Collision Avoidance for Multi-Vehicle Systems

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Happy Birthday Mark and thank you for hiring me (hope this is not one of the reasons why you left Illinois)!

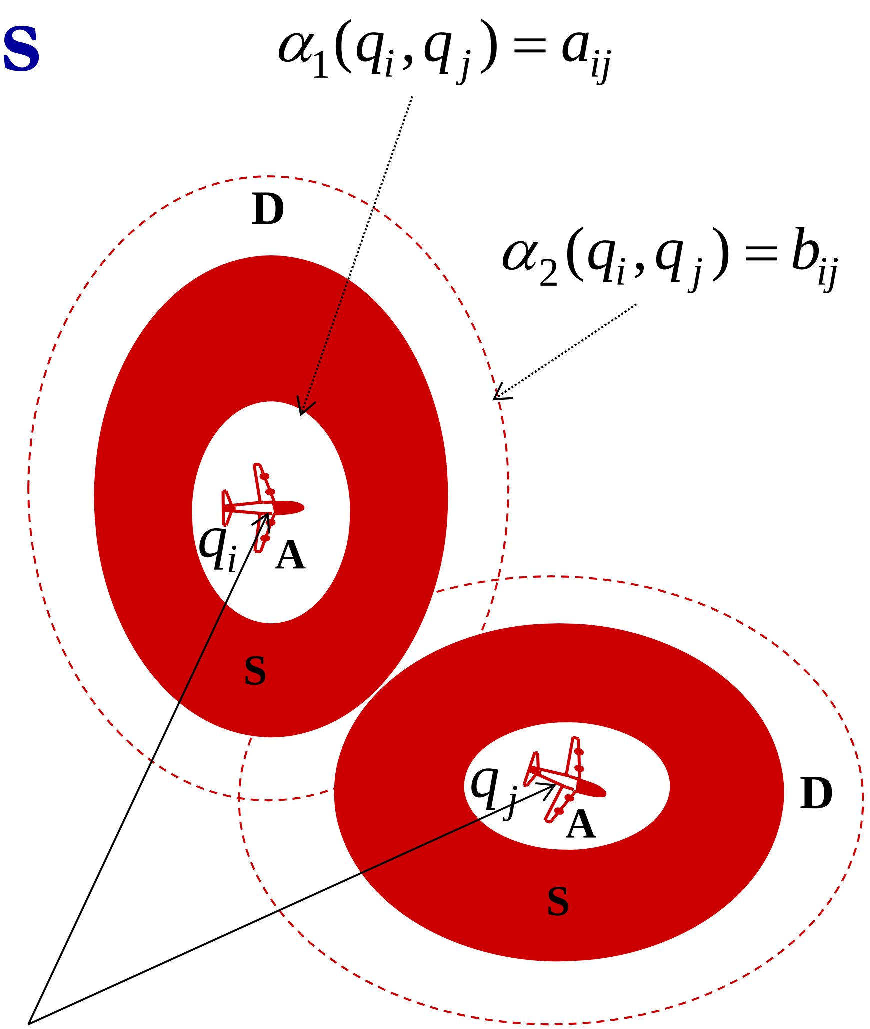
Avoidance Functions

“Quadratic” Avoidance Functions

