Obstacle Avoidance Under Relative Localization Uncertainty

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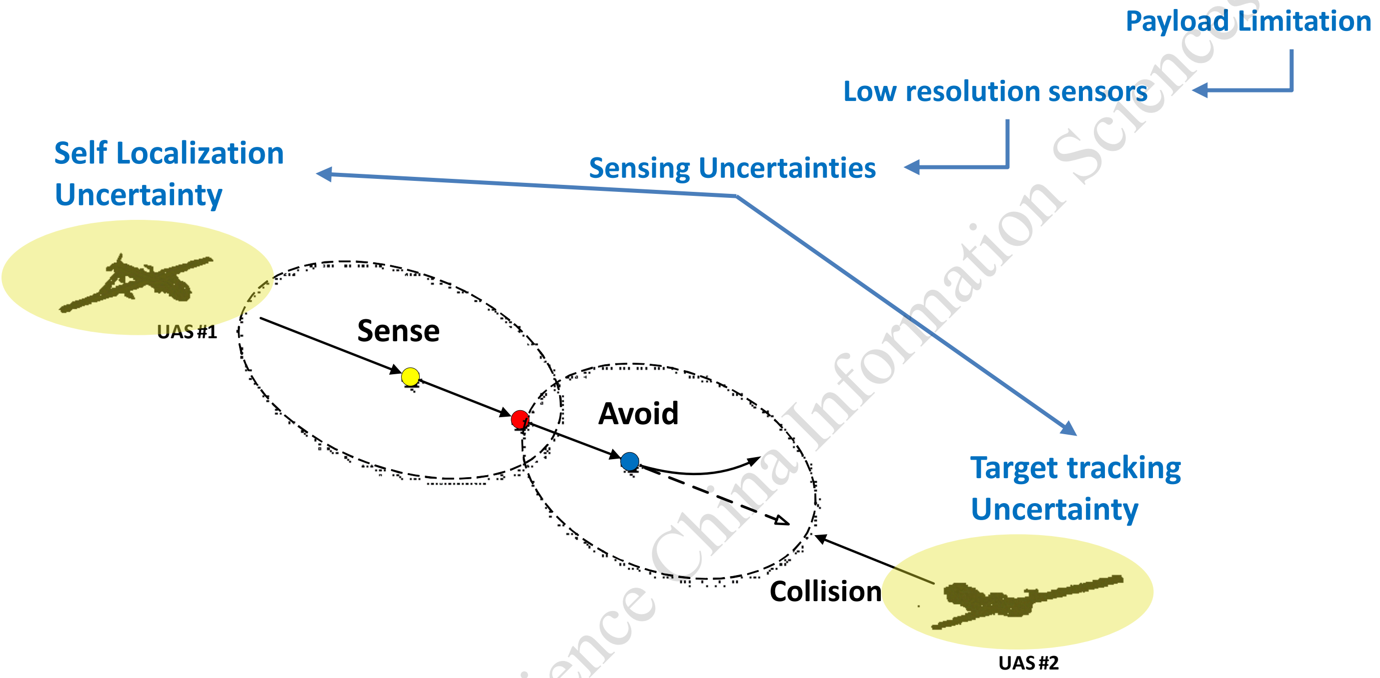
Introduction

Collision avoidance is one of the classical topics in robotics research and basic capability for autonomous operation of UAV, UGV, and so on.

Introduction



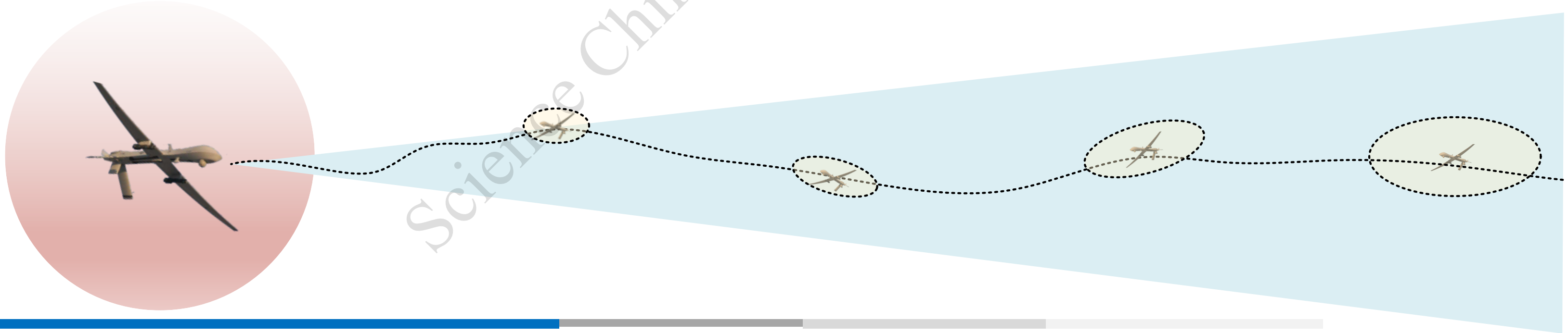
One greatest challenge is to generate proper control based on uncertain sensing results.

