CSCE 774 ROBOTICS SYSTEMS

Multi-Robot Systems
Multi-Robot Complete Coverage

• Multiple Robots:
  – Efficiency
  – Robustness
  – Higher Complexity

• Inter-Robot Communication Abilities

• Guarantee of Complete Coverage
• Communication is limited to Line of Sight
• Coverage of a single cell
  – Robots have two roles:
    • Explorers
    • Coverers
• Team coordination for complete coverage of the environment
  – Limited communication
  – Deterministic approach
  – Team splits only once
Single Cell Coverage

- Each team of $N$ robots has:
  - 2 explorers, $N-2$ coverers
- The explorers trace the top and bottom border of the Cell maintaining the same X-coordinate until the Line of Sight is broken (i.e. a critical point is detected)
Single Cell Coverage

• Each team of $N$ robots has:
  – 2 explorers, $N$-2 coverers

• The explorers trace the top and bottom border of the Cell maintaining the same X-coordinate until the Line of Sight is broken (i.e. a critical point is detected)

• The coverers use an up-and-down motion to cover the interior of the cell
The explorers are able to detect all critical points:

- Forward Concave CP (encountered only at start-up)
- Reverse Concave CP (explorers approach each other)
- Reverse Convex CP (Line of Sight breaks)
- Forward Convex CP (Explorer reverses direction)
Single Cell Coverage

Reverse Concave Critical Point

The circles represent the robot position not the sensor footprint.
Single Cell Coverage

Forward Convex Critical Point

The circles represent the robot position not the sensor footprint.
The circles represent the robot position not the sensor footprint.
Team Coverage

- The team splits only once into two sub-teams in order to encircle an obstacle
- One sub-team moves clockwise around the obstacle, the other sub-team moves counter-clockwise
- If a sub-team encounters a dead-end it backtracks
- Guaranteed re-joining of the two sub-teams
Team Splitting and Rejoining

Coverage direction
Multi-Robot Coverage Paradigm

Stripes Boundaries

Robots

Delivery Vehicle
Multi Robot Complete Coverage: Main Ideas

• Unrestricted Communication / Good Localization
• Environment is divided into as many stripes as robots
• Cooperative Exploration
  – Each robot explores the boundaries of its stripe
  – Robots Auction parts of the non reachable parts of their stripe
• Cooperative Coverage
  – Connectivity of the environment is known
  – Each robot covers the closest cell
  – Robots Auction coverage tasks
Example

Robot 3 is thinking.
Auctions!

- Used to improve performance
- A central coordinator or one team member call/administer the auction
- Robots bid for tasks based on some estimated reward/cost
Classification

• Team size
• Communication range
• Communication topology
• Communication bandwidth
• Processing ability
• Team Reconfigurability
• Team Composition
Marsupial Robots

Also watch: http://www.youtube.com/watch?v=hCGgoPS91Rw

Marsupial Robots

• From: http://distrob.cs.umn.edu/demos.php
Formations
Formations

• Follow the leader
• Unit Center
• Maintain position
• Avoid Obstacles
Cooperative Localization, Mapping, and Exploration
Cooperative Localization

- Pose of the moving robot is estimated relative to the pose of the stationary robot. **Stationary Robot** observes the **Moving Robot**.

**Robot Tracker Returns:**

\[ \langle \rho, \theta, \phi \rangle \]

\[
\mathbf{x}_{m_{est}}(k+1) = \begin{pmatrix}
    x_{m_{est}} \\
    y_{m_{est}} \\
    \theta_{m_{est}}
\end{pmatrix} = \begin{pmatrix}
    x_s + \rho \cos(\theta + \theta_s) \\
    y_s + \rho \sin(\theta + \theta_s) \\
    \pi - (\phi - (\theta + \theta_s))
\end{pmatrix}
\]
Laser Robot Tracker

Robot Tracker Returns:

$\langle \rho, \theta, \phi \rangle$
• If the line of visual contact is not interrupted during the motion, then the triangle $[R_s, T_1, T_2]$ is free space.

• Connect the triangles of free space in order to construct a map of the environment.
Triangulation Algorithm: Main Ideas

- **Bounded Area**: The range of the tracker sensor is larger than any diagonal of the environment.
Triangulation Algorithm: Main Ideas

• **Robot Position:**
  – Stationary Robot: Positioned at the corners of the environment (vertices of the polygon).
  – Moving Robot: Follows the walls.

• **Exploration order:** The two robots explore the free space by following the Dual Graph of the Triangulation.

• **Decision points:** Reflex vertices.
Cooperative Exploration
Experimental Results (Triangulation)
Moving out
2 Laboratories, Sonar Data

Sonar from Robot 0 (range less than 400cm)

Sonar from Robot 1 (range less than 400cm)
2 Laboratories, Laser Data

All Data Scan Matched Using S. Gutmann s/w based on Lu and Milios algorithm.
Sonar Map from Triangulation Algorithm

Perimeter: 42.71m. Mean error: 0.046m