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Adaptive output feedback formation tracking for a class of multiagent systems with quantized input signals

Key words: Multiagent system; Adaptive output feedback; Formation tracking; Hysteretic quantizer

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Motivations

1. Formation tracking control is a significant aspect in multiagent system control problems. It has widely applications in both military and civilian sectors, such as source seeking, traffic control, and surveillance.

2. The challenges in formation control design are mainly caused by the complicated agent dynamics, such as nonlinearities, uncertainties ,and immeasurable states.

3. In multiagent systems, signals are always processed by quantizer before being transmitted via networks. Strong nonlinear characteristics introduced by quantization can cause the system to have worse control performance or even instability.

Main ideas

1. An exact dynamic model is not required. Unknown parameters and immeasurable states in the agents are well solved through an adaptive output feedback control technique and a dynamic high-gain observer.

2. Taking the quantized input signals into account, the hysteretic quantizer is introduced to the systems to avoid chattering. In addition, the controller complexity is significantly reduced by the design of less dynamic gains.

3. With the proposed strategy, the multiagent system formation shape is achieved and maintained when systems asymptotically track the reference trajectory.

1. Nonlinear model of agent dynamics

$$\begin{cases} M_i \ddot{p}_{ix} + B_i \dot{p}_{ix} = q(u_{ix}) - k_{i,\mathrm{d}} \dot{p}_{ix}, \\ M_i \ddot{p}_{iy} + B_i \dot{p}_{iy} = q(u_{iy}) - k_{i,\mathrm{d}} \dot{p}_{iy}, \end{cases}$$

$\Rightarrow$

$$\begin{cases} \dot{x}_{ix,1} = x_{ix,2} + d_{ix,1}, \\ \dot{x}_{ix,2} = q(u_{ix}) + \theta_i x_{ix,2} + d_{ix,2}, \\ \overline{p}_{ix} = M_i p_{ix} = x_{ix,1}, \end{cases}$$

$$\begin{cases} \dot{x}_{iy,1} = x_{iy,2} + d_{iy,1}, \\ \dot{x}_{iy,2} = q(u_{iy}) + \theta_i x_{iy,2} + d_{iy,2}, \\ \overline{p}_{iy} = M_i p_{iy} = x_{iy,1}, \end{cases}$$

$\Rightarrow$

$$\begin{cases} \dot{x}_1 = x_2 + \phi_1(\boldsymbol{x}, \theta^*(t)) + d_1(t), \\ \dot{x}_2 = x_3 + \phi_2(\boldsymbol{x}, \theta^*(t)) + d_2(t), \\ \vdots \\ \dot{x}_n = q\left(v(t)\right) + \phi_n(\boldsymbol{x}, \theta^*(t)) + d_n(t), \\ y = x_1, \end{cases}$$

Hysteretic quantizer

$$q(v(t)) = \begin{cases} u_i \operatorname{sgn}(v), & \dfrac{u_i}{1+\delta} < |v| \le u_i, \dot{v} < 0, \text{ or } u_i < |v| \le \dfrac{u_i}{1-\delta}, \dot{v} > 0, \\ u_i(1+\delta)\operatorname{sgn}(v), & u_i < |v| \le \dfrac{u_i}{1-\delta}, \dot{v} < 0, \text{ or } \dfrac{u_i}{1-\delta} < |v| \le \dfrac{u_i(1+\delta)}{1-\delta}, \dot{v} > 0, \\ 0, & 0 < |v| \le \dfrac{u_{\min}}{1+\delta}, \dot{v} < 0, \text{ or } \dfrac{u_{\min}}{1+\delta} < |v| \le u_{\min}, \dot{v} > 0, \\ q(v(t^-)), & \dot{v} = 0. \end{cases}$$

2. Output feedback controller design

$$\begin{cases} \dot{\hat{x}}_1 = \hat{x}_2 + l a_1 (y - y_r - \hat{x}_1), \\ \dot{\hat{x}}_2 = \hat{x}_3 + l^2 a_2 (y - y_r - \hat{x}_1), \\ \quad \vdots \\ \dot{\hat{x}}_n = q(v(t)) + l^n a_n (y - y_r - \hat{x}_1), \\ v = -l^n k_1 \hat{x}_1 - l^{n-1} k_1 \hat{x}_1 - \ldots - l k_n \hat{x}_n, \end{cases}$$