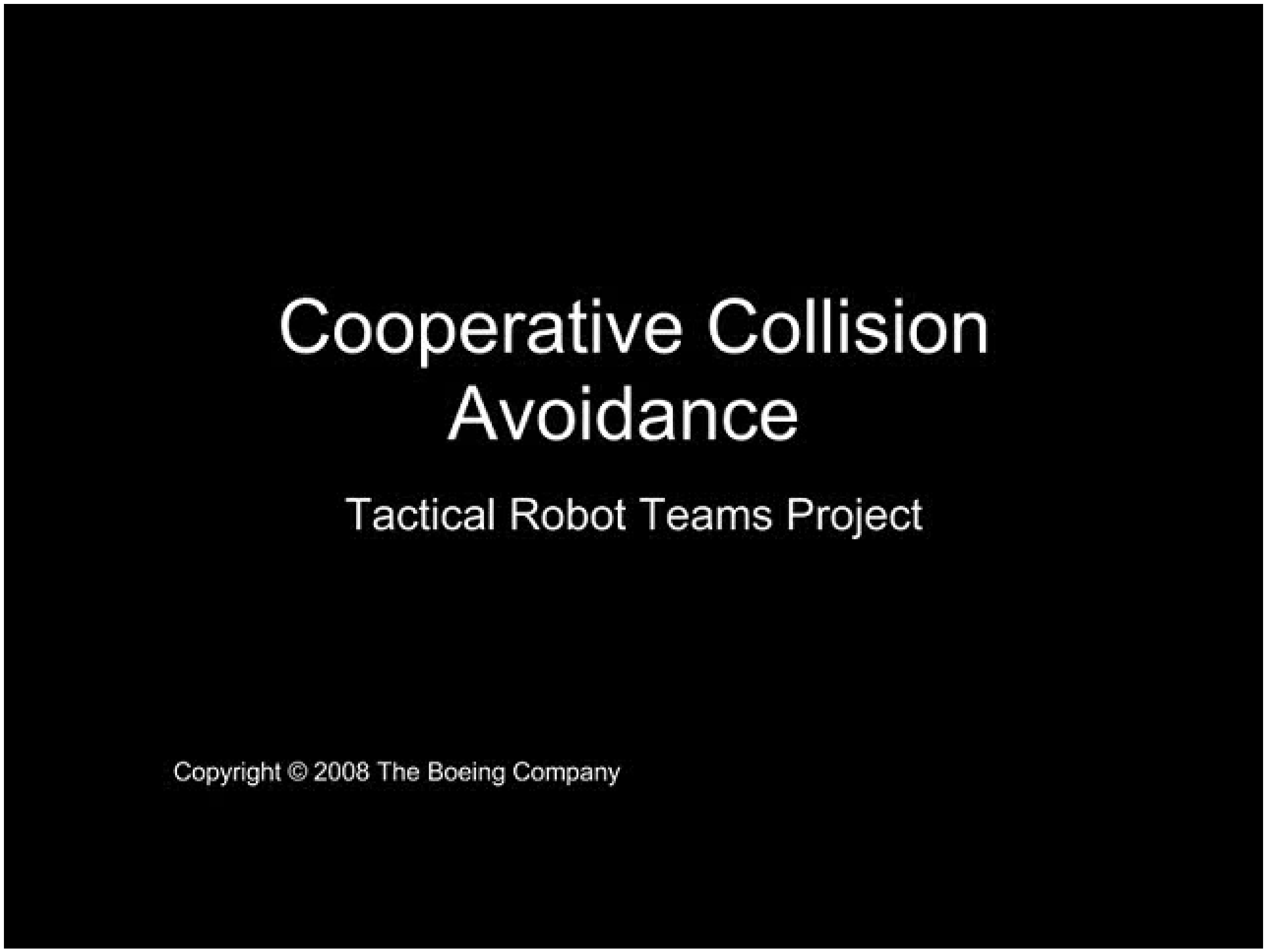
$$\upsilon_i = \sum_{i \in \mathbf{N}} \upsilon_{ij} \;,\; \upsilon_{ii} = \upsilon_{ii}^{o}$$

$$\upsilon_{ij} = \left(\min\left\{ 0, \frac{\alpha_2(q_i,q_j) - b_{ij}}{\alpha_1(q_i,q_j) - a_{ij}} \right\} \right)^2 \;,\; i \neq j$$

