Evolving Aquatic Robots

Anthony J. Clark, Jared M. Moore, and Philip K. McKinley
techniques

- Aquatic dynamics
- Passive components
- Flexible components
- Self-modeling uncertainty
motivations for small aquatic robots
major issues

• Speed and maneuverability
  – Limited actuation capability for small, inexpensive devices

• Accommodating aquatic environment
  – Highly dynamic conditions
  – Uncertainty in external conditions and robot orientation

• Overcoming hardware decay and physical damage
  – Controller designed/evolved for specific morphology
  – How can compensatory behaviors be generated dynamically if the a fin or flipper is damaged?
NSF-sponsored testbed

- Facilities
  - Configurable robots
  - 4,500 gallon test tank
  - Flow tank
  - Multi-material 3D printer
  - Compute cluster
3D printer
general process

Create Simulation
• Develop models
• Validate model

Evolve solutions
• Evolve in simulation
• Evolve online
target applications

Industrial
• Water quality
• Ecological monitoring

Biological research
• Elicit schooling
• Act as predator

Photograph by the State of Michigan
aquatic dynamics

• Lighthill’s: Large-amplitude elongated-body theory of fish locomotion (1971)
• Validated on the physical device
passive components

- Passive joints
- Evolved for flat terrain and water
  - fin dimensions
  - oscillating frequency
Evolved for both **ground** and aquatic environments
Evolved for both ground and **aquatic** environments
flexible components

- Paddles are flexible and sticky
- Evolution
  - arm length
  - foot radius
  - flexibility
flexible caudal fin

- Flexible caudal fin
  - spring coefficients
  - material properties
- Evolve with control
  - neural oscillators
  - resonant frequency for a given morphology
physical validation
3D maneuvers

• Increases complexity
  – no longer on the surface

• Station keeping
  – maintain position against laminar flow
3D maneuvers

- Fitness
  - transient phase
  - spherical gradient
3D maneuvers
self-modeling and uncertainty

- Physical damage can render a robot helpless
- Need to dynamically generate new behaviors to mitigate or overcome changes in actuation
- Approach based on Bongard-Lipson’s Exploration-Estimation Algorithm (EEA)
Damaged robot

Best performer from original EEA

Best performer from extended EEA
future work

• Increased complexity
  – tasks
  – adaptive control

• Continue evolution online
  – refine simulated solutions
  – self-modeling to handle damage
conclusions

- Simulation is course-grain
  - good for prototyping techniques/concepts
    - i.e. flexibility, passive parts, algorithms etc.
    - gain insight into problem before fabrication

- Online evolution will be necessary
  - finer grain evolution
The SENS Lab
The Smart Microsystems Laboratory
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THANK YOU
research projects

- Mathematical modeling
- Amphibious robot
- Crawler with flexible paddles
- Robotic fish
- Aquatic robot