Bio-inspired Underwater Robots Powered by Electroactive Polymer Artificial Muscles

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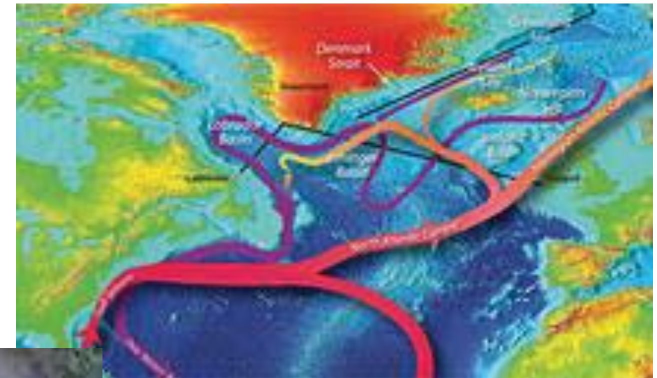
Application of Autonomous Underwater Vehicle

Environmental monitoring


Ocean circulation study


Sea floor mining


Fishing agriculture


Ocean life study

Image courtesy from Wood Hole Oceangraphic Institution

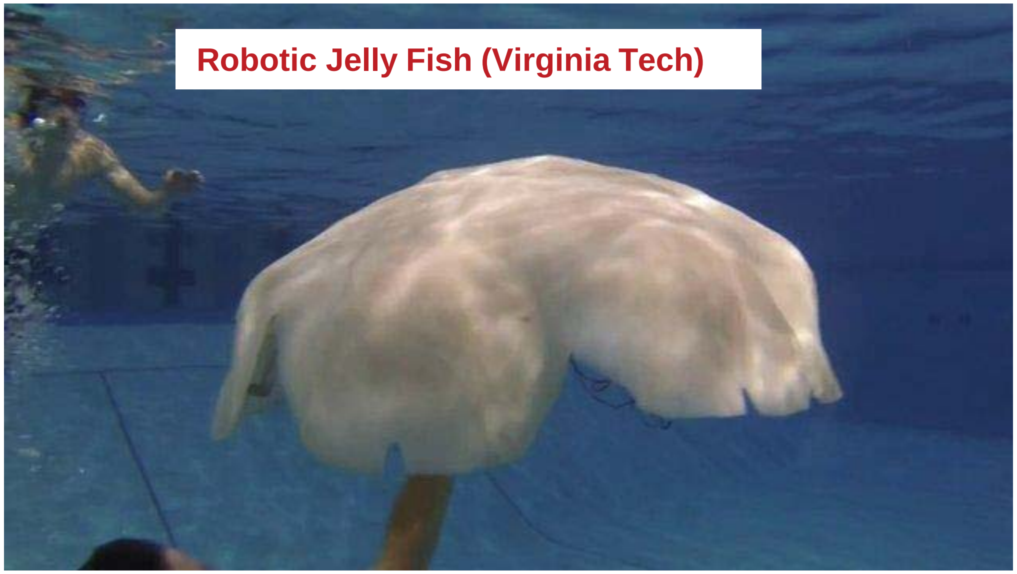
Conventional Underwater Vehicle

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 Oceangraphic Institution

Bio-inspired Underwater Robot

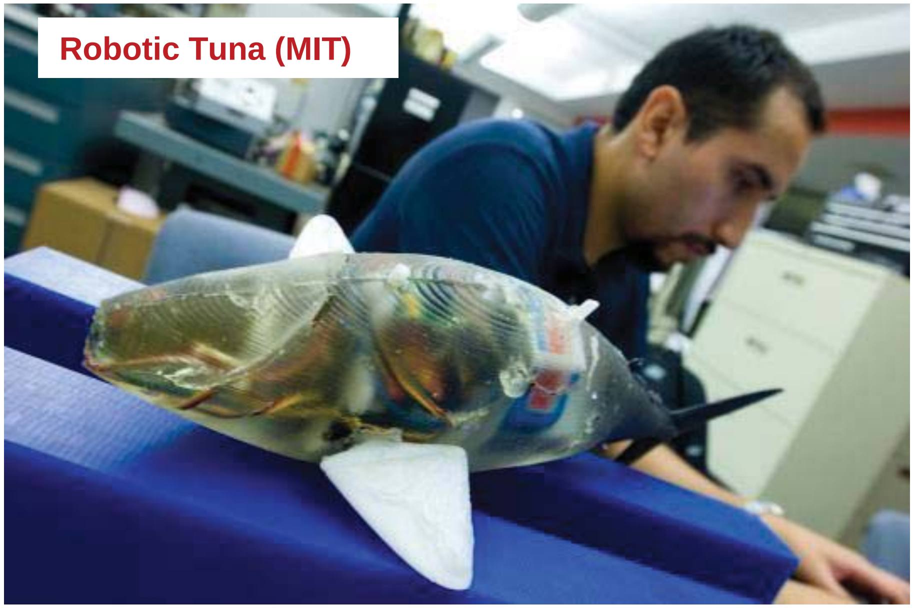


Advantages:

