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Distributed unmanned flocking inspired by collective motion of pigeon flocks

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1. Introduction

- Compared with a single UAV, the UAV swarm system has more exceptional performance, higher reliability, better adaptability, and lower cost through concentrating resources and complementing advantages.

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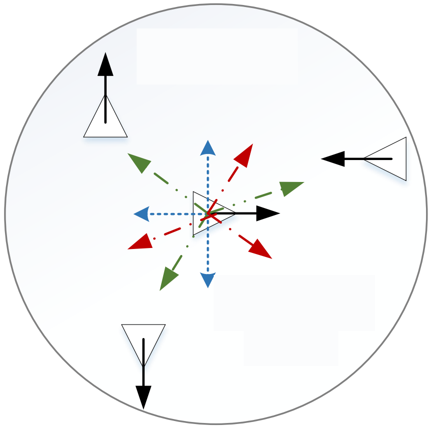
1. Introduction

- The mechanism in bird flocks inspires the design of the UAV flocking control algorithm.
- The existing methods are only for homogeneous groups or groups with a single leader and could not be applied to the UAV flocking control problem under multiple dominant individuals' conditions.

Bird flocks



Boid model

Swarm inspired by birds

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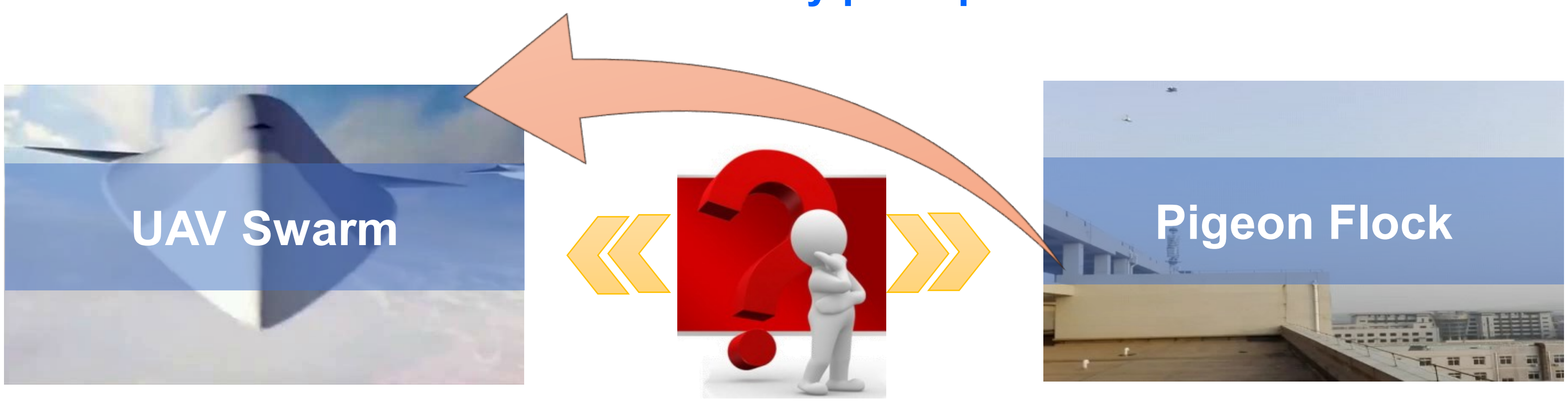
1. Introduction

- For solving this problem, this paper proposed a UAV flocking control algorithm for a heterogeneous swarm with multiple dominant individuals by studying the mechanism in the collective motion of pigeon flocks.

Core idea & key principle



similarities and differences & relations

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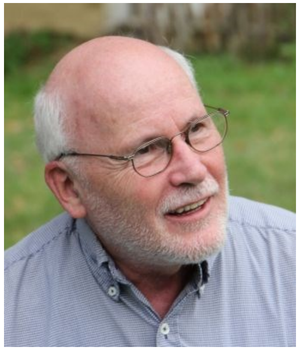
1. Introduction

➤ Although the qualitative analysis makes the pigeon swarm intelligence mechanism gradually limpid, it brings obstacles to reveal the simple rules behind pigeon flocks' orderly movement due to the lack of clear description of interaction patterns and switching relationships.



