Engineering
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Decentralized Swarming by Robot Collectives

Motivation:

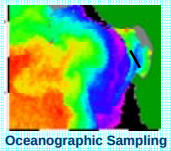
Group behavior in nature: fish, spiders, & bees.

Example of cooperative robot systems.

- Task may be inherently be too complex for a single robot to accomplish.
- Improved performance can be achieved using a group of robots.
- Developing simple small-sized robots can be cheaper, more flexible and fault tolerant.

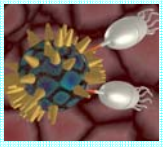
Application Arenas:

Military Swarm Robots



Oceanographic Sampling

Space Exploration



Medical Nanobots

Search & Recovery

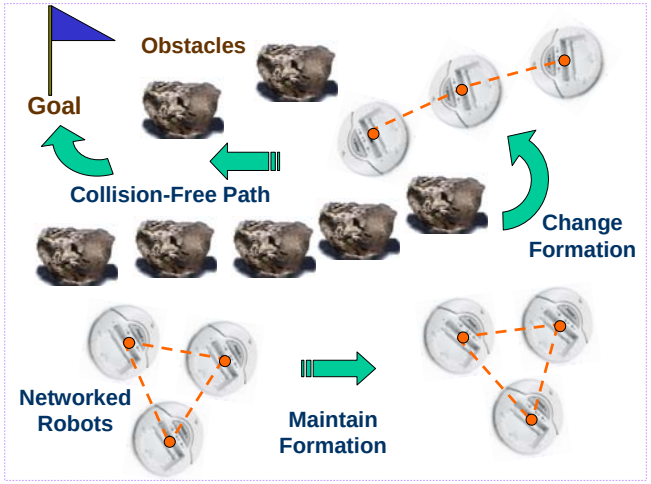
Cooperative Robots

Buildings Surveillance

Entertainment Industry

Research Goal:

Develop a framework for decentralized swarming by robot collectives using artificial potential fields.



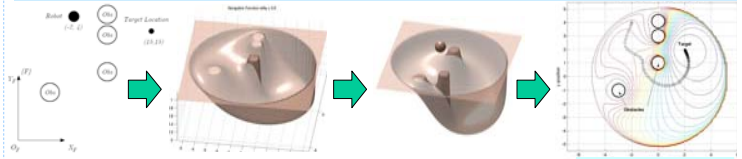
Our Approach:

Takes advantage of the **Artificial Potential Field Approach** for obstacle avoidance and with **Augmented Lagrangian Constraint Satisfaction** to ensure formation maintenance.

Challenges :

- **Decentralization** with minimal centralized coordination is critical from the view point of scalability.
- **Formation maintenance** at every stage of the motion is crucial for payload transport.

IDEA: By modeling workspace and obstacles as a potential field, the motion planning problem reduces to letting the robot follow the gradient of the potential field to reach the destination.



1. Workspace and Robot. | 2. Workspace Modeled using APF. | 3. The ball represents the robot. | 4. Simulation showing path of robot.

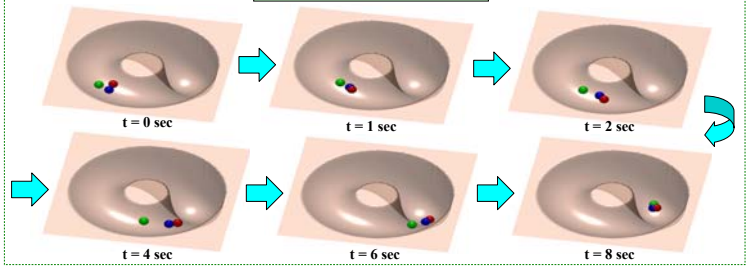
Dynamics Formulation:

$$\dot{\mathbf{q}} = \mathbf{v}$$
$$\mathbf{M}(\mathbf{q})\dot{\mathbf{v}} = \mathbf{f}(\mathbf{q},\mathbf{v},t,\mathbf{u}) - \mathbf{J}(\mathbf{q})^T \boldsymbol{\lambda}$$
$$\mathbf{C}(\mathbf{q},t) = \mathbf{0}$$

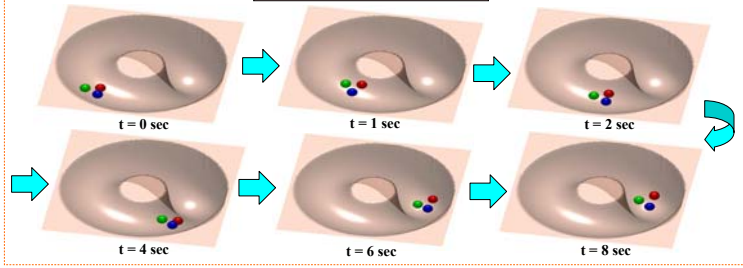
Solved using 3 methods:

I: Direct Lagrange Multiplier Elimination Approach
II: Penalty Formulation Approach
III: Constraint Manifold Projection Approach

Without Formation Constraints



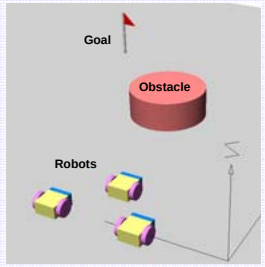
With Formation Constraints



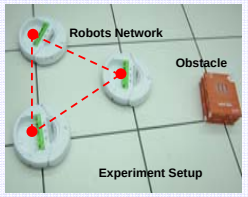
Methods:

VisualNastran Simulation:

- Test and evaluate swarming strategies using Visual Nastran simulation environment.
- Nonlinear, non-smooth effects, including slip and friction can be modeled and simulated.



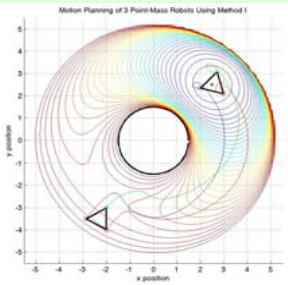
Hardware-in-the-loop Testing :



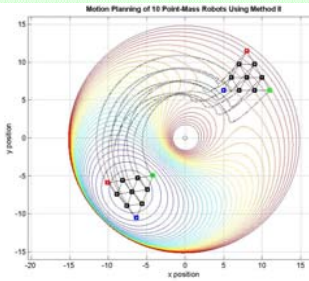
A sensor node (MICA Mote)

- Advances in networking and miniaturization of electro-mechanical devices allow the deployment of such system.
- iRobot's Create mobile robots and MICA Motes allow creation of an ad-hoc networked multi-robot testbed for experimental validation.

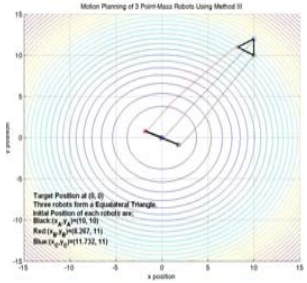
Results:



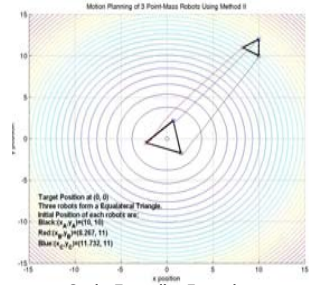
Study: 3 Robots and an Obstacle



Study: 10 Robots and an Obstacle



Study: Changing Formation



Study: Expanding Formation

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