BIOMIMETICS

Center for Laser, Energy, and Exploration Research

UCCS
Biomimetics: Exploring Flocks, Schools, and Herds for Robotic Swarms

Austin Ventura, Corbin Spells, Slade Rodrigues and Andrew Ketsdever
Mechanical and Aerospace Engineering
University of Colorado, Colorado Springs
Biomimetics

• **Bios = Life**
• **Mimesis = To Imitate**
• **Construct to develop technological solutions by learning from nature**
• **Many examples of what I would call “micro-biomimetics”**
  – Take some interesting feature of an animal and try to replicate it
  – Superficial look at behavior if at all
• **No examples of what I would call “macro-biomimetics”**
  – Take the global behavior of the animal and develop a control algorithm for true biomimicry
  – Never been attempted
“Macro-Biomimetics”

• **Taking ecology of animal group behavior**
  – Herds or Packs of mammals
  – Flocks of birds
  – Schools of fish
  – Swarms of insects

• **Developing control algorithms**
  – Automated control of large swarms
  – Improved efficiency and survivability

• **This has never been done before**
“Micro-Biomimetic” Examples
Other forms of biomimicry – Towards Macro?

In the end, these are just more micro-biomimetics examples
Micro vs. Macro – An Attempt at an Example

http://www.youtube.com/watch?v=YQIMGV5vtd4
Why “Macro-Biomimetics”?

• **AFRL study for constellation of satellites**
  – 85% of lifetime mission cost will be in the ground segment (i.e. Ops)
  – Automated control seen as mission enabling

• **Smart automation is needed**
  – Deep Space 1: Safe Mode
  – Human intervention required to resume normal ops
Why “Macro-Biomimetics”?

• Biological systems have evolved over millions of years
  – Optimization through evolution
  – Efficiency of task
  – Survivability
  – Remote environments
  – In hospitable environments
• Human intervention may be hours away
What things should be modeled?

- **Critical behavior**
  - e.g. Feeding
    - *What percentage of time?*
    - *During what time(s) of day?*
    - *How many participants?*
    - *What are the others doing that aren’t engaged in critical behavior?*
      - Sentinel
      - Nanny
      - Rest
  - What happens if interrupted from critical behavior?
Relating Feeding to Engineering

So a critical behavior for a herd is feeding, right?

What does that have to do with a control algorithm for a swarm of robots?

Presumably robots don’t need to eat.

Well, robotic swarms also have critical behavior functions.

Survivability

Surveillance, for example.

External threats are a constant challenge.

**PREDATOR**

While some individuals of the swarm perform the critical function, others play a support role.

**SENTINEL**
What things should be modeled?

- **Critical members**
  - Herds → Young
  - Robotic Swarms → Sensor packages
What things should be modeled?

• **Herds, Flocks, Schools, Swarms**
  – Minimum and maximum number of individuals
    • *Factors that effect group size*
  – Separation
    • *Avoiding contact and crowding with closest neighbors*
  – Alignment
    • *Steering towards a common average heading*
  – Cohesion
    • *Steering towards a common average position*
Ecology

- **Animal group behavior**
  - Protection from predation (prey)
  - Higher visibility to predators (prey)
  - More effective predation (predator)
  - Competition for resources
  - Efficiency of movement
  - Knowledge transfer
    - *Survival*
    - *Migration*
  - Spread of illness
Scenario 1

- **NASA mission to Europa**
  - Geology, terrain
  - Natural resources
  - Ancient or present-day life
- **Robotic explorers for land, “sea”, and “air”**
- **One way communication time is 35 to 52 minutes**
  - Almost 2 hour return signal time
  - Evaluation of issue on ground with minimal information
Scenario 1

- **Control based on biological systems**
  - Mission enabling
    - *Reduced cost*
    - *Reduced time*
    - *Reduced scale of problem*
      - Economy of scale: Generally refers to efficiency increasing as the number of manufactured goods increases
      - Here a new economy of scale might refer to the cost of the mission decreasing as the overall scale of the problem decreases
  - Efficient operation
  - Safe operation
  - Human intervention still possible for “major” issues
Scenario 2

- **UAV monitoring of global weather**
- **Distributed sensors**
  - Platoons of robotic explorers in different geographic locations
  - Multiple platoons necessary for large area coverage
  - Some redundancy in a platoon
  - Variable degradation due to operating environment
Scenario 2