Eötvös Loránd University
Tamás Vicsek

- When flying along a smooth trajectory, individuals will tend to follow their neighbors' average flight direction.
- When suddenly turning, they will tend to follow their leaders.

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[1] Zhang HT, Chen ZY, Vicsek T, et al. *Sci. Rep.*, 2014, 4: 5805.
[2] Chen D, Vicsek T, Liu X, et al. *Europhys. Lett.*, 2016, 114(6): 60008.

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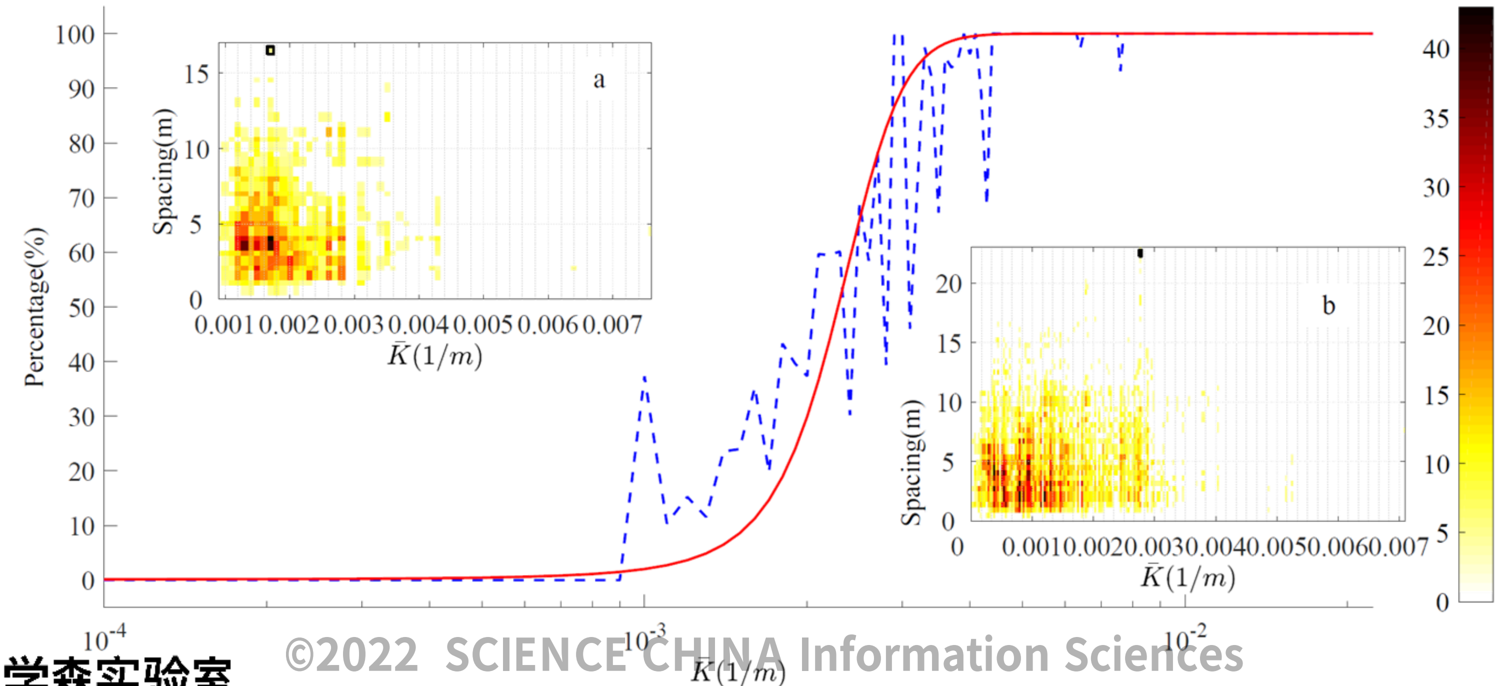
2. Dual-pattern mechanism of pigeons

- The homing flight data of pigeons analyzed in this paper are derived from hf2 in Ref. [7].
- The percentage of hierarchical interaction patterns increases roughly in an S-shape with the group trajectory curvature.