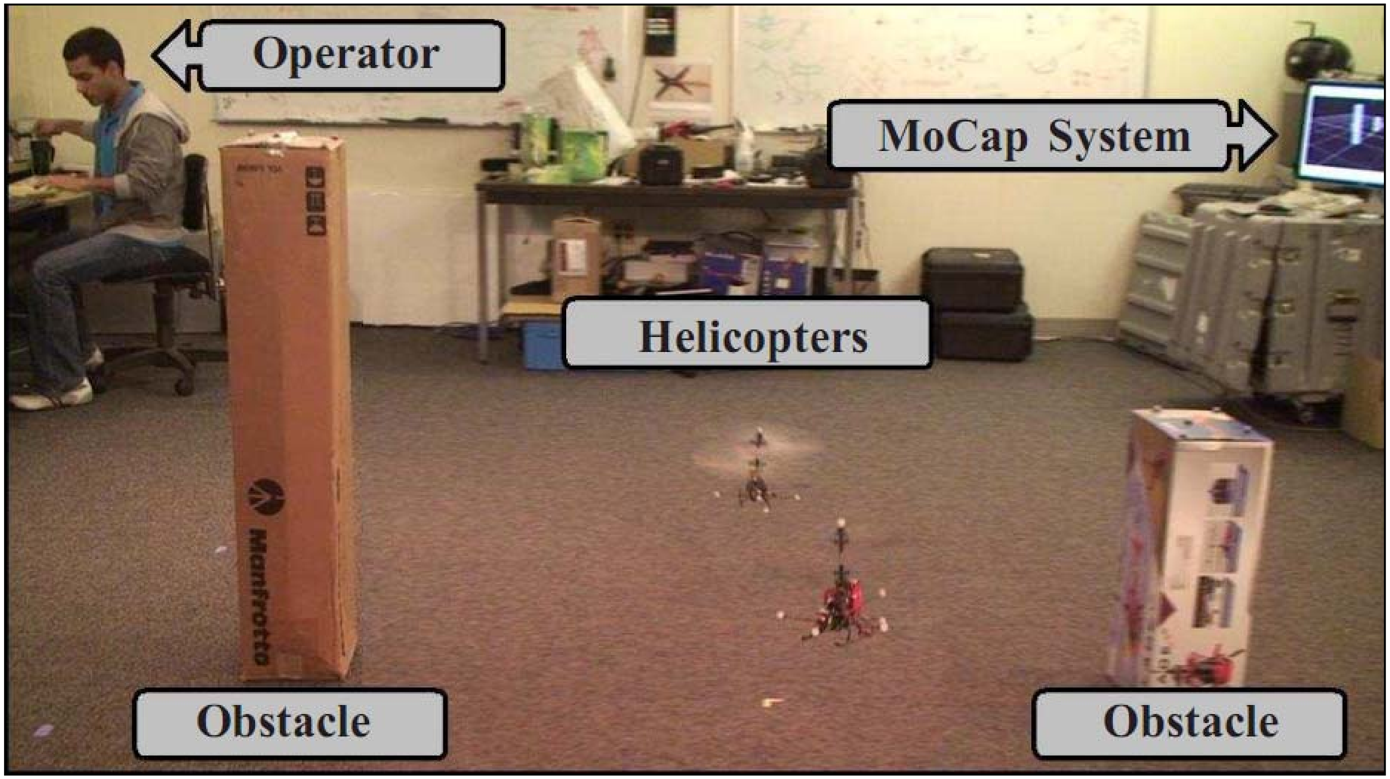
$$\alpha_k(q_i,q_j) = (q_i - q_j) P_k (q_i - q_j)^T ,\; k = 1,2$$

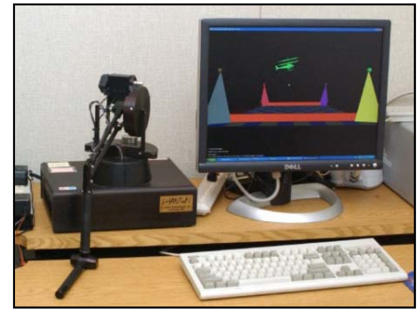


Cooperative Collision Avoidance for Co-axial Helicopters



Bilateral Teleoperation and Collision Avoidance





Master Robot

Slave Vehicles

Coordination:

- Trajectory Tracking
- Formation Control

Safety:

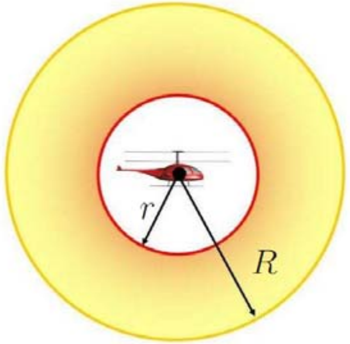
- Stability under Communication Delays
- Collision Avoidance

Transparency:

