j(t)] + \sum_{j=2}^{N} a_{ij}[z_j(t) + \delta(t)] - a_{i1}\xi_i(t) - \dot{x}_1(t), \end{aligned} \tag{3.5}$$

for $i = 2, \ldots, N$. And (3.5) can be written as follows

$$\dot{\xi} = -\hat{L}\xi + \hat{A}(z + \Delta) - \dot{x}_1 \cdot 1_{N-1}, \tag{3.6}$$

where $\hat{A} \in R^{(N-1)\times(N-1)}$ is the adjacency matrix of followers. $\hat{L}$ is the matrix defined in Lemma 1 in the paper [30, 31]. From (3.6), we can get

$$\|\xi(t)\| = \left\| \mathrm{e}^{-\hat{L}t}\xi(0) + \int_0^t \mathrm{e}^{-\hat{L}(t-s)}[\hat{A}(z(s) + \Delta(s)) - x_1(s) \cdot 1_{N-1}]ds \right\|. \tag{3.7}$$

So, we have

$$|x_1(t)| \leq \mathrm{e}^{a_1 t} |x_1(0)| + \frac{\bar{r}(1 - \mathrm{e}^{a_1 t})}{|a_1|}. \tag{3.8}$$

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Meanwhile, we can obtain

$$\begin{aligned}|\dot{x}_1(t)| &\le |a_1|\,|x_1(t)| + \bar{r}\\ &\le |a_1|\,|x_1(0)|\,\mathrm{e}^{a_1 t} + 2\bar{r} - \bar{r}\mathrm{e}^{a_1 t}.\end{aligned} \tag{3.9}$$

From (3.7)-(3.9), we can get

$$\begin{aligned}\|\xi(t)\| \le{}& \hat{\beta}\bar{\xi}\mathrm{e}^{-\hat{\lambda}t} + \beta\hat{\beta}\bar{d}_i\int_0^t \mathrm{e}^{-\hat{\lambda}(t-s)}\mathrm{e}^{-\lambda s}ds + \hat{\beta}(\bar{d}_i(\gamma+\bar{\Delta})+2\bar{r})\int_0^t \mathrm{e}^{-\hat{\lambda}(t-s)}ds\\ &+\hat{\beta}(|a_1|\,\bar{x}_{10}-\bar{r})\int_0^t \mathrm{e}^{-\hat{\lambda}(t-s)}\mathrm{e}^{a_1 s}ds\\ \le{}& \hat{\beta}\bar{\xi}\mathrm{e}^{-\hat{\lambda}t} + \tfrac{\beta\hat{\beta}\bar{d}_i}{\hat{\lambda}-\lambda}(\mathrm{e}^{-\lambda t}-\mathrm{e}^{-\hat{\lambda}t}) + \tfrac{\hat{\beta}}{\hat{\lambda}}(\bar{d}_i(\gamma+\bar{\Delta})+2\bar{r})(1-\mathrm{e}^{-\hat{\lambda}t})\\ &+\tfrac{\hat{\beta}}{\hat{\lambda}+a_1}(|a_1|\,\bar{x}_{10}-\bar{r})(\mathrm{e}^{a_1 t}-\mathrm{e}^{-\hat{\lambda}t}).\end{aligned} \tag{3.10}$$

From (3.10), we obtain

$$\lim_{t\to+\infty}\|\xi(t)\| \le \frac{\hat{\beta}}{\hat{\lambda}}[\bar{d}_i(\gamma+\bar{\Delta})+2\bar{r}]. \tag{3.11}$$

The “ideal gains” of the controller are given by

$$k^*_{\phi i} = -(a_i + k^*_{xi}), k^*_{\varphi i} = 1. \tag{3.12}$$

Let $\tilde{k}_{xi}(t) = k_{xi}(t) - k^*_{xi}, \tilde{k}_{\phi i}(t) = k_{\phi i}(t) - k^*_{\phi i}, \tilde{k}_{\varphi i}(t) = k_{\varphi i}(t) - k^*_{\varphi i}$ be the adaptive gain errors. Using (3.2)-(3.12), we can obtain

