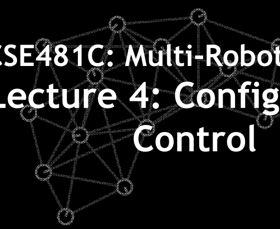


CSE481C: Multi-Robot Systems
Lecture 4: Configuration Control

Announcements

Announcements
- Zotero
- fear lab 3

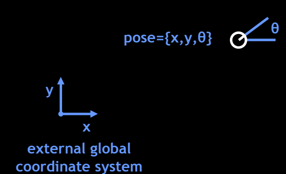
Paper review
- agreement 1
- agreement 2

introduction and definitions

Model: Robot State

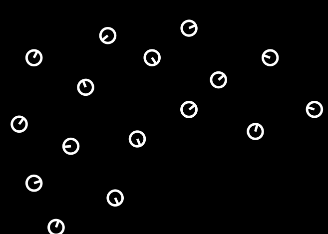
We can describe the **state**, *s*, of a single robot as a tuple of its ID, pose, and private and public variables:

$$s = \langle \text{ID, pose, private vars, public vars} \rangle$$



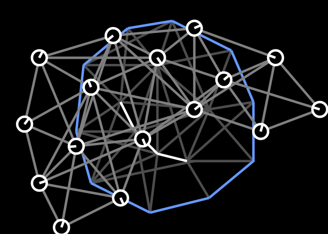
Model: Configuration

We define a **configuration**, *C*, as the states of *n* robots
All the robots use the same software and hardware



Model: Algorithm

An **algorithm** *A* runs on every robot and transforms any configuration C_1 through valid intermediate configurations to a new configuration C_2,
s.t. C_2 satisfies a given set of properties



Definitions

What is configuration control?
- A configuration is the output of every multi-robot algorithm
- We want to achieve some desired global physical configuration…
- …With global invariants

There are many applications in the literature
- flocking
- formations
- coverage
- dispersion

There is a large diversity of approaches. We roughly classify into:
- behavior-based approaches
- control-theoretic approaches
- other approaches

Behavior-Based Approaches vs. Control-Theoretic Approaches

What's the difference?
- What's control theory, anyway?
- PID control demo

The model
- Control-theoretic approaches have an explicit model of the systems state that they reason about
- This model is usually real-valued, and requires suitable analysis techniques

What's better?
- neither
- depends what you want to do

Are their other approaches?
- Semantic models
- Plan-based systems

behavior-based approaches

We look at three problems:

Flocking

Formation

Tree-based motion

Flocking: Boids

Craig W. Reynolds. "Flocks, herds and schools: A distributed behavioral model", SIGGRAPH, 1987

Boids

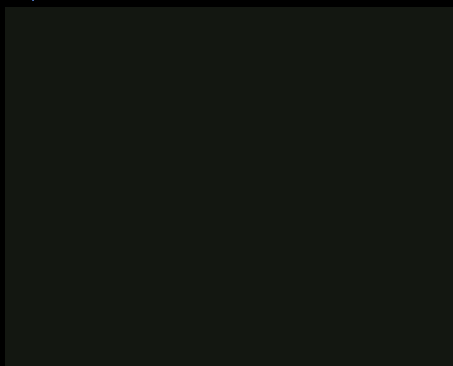
Three behaviors:
1. Collision Avoidance: avoid collisions with nearby flockmates
2. Velocity Matching: attempt to match velocity with nearby flockmates
3. Flock Centering: attempt to stay close to nearby flockmates

Limitations
- Tuning is important: Each behavior has range thresholds and gain tuning parameters
- Global goal location

Interesting effects in large populations

Craig W. Reynolds. "Flocks, herds and schools: A distributed behavioral model", SIGGRAPH, 1987

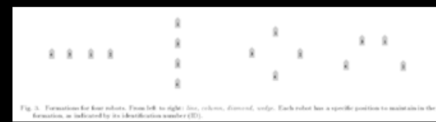
Boids Video



Alessandro Silva, Wallace Lages, Luiz Chaimowicz. “Improving Boids Algorithm in GPU using Estimated Self Occlusion”, Proceedings of SBGames'08 - VII Brazilian Symposium on Computer Games and Digital Entertainment, 2008

Formation Control: Behavior-based

Lots and lots of papers



Parameter	Value	Units
avoid-static-obstacle		
gain	1.5	
sphere of influence	50	meters
minimum range	5	meters
avoid-robot		
gain	2.0	
sphere of influence	20	meters
minimum range	5	meters
move-to-goal		
gain	0.8	
noise		
gain	0.1	
persistence	6	time steps
maintain-formation		
gain	1.0	
desired spacing	50	meters
controlled zone radius	25	meters
dead zone radius	0	meters

TABLE I

Motor schema parameters for formation navigation experiments in simulation.