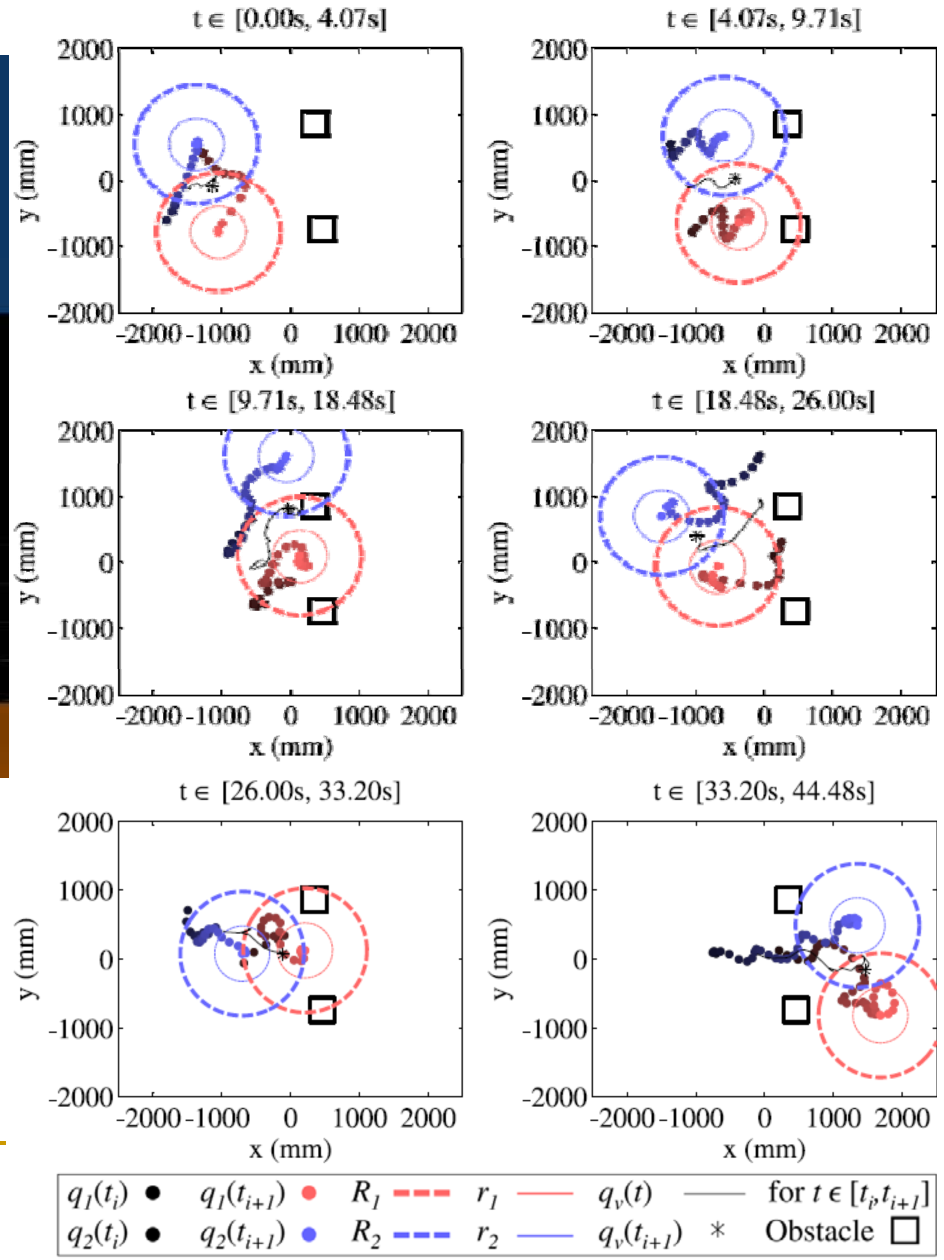
- Operator must feel environmental forces interacting with remote agents.

