Evolving Aquatic Robots

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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
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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
Trajectory of Undamaged and Target

Trajectory of EEA and Target

Trajectory of OoB EEA and Target
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
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THANK YOU
research projects

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