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A collaborative target tracking algorithm for multiple UAVs with inferior tracking capabilities

Key words: Collaborative target tracking; Intent estimation; MDA-Voronoi diagram; Multi-UAV; Inferior tracking capability

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Motivation

- For UAVs, how to achieve effective tracking through cooperation without superior tracking capabilities is a difficult problem.
- In many studies, the UAVs have wide enough sensing ranges, the target motion is simple, and the UAVs move faster than the targets. In addition, there is less emphasis on target intelligence and the trade-off between sensing performance and the number of UAVs.
- If the target moves faster than the tracker or the target motion trajectory has a certain decoy, passive tracking is difficult to execute well, and it is easy to lose the target or take more detours. Thus, the active tracking method based on effective prediction and cooperative preparation in advance has better performance.

Main idea

- We propose an intention estimation mechanism based on the environment and target trajectory features to reduce the tracking cost.
- We propose a novel Voronoi diagram, which divides the area with obstacles according to the minimum reachable distance and the minimum steering angle of each UAV, and the tracking strategies of the UAVs are designed to effectively reduce the tracking gaps to improve the target sensing time.
- We use the Nash *Q*-learning method to design the UAVs' collaborative tracking strategy, considering factors such as collision avoidance, maneuvering constraints, tracking cost, sensing performance, and path overlap. The optimal action strategies are obtained as the control input of the UAVs.

Method

1. We design a novel trajectory feature extraction method with least dimension and maximum coverage constraints, which not only reflects the trajectory features, but also enables the UAVs to have the maximum target coverage in less time.

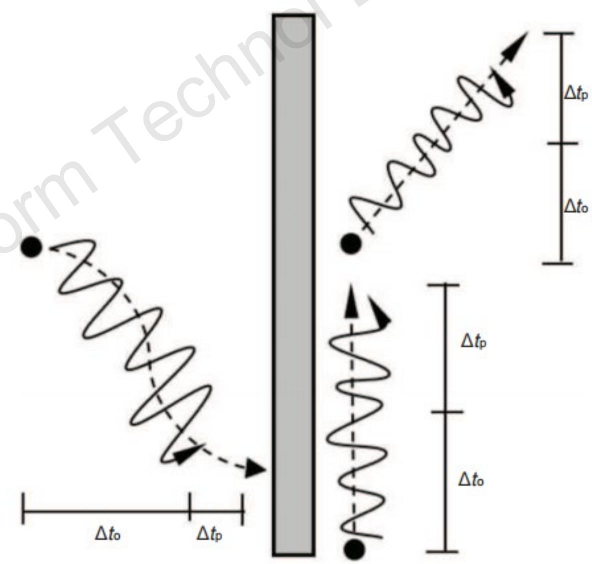

Fig. 3 The target escapes with a barrier cover

Method (Cont'd)

2. We propose a novel Voronoi diagram, which divides the area with obstacles according to the minimum reachable distance and the minimum steering angle of each UAV. The tracking strategies of the UAVs are designed to effectively reduce the tracking gaps.

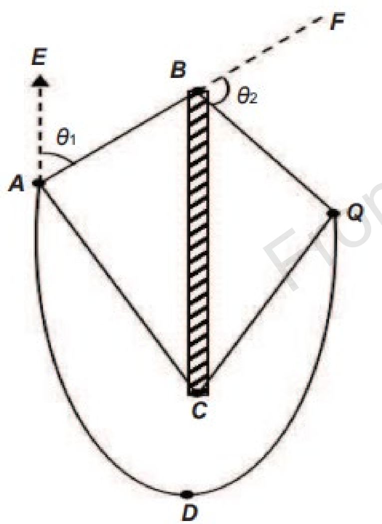

Fig. 4 MDA-Voronoi diagram

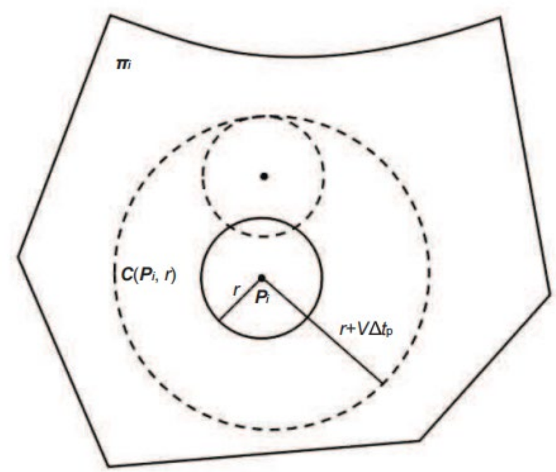

Fig. 5 Extreme coverage hole with respect to U_i

Method (Cont'd)

3. We use the Nash Q-learning method to design the UAVs' collaborative tracking strategy, considering factors such as collision avoidance, maneuvering constraints, tracking cost, sensing performance, and path overlap. By designing the reward mechanism, the optimal action strategies are obtained as the control input of the UAVs.

