Path Planning for Swarms in Dynamic Environments by Combining Probabilistic Roadmaps and Potential Fields

Alex Wallar [1]   Erion Plaku [2]

[1]School of Computer Science
University of St Andrews

[2]Departement of Electrical Engineering and Computer Science
The Catholic University of America

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Goals

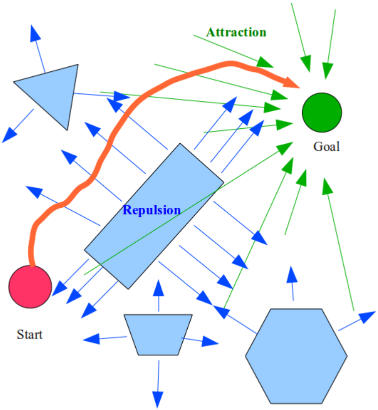
- Given an initial configuration of the swarm
- Move the entire swarm to the goal configuration without leaving any member behind
- Whilst avoiding collisions with static and dynamic obstacles

Motivation

- Enables a large group of robots to complete complex tasks through simple interactions
- *Uses*
  - Monitoring
  - Mapping
  - Inspection
  - Surveying
  - Exploration
  - Search and Rescue

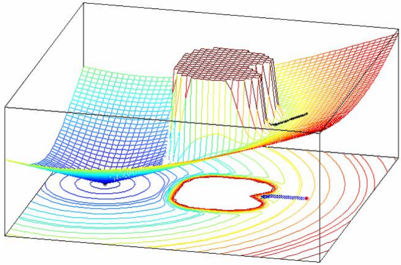
Path Planning for Swarms via Potential Fields

- Attractive potential field around the goal
- Repulsive potential field around obstacles
- Very fast field computation



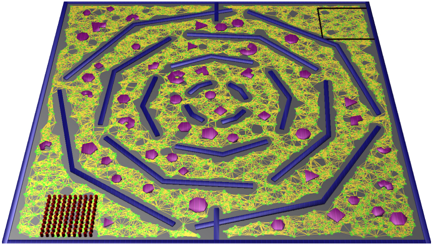
Limitations of Path Planning via Potential Fields

- Local minima problem
- Potential fields often lead robots into local minima especially when dealing with complex dynamic environments



Path Planning for Swarms via Probabilistic Roadmaps (PRMs)

- Randomly distribute points in the environment
- Connect collision free points
- Use a shortest path algorithm to determine path from initial configuration to goal configuration
- Captures the connectivity of the environment



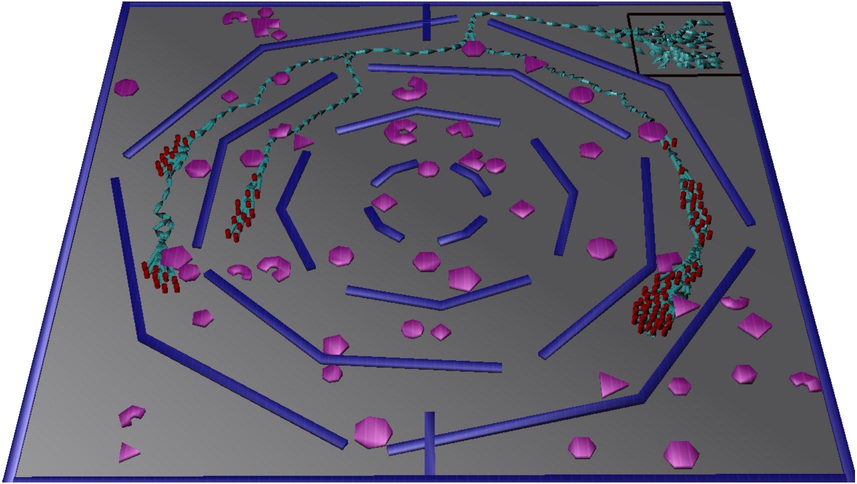
Limitations of path Planning via PRMs

- As the number of robots increases
  - It becomes difficult to sample collision-free configurations
  - It becomes difficult to generate collision free paths
  - Larger roadmaps are needed to capture the connectivity of the sample space
- PRMs do not promote fluidity in movement

Proposed Approach

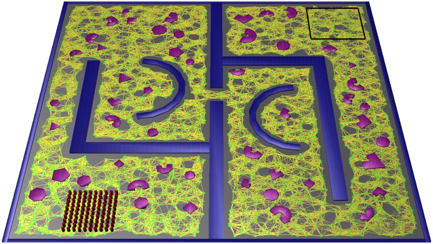
- Combine roadmaps and potential fields for swarms to enable fast path planning for swarms in dynamic environments
- Potential fields provide scalability
- Probabilistic roadmaps provide high-level guidance for how the swarm should move towards the goal
- Potential fields promote cohesion within the swarm