Experiments: Dynamic Formation

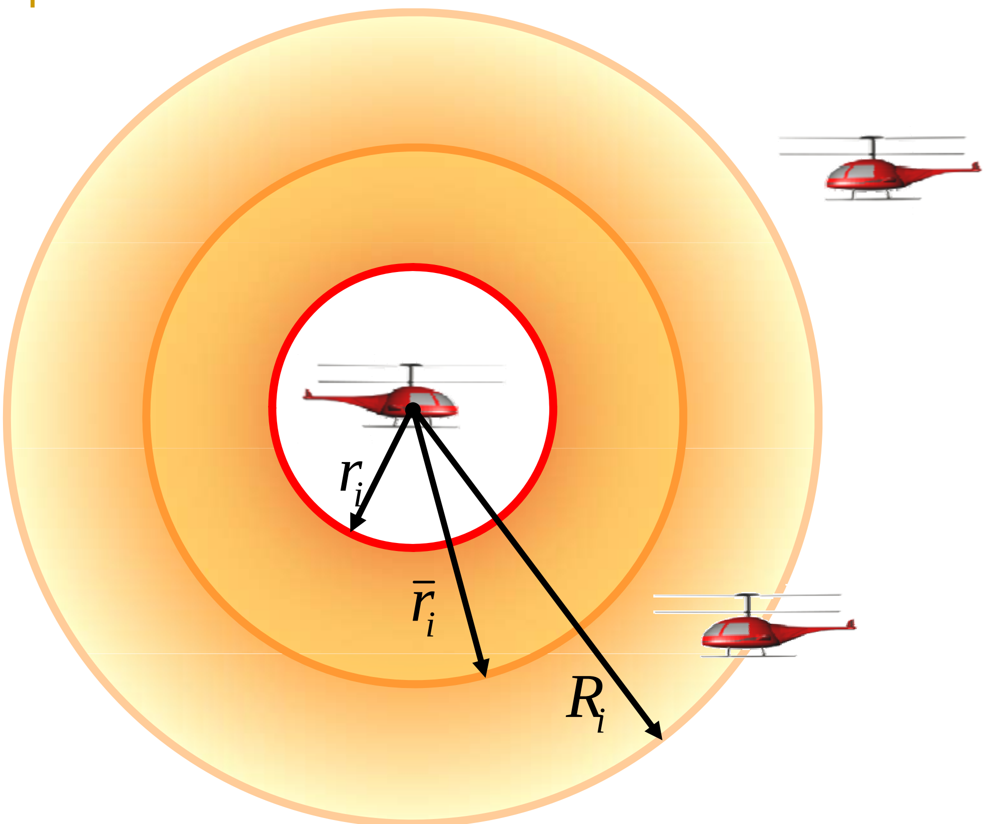
Workspace:
(*5m* long) x (*4m* wide) x (*1.7m* high)