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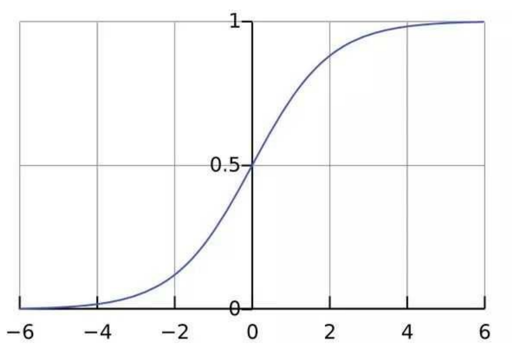
3. Collective motion model of pigeons

- A collective motion model will be established based on the above dual-pattern mechanism to describe pigeon flocks' homing flight.
- The model's unique characteristics lie in the quantitative description of the switching relationship between two interactive patterns of pigeon flocks.

Logistic function



The probability that the pigeon flock adopts the hierarchical interaction pattern:

$$p_{\mathrm{h}} = 1/\left(1+\alpha e^{-\beta \bar{K}^{t}}\right)$$

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3. Collective motion model of pigeons

- Individuals will generate control vector based on neighbor interaction information and target locations to synchronize with neighbors, maintain a desired distance with neighbors, and reach the target position vector with a maximum allowable error:

$$\begin{cases} \dot{\boldsymbol{x}}_i = \boldsymbol{v}_i \\ \dot{\boldsymbol{v}}_i = \boldsymbol{u}_i \end{cases}$$

$$\boldsymbol{u}_i = \begin{cases} -K^{\mathrm{F}} \sum_{j \in \mathcal{N}_i^1} \nabla_{\boldsymbol{x}_i} V_{ij}^{\mathrm{F}}\left(\|\boldsymbol{x}_{ij}\|\right) - K^{\mathrm{T}} \nabla_{\boldsymbol{x}_i} V_i^{\mathrm{T}}\left(\|\boldsymbol{x}_i - \boldsymbol{x}_{\mathrm{T}}\|\right) - K^{\mathrm{V}} w \sum_{j \in \mathcal{N}_i} \boldsymbol{v}_{ij}, & i \in S_{\mathrm{d}} \\ -K^{\mathrm{F}} \sum_{j \in \mathcal{N}_i^1} \nabla_{\boldsymbol{x}_i} V_{ij}^{\mathrm{F}}\left(\|\boldsymbol{x}_{ij}\|\right) - K^{\mathrm{V}} \left(\sum_{j \in \mathcal{N}_i \setminus S_{\mathrm{d}}} \boldsymbol{v}_{ij} + w \sum_{j \in \mathcal{N}_i \cap S_{\mathrm{d}}} \boldsymbol{v}_{ij} \right), & i \notin S_{\mathrm{d}} \end{cases}$$