State observer

Control input

Dynamic gain

$$\dot{l} = g(l, y, \hat{x}_1, y_r) = \max\left\{ -\alpha_1 l^2 + \alpha_2 l \left(1 + |y|^p\right)^2, \; (y - y_r - \hat{x}_1)^2 + \hat{x}_1^2 - \varsigma, \; 0 \right\},$$

Formation tracking illustration

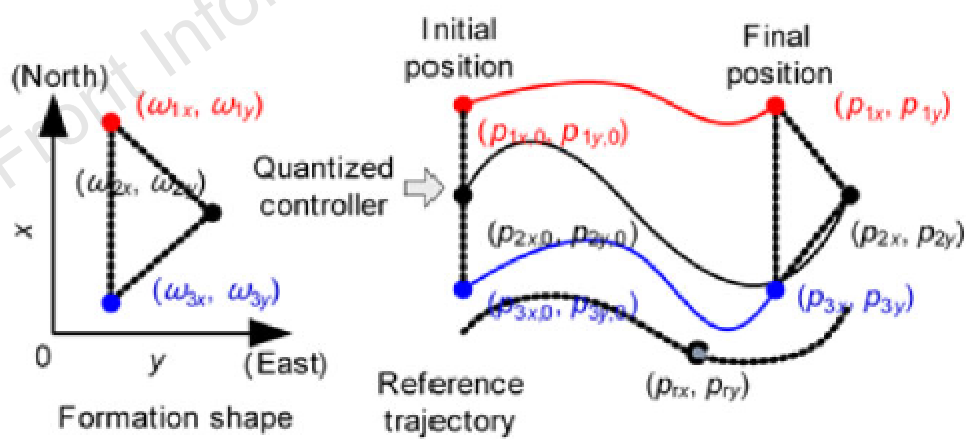

Fig. 1 Multiagent formation illustration

3. Stability analysis

Theorem 1 Under the condition that Assumptions 1 and 2 hold and the parameter μ in Lemma 2 is set to satisfy $0<2\mu p<1$, a closed-loop system is considered that consists of plant (3), hysteretic quantizer (5), output feedback controller (9), and update law (10). If the quantizer coefficient δ satisfies

$$2\delta\|\boldsymbol{P}_2\boldsymbol{b}\|\|\boldsymbol{k}\| \le \sigma_1, \tag{12}$$

then all the states in the closed-loop system remain bounded, and the tracking error $y-y_r$ can be steered to within a small neighborhood of the origin.

Tracking error

$$\begin{cases} \boldsymbol{e} = \boldsymbol{x} - \boldsymbol{Y}_r - \hat{\boldsymbol{x}}, \\ \boldsymbol{Y}_r = [y_r, 0, 0, \ldots, 0]^{\mathrm{T}}. \end{cases}$$

Transformation

$$\bar{e}_i = \frac{e_i}{l^{i-1+\mu}}, \quad \bar{x}_i = \frac{\hat{x}_i}{l^{i-1+\mu}}$$

$$\begin{cases} \dot{\bar{\boldsymbol{x}}} = l(\boldsymbol{A} - \boldsymbol{b}\boldsymbol{k}^{\mathrm{T}})\bar{\boldsymbol{x}} + l\boldsymbol{a}\bar{e}_1 - \frac{\dot{l}}{l}(\mu\boldsymbol{I} + \boldsymbol{D})\bar{\boldsymbol{x}}, \\ \dot{\bar{\boldsymbol{e}}} = l(\boldsymbol{A} - \boldsymbol{a}\boldsymbol{c}^{\mathrm{T}})\bar{\boldsymbol{e}} + \boldsymbol{L}^{-1}(\boldsymbol{\Phi} + \boldsymbol{d} - \dot{\boldsymbol{Y}}_r)\frac{\dot{l}}{l}(\mu\boldsymbol{I} + \boldsymbol{D})\bar{\boldsymbol{e}}, \end{cases}$$

Lyapunov function

$$V = \eta\bar{\boldsymbol{e}}^{\mathrm{T}}\boldsymbol{P}_1\bar{\boldsymbol{e}} + \bar{\boldsymbol{x}}^{\mathrm{T}}\boldsymbol{P}_2\bar{\boldsymbol{x}},$$

Time derivative

$$\dot{V} \le -\frac{1}{4}\sigma_1 l\|\bar{\boldsymbol{e}}\|^2 - \frac{1}{2}\sigma_1 l\|\bar{\boldsymbol{x}}\|^2 + \frac{u_{\min}^2}{l^{2(n-1+\mu)}} + \frac{1}{l^{2\mu}}\tilde{d} + 2\eta^2 n^4\|\boldsymbol{P}_1\|^2\theta^2\|\bar{\boldsymbol{e}}\|^2.$$

Major results

It can be seen that all the agents can track the reference trajectory and build the formation shape at the same time. Fig. 3 suggests that the dynamic gains are bounded.

