MAE 598: Multi-Robot Systems

Fall 2016

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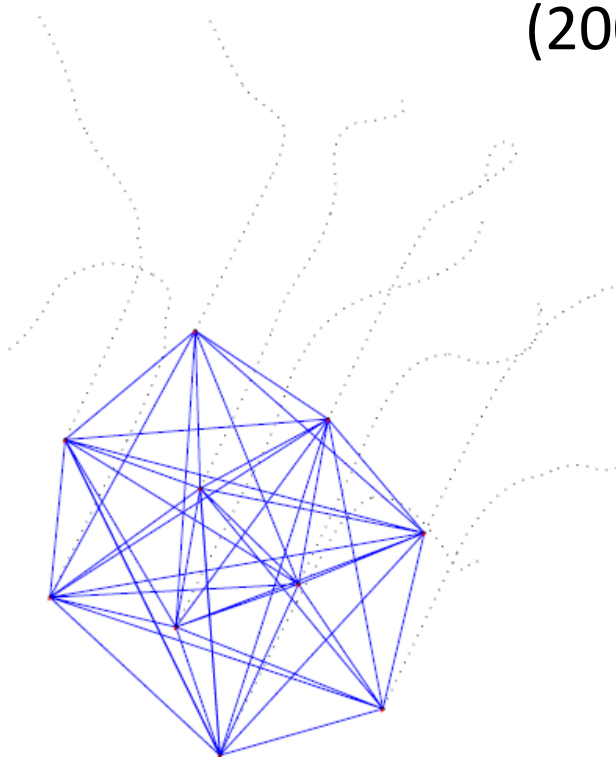
Lecture 11

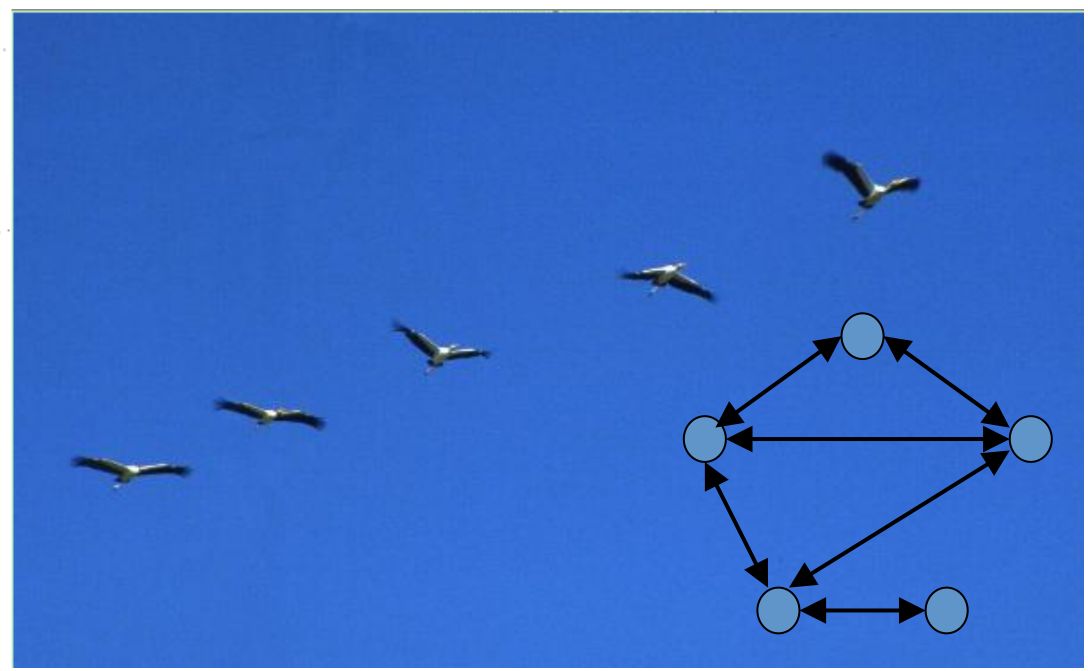
Consensus Problems in Multi-Robot Systems

Flocking in Fixed and Switching Networks

Herbert G. Tanner, Ali Jadbabaie, George Pappas

(2003, 2005 versions)