Nash Q-learning

$$\begin{aligned} &Q^i(\boldsymbol{s}_t, \boldsymbol{a}_t) \\ &\leftarrow Q^i(\boldsymbol{s}_t, \boldsymbol{a}_t) + \sigma[r_t^i + \gamma \mathrm{Nash}Q^i(\boldsymbol{s}_{t+1}) - Q^i(\boldsymbol{s}_t, \boldsymbol{a}_t)], \\ &\mathrm{Nash}Q^i(\boldsymbol{s}_{t+1}) = \pi^1(\boldsymbol{s}_{t+1}) \cdots \pi^N(\boldsymbol{s}_{t+1}) Q^i(\boldsymbol{s}_{t+1}), \end{aligned} \quad (1)$$

State space

$$S = \begin{cases} 1, & 0 < d_{ij}(k) \le \bar{d}_1, \\ 2, & \bar{d}_1 < d_{ij}(k) \le \bar{d}_2, \\ \vdots & \qquad \vdots \\ H, & \bar{d}_{H-1} < d_{ij}(k) \le \bar{d}_H, \end{cases} \quad (2)$$

Action space $\mathrm{A} = \{0°, \pm 15°, \pm 30°, \pm 45°, \pm 60°, \pm 75°, \pm 90°\}.$ (3)

Major results

Scenario 1

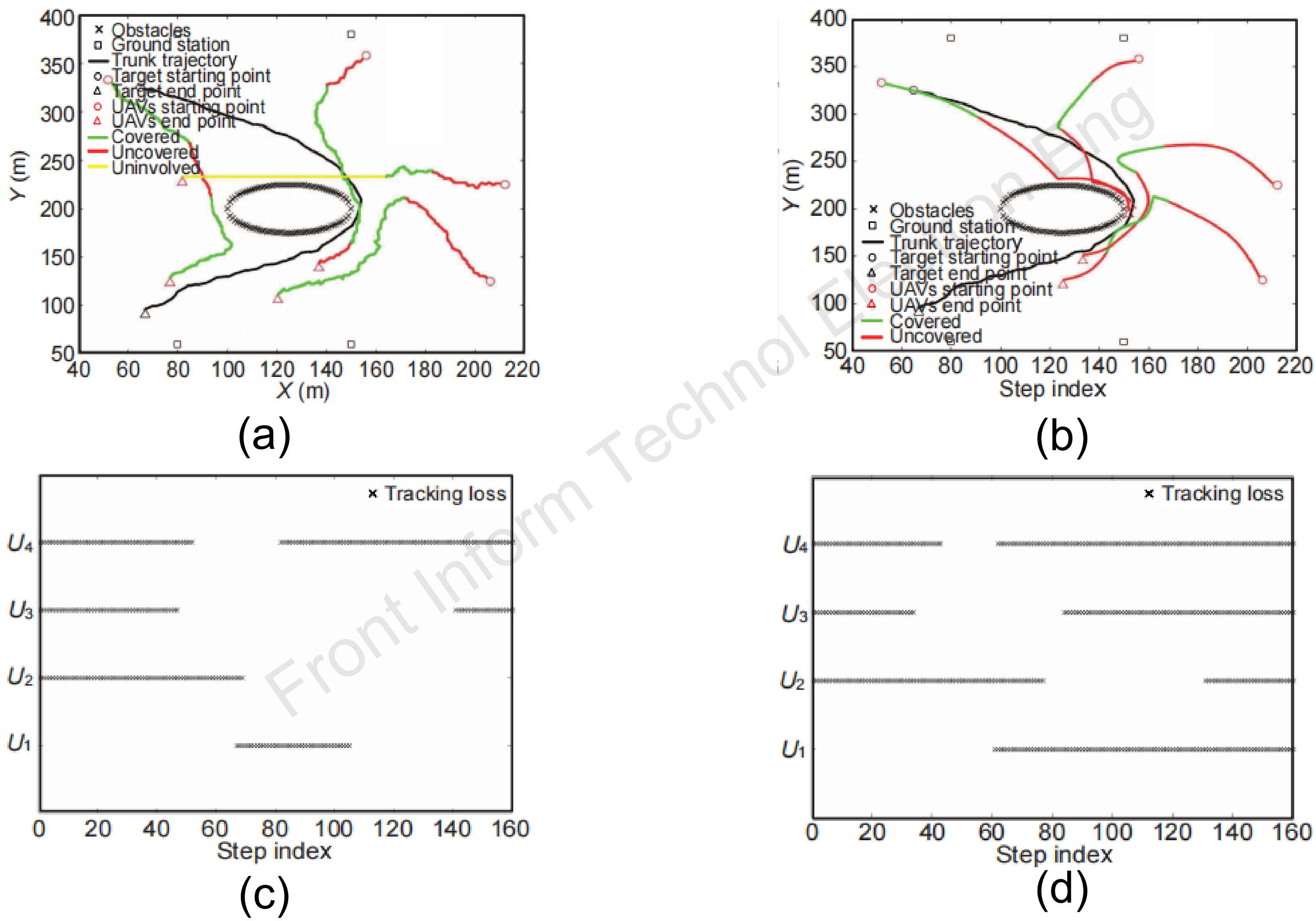

Fig. 7 Simulation results of scenario 1: (a) UAVs' tracking trajectories; (b) passive tracking trajectories of the UAVs; (c) tracking loss of the proposed method; (d) tracking loss of the passive method