$$\begin{aligned}\dot{\varepsilon}_i(t) ={}& a_i x_i(t) + k_{xi}x_i(t) + k_{\phi i}\phi_i(t) + k_{\varphi i}\varphi_i(t) - sign(\varepsilon_i(t))\bar{\sigma} + \sigma_i(t) - \varphi_i(t)\\ ={}& a_i x_i(t) + (k^*_{xi}+\tilde{k}_{xi}(t))x_i(t) + (k^*_{\phi i}+\tilde{k}_{\phi i}(t))\phi_i(t) + (k^*_{\varphi i}+\tilde{k}_{\varphi i}(t))\varphi_i(t)\\ &-sign(\varepsilon_i(t))\bar{\sigma} + \sigma_i(t) - \varphi_i(t)\\ ={}& (a_i + k^*_{xi})\,\varepsilon_i(t) + \tilde{k}_{xi}x_i(t) + \tilde{k}_{\phi i}(t)\phi_i(t) + \tilde{k}_{\varphi i}(t)\varphi_i(t) + \sigma_i(t) - sign(\varepsilon_i(t))\bar{\sigma}.\end{aligned} \tag{3.13}$$

Construct the following Lyapunov function

$$V_i = \frac{1}{2}\varepsilon_i^2(t) + \frac{1}{2g_{xi}}\tilde{k}^2_{xi}(t) + \frac{1}{2g_{\phi i}}\tilde{k}^2_{\phi i}(t) + \frac{1}{2g_{\varphi i}}\tilde{k}^2_{\varphi i}(t). \tag{3.14}$$

The derivative of V_i is

$$\begin{aligned}\dot{V}_i ={}& \varepsilon_i(t)\dot{\varepsilon}_i(t) + \tfrac{1}{g_{xi}}\tilde{k}_{xi}(t)\dot{\tilde{k}}_{xi}(t) + \tfrac{1}{g_{\phi i}}\tilde{k}_{\phi i}(t)\dot{\tilde{k}}_{\phi i}(t) + \tfrac{1}{g_{\varphi i}}\tilde{k}_{\varphi i}(t)\dot{\tilde{k}}_{\varphi i}(t)\\ ={}& \varepsilon_i(t)[a^*_i\varepsilon_i(t) + \tilde{k}_{xi}(t)x_i(t) + \tilde{k}_{\phi i}(t)\phi_i(t) + \tilde{k}_{\varphi i}(t)\varphi_i(t) - sign(\varepsilon_i(t))\bar{\sigma} + \sigma_i(t)]\\ &- \tilde{k}_{xi}(t)x_i(t)\varepsilon_i(t) - \tilde{k}_{\phi i}(t)\phi_i(t)\varepsilon_i(t) - \tilde{k}_{\varphi i}(t)\varphi_i(t)\varepsilon_i(t)\\ ={}& a^*_i\varepsilon_i^2(t) - \varepsilon_i(t)sign(\varepsilon_i(t))\bar{\sigma} + \varepsilon_i(t)\sigma_i(t)\\ \le{}& a^*_i\varepsilon_i^2(t) - \varepsilon_i(t)sign(\varepsilon_i(t))\bar{\sigma} + |\varepsilon_i(t)|\,|\sigma_i(t)|\\ ={}& a^*_i\varepsilon_i^2(t) \le 0,\end{aligned} \tag{3.15}$$

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where $\dot{\tilde{k}}_{xi}(t) = \dot{k}_{xi}(t)$,$\dot{\tilde{k}}_{\phi i}(t) = \dot{k}_{\phi i}(t)$ and $\dot{\tilde{k}}_{\varphi i}(t) = \dot{k}_{\varphi i}(t)$. Then, we can get

$$\lim_{t\to+\infty} \|\varepsilon(t)\| = 0,$$

according to Barbalat's lemma, where $\varepsilon(t) = [\varepsilon_2(t)\ldots\varepsilon_N(t)]^{\mathrm{T}}$. Also, we have

$$\begin{aligned}\varsigma(t) &= x(t) - x_1(t)\cdot 1_{N-1},\\ &= \varepsilon(t) + \phi(t) - x_1(t)\cdot 1_{N-1},\\ &= \varepsilon(t) + \xi(t).\end{aligned} \tag{3.16}$$

Hence,

$$\begin{aligned}\lim_{t\to+\infty} \|\varsigma(t)\| &\le \lim_{t\to\infty} \|\varepsilon(t)\| + \lim_{t\to\infty} \|\xi(t)\|\\ &\le \tfrac{\hat{\beta}}{\hat{\lambda}}[\bar{d}_i(\gamma+\bar{\Delta}) + 2\bar{r}].\end{aligned} \tag{3.17}$$

Hence, Theorem 3.1 holds. This completes the proof. □

4. Numerical simulations

In this section, numerical simulations are given in order to demonstrate the effectiveness of the control strategy proposed in this paper. The behaviors of the leader are

$$\dot{x}_1(t) = a_1 x_1(t) + r(t). \tag{4.1}$$

The behaviors of the followers are given by

$$\dot{x}_i(t) = a_i x_i(t) + u_i(t) + \sigma_i(t) \tag{4.2}$$

for $i = 2,\ldots,9$. The communication graph is described by Fig. 2, where the leader is agent 1.