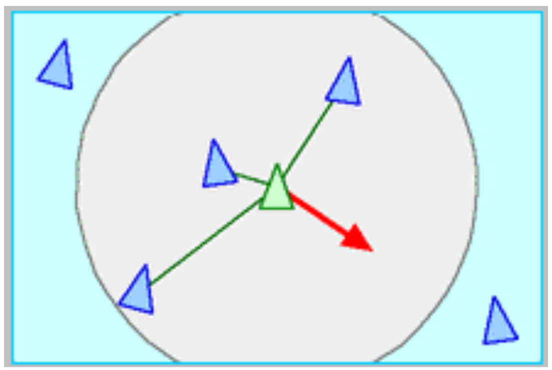


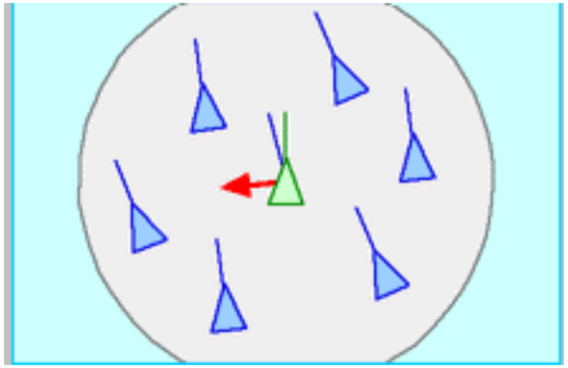


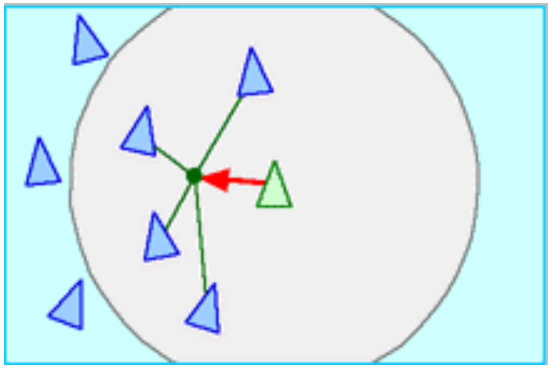
Motivation

- Theoretically explain the Reynolds [1987] flocking phenomenon

  - Flocking results from each individual following three steering behaviors based on the positions/velocities of its neighbors:







Separation	Alignment	Cohesion
Avoid crowding local flockmates	Steer toward average heading of local flockmates	Move toward average position of local flockmates

Reynolds C. "Flocks, birds, and schools: a distributed behavioral model." Computer Graphics: 21:25-34, 1987. / http://www.red3d.com/cwr/boids/

Local Robot Control Laws

Agent model: $\dot{r}_i = v_i$

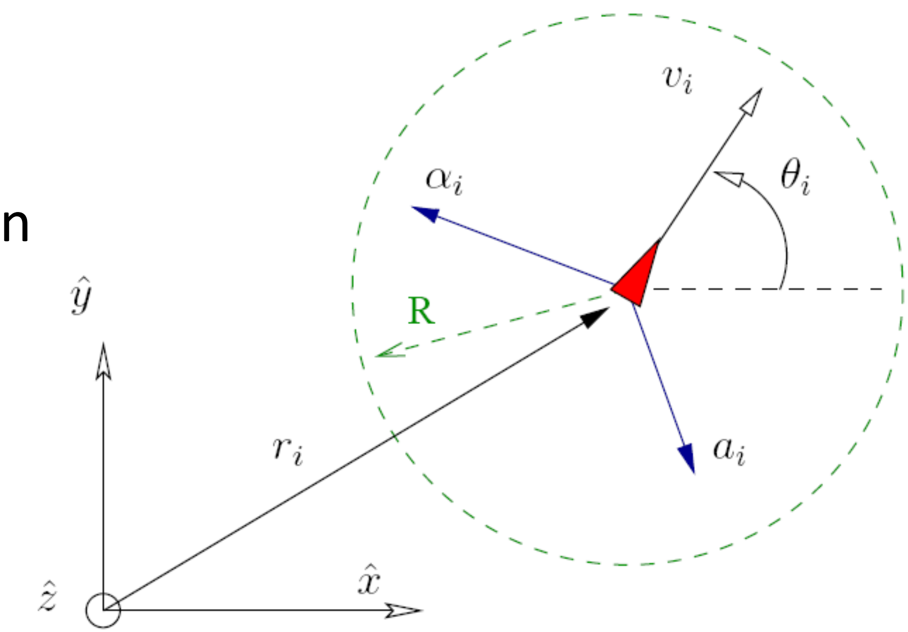
$$\dot{v}_i = u_i \quad i = 1, \ldots, N$$

$$r_i = [x_i \quad y_i]^T$$
$$v_i = [\dot{x}_i \quad \dot{y}_i]^T$$
$$r_{ij} = r_i - r_j$$
$$u_i = [u_x \quad u_y]^T$$

$$u_i = \alpha_i + a_i$$

α_i Align agent velocity vectors, make them move with common speed and direction

a_i Produce collision avoidance and cohesion



Local Robot Control Laws

$\mathcal{G} = \{\mathcal{V}, \mathcal{E}\}$ Neighboring graph

- Undirected graph consisting of:

  $\mathcal{V} = \{n_1, \ldots, n_N\}$; indexed by agents

  $\mathcal{E} = \{(n_i, n_j) \in \mathcal{V} \times \mathcal{V} \mid n_i \sim n_j\}$

  unordered pairs of vertices that represent neighboring relations

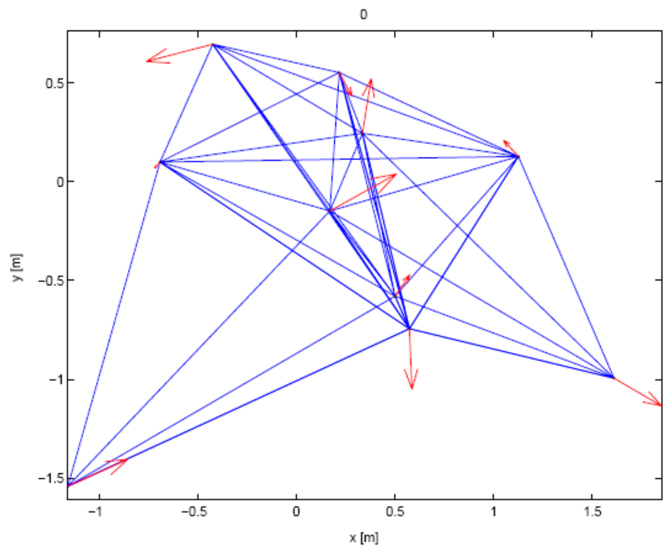
Neighboring set of agent *i:*

$$\mathcal{N}_i \triangleq \{j \mid i \sim j\} \subseteq \{1, \ldots, N\} \setminus \{i\}$$

- Reflects physical proximity or existence of communication channel

Flock Simulations: Fixed Network

1



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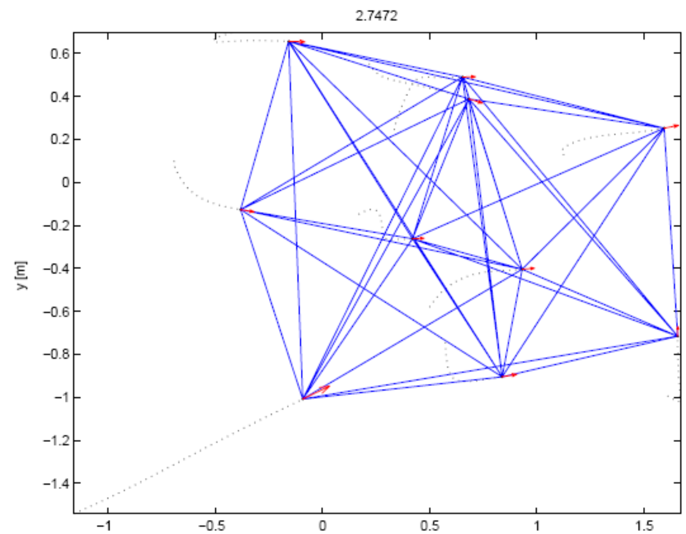

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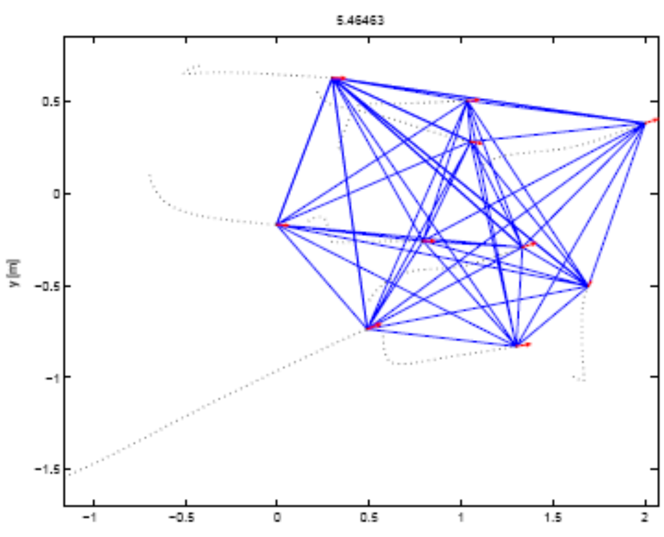