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

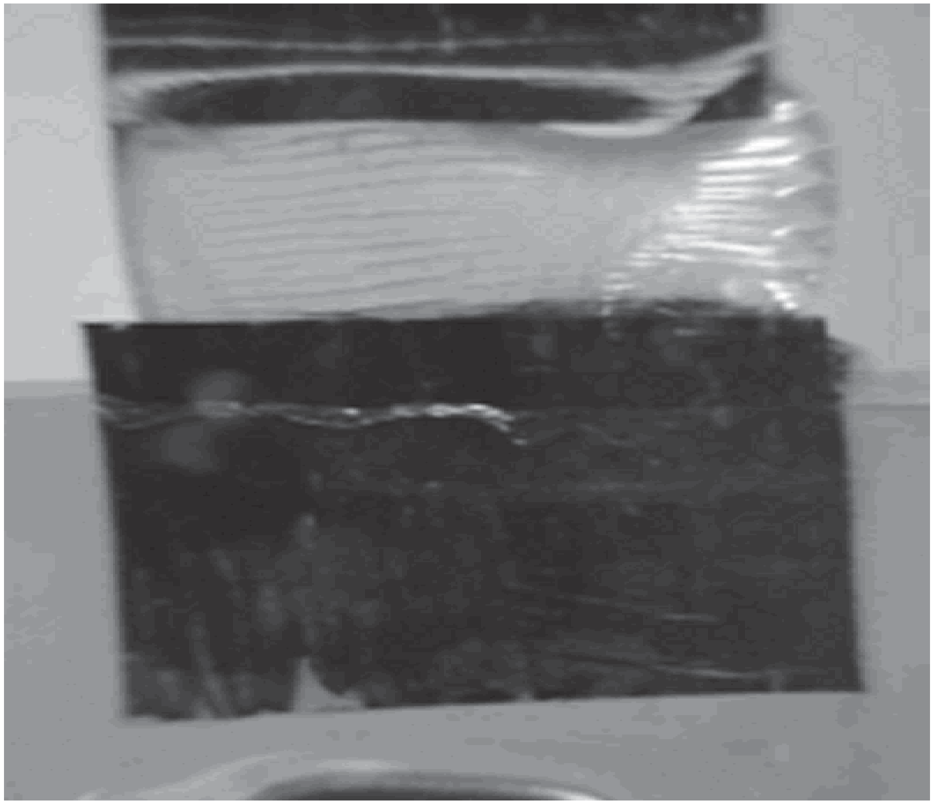
Challenges:

- Biomimetic design
- Bio-inspired control strategy
- Bio-inspired actuating material



