CSE-571
Robotics

Exploration

Single Robot Exploration

- Frontiers between free space and unknown areas are potential target locations
- Going to frontiers will gain information

- Select the target that minimizes a cost function (e.g. travel time / distance /...)

Frontier-Based Exploration

Multi-Robot Exploration

Robot 1:

Robot 2:
Coordinated Exploration

$$C(\theta) = \sum_{i,j \in \theta} \text{dist}(i,j)$$

$$U(\theta) = \sum_{i,j \in \theta} \text{explore}(i,j)$$

$$\theta^* = \arg \max_{\theta} (U(\theta) - C(\theta))$$

[Burgard et al. 00], [Simmons et al. 00]

Typical Trajectories in an Office Environment

Implicit / no coordination:  
Explicit coordination:

Exploration Time

Multi-Robot Mapping With Known Start Locations
Why are Unknown Start Locations Hard?

Need to know whether or not maps overlap
Need to know how maps overlap

Multi-robot Map Merging

• Problems
  – Number of possible merges is exponential in number of robots
  – Cannot merge maps by simply overlaying them

• Wanted
  – Scalability, robustness
  – Merge maps as soon as possible
Multi-robot Map Merging

Experimental setup

Coordinated exploration with three robots from unknown start locations

The robots are fully autonomous.
All computation is performed on-board.

Shown is the perspective of one robot

Sponsored by DARPA-SDR, NSF, Intel

- Map an unknown area
- Search for an “object of value”
- Set up a surveillance network
- Track any intruders
CentiBots: Experimental Evaluation

- Rigorously tested by outside evaluation team
- No testing allowed in 1/2 of environment
- Limited communication
- No intervention / observation during experiment
- Comparison to “ground truth” map

Control Center and Test Team

Comparison to “Ground Truth Map”
Three Mapping Runs

 Courtesy of Vijay Kumar

 3D Exploration

 Active Object Modeling:
 Joint Tracking and Modeling

 - EKF with articulated ICP over manipulator joint angles, camera pose and pose of (partial) object

 [Krainin-Henry-Ren-F: IJRR-11]
Uncertainty in Object Surface

- Signed-distance function voxel grid [Curless '96]
- Surface uncertainty from beam-based noise model

View Selection Algorithm

- Conceptually similar to Planetarium Algorithm [Connolly '85]

  Procedure:
  - Generate kinematically achievable viewpoints
  - Compute information gain (quality) for each viewpoint
  - Select view as tradeoff between quality and cost

Re-Grasp Selection

- Generate candidate grasps [Diankov '10]
- Select grasp by maximum information gain, accounting for occlusion caused by grasp

Multiple Grasp Results

- Evaluated regrasping on four objects
- Includes box with three grasps
Active Object Modeling

Next Best View Planning for 3D In-Hand Modeling