Existing Methods:

- Perfect sensing assumption-> not applicable in noisy scenario
- Separation distance inflation
    - Predefined uncertainty ->over confident/conservative

Proposed Method:

- Separation distance inflation based on dynamical estimation results



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Method

Modeling:

- Initially the dynamics of local robot *i* and obstacle *o* are denoted respectively as

$$x_{i,k+1} = f_i(x_{i,k}, u_{i,k}, w_{i,k}) \qquad x_{o,k+1} = f_o(x_{o,k}, w_{o,k})$$

- The uncooperative measurement process is

$$z_k = h_{oi}(x_{i,k}, x_{o,k}, v_{oi,k})$$

Denote the relative state as $x_{oi,k} = x_{o,k} - x_{i,k}$,

then based on the target tracking methods, an estimation of $x_{oi,k}$ can be obtained based on the observation z from *1 to k*

$$\hat{x}_{oi,k} \sim p_{oi}(x_{oi,k} | z_{1:k}).$$

Method

Modeling:

- The collision avoidance is to keep a minimum separation distance between the local robot and the obstacle as

$$\|x_{oi,k}\| = \|x_i - x_o\| \geqslant r_c$$

- A collision zone $\mathcal{S}$ can be denoted as a disc in 2D or spherical area in 3D as

$$\mathcal{S} = \{x \mid \|x\| \leqslant r_c\},$$

- A collision probability can be defined as the probability of obstacle falls into $\mathcal{S}$:

$$p(x_{oi,k} \in \mathcal{S} | z_{1:k}) = \int_{\mathcal{S}} p_{oi}(x|z_{1:k}) dx$$

Difficult to calculate

To realize the collision avoidance with a confidence threshold ε , a collision need to be declared when

$$p(x_{oi,k} \in \mathcal{S} | z_{1:k}) \geqslant 1 - \varepsilon.$$

Method

PR based CA

- PR is implemented to approximate the relative localization distribution and N particles are drawn as

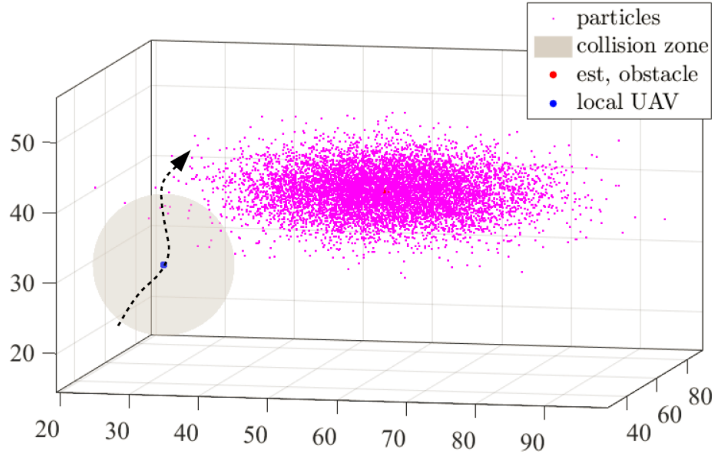
$$\{x^j_{oi,k}, w^j_{oi,k}\}, j \in \{1, 2, ..., N\}$$

- the collision probability can be approximated as

$$p(x_{oi,k} \in \mathcal{S} | z_{1:k}) \approx \frac{1}{N} \sum_{x^j_{oi} \in \mathcal{S}} \delta_{r_c}\left(x^j_{oi}\right),$$

with

$$\delta_{r_c}\left(x^j_{oi}\right) = \begin{cases} 1 & \|x^j_{oi}\| \leqslant r_c, \\ 0 & \|x^j_{oi}\| > r_c. \end{cases}$$