Proposed Approach



Roadmap Construction

- Nodes are randomly distributed in the environment
- Nodes are connected to k collision free nodes within a radius
- Only static obstacles are taken into account



Roadmap Weights

- To bias the swarm away from cluttered areas, a weight is added to an edge indicating its minimum distance to an obstacle

Roadmap Weight Bias

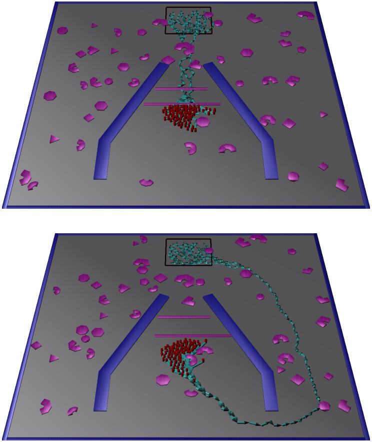
$$w(q_i, q_j) = \left(\min_{o \in \mathit{StaticObstacles}} \mathit{dist}((q_i, q_j), o) \right)^{-3}$$

Guiding the Swarm

- To move the swarm towards the goal region, the swarm is provided with a global guide
- The path is made up of the shortest path from the current robot position to the goal region
- A* search is used to determine the shortest path

Global Replanning via Alternative Guides

- If a robot gets stuck in a local minima or is obstructed by a dynamic obstacle, an alternative route is used
- The weights on the roadmap are adjusted to account for the obstruction
- The next few edges along the guide are penalized by some constant
- A new guide is devised using the re-weighted roadmap



Local Path Planning

- dCRoPS uses four artificial potential fields as a local planner
- For a robot b
  - b is attracted to the next sub-goal in the path
  - b is repulsed away from obstacles
  - b moves in cohesion with other robots whilst maintaining some separation
  - b leverages the headings of other robots that used to be near b's curent position

Attraction to the Next Target

- dCRoPS defines an attractive potential field towards the next immediate goal

Goal Attraction

$$
\begin{aligned}
PF_{\mathit{next}}(b) \quad = \quad & \delta_{\mathit{next}} \cdot (b.\mathit{guide}(b.\mathit{next}) - b.\mathit{pos}) \cdot \\
& ||b.\mathit{guide}(b.\mathit{next}) - b.\mathit{pos}||_2
\end{aligned}
$$

Repulsion from Obstacles

- To avoid collisions, dCRoPS relies on a repulsive potential to push robots away from obstacles
- The potential only applies to obstacles which are less than Δ_{obst} away

Obstacle Repulsion

$$PF_{obst}(b, o) = \delta_{obst} \frac{b.pos - ClosestPoint(o, b.pos)}{(dist(b.pos, o))^2}$$

$$PF_{obst}(b) = \sum_{\substack{o \in StaticObstacles \cup DynamicObstacles \\ dist(b.pos, o) \leq \Delta_{obst}}} PF_{obst}(b, o)$$

Repulsion from Neighbouring Robots

- A weak potential is used to repulse robots from each other
- The potential promotes cohesion but also separation
- The field only acts upon neighbours within a certain radius, Δ_{sep}

Neighbour Repulsion

$$PF_{sep}(b_i, b_j) = \delta_{sep} \frac{b_i.pos - b_j.pos}{||b_i.pos, b_j.pos_{b_j}||_2}$$

$$PF_{sep}(b) = \sum_{\substack{b_i \in Robots - \{b\} \\ dist(b, b_i) \leq \Delta_{sep}}} PF_{sep}(b, b_i)$$

Leveraging History

- The heading for a robot, b, are also influenced by the headings of other robots that used to be near b's current position

History Potential

$$PF_{\mathit{hist}}(b) = \frac{\delta_{\mathit{hist}}}{|\mathit{cell}(b).\mathit{Robots}|} \sum_{b' \in \mathit{cell}(b).\mathit{Robots}} b'.\mathit{lastHeading}$$

