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Finite-time coordinated path-following control of leader-following multi-agent systems

Key words: Finite-time; Coordinated path-following; Multi-agent systems; Barrier function

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Motivation

1. In the application scenarios such as oceanic and planetary explorations, to achieve better performance of multi-agent systems, unmanned systems are required to simultaneously follow a set of given orbits with a desired formation, that is, the coordinated path-following control problem.
2. In the area of coordinated path-following control, most scholars focused on the asymptotic stability of the resulting multi-agent systems, and the coordinated path-following control problem within a finite settling time is still unsolved.

Main idea

1. Decouple the whole system as a path-following subsystem and a formation subsystem;
2. Design the control law by backstepping to achieve finite-time path-following along the given orbits;
3. Design the control law by backstepping to achieve finite-time formation along the given orbits;
4. According to steps 1 and 2, give the control law and show the finite-time convergence of the coordinated path-following control system.

Method

Path-following controller design

1. Consider the path-following subsystem consisting of the following equations:

$$\dot{\lambda}_i = \|\nabla \lambda_i\| \, v_{N_i}$$

$$\dot{v}_{N_i} = u_{N_i} + \Delta_{N_i}$$

2. Consider the path-following candidate Lyapunov function as

$$V_{\mathrm{P}} = \sum_{i=1}^{n} \Psi_i(\lambda_i) + \gamma_1 \sum_{i=1}^{n} \int_{\hat{v}_{N_i}}^{v_{N_i}} \left(\tau^{\alpha} - \hat{v}_{N_i}^{\alpha}\right)^{2-\frac{1}{\alpha}} \mathrm{d}\tau$$

3. Let the virtual control $\hat{v}_{N_i}$ be $\hat{v}_{N_i} = -k_1 \left(\nabla \Psi_i\right)^{\frac{1}{\alpha}}$.

4. Design u_{N_i} by the backstepping method.

Method (Cont'd)

Coordinated formation controller design

1. Consider the formation subsystem consisting of the following equations:

$$\dot{v}_{T_i} = u_{T_i} + \Delta_{T_i}$$

$$\dot{\varsigma}_i = \sum_{j=0}^{n} a_{ij} \left(\frac{\partial \xi_i}{\partial s_i} v_{T_i} + \Delta_{\xi_i} - \frac{\partial \xi_j}{\partial s_j} v_{T_j} - \Delta_{\xi_j} \right)$$

2. Consider the coordinated formation candidate Lyapunov function as

$$V_{\mathrm{F}} = \frac{1}{2} \sum_{i=1}^{n} \varsigma_i^2 + \gamma_2 \sum_{i=1}^{n} \int_{\hat{v}_{T_i}}^{v_{T_i}} \left(\tau^{\alpha} - \hat{v}_{T_i}^{\alpha} \right)^{2-\frac{1}{\alpha}} \mathrm{d}\tau$$

3. Let the virtual control $\hat{v}_{T_i}$ be $\hat{v}_{T_i} = -\left(\frac{\partial \xi_i}{\partial s_i} \right)^{-1} k_3 {\varsigma_i}^{\frac{1}{\alpha}}$.

4. Design u_{T_i} by the backstepping method.

Major results

Theorem 3 Suppose that the initial positions of vehicles are such that $p_i(0) \in \Omega_i$. Assume moreover that Assumption 1 holds. For $i = 1, 2, \cdots, n$, the finite-time coordinated path-following control problem is solved by the coordinated path-following control:

$$u_i = \begin{bmatrix} N_i^{\mathrm{T}} \\ T_i^{\mathrm{T}} \end{bmatrix}^{-1} \begin{bmatrix} u_{N_i} \\ u_{T_i} \end{bmatrix}, \tag{47}$$

where u_{N_i} and u_{T_i} are as given in Eqs. (19) and (41), respectively.

