Multi-vehicle Collaborative Autonomous Control Under Difficult Communications Conditions

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The Swarming Autonomy “Theme Bug”
Our MVC Vision

Unmanned Vehicles as a Ubiquitous Service for the Warfighter
Underwater MVC Challenges

- UUVs need Collaborative MVC that is
  - Effective under Poor Communications Environments
  - Effective in Dynamic and/or Intractably Complex Conditions
  - Rapid in Response to Perturbations in the Environment or the Objectives
  - Robust and Survivable
Bottom Line

We Have Achieved Robust Militarily Useful Behaviors Reactively and Emergently
# Generated Behaviors

<table>
<thead>
<tr>
<th>Fields Generated by</th>
<th>Targets</th>
<th>Peers</th>
<th>Area Effects</th>
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<tbody>
<tr>
<td>Patrol</td>
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<tr>
<td>Track &amp; Trail</td>
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<tr>
<td>Survey &amp; Map</td>
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<tr>
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<tr>
<td>‣ Vehicle Damage</td>
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<td>‣ Objective Change</td>
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<td>‣ Environmental Change</td>
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</tbody>
</table>
Emergent Swarming
Emergent Swarming IS…

Locally-Executed Control Algorithms That Provide Globally Self-Organizing Behavior Amongst Cooperating Vehicles
Emergent Swarming IS...

Locally Controlled:
Individual Decision Makers (Agents) on Each Platform
Emergent Swarming IS…

NOT Deliberative:

A

B

C

D
Emergent Swarming IS… NOT Deliberative:

I’ll Attack C – you go after D!
Emergent Swarming IS…

NOT Deliberative:

I’ll Attack C – you go after D!

Good Plan!
Emergent Swarming IS...

NOT Deliberative:

I’ll Attack C – you go after D!

Good Plan!
Emergent Swarming IS...

NOT Deliberative:

I’m Closer to D and A is Near C so I’ll take D

Coordination Emerges from Sympathetic Decision Processes and Shared Knowledge
Emergent Swarming IS…

Heterarchical:
An Unstructured Network of Cooperating Peers
No dedicated leaders* ever!

(*single points of vulnerability)
With a Flat Communications Topology any one Swarming Element can be Sufficient to Communicate any End User/Decision Maker
There’s no single point of vulnerability, and no particular pre-determined critical path to get information back to the operator.

Find the Enemy!
The nature of the swarming system is such that it can adapt and reshape itself until the requirements are met. This isn’t commander Cicada – just the Cicada that was handy and happened to be close enough to relay the relevant information.

We hear and Obey!
Swarming Models

Many Exist, mostly patterned off of natural systems, major themes are:

- Physicomimetic – Pattered after sub-atomic particle interactions
- Biomimetic – patterned after social animals
  - Flocking Behavior
  - Ant Colony Behavior
  - Termite/Wasp Nest Building
  - Wolf-Pack Hunting
  - Mold Growth
Generating Behavior by associating fields with a movement vector.

**Co-fields Behaviors**

An Influence Co-field (light blue) Derived from Three Influence Fields

- Strong “attraction” to target
- Weak “attraction” to peer vehicle
- Weak “repulsion” from peer

Resulting vector

Co-fields Generated by a Single Phenomena may be Used to Keep a Distance “d” from the Phenomena.

**Co-Fields: Towards a Unifying Model for Swarm Intelligence** Letizia Leonardi, Marco Mamei, Franco Zambonelli
JHUAPL Innovation: **Dynamic Co-Fields**

**Dynamic Co-Fields Extends Co-Fields by Allowing Individual Fields to Change as a Function of Time**

Dynamic Influences May be Generated by:
- Historical Observations
- Introducing Temporal Decay To Knowledge
- Using Observations as an Impetus for Formula Modifications
- Using Field Strengths as an Impetus for Formula Modifications
- **Generating One’s Own Field**

This Allows Vehicles to:
- Patrol
- **Avoid Local Minima**
- Limit Oscillatory Behavior
- Adapt by Learning
- Manage Uncertainty (Intermittent Contacts or Communications)
Movement is Not Enough…

Vehicles need to be able to take actions and change from one behavior to another. For example, shifting from patrolling to tracking when a target is detected.

Field Thresholds may be Used to Adjust Behavior in Response to Phenomena

Mode Transitions and Transitory acts may be Precipitated by Applying Thresholds to Co-field Magnitudes
Simulator for Autonomous Agents
Cooperative Search (weak comms)
Cooperative Search
(longer comms range)
Cooperative Search (faster UUV)
Comms vs. Speed Results
Mode Transition to Comms Chain
Swarming Autonomy Benefits

1,000,000,000,000 Cicadas Can’t Be Wrong!
Thank you!

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(and David H. Scheidt)
BACKUP SLIDES
Swarming Engagement Simulator Input/Output

- Python Scripting
- File Output
- Simulation Engine
- Animated Display
- Internal Agent
- Human Operator
- Remote Control Software
Agent Architecture