T. Balch, R. Arkin, “Behavior-based Formation Control for Multi-robot Teams”, IEEE Transactions on Robotics and Automation, 1998

Formation Control

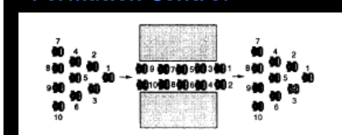


Figure 1: Formation of robots changing shapes.

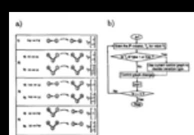


Figure 7: a) Enumeration of transitions between control laws for robot R_j and b) Control graph transition algorithm flowchart.

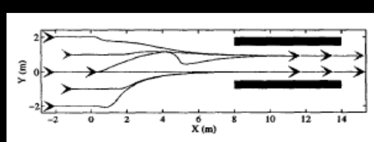
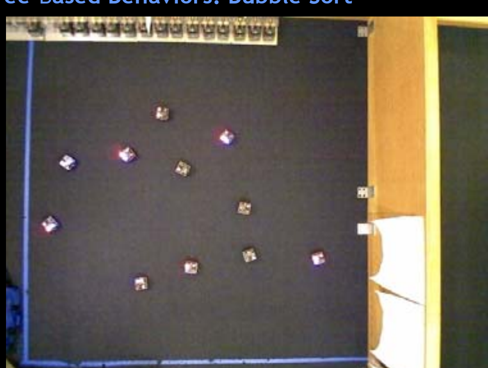


Figure 10: Formation change for six robots.

J.P. Desai, V. Kumar, J.P. Ostrowski, “Control of changes in formation for a team of mobile robots”, ICRA, 1999

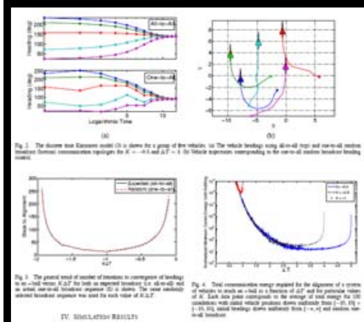
Tree-Based Behaviors: Cluster

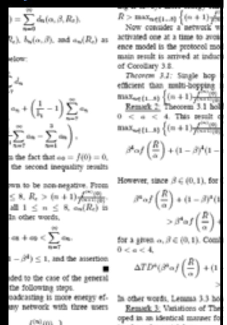
Tree-Based Behaviors: Bubble Sort



control-theoretic approaches

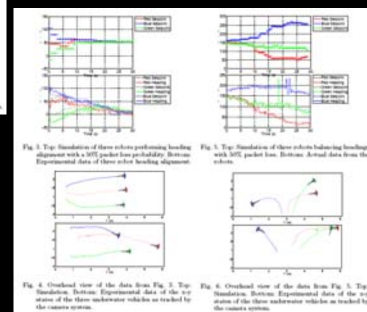
Formation Control: Control Theory





Daniel J. Klein, Phillip Lee, Kristi A. Morgansen, “Integration of Communication and Control using Discrete Time Kuramoto Models for Multivehicle Coordination over Broadcast Networks”, IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS,

Formation Control: Control Theory



Daniel J. Klein, Patrick K. Bettale, Benjamin I. Triplett, Kristi A. Morgansen, “Autonomous Underwater Multivehicle Control with Limited Communication: Theory and Experiment”, 2008 IFAC Workshop on Navigation,Guidance and Control of Underwater

other approaches

Centroidal Voronoi Configurations

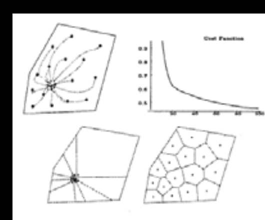


Fig. 2. Uniform distribution of sensors obtained by 16 vehicles in a polygonal environment. The vehicles' initial positions are in a tight group in the lower left corner and their final positions are optimally distributed.