Major results (static case)

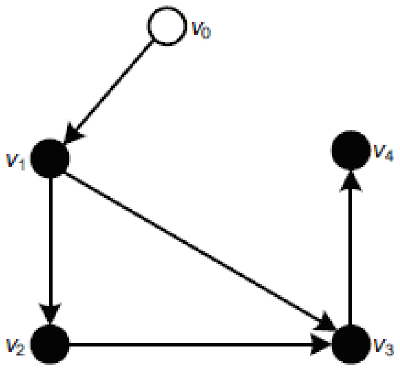

Fig. 2 A directed topology

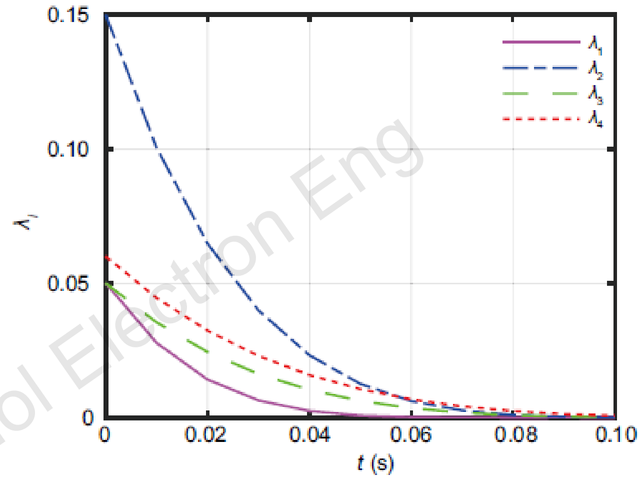

Fig. 4 Path-following errors in the static virtual leader case

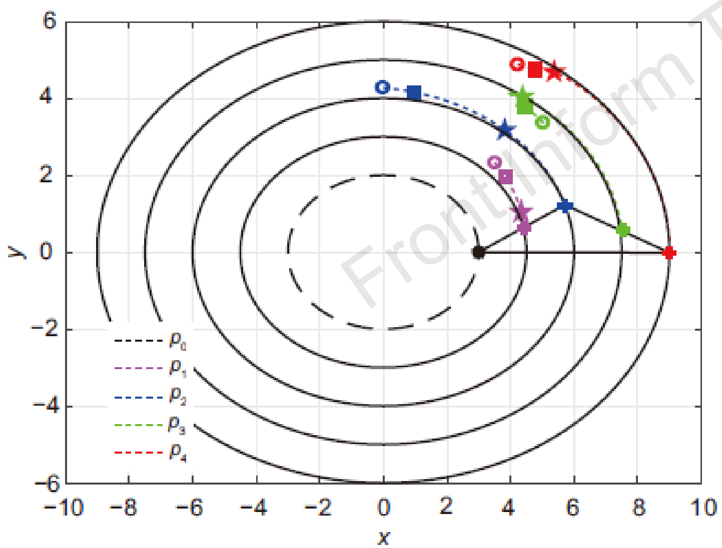

Fig. 3 Motion of the agents in the static virtual leader case

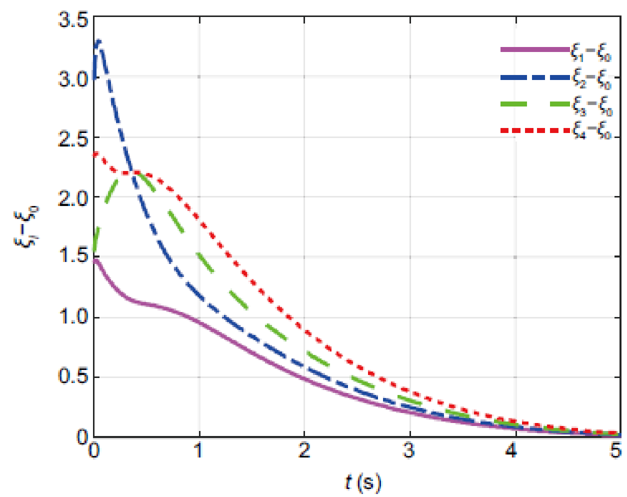

Fig. 5 Formation errors in the static virtual leader case

Major results (dynamic case)