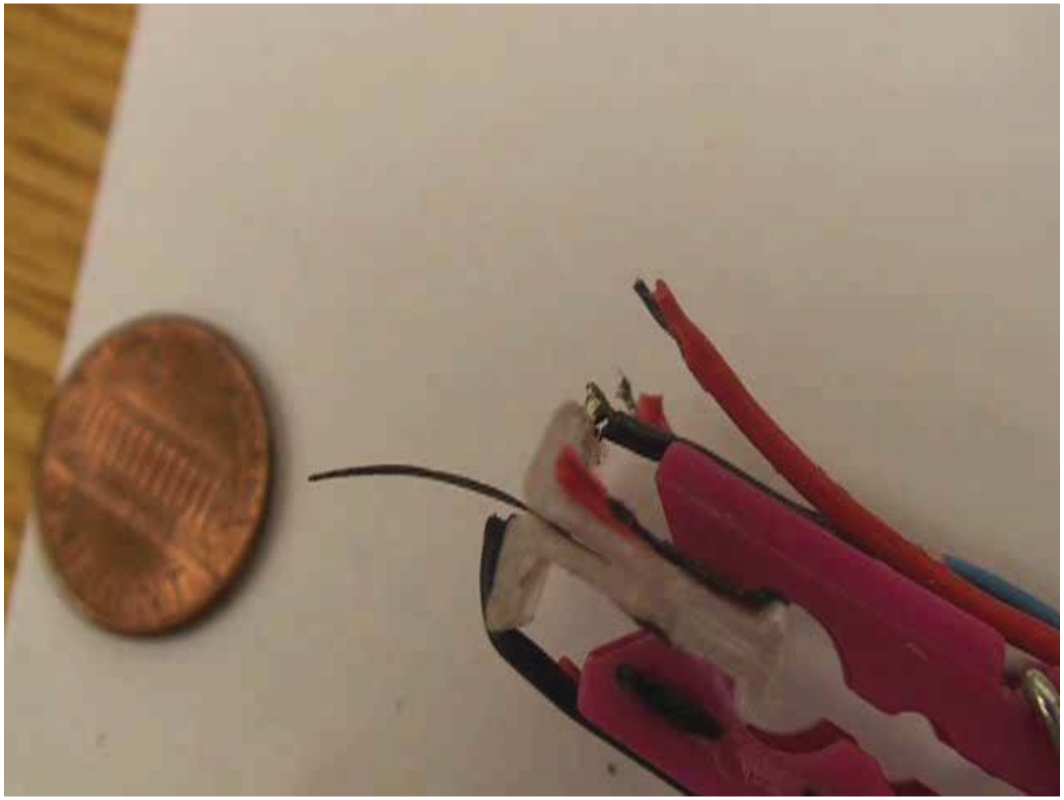
Electroactive Polymer Artificial Muscle

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



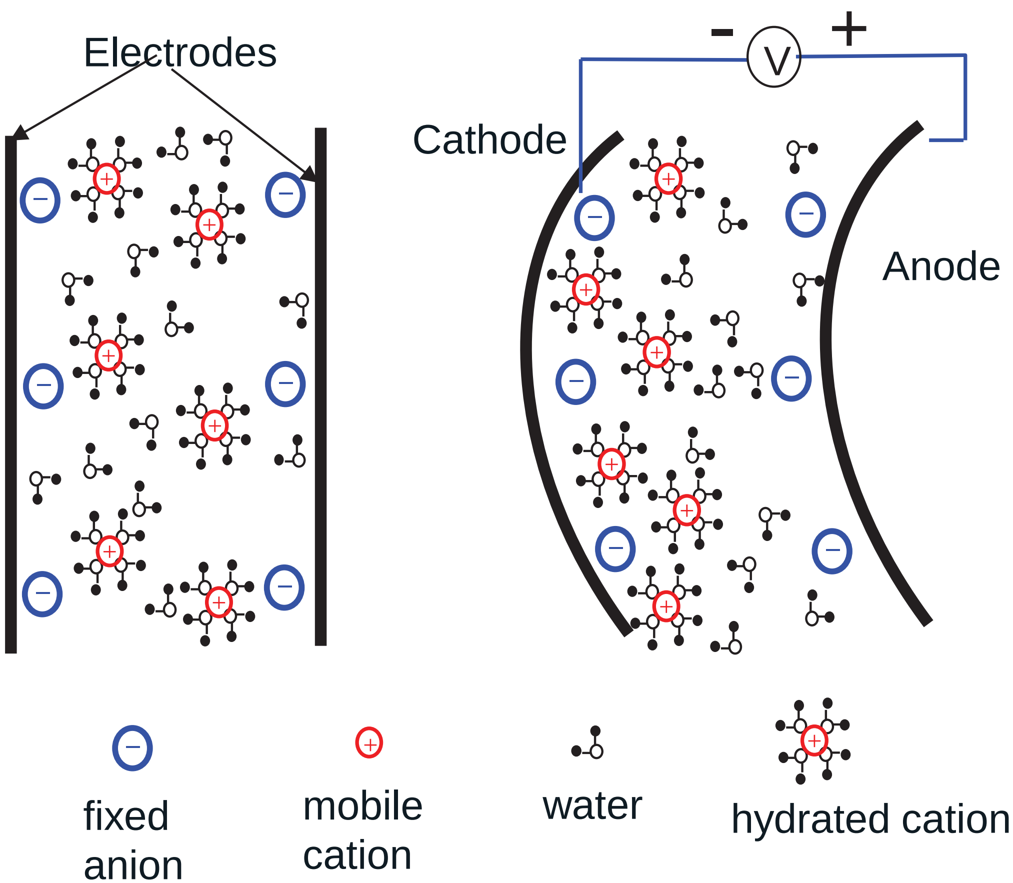
Dielectric elastomer

Courtesy of University of New Mexico



Ionic polymer metal composite

Ionic Polymer-Metal Composite



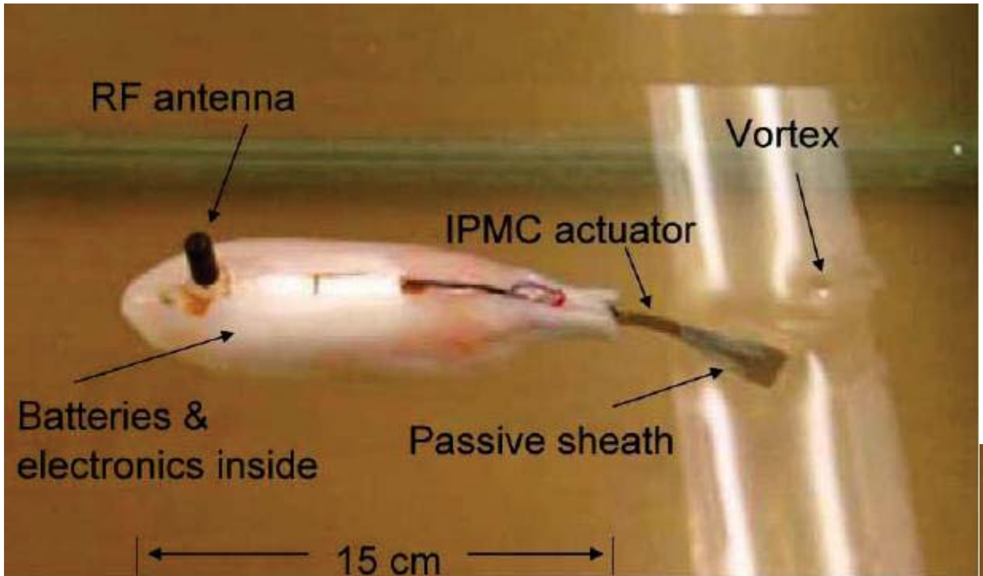
Mechanism of IPMC
(Cross setion view)

Z. Chen, et al., IEEE Trans. On Mechatronics, 2008