Major results (Cont'd)

Scenario 2

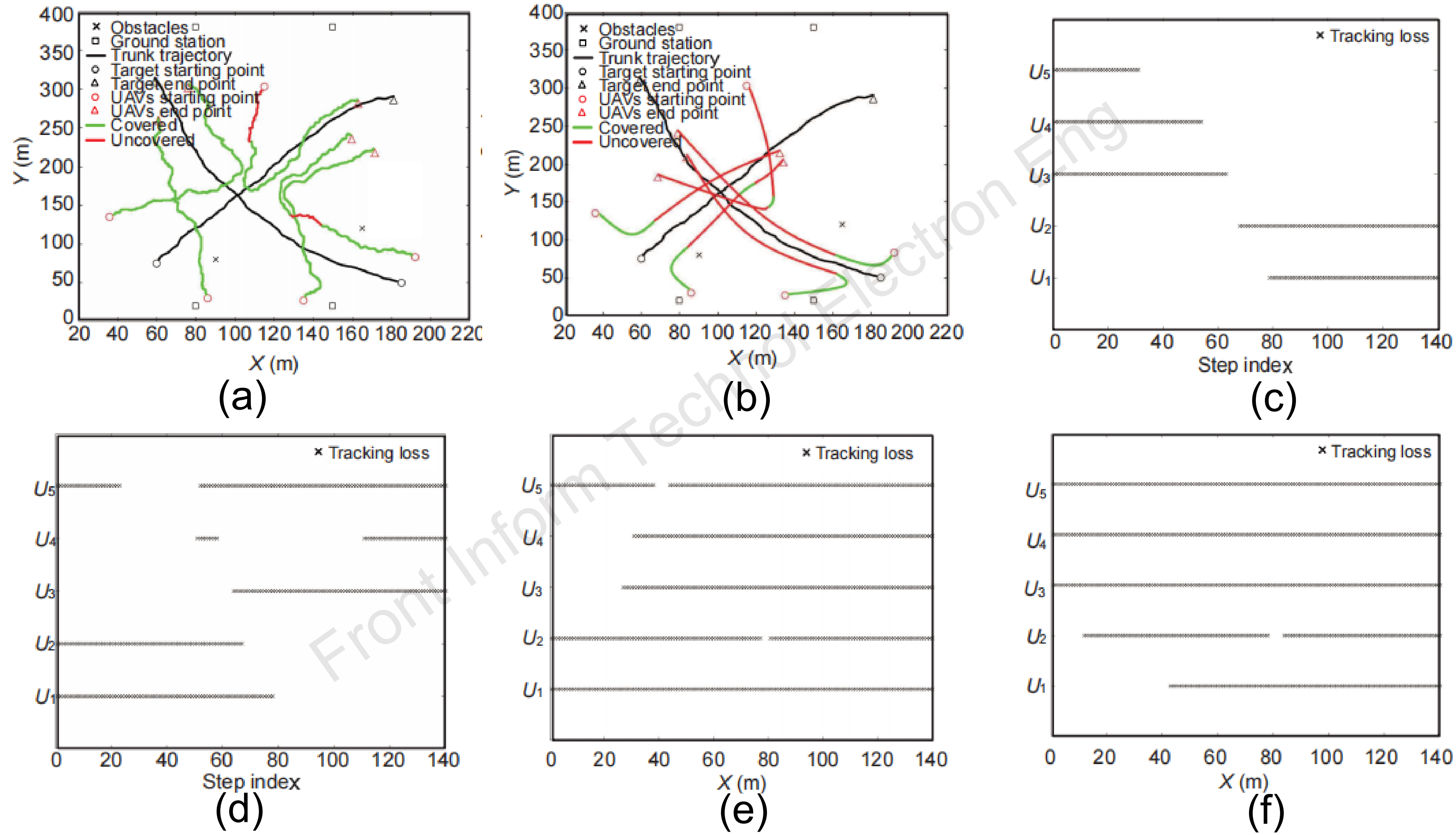

Fig. 8 Simulation results of scenario 2: (a) UAVs' tracking trajectories; (b) passive tracking trajectories of the UAVs; (c) tracking loss of the proposed method about target 1; (d) tracking loss of the proposed method about target 2; (e) tracking loss of the passive method about target 1; (f) tracking loss of the passive method about target 2

Conclusions

- In this study, we propose a collaborative target tracking algorithm for multiple UAVs with inferior tracking capabilities.
- A novel trajectory feature extraction method with least dimension and maximum coverage constraints is designed.
- We propose a novel Voronoi diagram. The tracking strategies of the UAVs are designed to effectively reduce the tracking gaps.
- Based on Nash *Q*-learning, the learning strategies are taken as the UAV control inputs, and collision avoidance with UAVs and obstacles, sensing performance, and path overlap are also considered to improve the tracking efficiency.