Method

PR based CA

Using the proposed PR method, the collision avoidance maneuvers the collision zone $\mathcal{S}$ away from high-particle to low particle as

$$U_{oi}^{j}=\begin{cases} w_{oi,k}^{j}g\left(x_{oi,k}^{j}\right) & p_{oi,k}\geqslant 1-\varepsilon \\ 0 & p_{oi,k}<1-\varepsilon \end{cases}$$

where g(·) is a pairwise potential function

$$g\left(x_{oi,k}^{j}\right)=\frac{\kappa}{2}\left(\frac{1}{\|x_{oi,k}^{j}\|+\epsilon}-\frac{1}{r_c+\epsilon}\right)^2,$$

Finally, the collision avoidance control is

$$u_{oi,k}=-\sum_{x_{oi,k}^{j}\in\mathcal{S}}\nabla_{x_{oi,k}^{j}}U_i^o(x_{oi,k}^{j}).$$

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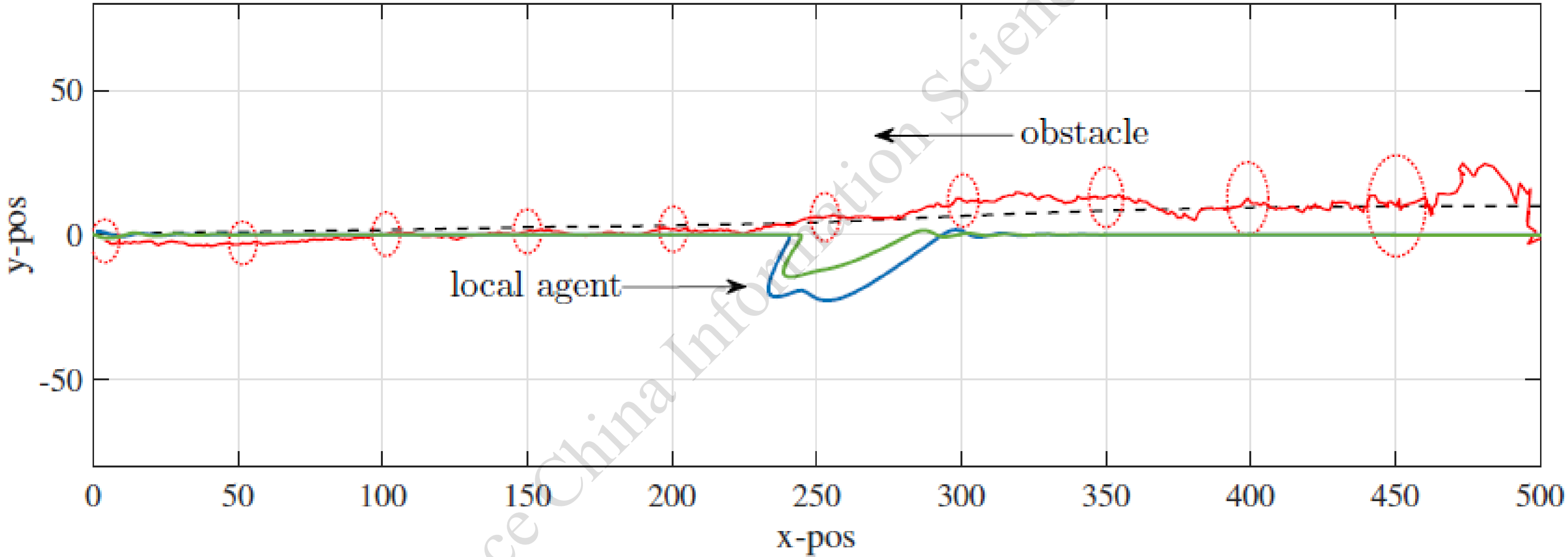
Simulation & Experiment

