Motion Planning for Finding Evasive Targets in a Cluttered Environment

Map Building

Problem

- A target is hiding in an environment cluttered with obstacles
- A robot or multiple robots with vision sensor must find the target
- Compute a motion strategy with minimal number of robot(s)

Assumptions

- Target is unpredictable and can move arbitrarily fast
- Environment is polygonal
- Both the target and robots are modeled as points
- A robot finds the target when the straight line joining them intersects no obstacles (omni-directional vision)

Animated Target-Finding Strategy

Does a solution always exist for a single robot?

No!

Easy to test: "Hole" in the workspace
Hard to test: No "hole" in the workspace
Effect of Geometry on the Number of Robots

Two robots are needed.

Effect of Number \( n \) of Edges

Minimal number of robots \( N = \Theta(\log n) \)

Effect of Number \( h \) of Holes

\( N = \Theta(\sqrt{h}) \)

Information State

- Example of an information state = \((x, y, a=1, b=1, c=0)\)
- An initial state is of the form \((x, y, a=1, b=1, \ldots, u=1)\)
- A goal state is any state of the form \((x, y, a=0, b=0, \ldots, u=0)\)

Critical Line

- Information state is unchanged \((x, y, a=0, b=1)\)
- \((x, y, a=0, b=0)\)

Grid-Based Discretization

- Ignores critical lines → Visits many "equivalent" states
- Many information states per grid point
- Potentially very inefficient
Discretization into Conservative Cells

In each conservative cell, the "topology" of the visibility region remains constant, i.e., the robot keeps seeing the same obstacle edges.

Search Graph

- \((\text{Nodes}) = (\text{Conservative Cells}) \times (\text{Information States})\)
- Node \((c, i)\) is connected to \((c', i')\) iff:
  - Cells \(c\) and \(c'\) share an edge (i.e., are adjacent)
  - Moving from \(c\), with state \(i\), into \(c'\) yields state \(i'\)
- Initial node \((c, i)\) is such that:
  - \(c\) is the cell where the robot is initially located
  - \(i = (1, 1, \ldots, 1)\)
- Goal node is any node where the information state is \((0, 0, \ldots, 0)\)
- Size is exponential in the number of edges

Example

- \((B, b=1)\)
- \((D, \rho=1)\)
Example

Example

Example

Example of Target-Finding Strategy

Much smaller search tree than with grid-based discretization!

More Complex Example

Example with Recontaminations
Example with Linear Number of Recontaminations

- Example with Two Robots (Greedy algorithm)

Example with Two Robots

Example with Three Robots

Robot with Cone of Vision

Other Topics
- Dimensioned targets and robots, three-dimensional environments
- Non-guaranteed strategies
- Concurrent model construction and target finding
- Planning the escape strategy of the target
Map Building

Sensing

Alignment of Contours

Merging of Four Partial Models

Dealing with Uncertainty

Next-Best View Planning

1. Simultaneous Localization and Mapping (SLAM)
2. Next-Best View (NBV) Planning