Advanced Simulation Framework for UAV Path Planning: Integrating Monte Carlo Prediction and MAPPO

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Research Interests: Humanitarian rescue planning， Learning-based optimization

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- **2014–2018 B.S. in Management Science and Engineering, College of Economics and Management, Hebei University of Technology (HEBUT)**

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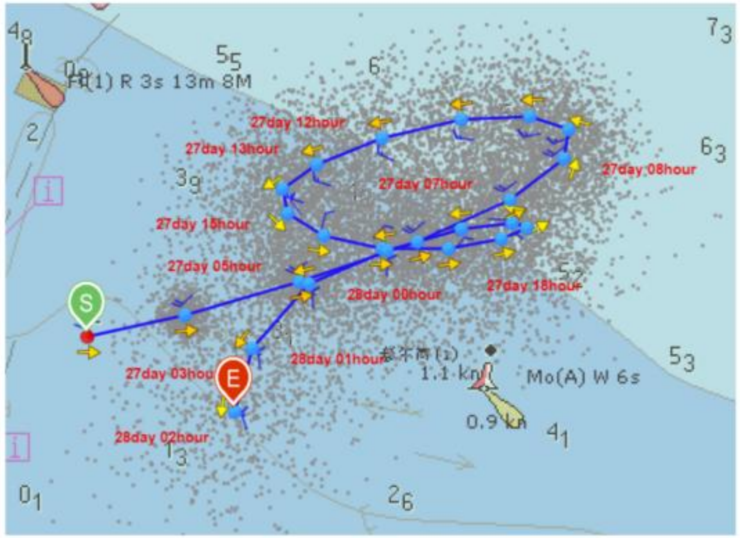
Background: Maritime Search and Rescue (MSAR)

- MSAR remains a major challenge despite maritime tech advancements.
- Major disasters (MH370, Air France 447) highlight MSAR inadequacies, causing tragic loss of lives.
- Many overboard individuals become missing or deceased due to prolonged search times.



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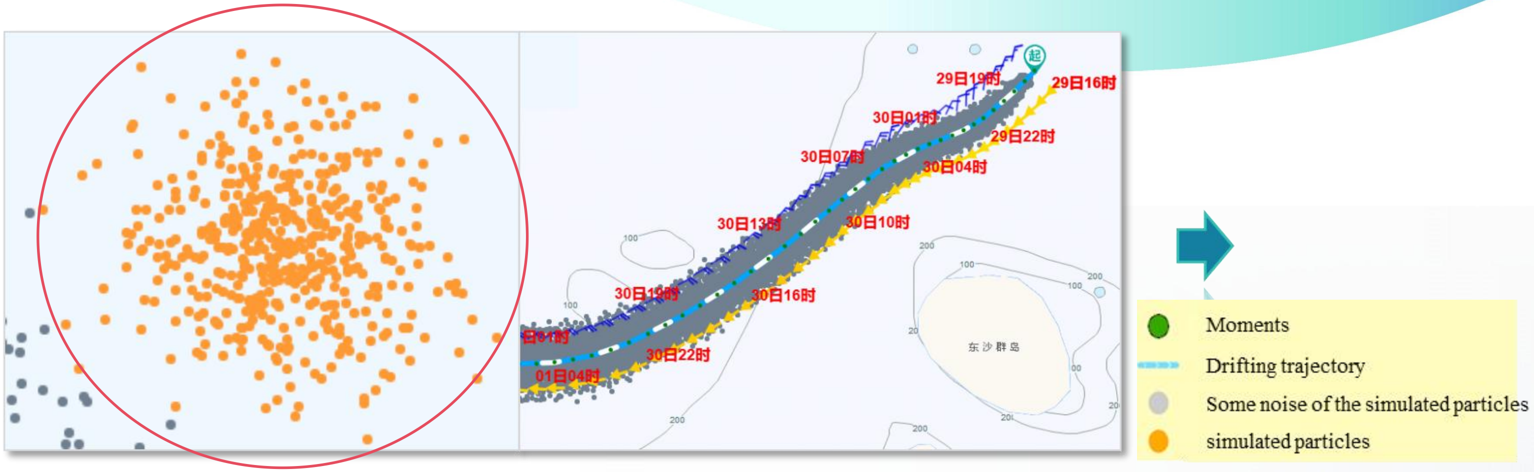
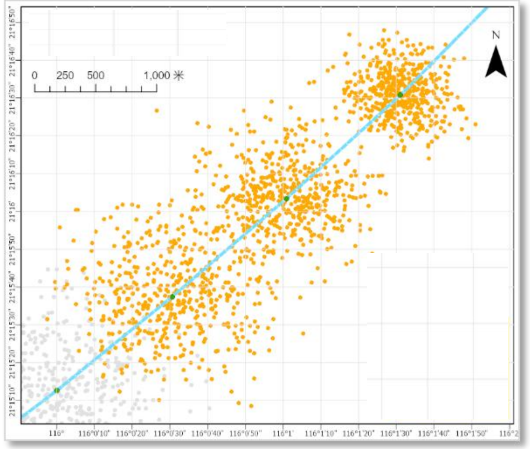
Background & dataset