$i \in S_{\mathrm{d}}$ ⇨ Dominant individuals

$i \notin S_{\mathrm{d}}$ ⇨ Ordinary individuals

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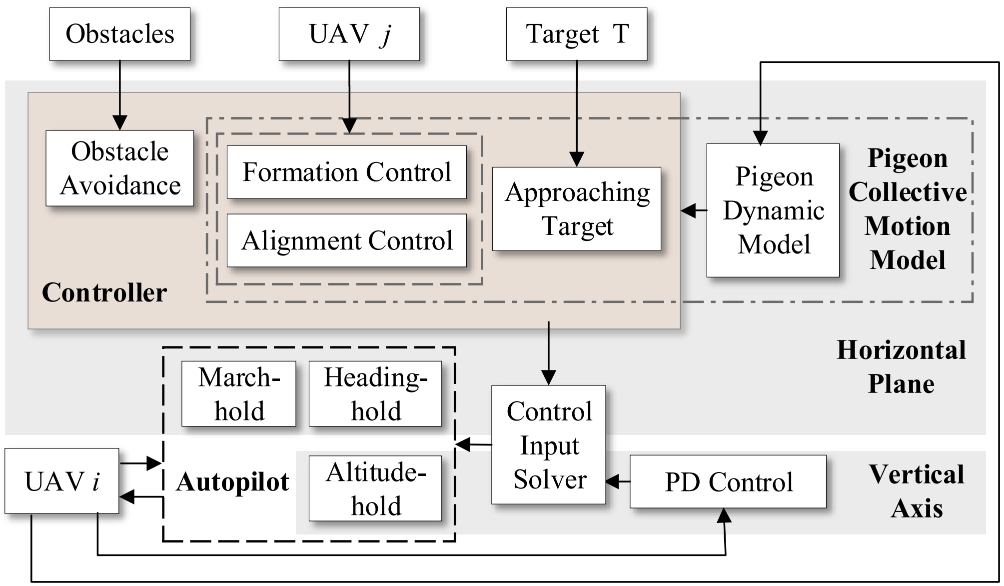
4. UAV flocking algorithm

➢ The UAV flocking control is decoupled into the control on the horizontal plane and the vertical direction.



UAV flocking frame based on pigeon collective motion model

- On the horizontal plane, each UAV not only carries out the formation, alignment, and approaching target based on the collective motion model of pigeon flocks but also evades obstacles.
- In the vertical direction, each UAV attempts to remain at the desired altitude.

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4. UAV flocking algorithm

➢ **Algorithm 1-Step 1:**

- Transform UAV dynamics into the second-order agent model similar to that of pigeons.
- Choose the interaction pattern based on the probability.

➢ **Algorithm 1-Step 2:**

Calculate the current control input vector on the horizontal plane:

$$\boldsymbol{u}_i=\begin{cases}-K^{\mathrm{F}}\sum\limits_{j\in\mathcal{N}_i^1}\nabla_{\boldsymbol{x}_i}V_{ij}^{\mathrm{F}}\left(\left\|\boldsymbol{x}_{ij}\right\|\right)-K^{\mathrm{O}}\sum\limits_{j=1}^{N_{\mathrm{O}}}\nabla_{\boldsymbol{x}_i}V_i^{\mathrm{O}}\left(\left\|\boldsymbol{x}_i-\boldsymbol{x}_j^{\mathrm{O}}\right\|\right)-K^{\mathrm{T}}\nabla_{\boldsymbol{x}_i}V_i^{\mathrm{T}}\left(\left\|\boldsymbol{x}_i-\boldsymbol{x}_{\mathrm{T}}\right\|\right)-K^{\mathrm{V}}w\sum\limits_{j\in\mathcal{N}_i}\boldsymbol{v}_{ij}, & i\in S_{\mathrm{d}}\\ -K^{\mathrm{F}}\sum\limits_{j\in\mathcal{N}_i^1}\nabla_{\boldsymbol{x}_i}V_{ij}^{\mathrm{F}}\left(\left\|\boldsymbol{x}_{ij}\right\|\right)-K^{\mathrm{O}}\sum\limits_{j=1}^{N_{\mathrm{O}}}\nabla_{\boldsymbol{x}_i}V_i^{\mathrm{O}}\left(\left\|\boldsymbol{x}_i-\boldsymbol{x}_j^{\mathrm{O}}\right\|\right)-K^{\mathrm{V}}\left(\sum\limits_{j\in\mathcal{N}_i\setminus S_{\mathrm{d}}}\boldsymbol{v}_{ij}+w\sum\limits_{j\in\mathcal{N}_i\cap S_{\mathrm{d}}}\boldsymbol{v}_{ij}\right), & i\notin S_{\mathrm{d}}\end{cases}$$

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4. UAV flocking algorithm

➢ **Algorithm 1-Step 3:**

Generate current control input in the vertical direction:

$$u_{\mathrm{h}} = -K^{\mathrm{P}}\left(h_i - h_{\mathrm{exp}}\right) - K^{\mathrm{D}}\zeta_i$$

