Search/Coverage, Part II

February 4, 2003

Class Meeting 7
Objectives

• Bonus! Application of swarm technology to music

• Search/Coverage, Part II

• Paper #8 presentation: Yifan Tang
Bonus! Application of Swarm Technology to Music

• Discover, March 2003: “Music of the Swarms”

• See http://www.timblackwell.com
Search/Coverage, Part II:
Recall: Three Types of Search/Coverage (from Gage)

Blanket/Field

Barrier

Sweep
Recall Paper from last Time: Gage’s Analysis

• What type of search/coverage addressed?
  – Sweep

• Issues in algorithm development for sweep coverage?
  – Group pattern followed (i.e., how does group as a whole move?)
  – Formation-keeping
    • We’ll study this more a bit later in the semester
From Gage: Target Detection Sensor Abstractions

• Basic search problem:
  – One or more searchers
  – Each searcher carries a detection sensor
  – Each searcher moves through a predefined search area to detect one or more stationary target objects
  – Targets are a priori equally likely to be at any point within the search area
  – Searcher detection of any given target at any instant depends on:
    • Relative geometry of searcher and target at that instant
    • Physical characteristics of the detection sensor(s), the environment, and the target itself.
Probability of Detection with Abstract Sensors

• Calculate cumulative probability of detection:
  - Integrate over instantaneous probability of detection as searcher moves toward target, passes by, and retreats

• Result: Lateral Range Curve
The Search Process

• $N$ robots
• Imperfect sensor: range $r$, detection probability $p$
• Max travel distance: $d$
• Search space has area $A$

• Calculate “sweep fraction”:

$$ S = 2 r d N / A $$
Coordinated vs. Random Searching

- Expected fraction of targets detected: $D$
- Coordinated Search:
  - "Lawnmower-type" motions
  - Do not revisit locations that have already been visited
  - $S_c$ represents "Sweep fraction" of locations visited
    $$D_c = 1 - (1 - p)^{S_c}$$
- Random Search:
  - Completely random motions within search area
  - (Not unlike Roomba)
  - $S_r$ represents "Sweep fraction" of locations visited
    $$D_r = 1 - e^{-pS_r}$$
Calculating “Search Gain” of Coordinated vs. Random Search

- Equate $D_c$ and $D_r$, yielding Search Gain $G$:

\[
G_{\text{many targets}} = \frac{S_r}{S_c} = -\ln \frac{1-p}{p}
\]

\[
G_{\text{single target}} = \frac{S_r}{S_c} = \frac{1/p}{1/p-1/2} = \frac{2}{2-p}
\]

Goal: minimize cost of detecting specified fraction $D$ of targets

Goal: minimize search effort for detecting single target
Important “Take-Home” Message

• Since gain, $G$, is different for multi-target vs. single-target search:
  – Optimal choice of sensor, search strategy, etc., may be different

• Possible to have 2 algorithms, $A$ and $B$, such that:
  – $A$ finds any specified percentage of a field of targets with less cost than $B$
  – $B$, on average, finds a single mine with less cost than $A$
Randomized Search Strategies

• In circular area:
  – Use paths consisting of chords within search area
  – Reflection approaches:
    • Specular
    • Uniform
    • Diffuse: Only approach shown to provide uniform search coverage

• Extension to convex search areas:
  – Use chord-lengths to opposite boundary to select direction of reflection

• General approach cannot be extended to nonconvex areas, since some points in search space aren’t reachable by a chord trajectory
Results: Diffuse vs. Chord Searches

- Square search area – 1:1 aspect ratio

**Chord Length Algorithm**
- mode 2, chords 19, length 52.9
- mode 2, chords 20, length 50.3
- mode 2, chords 21, length 50.5

**Diffuse Reflection Algorithm**
- mode 1, chords 24, length 52.2
- mode 1, chords 26, length 50.6
- mode 1, chords 23, length 51.4
Results: Diffuse vs. Chord Searches

• Rectangular search area – 4:1 aspect ratio

**Chord Length Algorithm**

- mode 2, chords 25, length 51.1
- mode 2, chords 20, length 50.1

**Diffuse Reflection Algorithm**

- mode 1, chords 35, length 51.7
- mode 1, chords 33, length 50.6
- mode 2, chords 22, length 51.1
- mode 2, chords 22, length 53.3
- mode 1, chords 29, length 50.9
- mode 1, chords 34, length 52.7
Results: Diffuse vs. Chord Searches

• Rectangular search area – 10:1 aspect ratio

**Chord Length Algorithm**
mode 2, chords 9, length 52.7

mode 2, chords 7, length 51.4

**Diffuse Reflection Algorithm**
mode 1, chords 32, length 51.1

mode 1, chords 21, length 50.9
Results: Diffuse vs. Chord Searches

• Rectangular search area – 25:1 aspect ratio

**Chord Length Algorithm**

- mode 2, chords 13, length 54.0
- mode 2, chords 12, length 56.8
- mode 2, chords 12, length 50.6

**Diffuse Reflection Algorithm**

- mode 1, chords 63, length 50.3
- mode 1, chords 61, length 50.5
- mode 1, chords 49, length 50.5
Conclusions from Gage’s Studies

• Many inexpensive robots ➔ randomized instead of coordinated search:
  – Increase in effectiveness provided by coordinated search decreases as capability of search sensor decreases
  – Cost of implementing navigation capabilities necessary to support coordinated search may be prohibitive, relative to cost of less capable searchers

• Need careful analysis to select and implement appropriate strategy
Student Paper Presentation


• Presented by Yifan Tang
Recall: Three Types of Search/Coverage

Blanket/Field

Sweep

Barrier

What type of search/coverage does Howard et al. address?

• Blanket/Field
Issues in Blanket/Field Coverage

• Key Issue in algorithm development for blanket/field coverage?
  – Deployment strategy

• What are possible deployment strategies?
  – For wide-open area:
    • Aggregation/dispersion (closely related to potential fields)
  – For area with structure, obstacles, etc:
    • Potential fields (adding in obstacle repulsion vectors)
    • Incremental deployment (as described in Howard et al., 2002)
• Understanding of general technique for incremental deployment:
  – Deployment positioning determined based on coverage and reachable/unreachable boundaries

• Note how the experiments and analysis use the empirical evaluation technique we discussed previously

• Environment plays a key role in the performance of the algorithm

• Optimal solutions may be difficult to compute; therefore, heuristics that perform well in practice are appropriate
Preview of Next Class

• Sensor Networks