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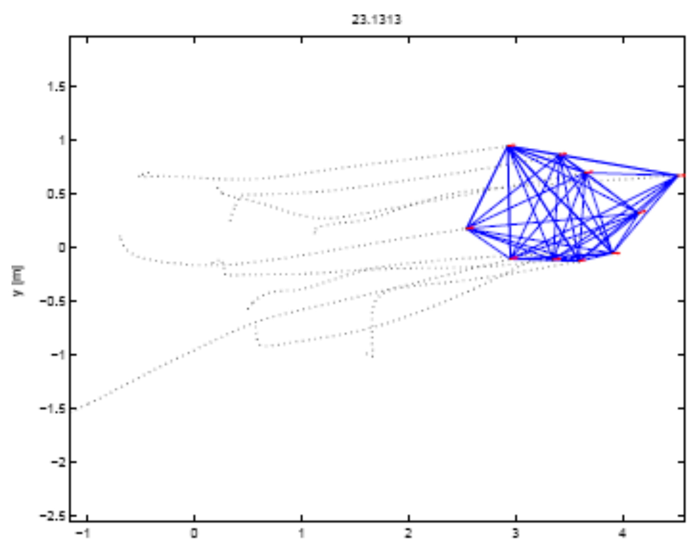
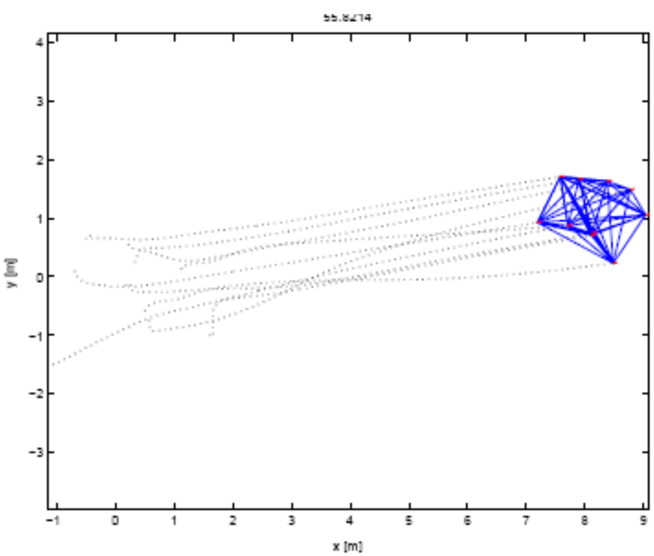


Flock Simulations: Fixed Network

5



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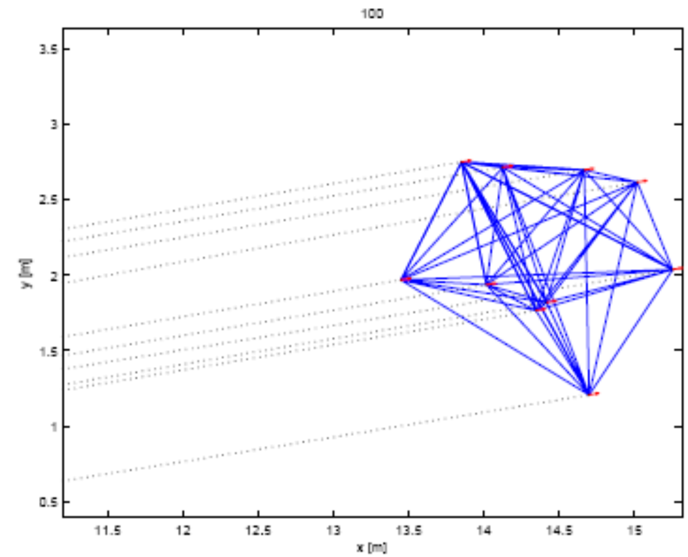
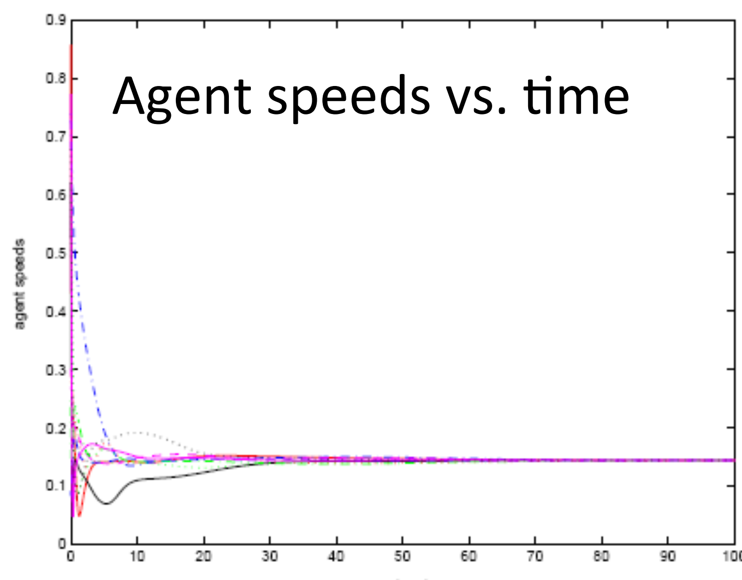
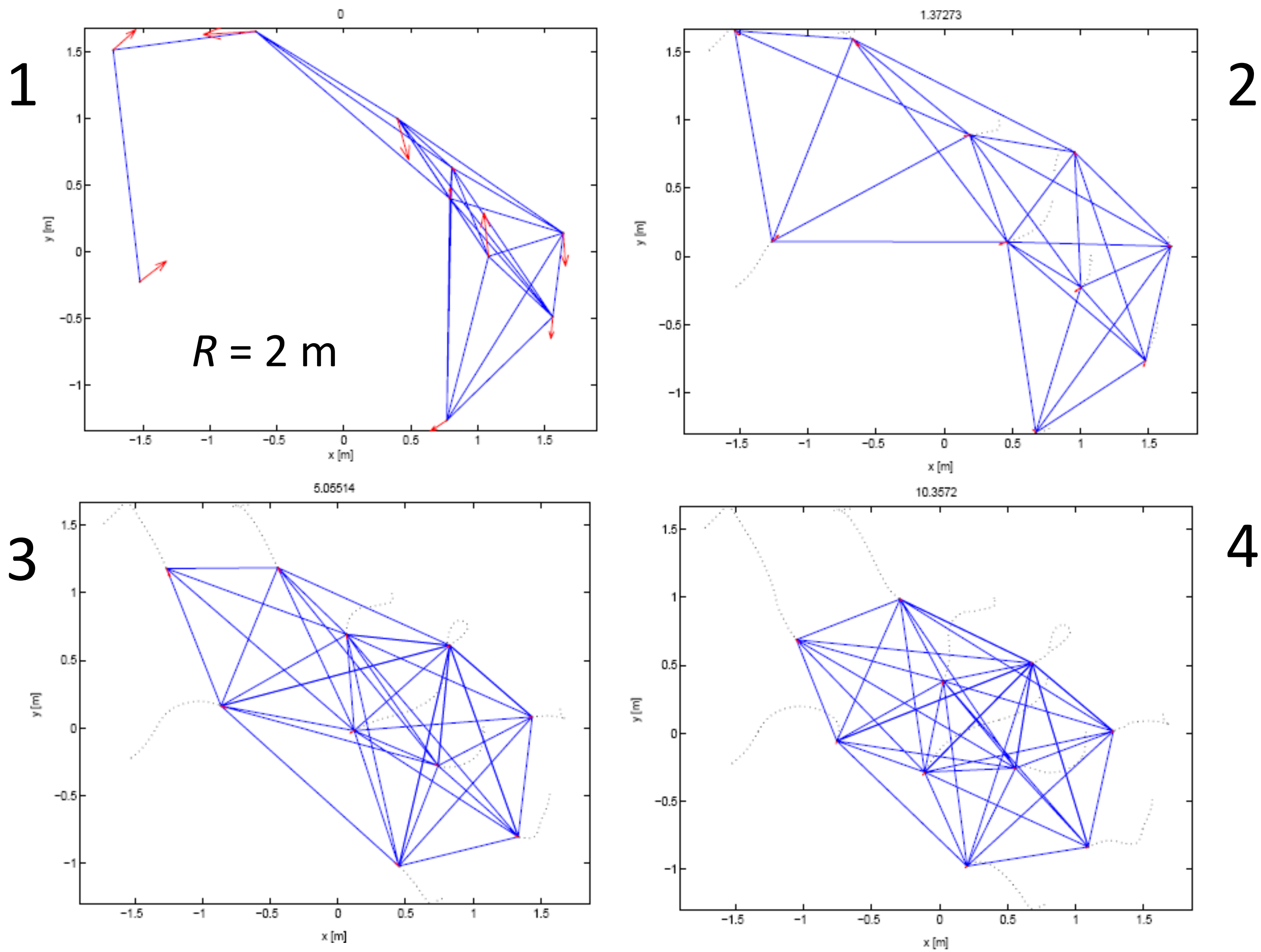


