EE631 Cooperating Autonomous Mobile Robots

Lecture 2: Introduction to Multi-Robot Systems

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Application Domains of Multi-Robot Teams

Space Exploration

Mining

Surveillance and Reconnaissance

Hazardous Waste Cleanup
Intelligent Systems in Industry
Caterpillar

Planetary Exploration
NASA/JPL

Military Operations
DARPA (TTO/ATO, ITO)

Surveillance & Security
DHS
Research in multi-robotics growing rapidly

- Conducted an INSPEC* Search:
  - Yearly query, 1979 -2001
  - Searched for articles including at least one of the following terms:
    - Multi-robot
    - Multirobot
    - Cooperative robot
    - Collaborative robot
    - Distributed robot

* Citation index for physics, electronics, and computing
Parker'03

# Articles in INSPEC


0 50 100 150 200 250 300 350
Primary Research Areas in Distributed Robotics

- Biological Inspirations
- Motion Coordination
- Communication
- Object Transport and Manipulation
- Reconfigurable Robotics
- Architectures, Task Planning, and Control
- Localization, Mapping, and Exploration
- Learning
(Values based upon INSPEC search for years 1979 - 2001)
## Biological Inspirations

**Locomotion Concepts: Principles Found in Nature**

<table>
<thead>
<tr>
<th>Type of motion</th>
<th>Resistance to motion</th>
<th>Basic kinematics of motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow in a Channel</td>
<td>Hydrodynamic forces</td>
<td>Eddies</td>
</tr>
<tr>
<td>Crawl</td>
<td>Friction forces</td>
<td>Longitudinal vibration</td>
</tr>
<tr>
<td>Sliding</td>
<td>Friction forces</td>
<td>Transverse vibration</td>
</tr>
<tr>
<td>Running</td>
<td>Loss of kinetic energy</td>
<td>Oscillatory movement of a multi-link pendulum</td>
</tr>
<tr>
<td>Jumping</td>
<td>Loss of kinetic energy</td>
<td>Oscillatory movement of a multi-link pendulum</td>
</tr>
<tr>
<td>Walking</td>
<td>Gravitational forces</td>
<td>Rolling of a polygon (see figure 2.2)</td>
</tr>
</tbody>
</table>
Communication
- Auditory, chemical, tactile, visual, electrical
- Direct, indirect, explicit, implicit

Roles
- Strict division vs. loose “assignments”

Hierarchies
- Absolute linear ordering, partial ordering, relative ordering
- Purpose: reduction in fighting, efficiency

Territoriality
- Reduces fighting, disperses group, simplifies interactions

Social facilitation/sympathetic induction
- Allows for efficient use of resources

Imitation
- Complex mechanism for learning

Leaf cutter ants

Bees colony
Biological Inspirations

- **Objective:** Study biological systems to achieve engineering goals
Motion Coordination

- Objective: enable robots to navigate collaboratively to achieve spatial positioning goals

- Issues studied:
  - Multi-robot path planning
  - Traffic control
  - Formation generation
  - Formation keeping
  - Target tracking
  - Target search
  - Multi-robot docking
Reconfigurable Robotics

- **Objective:** Obtain function from shape, allowing modules to (re)connect to form shapes that achieve desired purpose
  - Earliest research included reconfigurable/cellular robotics
  - Several newer projects:
    - Various navigation configurations (rolling track, spider, snake, etc.)
    - Lattices, matrices (for stair climbing, object support, etc.)

[Image of reconfigurable robot]

[Image of reconfigurable robot]

- Castano et. al.
Architectures, Task Planning, and Control

- **Objective:** Development of overall control approach enabling robot teams to effectively accomplish given tasks
- **Issues studied:**
  - Action selection
  - Delegation of authority and control
  - Communication structure
  - Heterogeneity versus homogeneity of robots
  - Achieving coherence amidst local actions
  - Resolution of conflicts
Localization, Mapping, and Exploration

Objective: Enable robot teams to cooperatively build models of their environment, or to accomplish spatial tasks requiring knowledge of other robot positions

Issues studied:
- Extension of single-robot mapping approach to multi-robot teams
- Hardware, algorithms for robot positioning
- Sonar vs. laser vs. stereo imagery vs. fusion of several sensors
- Landmarks vs. scan-matching