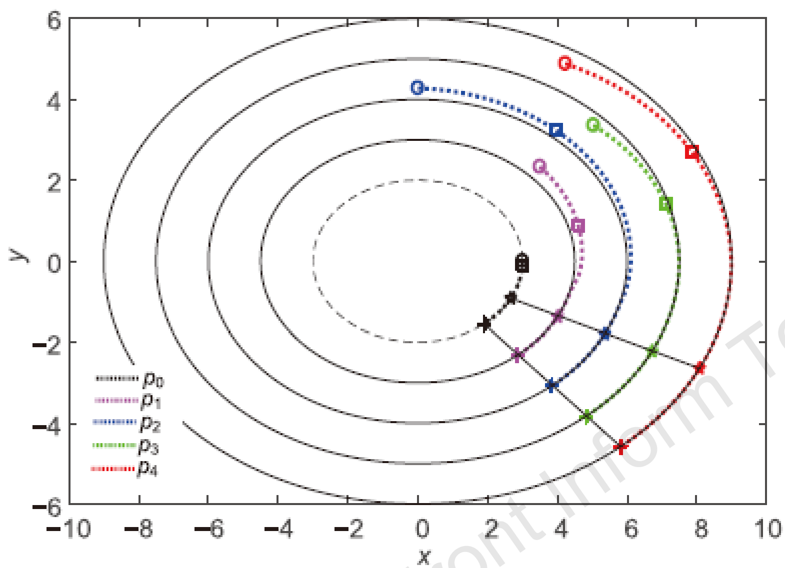

Fig. 6 Motion of the agents in the dynamic virtual leader case

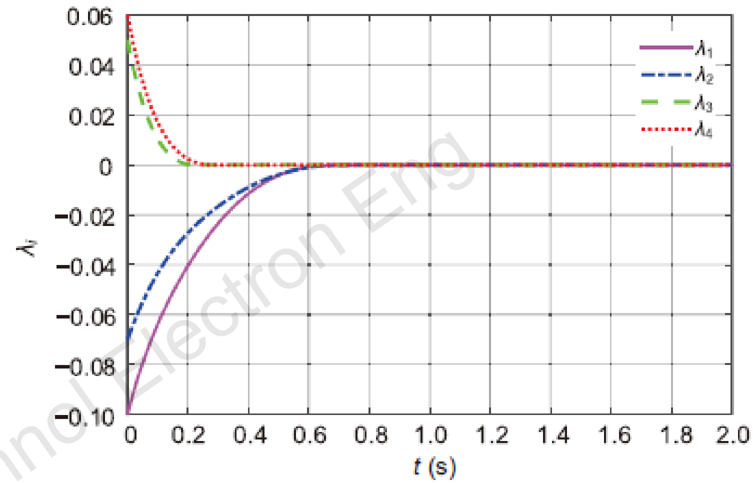

Fig. 7 Path-following errors in the dynamic virtual leader case

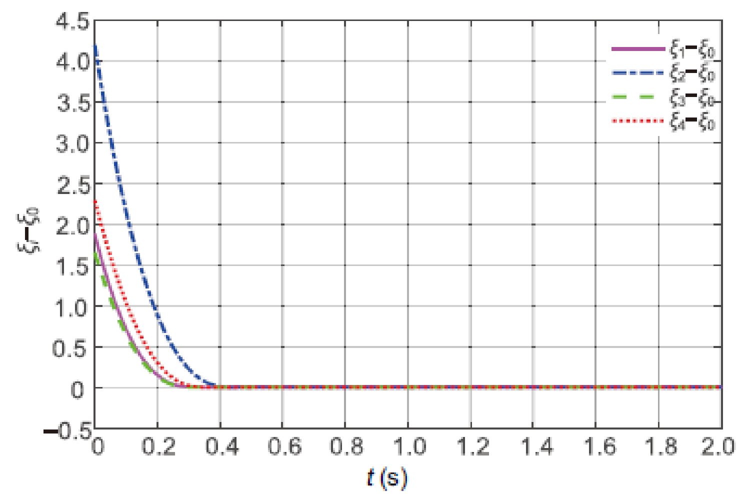

Fig. 8 Formation errors in the dynamic virtual leader case

Conclusions

1. A continuous feedback method to solve the finite-time coordinated path-following control problem is presented, where the topology for the virtual leader and followers is directed.

2. Conditions on the control gains to guarantee that the path-following errors and the formation errors converge to zeros in finite time are presented.

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