- No way to ensure collision avoidance between two agents unless they are interconnected; switching network solves this problem



Flock Simulations: Switching Network



Flock Simulations: Switching Network

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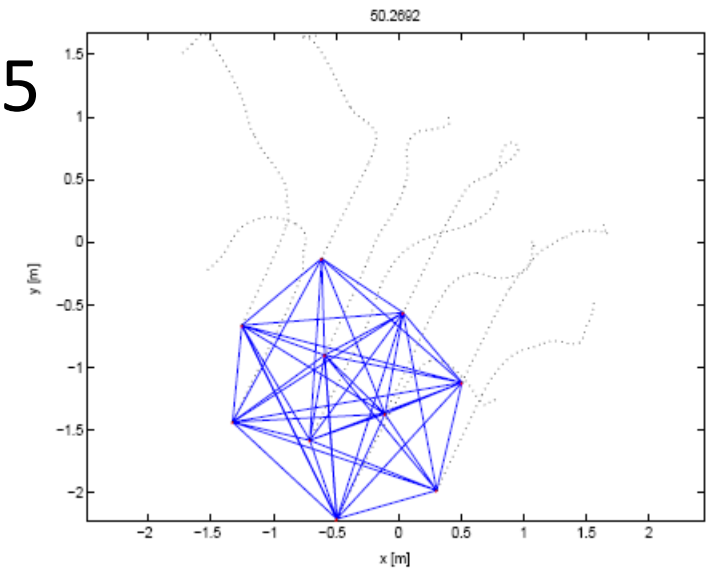