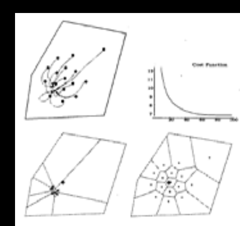
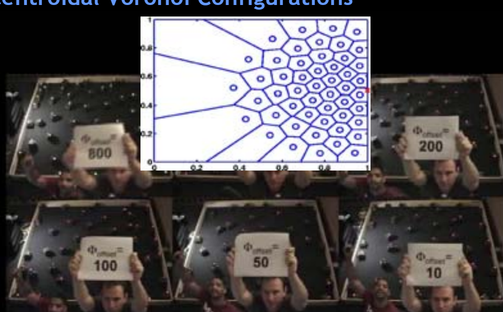


Fig. 3. Non-uniform setting. The distribution density function has an inverse exponential about the location shown by the large circle in the bottom left and right figures.

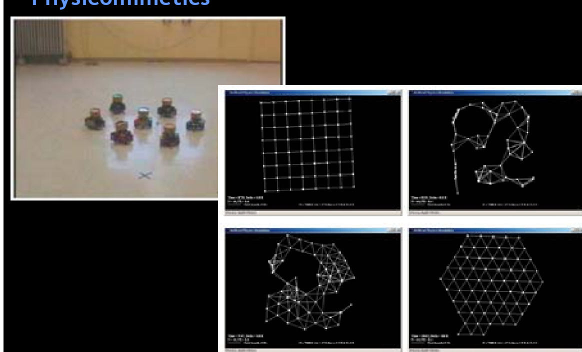
J. Cortes, S. Martinez, T. Karatas, F. Bullo, “Coverage control for mobile sensing networks”, ICRA 2002

Centroidal Voronoi Configurations



Mac Schwager, James McLurkin, “Distributed Coverage Control with Sensory Feedback for Networked Robots”, RSS 2006

Physicomimetics



Agents can also transform from perfect square lattices to perfect hexagonal lattices (shown) and back (not shown).

W. M. Spears, D. F. Spears, J. C. Hamann, R. Heil, “Distributed, Physics-Based Control of Swarms of Vehicles”, Autonomous Robots 2004

Graph Grammers

Fig. 1. Robotic "programmable parts" [4]. Each edge of a part may attach via a magnetic latch to another part. Once attached, the parts may communication and decide to remain attached or may de-attach by rotating a permanent magnet, which disengages the latch.

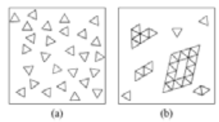


Fig. 2. (a) Initial configuration of programmable parts on an air table. The parts are stirred by air jets (not shown) so as to produce collisions. (b) Assembly of programmable parts after the assembly process has completed. A complete final assembly and several partial assemblies are shown.

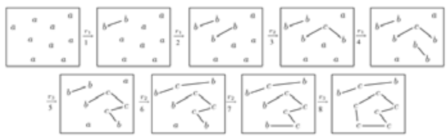


Fig. 3. Trajectory of the system defined in Example IV-A. The relative positions of the nodes denote the identities of the nodes and do not change after each rule application. The rules used are shown above the arrows. The monomorphisms witnessing the actions should be clear from the figure. For convenience (to the discussion in Section VI-C) the actions are numbered sequentially by the integers 1, . . . ,8 appearing below the arrows.

Eric Klavins, Robert Ghrist, and David Lipsky, "A grammatical approach to self-organizing robotic systems", IEEE Transactions on Automatic Control, 2006

summary

Summary

A diversity of problems and solutions

There are many, many ways to control the configuration of robots

There are many, many applications, each with their own assumptions and requirements

Standard robot issues of sensing and navigating from a to b+
communications constraints +
distributed processing challenges =
This will be an active area for many years to come

final project mini-brainstorming

Final Project Goals

Ideally, a research project
- Something new, or
- extension of existing work

Cool demo (maybe in atrium)
- often antagonistic to above constraint

Research paper-like final report
- 6-8 pages
- problem statement
- algorithm design
- data
- analysis

"The Literature"

Use the papers I've referenced here to research the literature
- Use Google Schoolar or Citeseer while on campus, and you should be able to find the actual papers.
- Use their references to find more papers to help design your final project
- Use Firefox and Zotero to keep references you find organized

How do you know if you like a paper?
- Do they use real robots?
- Look at the pictures.
- Look at the experiments. Can you do something like that?

If you plan on going to grad school, learn Latex now
- Miktex and Winedt is good to get started for windows users
- In any case, use PDFtex

Mini-Brainstorming Session

no squashing

- all ideas are good ideas

no hording

- must share ideas freely