$R=0.9m$
$r=0.4m$

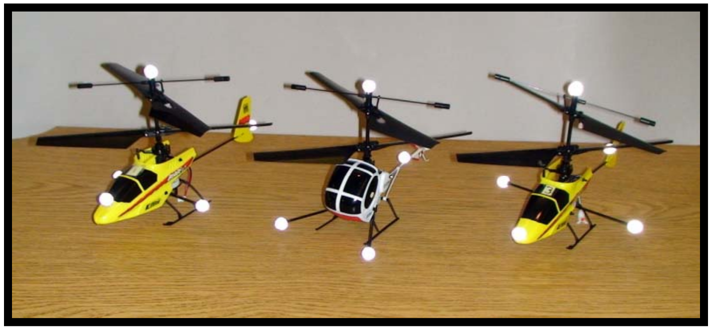


Collision Avoidance with Detection Errors

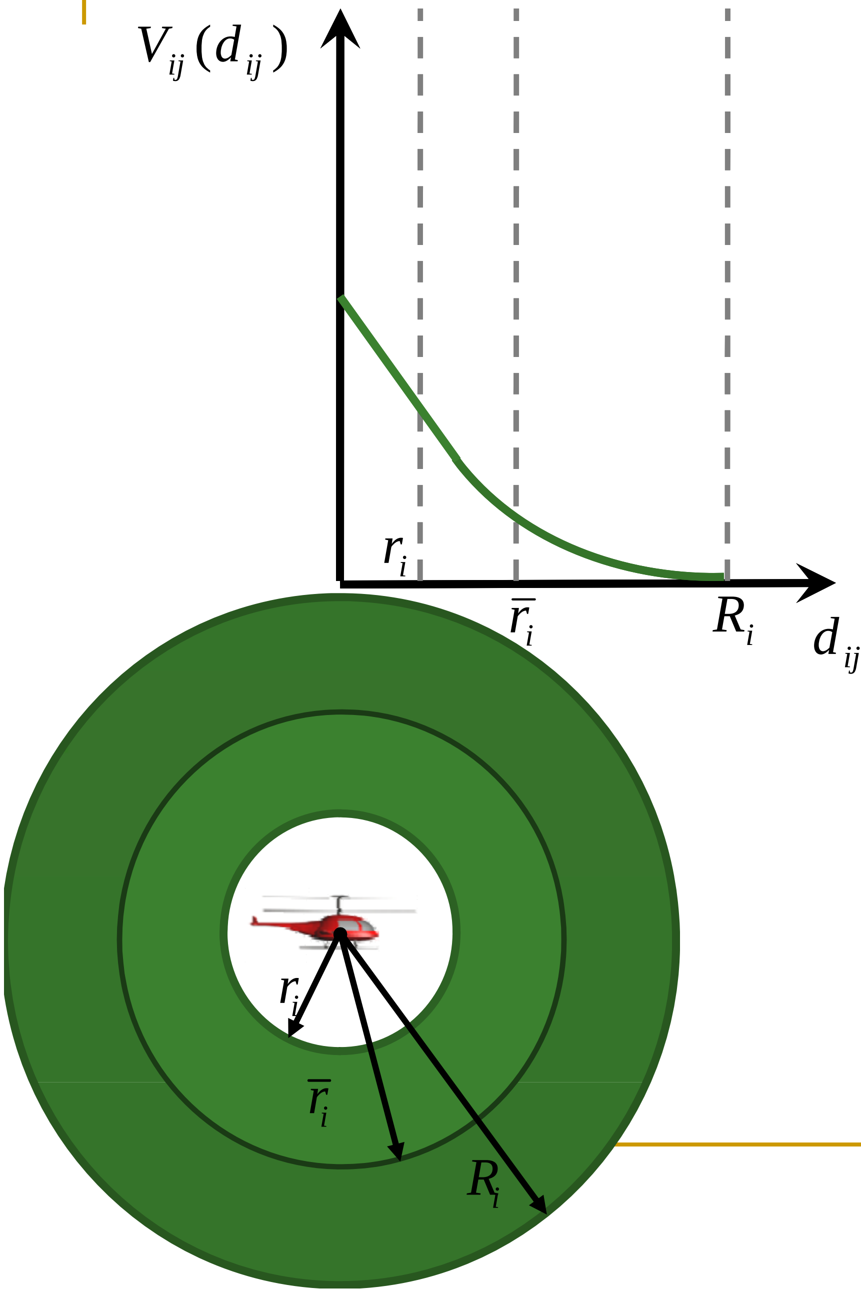


Problem:

To guarantee safe navigation of mobile vehicles through obstructed and shared environments when the information is not perfect.



Bounded Avoidance Control



Avoidance Functions

$$V_{ij}(d_{ij}) = \begin{cases} \alpha_i \left(\min\left\{0, \dfrac{d_{ij}^{\,2} - R_i^{\,2}}{d_{ij}^{\,2} - r_i^{\,2}}\right\} \right)^2, & \text{if } \bar{r}_i \le d_{ij} \\ -\mu_i \left\| d_{ij} \right\| + c_i, & \text{if } 0 < d_{ij} < \bar{r}_i \end{cases}$$

$$d_{ij}(t) = \| q_i(t) - \hat{q}_j(t) \|$$

$$\hat{q}_j(t) = q_j(t) + \varepsilon_j(t), \left\| \varepsilon_j(t) \right\| \le \Delta_j$$

Avoidance Control Component

$$u^a = -\sum_j \frac{\partial V_{ij}}{\partial q_i}$$

Collision Avoidance with Detection Delays

Three Coaxial Helicopters

$$T_{12} = 0.30s,\ T_{13} = 0.24s$$

$$T_{21} = 0.30s,\ T_{23} = 0.27s$$

$$T_{31} = 0.30s,\ T_{32} = 0.30s$$

$$v_1 = v_2 = v_3 = 1m/s$$

$$R = 1.00m,\ r = 0.25m$$

Collision Avoidance with Sensing Uncertainties: Avoiding Singular Points

Objective Control

Avoidance Control

Control Law: $u_i = u_i^o + u_i^a + u_i^\varepsilon - k_i \dot{q}_i$

Perturbation (vector) perpendicular to the avoidance control when the *i*-the agent approaches an unwanted local minima