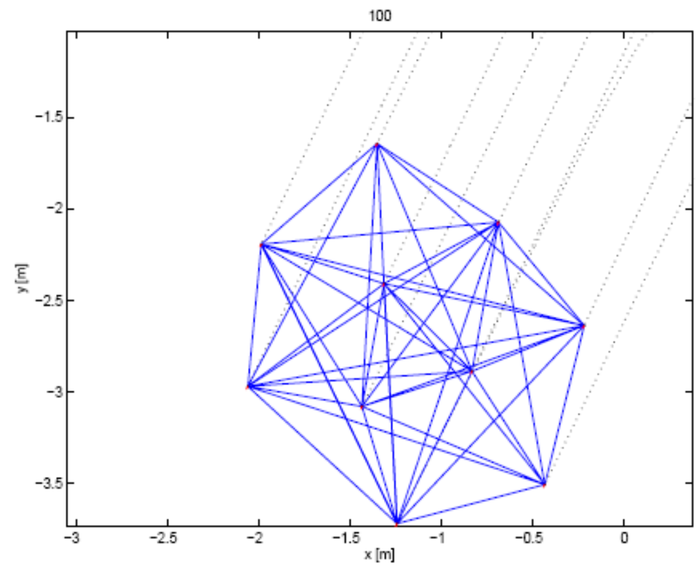

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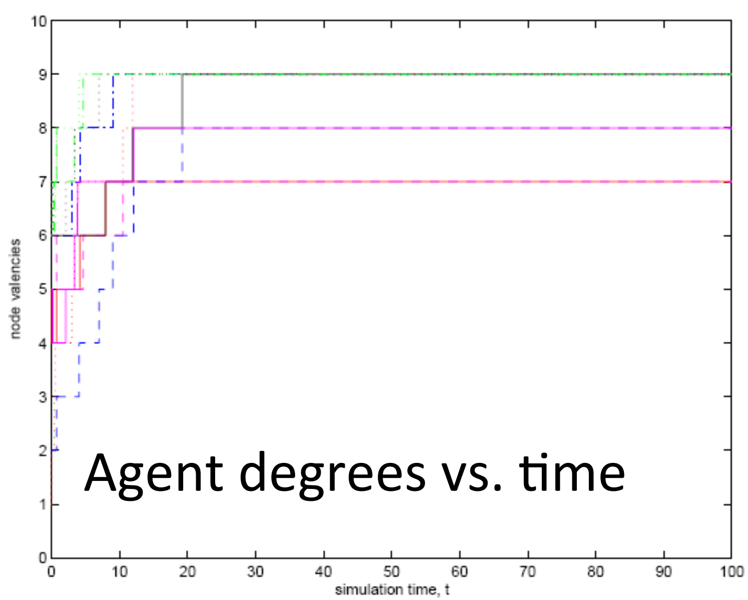
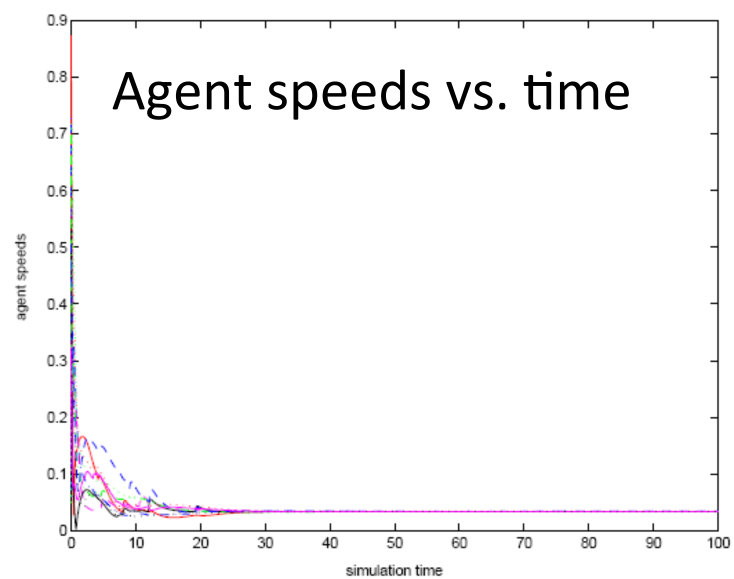
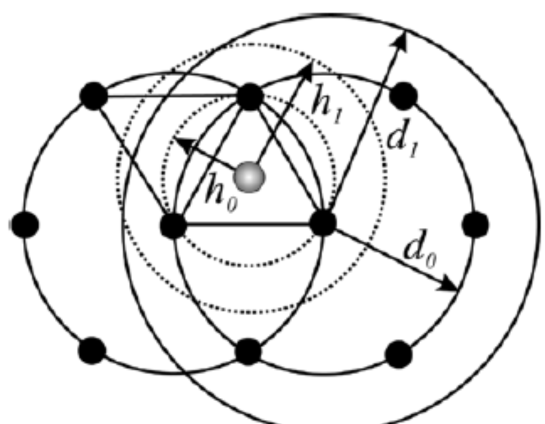