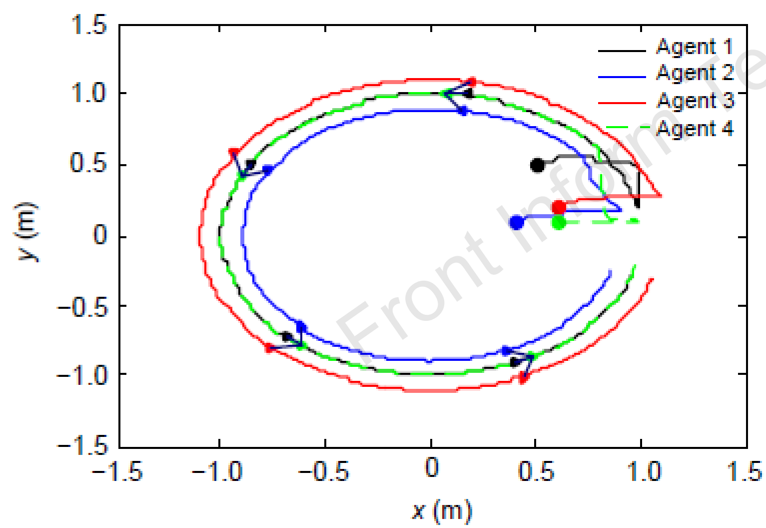

Fig. 2 Formation trajectory

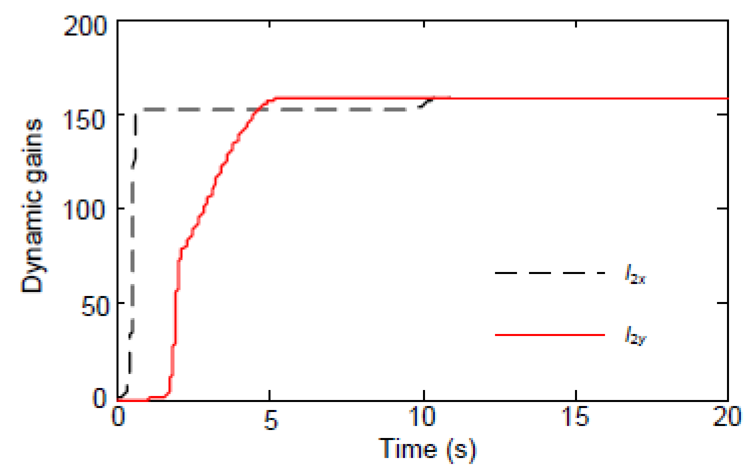

Fig. 3 Dynamic gain *l*

Major results

We can figure out that the tracking errors can converge to a small neighborhood of the origin. It proves that agents can maintain the formation shape and track the reference trajectory.

