Bio-inspired Underwater Robots Powered by Electroactive Polymer Artificial Muscles

Dr. Zheng Chen
Department of Electrical Engineering and Computer Science
Wichita State University
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Application of Autonomous Underwater Vehicle

- Environmental monitoring
- Ocean circulation study
- Sea floor mining
- Fishing agriculture
- Ocean life study

*Image courtesy from Wood Hole Oceanographic Institution*
Conventional Underwater Vehicle

Advantages:
- High speed
- Large payload
- Well-developed control strategy

Disadvantage:
- Large size
- Low maneuvering capability
- Environmentally unfriendly
- Low propulsion efficiency

Image courtesy from Wood Hole Oceanographic Institution
Bio-inspired Underwater Robot

Advantages:
- High maneuvering capability
- High propulsive efficiency
- Environmentally friendly
- Compact size

Challenges:
- Biomimetic design
- Bio-inspired control strategy
- Bio-inspired actuating material
Electroactive Polymer Artificial Muscle

- **Electronic EAP** (piezoelectric polymers, dielectric elastomers)
- **Ionic EAP** (conjugated polymer, ionic polymer metal composite)

*Dielectric elastomer

*Ionic polymer metal composite

*Courtesy of University of New Mexico*
Ionic Polymer-Metal Composite

Advantages
• Low voltage/large deformation
• Light and resilient
• Compatible with human body
• Work well under wet conditions

Applications
• Biological, biomedical devices
• Biomimetic robots
• Micro/nanotechnology

Mechanism of IPMC
(Cross section view)

Robotic Fish Propelled by an IPMC Tail

- **Characteristics:**
  - Speed: 2 cm/sec (0.125 BL/sec)
  - Dimension: 15 cm long

- **Advantages:**
  - No motors and gears
  - Low noise
  - Close to biological fish
  - Small size

*Designed by S. Shatara, et al.  
SML at Michigan State University*
Speed Model of The Robotic Fish

- Steady-state speed under a square wave voltage

\[
\overline{U} = \sqrt{\frac{m \cdot \frac{2 \omega^2 A_m^2}{\pi^2} \sum_{n=1,3,5\ldots}^\infty |H_3(jn\omega)|^2}{C_D \rho_w S + m \cdot \frac{2 A_m^2}{\pi^2} \sum_{n=1,3,5\ldots}^\infty \frac{|H_3d(jn\omega)|^2}{n^2}}}
\]

- Model validation

Z. Chen, et al., IEEE/ASME Trans on Mechatronics, 2010
IPMC Powered Robotic Manta Ray

- **Bio-inspiration**

![Movie Courtesy from ARKIVE](image)

- **Autonomous robotic manta ray powered by IPMC artificial muscle**
  - Create artificial pectoral fin capable of generating 3D kinematic motions
  - Build small size and free swimming robotic manta ray
Micro-fabrication of Pectoral Fin

(a) Selectively thin down passive area with plasma etch

(b) Deposit PR and then pattern PR through lithography

(c) Perform electroless plating of platinum and final treatment

PDMS Molding Based Fabrication of Pectoral Fin

(a) Make two plastic molds

(b) Clamp the IPMC and PDMS with two molds

(c) Cure the PDMS and remove the molds

Fabrication process (cross section view)

Twisting motion test

Underwater test
Comparison of the Fabrication Processes

- **Based on microfabrication technology:**
  - **Advantages:** Able to fabricate in micro/meso scale; Capable of batch production;
  - **Disadvantages:** Unable to select soft material in passive region; Time consuming and expensive;

- **Based on PDMS molding method:**
  - **Advantages:** Able to select soft material in passive region; Easy and cheap;
  - **Disadvantages:** Unable to fabricate in micro/meso scale; Incapable of batch production;
IPMC Powered Robotic Manta Ray

- **Characteristics**
  - Total mass: 55 grams
  - Maximum speed: 0.053 BL/S
  - Power consumption: < 1W

Re-Design of the Pectoral Fin and Robot

New robot design

Underwater test of pectoral fin

Free swimming test (side view)

Free swimming test (top view)

Z. Chen, et al., Int. J. of Smart and Nano Materials, 2012
Conclusion and Future Work

**Conclusion**
- Demonstrated free swimming robotic fish propelled by IPMC tail
- Developed speed model of the robotic fish
- Developed two fabrication processes of artificial pectoral fin
- Demonstrated free swimming robotic manta ray powered by IPMC artificial muscles

**Future Work**
- Optimize the design and improve the speed of robotic manta ray
- Develop bio-inspired underwater robot capable of 3D maneuvering
- Build autonomous and intelligent robots with underwater communication devices
- Develop multi-agent cooperative control strategy for a school of underwater robots
- Develop applications in environmental monitoring and fishing agriculture
References

**Journal publications**


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