Cooperative Control of Mobile Sensor Networks: Adaptive Gradient Climbing in a Distributed Environment

Petter Ögren, Edward Fiorelli, Naomi Leonard

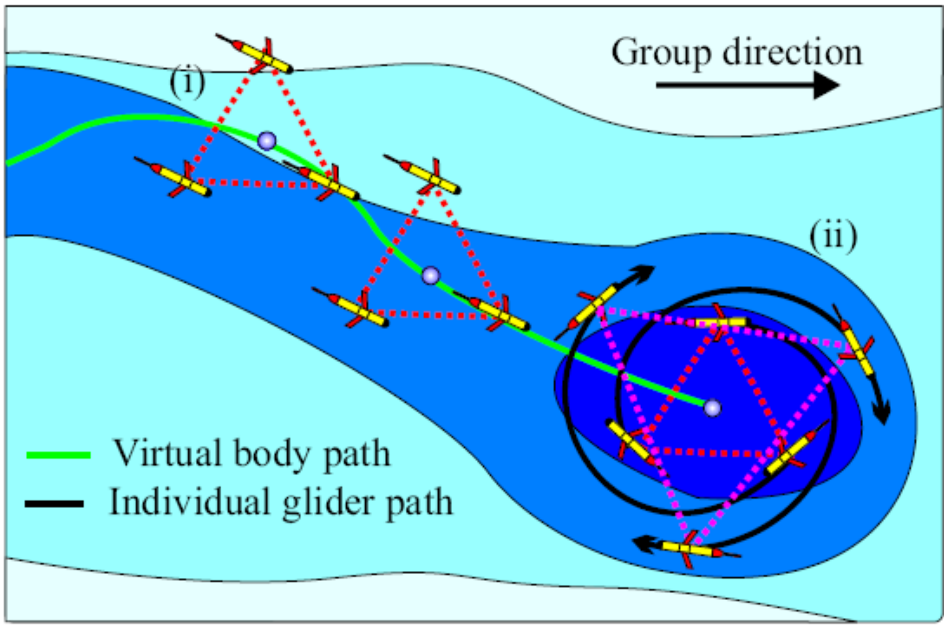


Motivation

- Stable coordination of a group of vehicles to cooperatively climb the gradient of an environmental field

  - Inspired by fish schools, which efficiently climb nutrient gradients using local rules at the individual level
  - Can be used to track ocean features such as fronts and eddies

- Decouple formation stabilization problem from performance of network mission



E. Fiorelli, P. Bhatta, N. E. Leonard, I. Shulman. "Adaptive sampling using feedback control of an autonomous underwater glider fleet." Proc. Symp. Unmanned Untethered Submersible Technology, 2003, pp. 1-16.

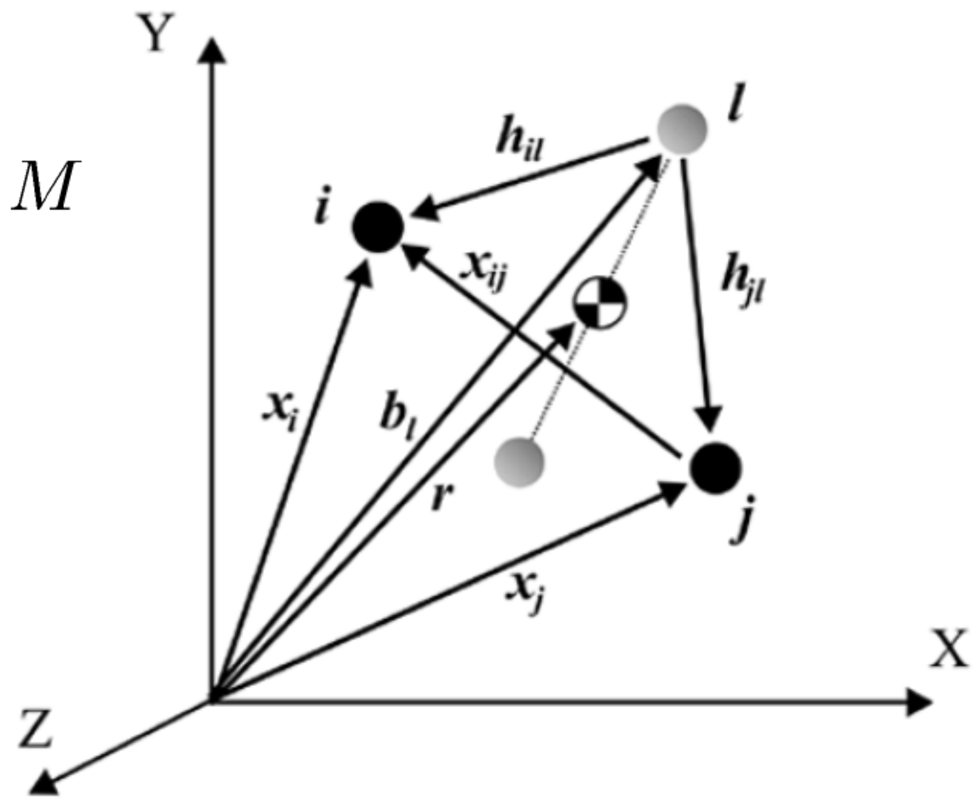
Framework for Formation Control

➢ Vehicle modeled as point mass with fully actuated dynamics

- vehicle $i = 1, \ldots, N$
- virtual leader $l = 1, \ldots, M$
- COM of "virtual body"