Simulation



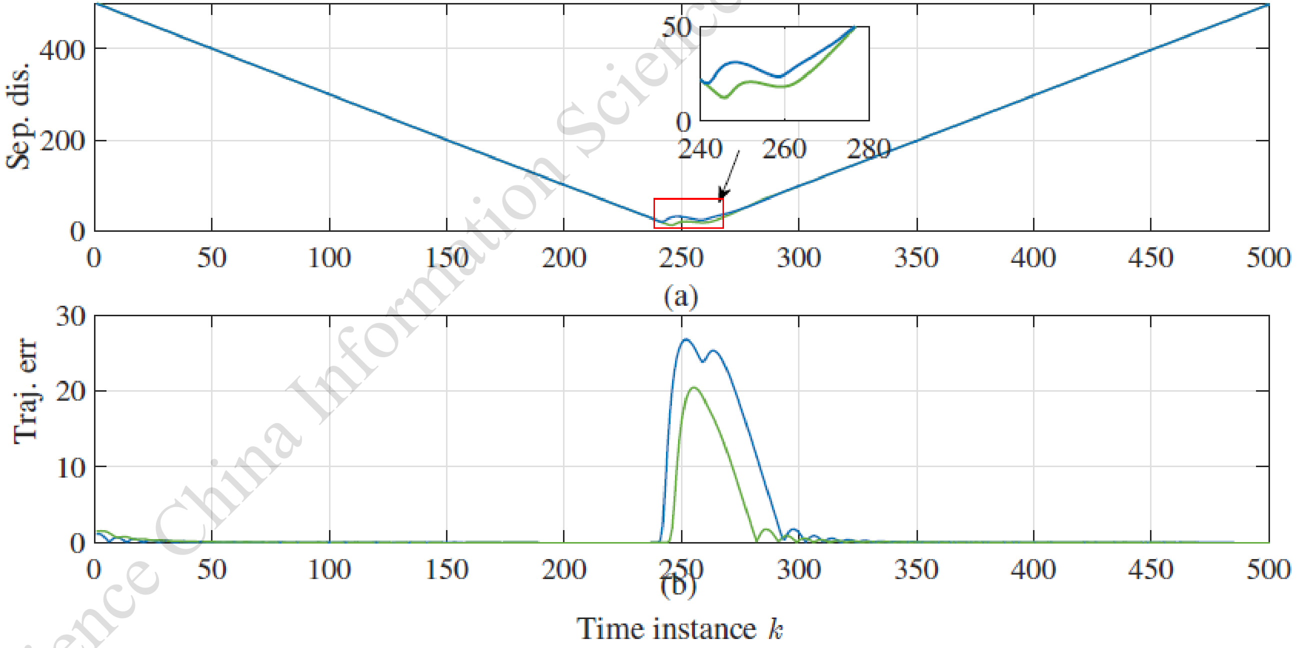
The obstacle collision avoidance trajectories (our method: green solid line, method in [1]: blue solid line) and the obstacle trajectory estimation (red solid line)

[1] Hennes D, Meeussen W, Tuyls K. Multi-robot collision avoidance with localization uncertainty. In: Proceeding of International Conference on Autonomous Agents and Multiagent Systems, Singapore, 2016,147{154.

Simulation & Experiment

Simulation

The separation distance and reference trajectory tracking error of the proposed method (green solid line) and the method in [1] (blue solid line).



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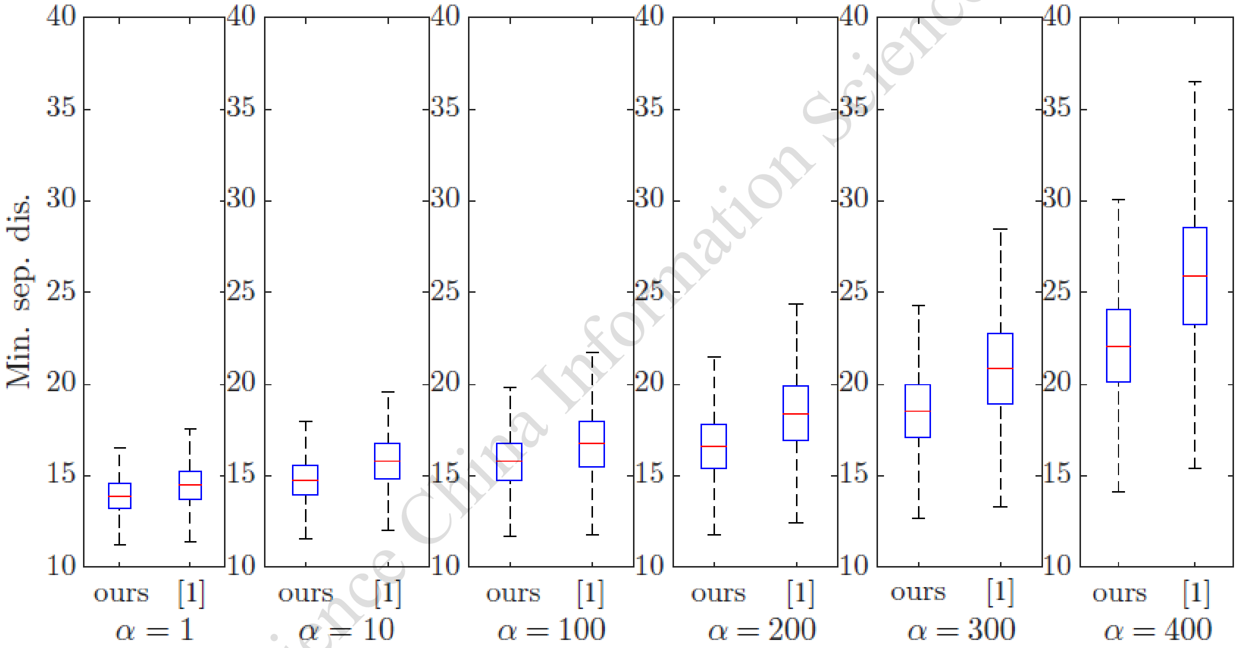
Simulation & Experiment

