Dynamic Uncertainty Simulation for Path Optimization Maritime Search and Rescue

Presenter: Yingying Gao (gaoyingying21@nudt.edu.cn)

Authors: Yingying Gao, Qingqing Yang*, Jing Xu, Pengcheng Yang, Yonglin Lei

Affiliation: College of Systems Engineering, National University of Defense Technology

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GAO Yingying

College of Systems Engineering,

National University of Defense Technology

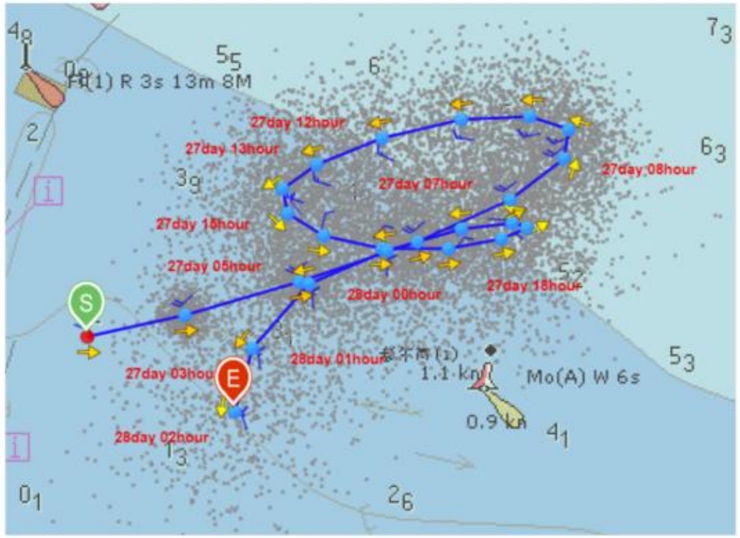
Email: gaoyingying21@nudt.edu.cn

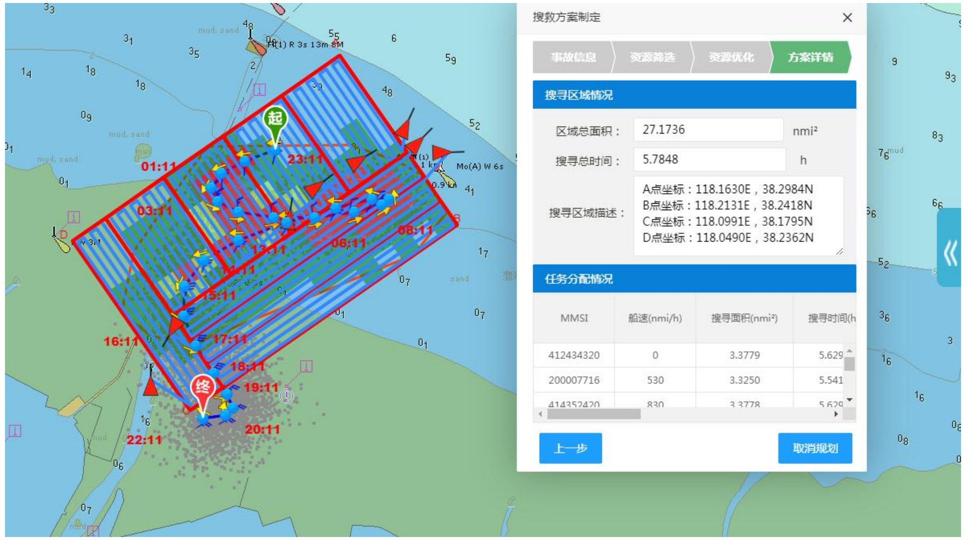
Research Interests: Humanitarian rescue planning， Learning-based optimization

- **2021–Present Ph.D. Candidate in Management Science and Engineering, College of Systems Engineering, National University of Defense Technology (NUDT)**
- **2018–2020 M.S. in Management Science and Engineering, College of Systems Engineering, National University of Defense Technology (NUDT)**
- **2014–2018 B.S. in Management Science and Engineering, College of Economics and Management, Hebei University of Technology (HEBUT)**

Background: Maritime Search and Rescue (MSAR)

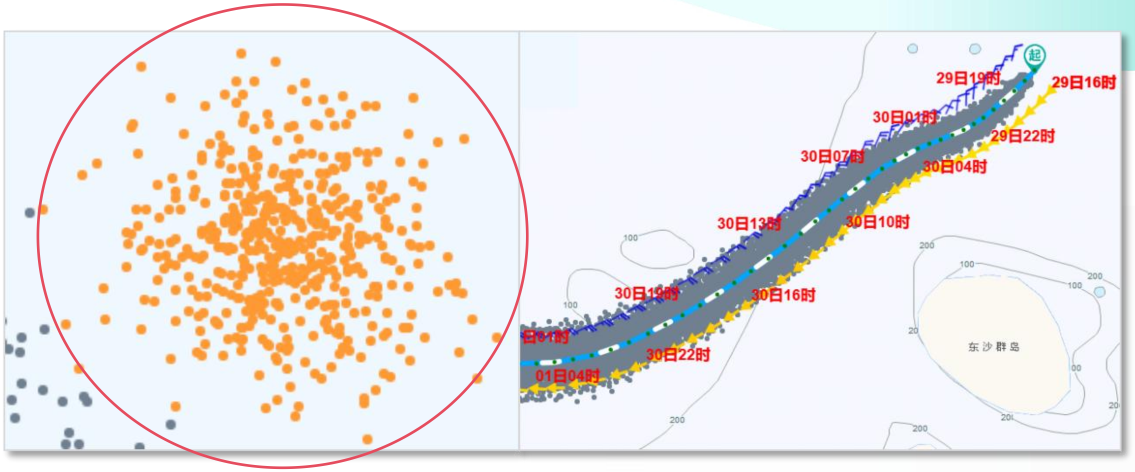
- MSAR remains a major challenge despite maritime tech advancements.
- Major disasters (MH370, Air France 447) highlight MSAR inadequacies, causing tragic loss of lives.
- Many overboard individuals become missing or deceased due to prolonged search times.

