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.

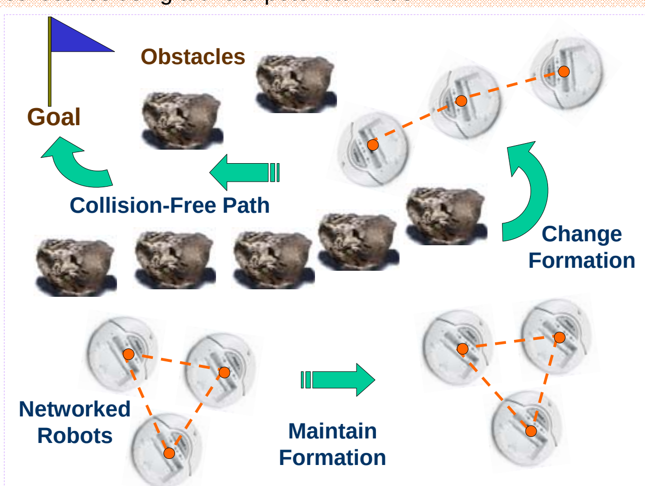
Application Arenas:

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.



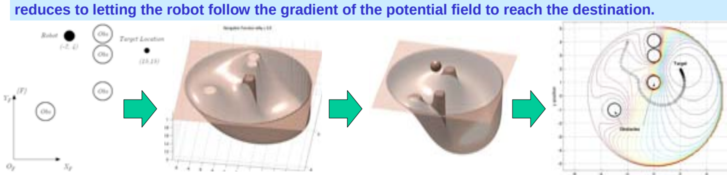
Our Approach:

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.

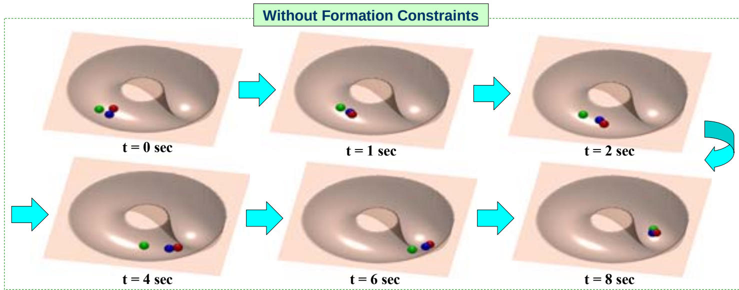
Dynamics Formulation:

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

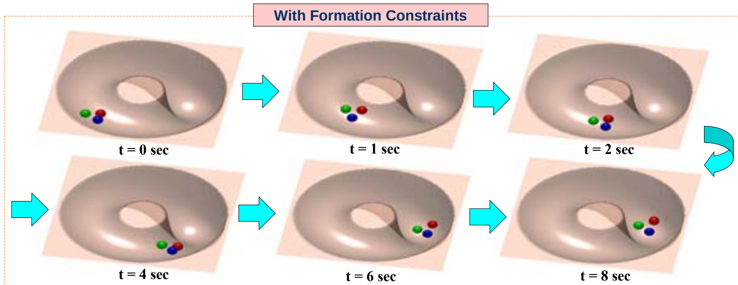
Solved using 3 methods:

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

Without Formation Constraints



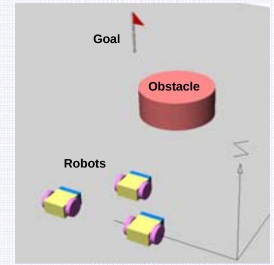
With Formation Constraints



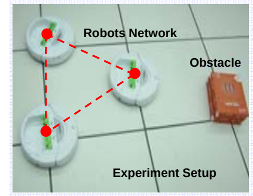
Methods:

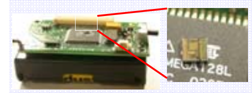
VisualNastran Simulation:

- 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 :

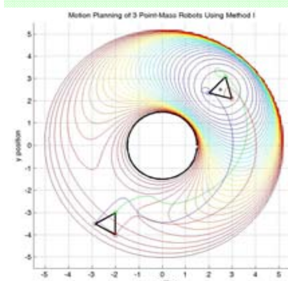




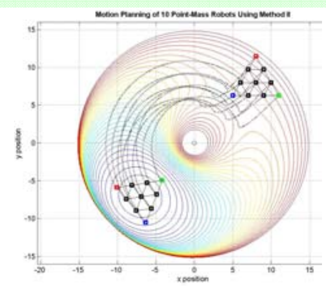
A sensor node (MICA Mote)

- 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.

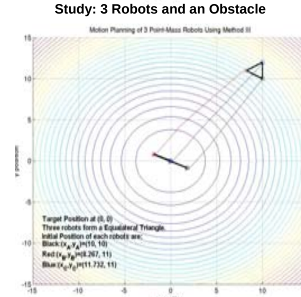
Results:



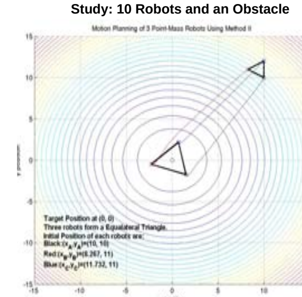
Study: 3 Robots and an Obstacle



Study: 10 Robots and an Obstacle



Study: Changing Formation



Study: Expanding Formation

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