Simulation



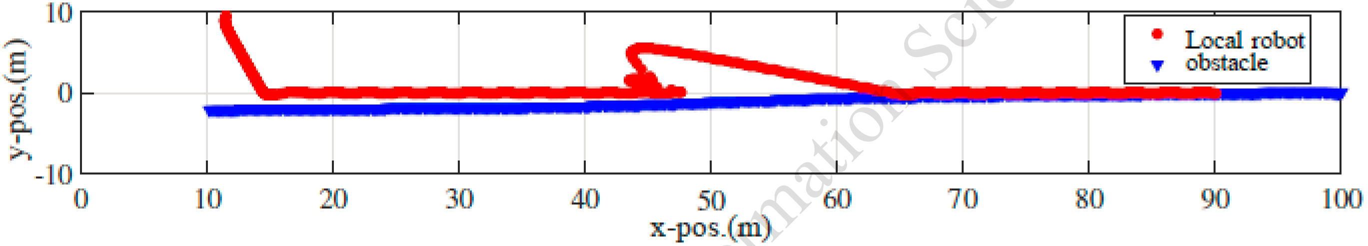
The minimum separation distance with different measurement covariance.

Experiment

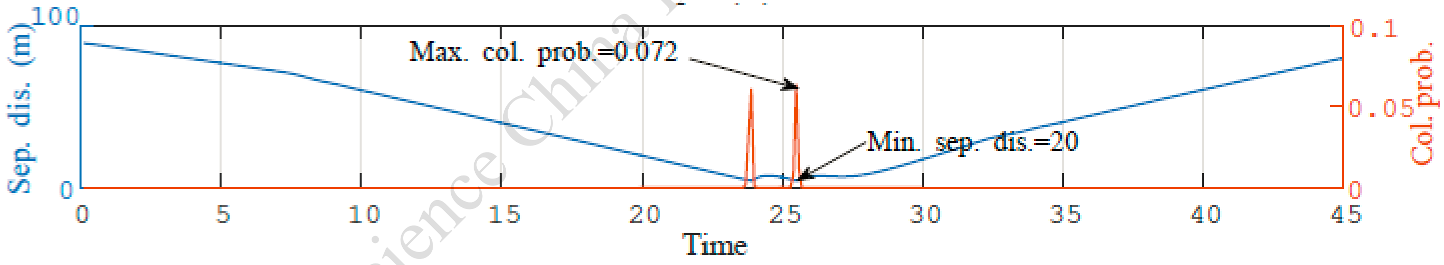
Two DJI M100 quadrotors that function as the local robot and obstacle are used in a head on experiment scenario.
The obstacle is detected with
- A onboard camera (angle)
- UWB transmitters (range)

Simulation & Experiment

Experiment



(b) Collision avoidance trajectory of local robot (red) to the obstacle (blue).



Experiment results of the two DJI M100 quadrotors in the head-on collision avoidance scenario.

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Conclusion

Our method provided

- A collision avoidance method consider navigation and target localization uncertainties simultaneously

- A PR based collision avoidance probability approximation method

- A collision avoidance controller according predefined collision probability and separation distance

Thank U