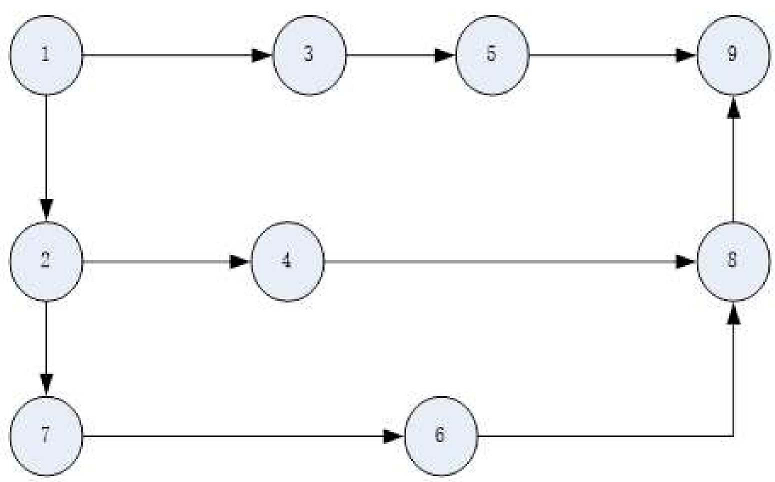

Figure 2. Communication graph.

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The initial values of the leader and the followers are $x_1(0) = 10, r(t) = 15$, and $x_i = [4, 4, 2, 6, -1, -3, -7, -5]$, respectively. The parameter a_1 is chosen as $a_1 = -3$. The parameter a_i is chosen as $a_i = [3, 1, 2, -2, 7, 4, 5, 6]$. Random disturbances are given at the ith follower by $\sigma_i(t) = \text{rand}(1) * \cos(t)$ and rand() denotes the random function. Channel noise is chosen as $\delta(t) = 0.5*\text{rand}(1)*\cos(t)$. The event-triggered control parameters are chosen as $\beta = 0.5, \lambda = 0.2$ and $\gamma = 0.05$ according to Theorem 3.1. Fig. 3 shows that the agent states can reach consensus. Fig. 4 shows the norm of error ς. The triggered events are shown in Fig. 5.

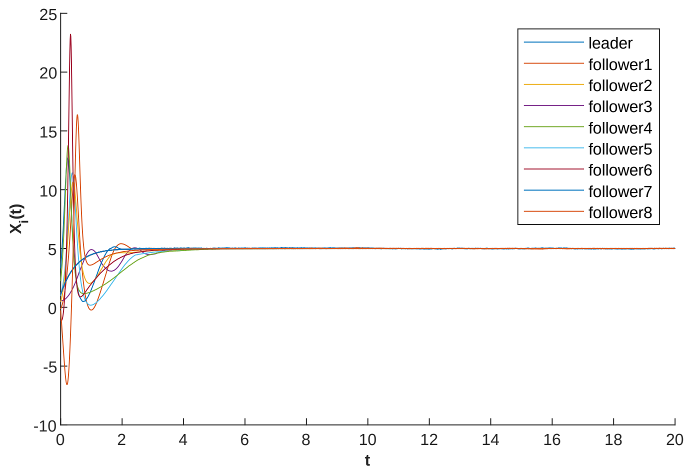

Figure 3. The process of evolution for leader and followers.

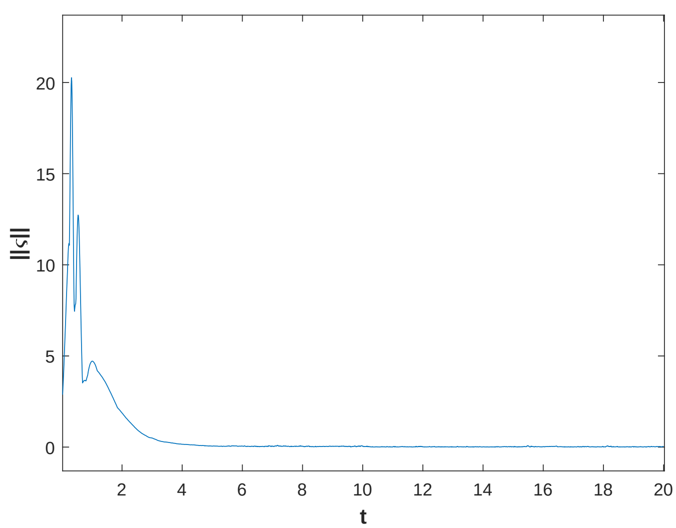

Figure 4. The norm of error ς.

