Multi-Robot Adaptive Navigation

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Topics

- SCU robotics program
- Multi-robot control systems
- Adaptive sampling
• We design & operate advanced robotic systems and control technology for land, sea, air, and space
Robotic Systems Laboratory

• We conduct field operations to provide advanced engineering services to professional partners
Robotic Systems Laboratory

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Robotic Systems Laboratory

• We do this with interdisciplinary student teams, from freshman to PhD, to provide world-class education and research experiences
Topics

- SCU robotics program
- Multi-robot control systems
- Adaptive sampling
Our specific interest is in applications requiring:

- Highly reactive to the environment
- Tight interaction between robots
- Relative spatial/position control
Multi-Robot Control Approach

Command

↓

Sense → Decide → Act

Robot

↓

Wheels
Multi-Robot Control Approach

Optimize Application ...

Vary Formation ...

Operate Robots ...

Diagram:

- Sense → Decide → Act
- Application
- Formation
- Robot
- Wheels
Adaptive Navigation Achieved

3 kayaks follow a contour & descend a gradient
Multi-Robot Systems

• Potential applications
  – Physically escort / guard objects
  – Implement sparse antenna arrays
  – Track the location of objects
  – Transport “large” objects
  – Efficiently find features in an environmental field

• Multi-robot are in their infancy
  – Perhaps they are a bad idea....
  – Hopefully, it is simply because it is hard to do!
Formation Control Results

**Testbeds**

- Basic Maneuvering
- Obstacle avoidance

![Testbed images](image)
Formation Control Results

Cluster $x, y, z$ Actual vs Desired

Cluster $\alpha, \beta$ Actual vs Desired

Cluster $\phi_1, \phi_2, \phi$ Actual vs Desired
Patrolling / Guarding

Rotating Escort

Dynamic Guarding
Multi-Robot Control Approach

Cooperative Mission Management
Task coordination
Resource allocation
Topics

- SCU robotics program
- Multi-robot control systems
- Adaptive sampling
Navigation Approaches

- Standard navigation – follow a pre-planned path
Navigation Approaches

• Adaptive navigation – update your path as you go
Navigation Approaches

- Adaptive sampling – update your path AND your destination as you move by taking measurements
Navigation Approaches

- Adaptive sampling – update your path AND your destination as you move by taking measurements.

Find the hot spot. Read temperature, and change path.
• Adaptive sampling – update your path AND your destination as you move by taking measurements

But – need to know what direction to travel – direction of maximum increase – the “gradient.”
Adaptive Sampling

- A powerful concept
- Limited implementation in field
- Requires inefficient motion
Adaptive Sampling

• A powerful concept
• Limited implementation in field
• Requires inefficient motion

• A group of robots can instantly sense gradient
  – Control formation to get good 2-D spread of samples
  – Wave of research in multi-robot adaptive sampling
  – BUT FEW HAVE DONE IT!!!
Navigation Approaches

- Adaptive sampling – update your path AND your destination as you move by taking measurements

Find the hot spot.
Navigation Approaches

- Adaptive sampling – update your path AND your destination as you move by taking measurements

Patrol the perimeter
Adaptive Navigation Achieved

3 kayaks follow a contour & descend a gradient
Adaptive Navigation Achieved

3 kayaks follow a contour & descend a gradient

Initial Simplifications

Fixed geometry and a fixed forward speed.

Vary only the direction of travel.

Note – formation control must be good enough to provide high quality gradient estimates.
Adaptive Navigation Achieved

3 kayaks follow a contour & descend a gradient

Gradient Estimation
Compute gradient given the instantaneous samples of the field from each distributed robot.
Adaptive Navigation Achieved

3 kayaks follow a contour & descend a gradient

Desired Bearing

Different navigation modes for:

- “up” gradient: bearing = gradient
- “down” gradient: bearing = -gradient
- CW contour: bearing = gradient - 90°
- CCW contour: bearing = gradient + 90°
Adaptive Navigation Achieved

3 kayaks follow a contour & descend a gradient

Turn Direction
Option for either an aggregate “column left/right” maneuver or a “flank” maneuver.
Adaptive Navigation Achieved

3 wheeled robots descend an RF field gradient
Adaptive Navigation Achieved

3 kayaks follow a bathymetric contour
Adaptive Navigation Achieved

3 kayaks follow a bathymetric contour

Contour Command: 11.5 meters
RMS Error: 1.2 meters
Sonar Accuracy 1 meter

Truth Data Produced by SCU SWATH Boat
Adaptive Navigation Achieved

3 kayaks follow a contour & descend a gradient
General “Scalar” Field
General “Scalar” Field

Extreme points indicate sources or sinks, such as hot spots or starvation points. Examples: source of pollution, anoxic zones
Contour lines indicate specific concentration levels or thresholds that define a zone. Examples: boundary of a toxic spill, definition of a safety zone.
Scalar fields include other features that hold significance for certain applications and which we’d like to locate and/or navigate with respect to...
General “Scalar” Field

Going down crests (up trenches): divides (accumulators) of gradient-driven products, and often paths of minimum descent (ascent) for mechanical advantage
Saddle points: Gateways often providing minimum energy paths between extreme points.
We are refining control primitives for all of these features, yielding a toolbox for the methodical global exploration of scalar fields.
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We are also exploring how to effectively vary the number of robots, how to optimally control the size and shape of the cluster, etc.
Ongoing & Future Work

- Comprehensive Adaptive Sampling
  - All primitive capabilities
  - Consolidated motion strategies
- 3-dimensional fields & vector fields
  - Aerial vehicles, ROV/AUVs, spacecraft
- Different types of fields
  - Terrain, RF, Chemical
  - Thermal, Turbidity
- Real field missions?
  - Oil spills
  - Pollution plumes
  - Hydrothermal vents
Summary

• Exciting & comprehensive field robotics program
• Particular interest in fielding multi-robot tasks with underlying formation control capabilities
• Initiative in multi-robot adaptive navigation for exploring scalar fields
Questions?

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