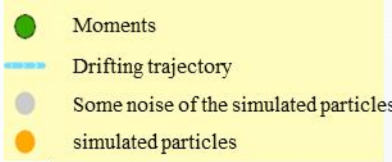




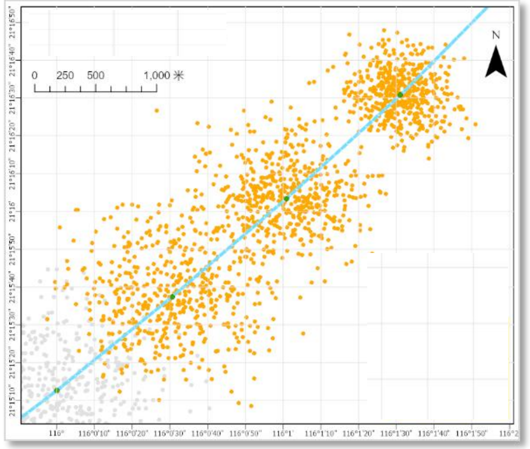
Background & dataset

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

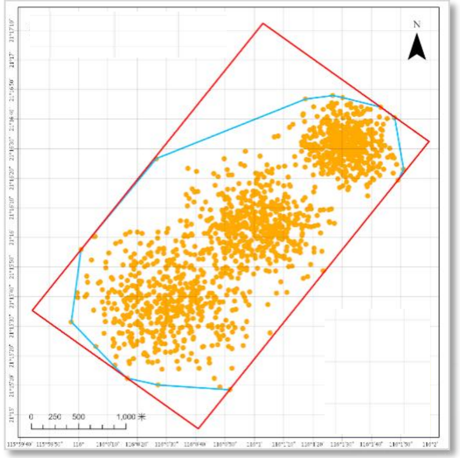




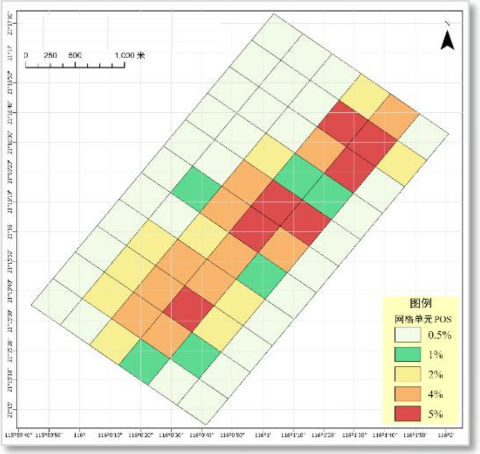
② Simulate the target's trajectory in water through particles



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

Problem Formulation

A. Drift Dynamics Model for Overboard Targets

- The motion of overboard targets can be decomposed into active drift and passive drift components:

$$\mathbf{r}(t) = [x(t), y(t)]^T$$

$$\frac{d\mathbf{r}(t)}{dt} = \mathbf{v}_c(t) + \mathbf{v}_w(t) + \mathbf{v}_d(t) + \boldsymbol{\xi}(t)$$

B. Uncertainty Modeling

- Current uncertainty is modeled using Gaussian random fields:

$$\mathbf{v}_c(t) \sim \mathcal{N}(\boldsymbol{\mu}_c(t), \Sigma_c(t))$$

- Wind field uncertainty accounts for random variations in wind speed and direction:

$$\mathbf{v}_w(t) = f(\mathbf{V}_{wind}(t), \theta(t))$$

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Problem Formulation

C. Rescue Path Planning Formulation

- **Define the rescue vessel set as:** $\mathcal{S} = \{s_1, s_2, \ldots, s_m\}$
- **Each vessel at time having state, including position, velocity and heading:**

$$\mathbf{x}_i(t) = [x_i(t), y_i(t), v_i(t), \theta_i(t)]^T$$

- **The rescue path planning objective minimizes expected rescue time:**

$$\min_{\pi} \mathbb{E}[T_{rescue}(\pi)] = \min_{\pi} \mathbb{E}\left[\min_{i \in \mathcal{S}} T_i^{arrival}\right]$$

- **Constraints include vessel dynamics, collision avoidance, fuel consumption.**

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Optimization Algorithm Design

A. Receding Horizon Optimization Strategy

Formulate the rescue path planning as a Partially Observable Markov Decision Process (POMDP). Adopt a Model Predictive Control (MPC) framework, solving finite-horizon optimization at each decision epoch:

$$\pi^*(t) = \arg\min_{\pi} \sum_{\tau=t}^{t+H} \mathbb{E}[R(x_\tau, u_\tau)],$$

where H is the prediction horizon length. Real-time path adjustment through receding horizon optimization accommodates dynamic environmental changes.

Optimization Algorithm Design

B. Uncertainty Propagation and Bayesian Update

- **Employ particle filtering for state estimation and uncertainty propagation.**
- **Predict next-state distribution using dynamics model and current particle distribution.**
- **Incorporate observation information to update posterior distribution via Bayes' theorem.**
- **Prevent particle degeneracy and maintain particle diversity.**

Conclusion and Future Work

- **Key contributions include:**

1) This paper proposes a dynamic optimization algorithm for maritime rescue path planning based on uncertainty simulation, with main contributions.

2) Developed comprehensive multi-source uncertainty drift model improving drift prediction accuracy.

3) Designed Markov decision process-based dynamic optimization framework enabling real-time path adjustment.

- **Future research directions include:**

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

THANKS