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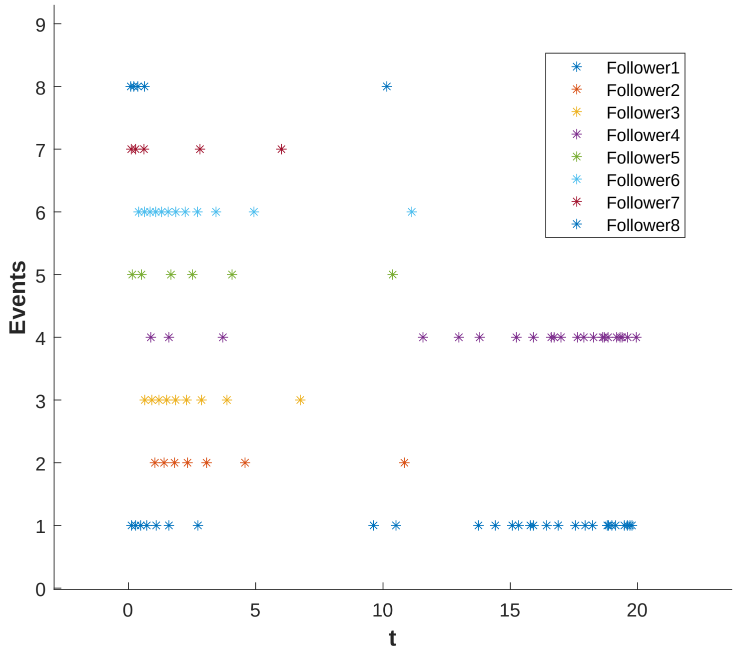

Figure 5. The graphic of triggered events.

5. Conclusions

The event-triggered adaptive consensus tracking control problem of multi-agents with noise and disturbances is studied in this paper. Finally, numerical simulations are carried out to demonstrate the effectiveness of the protocol. In the future, we will study the consensus conditions of multi-agent systems under time-varying topology or switching topology.

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References

[1] W. Ren, *Multi-vehicle consensus with time-varying reference state*, Systems and Control Letters, 2007, 56(7-8), 474–483.

[2] Y. Wang, W. Yan, J. Li, *Passivity-based formation control of autonomous underwater vehicles*, IET Control Theory and Applications, 2012, 6(4), 518–525.

[3] X, Sun, C. Cassandras, *Optimal dynamic formation control of multi-agent systems in constrained environments*, Automatica, 2016, 73, 169–179.

[4] Y. Chen, Y. Zhang, C. Liu, Q. Wang, *Formation circumnavigation for unmanned aerial vehicles using relative measurements with an uncertain dynamic target*, Nonlinear Dynamics, 2019, 97, 2305–2321.

[5] Z. Li, Z. Duan, F. Lewis, *Distributed robust consensus control of multi-agent systems with heterogeneous matching uncertainties*, Automatica, 2014, 50(3), 883–889.

[6] H. Rezaee, F. Abdollahi, *Adaptive consensus control of nonlinear multiagent systems with unknown control directions under stochastic topologies*, IEEE Transactions on Neural Networks and Learning Systems, 2018, 29(8), 3538–3547.

[7] J. Qin, G. Zhang, W. Zheng, Y. Kang, *Neural network-based adaptive consensus control for a class of nonaffine nonlinear multiagent systems with actuator faults*, IEEE Transactions on Neural Networks and Learning Systems, 2019, 30(12), 3633–3644.

[8] X. Wang, M. Lemmon, *Event-triggering in distributed networked control systems*, IEEE Transactions on Automatic Control, 2011, 56(3), 586–601.

[9] H. Li, Y. Shi, *Event-triggered robust model predictive control of continuous-time nonlinear systems*, Automatica, 2014, 50(5), 1507–1513.

[10] E. Garcia, P. J. Antsaklis, *Model-based event-triggered control for systems with quantization and time-varying network delays*, IEEE Transactions on Automatic Control, 2013, 58(2), 422–434.