- **General automation would not inherently address safety**
  - Ascend, descend, land, enter safe mode
  - Exit safe mode automatically by assessing risk and evaluating consequences

- **General automation would not address efficiency of task**
  - Bio-mimicry can address efficiency
  - Virtual head-butt
  - Which member will perform a task?
    - Efficiency
    - Risk
    - Consequences
Preliminary Research
Virtual Head-Butt

- Simple or more complex math problem sent to each member’s core processor
- Healthiest member identified
  - Leader
  - Efficient task performance
- Consistent failure
  - Risky assignment
  - Loss to “herd” not as critical
Virtual Head-Butt

• **PIC processors selected to compete against each other**
  – Series of simple subtraction calculations
  – Control calculations performed at ambient room temperatures
  – Chip put at 0°C for 45 minutes
  – Chip put at 80°C for 45 minutes
  – Monitored time to perform calculations
Virtual Head-Butt

- Control computation time was nearly 81 seconds
- Lack of accurate timers was an issue
- Shows that environmental issues can determine the dominant member
- Future tests in the Chamber for Atmospheric and Orbital Space Simulation (ChA OSS) planned

<table>
<thead>
<tr>
<th></th>
<th>Heated Chip</th>
<th>Frozen Chip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1 (sec)</td>
<td>90.25</td>
<td>93.4531</td>
</tr>
<tr>
<td>Run 2 (sec)</td>
<td>94.1719</td>
<td>87.9219</td>
</tr>
<tr>
<td>Run 3 (sec)</td>
<td>69.7187</td>
<td>84.3906</td>
</tr>
<tr>
<td>Run 4 (sec)</td>
<td>84.2969</td>
<td>92.6562</td>
</tr>
<tr>
<td>Run 5 (sec)</td>
<td>67.4062</td>
<td>84.4062</td>
</tr>
<tr>
<td>Run 6 (sec)</td>
<td>74.4375</td>
<td>76.4531</td>
</tr>
<tr>
<td>Run 7 (sec)</td>
<td>82.7031</td>
<td>82.4062</td>
</tr>
<tr>
<td>Average (sec)</td>
<td>80.4263</td>
<td>85.9553</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>9.45405</td>
<td>5.512615</td>
</tr>
</tbody>
</table>
Stereoscopic Imaging

• **3-D position and velocity data required**
  – Separation
  – Alignment
  – Cohesion

• **Still and video options**

• **Fast response for bats and birds**

• **Long reach optics**

• **Preliminary System**
  – 2 DSLR cameras
  – HD video capable
  – Interchangeable lenses
  – HD capable GoPro video for full field of view
  – Machined and calibrated alignment plates
  – Developed image recognition software
Imaging

- Average many samples
  - Separation
  - Alignment
  - Cohesion

Biological System → Numerical Model → Control Algorithm

University of Colorado
Colorado Springs
Stereoscopic Imaging

Filter for objects of interest and the moments of each distance from the cameras.
Calibration
Calibration
Data: Bighorn Sheep Herd (US50)

15 Sheep. 3 Rams, 9 ewes, 3 yearling lambs
Data: Bighorn Sheep Herd (US50)
Bison – Yellowstone National Park
Geese V-Formation Flying
Geese
Geese

Table 2. Statistical results of geese in steady flight.

<table>
<thead>
<tr>
<th>Average Spacing (m)</th>
<th>Standard Deviation of Spacing (m)</th>
<th>Avg. Angle (Degrees)</th>
<th>Standard Deviation of Angle (Degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.975</td>
<td>0.966</td>
<td>58.580</td>
<td>30.883</td>
</tr>
</tbody>
</table>
No animals were harmed in the making of this PowerPoint presentation

University of Colorado
Colorado Springs
Cool Videos

- [http://www.youtube.com/watch?v=eakKfY5aHmY](http://www.youtube.com/watch?v=eakKfY5aHmY)
- [http://www.youtube.com/watch?v=m9mn7EB1H6k](http://www.youtube.com/watch?v=m9mn7EB1H6k)
- [http://www.youtube.com/watch?v=W1czBcnX1Ww](http://www.youtube.com/watch?v=W1czBcnX1Ww)