Maximum Velocity Regulation

Singular Points: $u_i^o \to -\lambda u_i^a \,,\; \lambda > 0$

Collision Avoidance with Sensing Uncertainties: Simulation Results

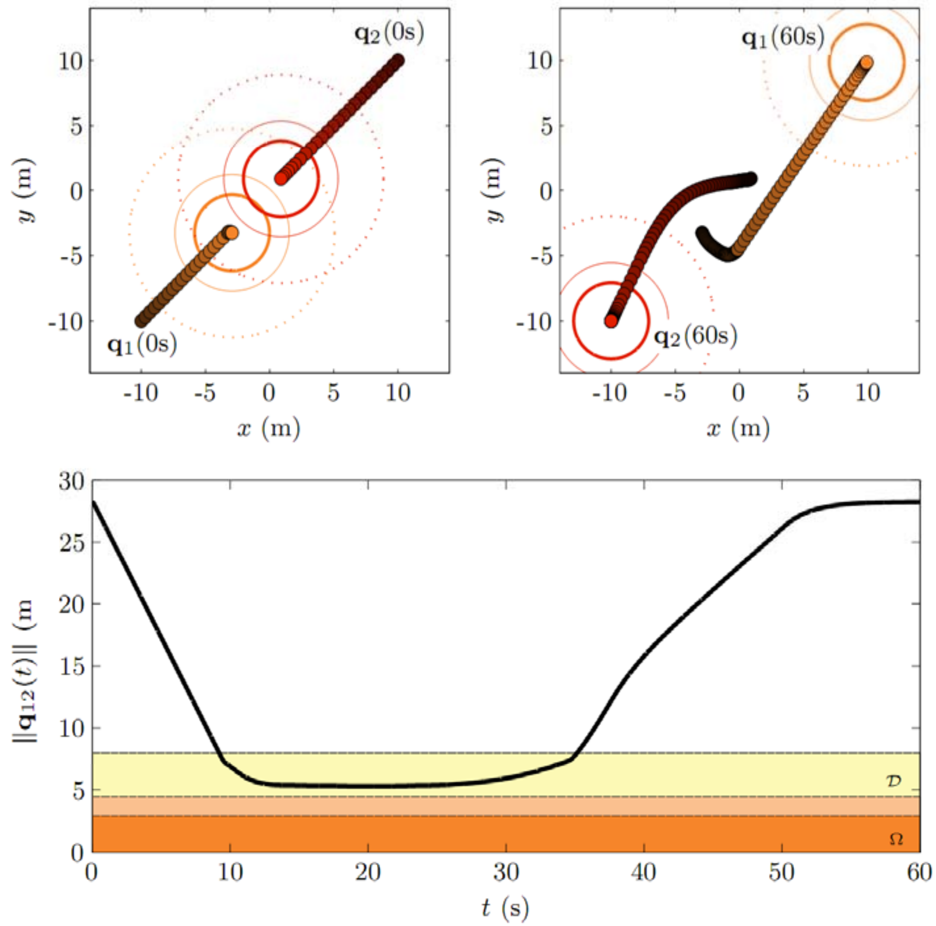
Sensing Uncertainty (Error):

$$\mathbf{d}_i(\mathbf{q}_i, \mathbf{q}_j) = \zeta_{qi}(\mathbf{q}_i, \mathbf{q}_j) + \zeta_{ei}(\mathbf{q}_i)$$

$$\zeta_{qi}(\mathbf{q}_i, \mathbf{q}_j) = a_{1i}\left[\left\lfloor \frac{q_{j_1} - q_{i_1}}{a_{2i}} \right\rfloor, \left\lfloor \frac{q_{j_2} - q_{i_2}}{a_{2i}} \right\rfloor\right]^T$$

$$\zeta_{ei}(\mathbf{q}_i) = a_{3i}\left[\cos(q_{i_1}), \sin(q_{i_2})\right]^T$$

- First Agent, $\Delta_1 = 1.0$m
- Second Agent, $\Delta_2 = 0.5$m



Questions?