$$\boxed{\ddot{x}_i = u_i} \qquad u_i \in \mathbb{R}^3$$

$$x_{ij} = x_i - x_j$$
$$h_{il} = x_i - b_l$$



Implementation

AOSN-II project: Adaptive, coupled observation/modeling system in the ocean

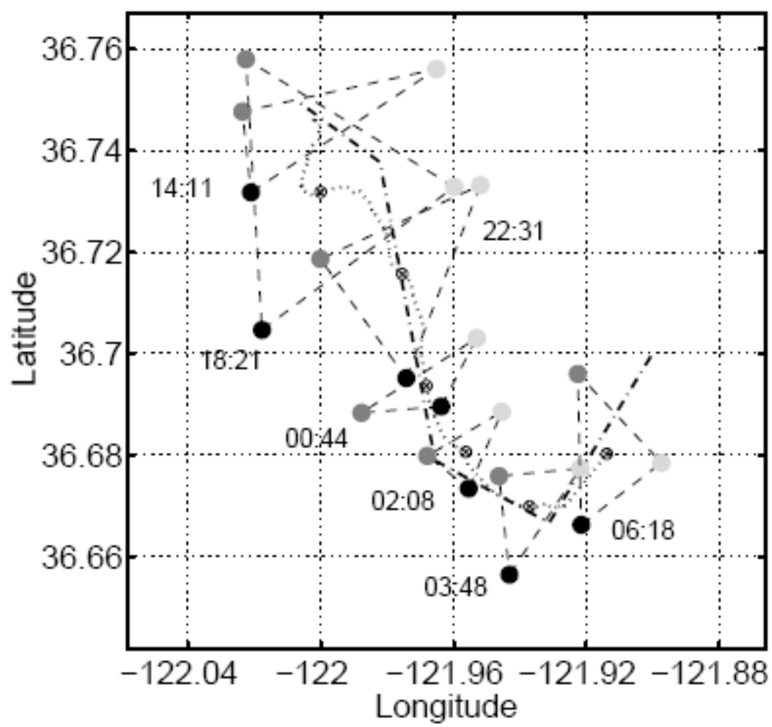


Figure 3. Triangle formation snapshots at various UTC times on August 16, 2003. Dotted line: path of formation centroid; Piecewise linear dash-dotted line: desired virtual leader path.

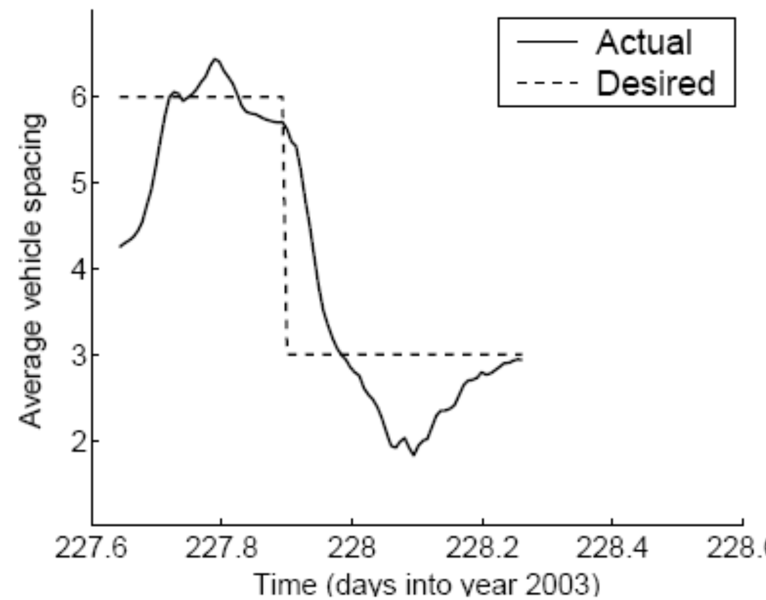


Figure 4. The actual average of vehicle distances during the demonstration and the desired vehicle spacing as a function of time from the August 16, 2003 demonstration.

P. Bhatta et al. Coordination of an Underwater Glider Fleet for Adaptive Ocean Sampling. *Proc. Int'l Workshop on Underwater Robotics*, (IARP), Genoa, Italy, Nov. 2005.