➢ **Algorithm 1-Step 4:**

- Produce the current autopilot control input:

$$\begin{cases} V_{\mathrm{C}}^i = \tau_{\mathrm{V}}\left(\boldsymbol{u}_i^1 \cos\psi_i + \boldsymbol{u}_i^2 \sin\psi_i\right) + V_i \\ \psi_{\mathrm{C}}^i = \tau_{\psi}\left(\boldsymbol{u}_i^2 \cos\psi_i - \boldsymbol{u}_i^1 \sin\psi_i\right) / V_i + \psi_i \\ h_{\mathrm{C}}^i = h_i + \left(\tau_{\mathrm{a}} + \tau_{\mathrm{b}}\right)\xi_i + \tau_{\mathrm{a}}\tau_{\mathrm{b}} u_{\mathrm{h}} \end{cases}$$

- Gain the UAV state at the next time by the UAV model

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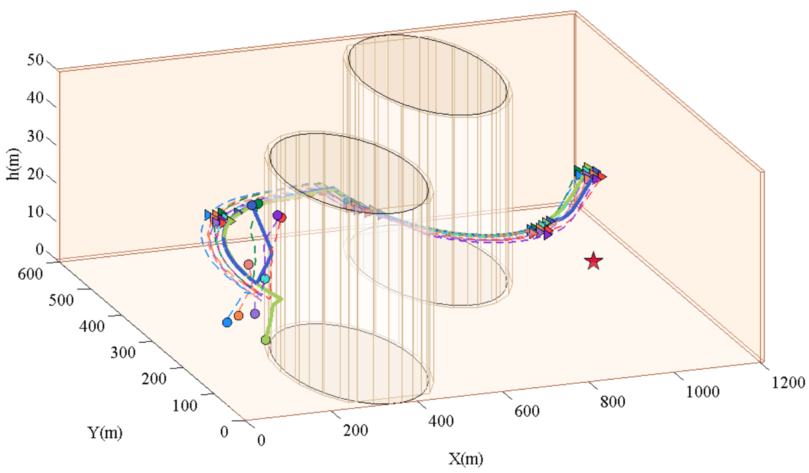
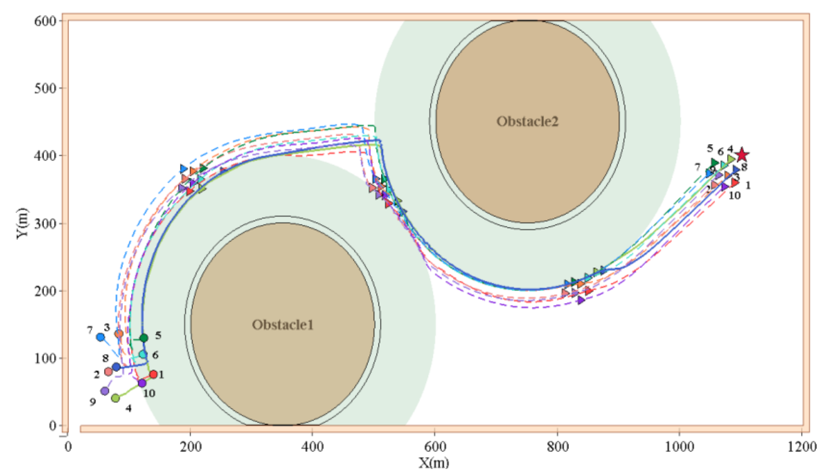
5. Simulation results

- A swarm of 10 UAVs are assigned to reach a target as a whole under the environment with obstacles.
- The UAV swarm could gradually converge to the same altitude and reach the target as a whole without clustering based on **Algorithm 1**.



3D view of flight trajectories



Top view of flight trajectories

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6. Conclusion

- An S-shaped curve of interaction pattern switching is obtained to give the quantitative relationship between the interaction pattern of pigeon flocks and the curvature of group trajectories.
- A heterogeneous and multi-modal collective motion model is established to better reflect the natural life system’s characteristics.
- A distributed UAV flocking algorithm is proposed to guide a UAV swarm with multiple dominant individuals to approach a target synchronously without collisions.

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Thanks for your attention!

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