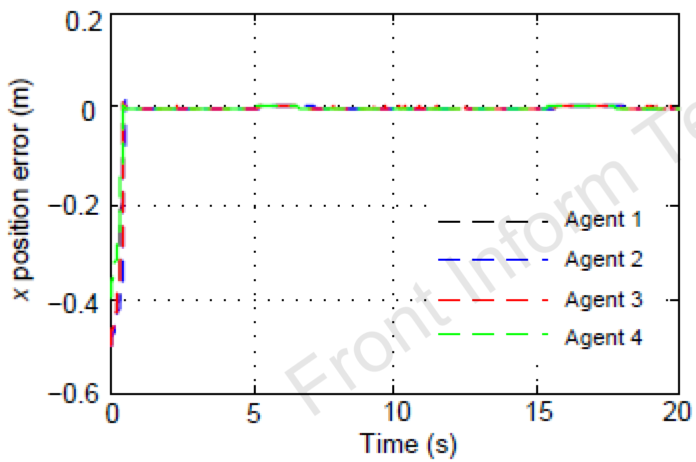

Fig. 4 Trajectory tracking errors x_e

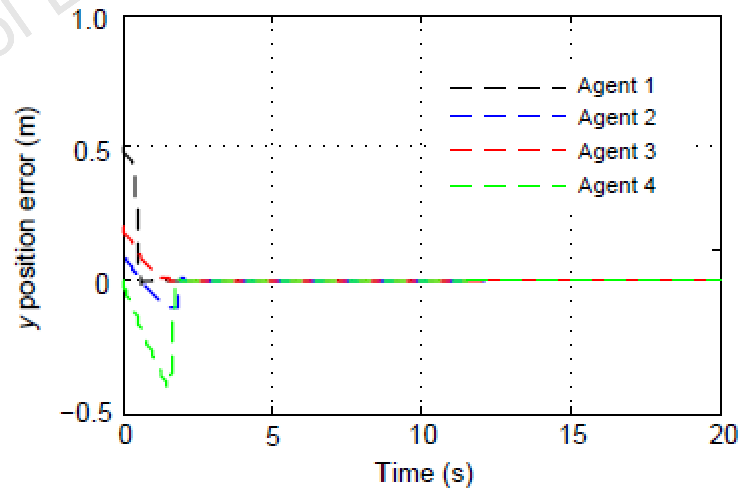

Fig. 5 Trajectory tracking errors y_e

Major results

Fig. 6 shows that the quantized inputs can highly reduce the input signal, and Fig. 7 shows that the state estimates are bounded.

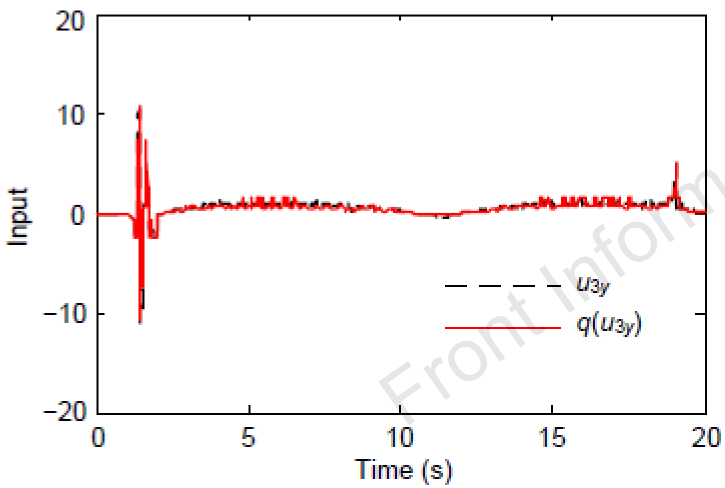

Fig. 6 The 3rd agent quantized input

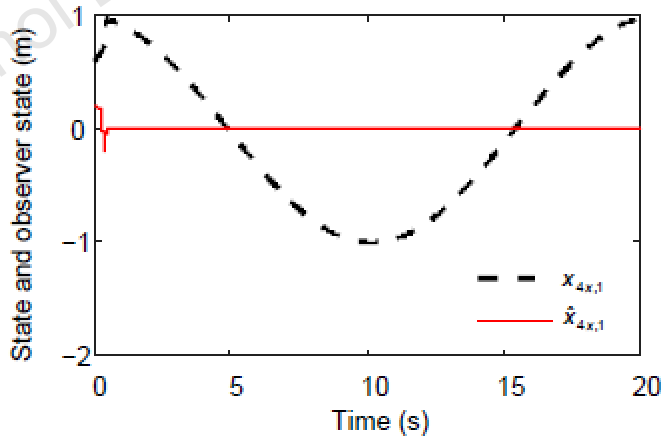

Fig. 7 State $x_{4x,1}$ and its estimate $\hat{x}_{4x,1}$

Conclusions

1. An adaptive output feedback controller has been presented for formation tracking of multiagent systems with uncertainties and quantized input signals based on a hysteretic quantizer and a high-gain dynamic observer.

2. The system is consist of multiple nonlinear agents that are established with immeasurable states and unknown parameters.

3. With the proposed control approach, all the system signals are bounded and all the agents can maintain the prescribed formation shape while tracking the reference trajectory with tracking errors within a small neighborhood of the origin.