[11] E. Garcia, P. J. Antsaklis, *Event-triggered output feedback stabilization of networked systems with external disturbance*, In 53rd IEEE Conference on Decision and Control, 2014, 3566–3571.

[12] X. Jia, X. Chi, Q. Han, N. Zheng, *Event-triggered fuzzy H control for a class of nonlinear networked control systems using the deviation bounds of asynchronous normalized membership functions*, Information Sciences, 2014, 259(20), 100–117.

[13] L. Hetel, C. Fiter, H. Omran, A. Seuret, E. Fridman, J. Richard, S. I. Niculescu, *Recent developments on the stability of systems with aperiodic sampling: an overview*, Automatica, 2017, 76, 309–355.

[14] D. V. Dimarogonas, E. Frazzoli, K. H. Johansson, *Distributed event-triggered control for multi-agent systems*, IEEE Transactions on Automatic Control, 2012, 57(5), 1291–1297.

[15] Z. Wei, Z. Jiang, G. Feng, *Event-based consensus of multi-agent systems with general linear models*, Automatica, 2014, 50(2), 552–558.

DOI https://doi.org/10.12150/jnma.2024.602 | Generated on 2024-12-19 04:59:16
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[16] Z. X. Liu, Z. Q. Chen, Z. Z. Yuan, *Event-triggered average-consensus of multi-agent systems with weighted and direct topology*, Journal of Systems Science and Complexity, 2012, 25(5), 845–855.

[17] D. Yang, W. Ren, X. Liu, W. Chen, *Decentralized event-triggered consensus for linear multi-agent systems under general directed graphs*, Automatica, 2016, 69, 242–249.

[18] W. Zhu, H. Pu, D. Wang, H. Li, *Event-based consensus of second-order multi-agent systems with discrete time*, Automatica, 2017, 79, 78–83.

[19] W. Hu, L. Liu, G. Feng, *Output consensus of heterogeneous linear multi-agent systems by distributed event-triggered/self-triggered strategy*, IEEE Transactions on Cybernetics, 2017, 47(8), 1914–1924.

[20] Y. Yang, Y. Li, D. Yue, W. Yue, *Adaptive event-triggered consensus control of a class of second-order nonlinear multiagent systems*, IEEE Transactions on Cybernetics, 2020, 50(12), 5010–5020.

[21] C. Wang, X. Wang, H. Ji, *Leader-following consensus for a class of second-order nonlinear multi-agent systems*, Systems and Control Letters, 2016, 89, 61–65.

[22] T. Liu, J. Huang, *Leader-following attitude consensus of multiple rigid body systems subject to jointly connected switching networks*, Automatica, 2018, 92, 63–71.

[23] W. Wang, C. Wen, J. Huang, *Distributed adaptive asymptotically consensus tracking control of nonlinear multi-agent systems with unknown parameters and uncertain disturbances*, Automatica, 2017, 77, 133–142.

[24] E. Garcia, I. Weintraub, D. W. Casbeer, *Adaptive event-triggered cooperative control of uncertain networked systems*, IFAC Papers OnLine, 2018, 51(12), 82–87.

[25] T. Li, J. F. Zhang, *Mean square average-consensus under measurement noises and fixed topologies: necessary and sufficient conditions*, Automatica, 2009, 45(8), 1929–1936.

[26] C. Ma, T. Li, J. Zhang, *Consensus control for leader-following multi-agent systems with measurement noises*, Journal of Systems Science and Complexity, 2010, 23(1), 35–49.

[27] T. Li, J. Zhang, *Consensus conditions of multi-agent systems with time-varying topologies and stochastic communication noises*, IEEE Transactions on Automatic Control, 2010, 55(9), 2043–2057.

[28] Y. Ni, X. Li, *Consensus seeking in multi-agent systems with multiplicative measurement noises*, Systems and Control Letters, 2013, 62(5), 430–437.

[29] A. Hu, J. Cao, M. Hu, L. Guo, *Event-triggered consensus of multi-agent systems with noises*, Journal of the Franklin Institute, 2015, 352(9), 3489–3503.

[30] W. Ren, R. W. Beard, *Distributed Consensus in Multi-vehicle Cooperative Control Theory and Applications*, Springer-Verlag, London, 2008.

[31] E. Garcia, Y. Cao, D. Casbeer, *An event-triggered control approach for the leader-tracking problem with heterogeneous agents*, International Journal of Control, 2018, 91(5), 1209–1221.

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