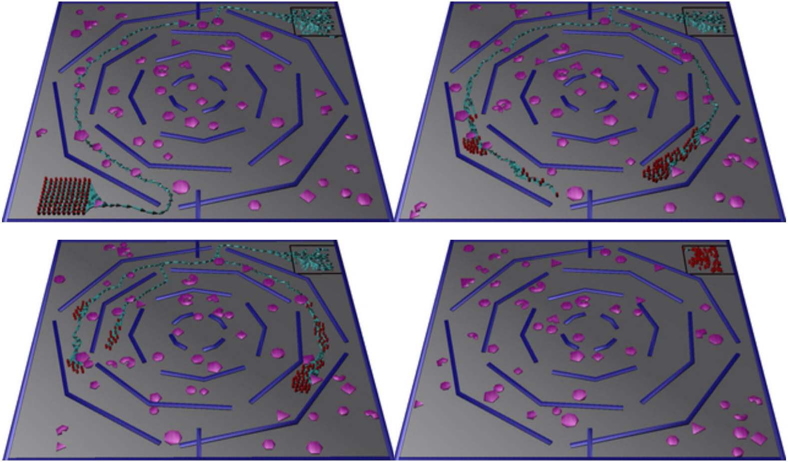
Combining the Potential Fields

- The overall effect of the potential fields is obtained by combining the four different fields
- The overall force is used to update the heading and position of the robot

Field Combination

$$PF(b) = \frac{\sum_{\phi \in \textit{fields}} (||PF_\phi(b)||_2 PF_\phi(b))}{\sum_{\phi \in \textit{fields}} ||PF_\phi(b)||_2}$$

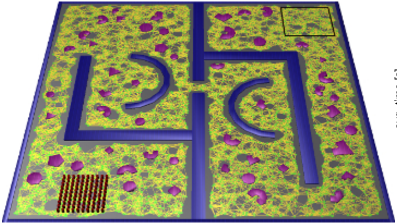
Experiments and Results

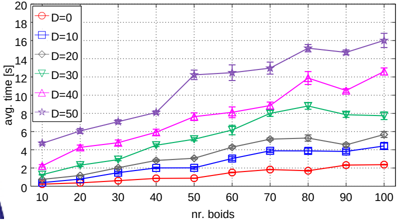


Experimental Setup

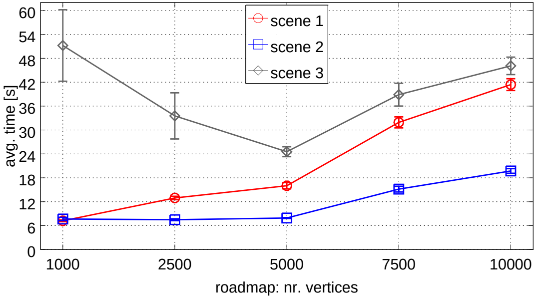
- The problem instance is defined by
  - A scene
  - The number of dynamic obstacles
  - The number of robots
- The number of robots varied from 10 to 100 with increments of 10
- The number of dynamic obstacles varied from 0 to 50 with increments of 10

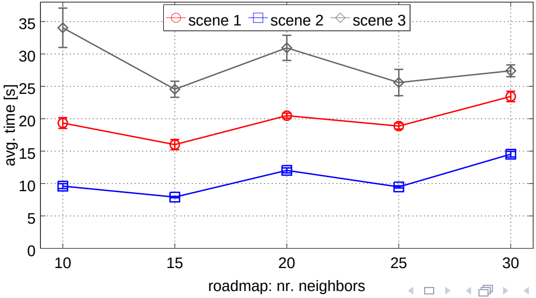
Scalability as a Function of the Number of Robots and Dynamic Obstacles



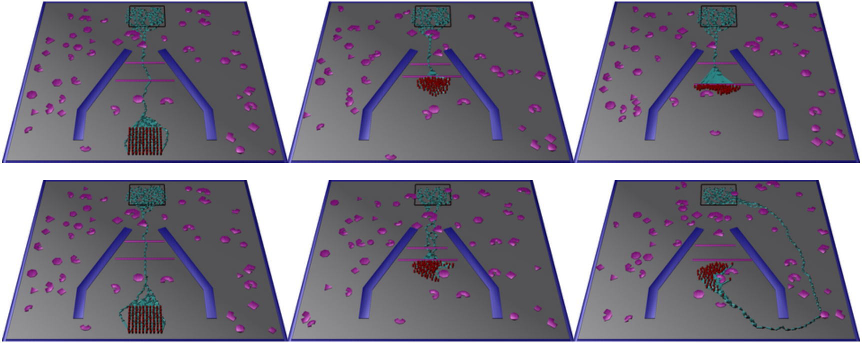


Impact of the Roadmap





Impact of Global Replanning



Conclusions

- dCRoPS is a path-planning approach to enable a swarm of robots to move to a goal region while avoiding collisions with static and dynamic obstacles
- Scalability is obtained by an efficient combination of PRMs and potential fields
- dCRoPS leverages past history and global replanning via alternate guides to help stuck robots find their way to the goal
- Experimental results show the efficiency and scalability of the approach

Future Work

- To predict the motion of the dynamic obstacles and incorporate these predictions to adjust the roadmap
- To conduct practical experiments on real robots