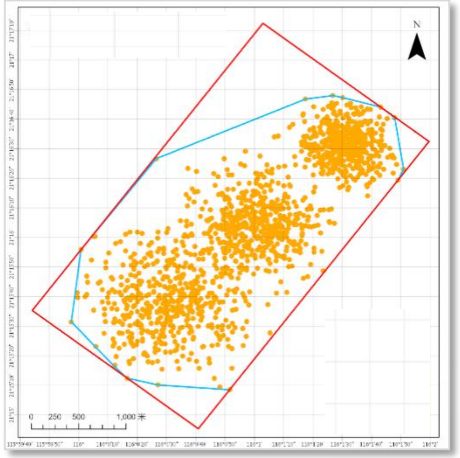
① Get the last location of some people or ships before lost in water



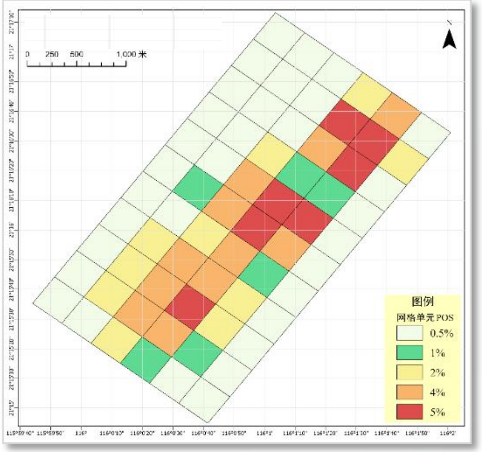
② Simulate the target's trajectory in water through particles



③ Locate possible drifting trajectories by selecting a search time period



④ Delineate the smallest area to search



⑤ Normalize the possibility distributions and plan the shortcut to the target

Methodology

A. Advanced Monte Carlo Simulation for Target Drift Prediction

- **Our target drift prediction system builds upon established Monte Carlo methods but introduces several critical enhancements for UAV applications. The core prediction model represents target position as a time-varying stochastic process influenced by environmental parameters:**

$$\theta = \{wind\ speed\ (w),\ current\ velocity\ (c),\ target\ buoyancy\ (b),\ temperature\ gradient,\ and\ precipitation\ intensity\ (p)\}$$

- **For each time step the target position update is given by:**

$$x_{t+\Delta t} = x_t + v_{target}\,\Delta t + \sum_{i=1}^{s} w_i f_i(\theta_i)\Delta t + \varepsilon + \eta(\Delta t)^2$$

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Methodology

B. Optimized Discrete Space Environment Modeling

- **The operational environment is discretized into an adaptive 3D grid with variable resolution， ranging from 0.5m in critical regions to 5m in open areas. Each cell in our enhanced model contains five attribute.**

1) Dynamic obstacle density with temporal variation: $\rho_{obs} \in [0,1]$

2) Wind velocity vector field with turbulence modeling: v_{wind}

3) Time-dependent target presence probability : $p_{target}(t)$

4) Communication quality metric accounting for multi-path effects: q_{comm}

5) Energy cost coefficient for path optimization: e_{ijk}

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Methodology

C. Enhanced MAPPO Framework for UAV Path Planning

- **Observation Space: Each UAV's observation includes:**

1) A 7×7×3 cell local neighborhood with 8 feature channels (obstacles, wind, targets, etc.)

2) Internal state (battery level, velocity, orientation),

3) Predicted target probability distribution,

4) Teammate status (relative positions, task assignments).

- **Action Space: Our hybrid action space combines:**

1) 7 discrete movement primitives with adaptive step sizes,

2) Continuous velocity adjustment in,

3) Sensor orientation control for improved target detection.

- **Reward Function:**

$$Rt = \alpha R_{target} + \beta R_{collision} + \gamma R_{energy} + \delta R_{coordination} + \zeta R_{exploration} + \eta_{smoothness}$$

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Conclusion and Future Work

- **Key contributions include:**

1) A novel Monte Carlo target prediction system with much improved accuracy through advanced sampling and environmental modeling.

2) A modified MAPPO framework achieving more mission success rate in complex dynamic environments.

3) Comprehensive experimental validation across diverse scenarios demonstrating consistent superiority over baseline methods.

- **Future research directions include:**

1) Extension to heterogeneous UAV teams with specialized capabilities.

2) Integration of real-time sensor data for online model adaptation.

3) Application to multi-domain operations involving ground and aerial vehicles.

THANKS