Interacting With Multi-Robot Networks

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Outline:
1. Human-Swarm Interactions
2. From Lagrange to Euler
3. Conducting Robots
Outline:

*Least-Squares*
What Facebook Has Taught Me About Mark Spong

#1: The Family Man

As an admirer, don't she and her a date for myself, for John and Paul.

Like · 0

#2: The Wonk

At the Tech Titans Awards Gala in Dallas. I had the most beautiful date at the banquet. — with Lila Acosta Spong.

Like · 0

#3: The Crank

As an admirer, don't she and her a date for myself, for John and Paul.

Like · 0

#4: The Scientist

The UT Dallas robot chess team in action.

Like · 0

Magnus Egerstedt - SpongFest, November 2012
Human-Swarm Interactions?
Application Domains

- Multi-agent robotics
- Sensor and communications networks
- Biological networks
- Coordinated control
Leader-Based Interactions

Multi-Robot Assignment and Formation Control
Edward MacDonald    Magnus Egerstedt

GRITS
Georgia Robotics and Intelligent Systems Lab
Georgia Institute of Technology    May 2011
Interaction Models?

- It is not clear how people should interact with networks of robots
- Overall, we are pretty bad* at this…

- Leader-Follower Models (virtual and actual)
- Boundary Control
- Behavioral Interactions
- **Fluid-Based Interactions**
Multi-Agent Interactions
...With Infrastructure

Wireless LANs (802.11)
Cellular Networks (GSM, "4G" / 802.16)
Air Traffic Control (ATCT, TRACON, ARTCC)
The Infrastructure Network
The Infrastructure Network
The Infrastructure Network
The Infrastructure Network
Two Views of the World

- Lagrangian

\[ \dot{x}_i = f(x_i, u_i) \]

- Eulerian

\[ \dot{m}_i = v_{ij} \]
\[ \dot{m}_j = -v_{ij} \]
What We'll Do…

• Let users specify “flows” through the network
• Distribute the flows across the network so robots don't "pile up" anywhere
  – by solving a problem on the dual graph
  – in a distributed way.
• Produce, from these flows, continuous control laws
  – "no piling up”
  – collision avoidance
  – in a distributed way.
Controlled Laplacian Dynamics

Infrastructure Cell Dynamics

\[ \dot{p}_i = - \sum_{j \in \mathcal{N}(i)} (p_i - p_j) + u_i \]

Ensemble dynamics

\[ \dot{p} = -Lp + u \]

where \( L \), the *Graph Laplacian*, is defined s.t.,

\[ L_{ij} = \begin{cases} \text{deg}(i) & i = j \\ -1 & j \in \mathcal{N}(i) \\ 0 & \text{o.w.} \end{cases} \]
Controlled Laplacian Dynamics

Infrastructure Cell Dynamics

\[ \dot{p}_i = - \sum_{j \in \mathcal{N}(i)} (p_i - p_j) + u_i \]

Ensemble dynamics

\[ \dot{p} = -Lp + u \]

\[ D = \begin{bmatrix}
0 & 1 \\
1 & -1 \\
0 & 0 \\
-1 & 0 \\
0 & 0
\end{bmatrix} \]

\[ L = DD^T \]

Grammian
A Least Squares Interpretation

\[ Ax = b \]
\[ \min_x \| Ax - b \|^2 \]
\[ \frac{1}{2} \frac{\partial (\cdot)}{\partial x} = A^T Ax - A^T b \]
\[ A^T Ax = A^T b \]  

Grammian

\[ D^T p = f \]
\[ \min_p \| D^T p - f \|^2 \]
\[ D D^T p = D f \]
\[ \dot{p} = -\frac{1}{2} \frac{\partial (\cdot)}{\partial p} = -D D^T p + D f \]
\[ \dot{p} = -Lp + D f \]  
The input!!
Punchline

- The forced consensus dynamics

\[ \dot{p} = -L p + D f \]

“solve”

\[ D^T p = f \]

- Computes differences across edges
  - **Gradient**
- Assigns a number to each vertex
  - **Scalar Field**
    - (PRESSURE)
- Assigns a number to each edge
  - **Vector Field**
    - (FLOW)
Example

Simplices
Example

Input Flow $f$
Example

Resulting Flow $D^T p$
Example

Resulting Flow $D^T p$

Add local, hybrid stream functions
But, What About This Picture?
Swarm Conducting

- Interface: Motion capture wand
Swarm Conducting
THANK YOU!

Peter Kingston