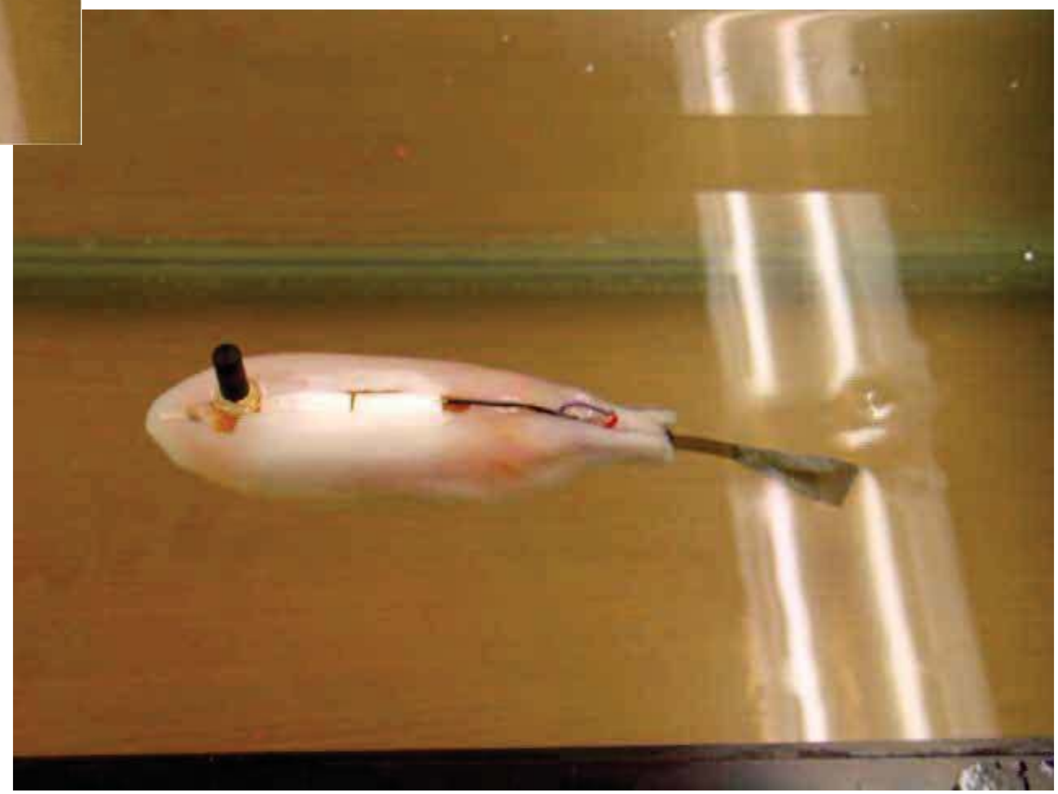
- **Advantages**
  - Low voltage/large deformation
  - Light and resilient
  - Compatible with human body
  - Work well under wet conditions

- **Applications**
  - Biological, biomedical devices
  - Biomimetic robots
  - Micro/nanotechnology

Robotic Fish Propelled by an IPMC Tail



Designed by S. Shatara, et al.
SML at Michigan State University



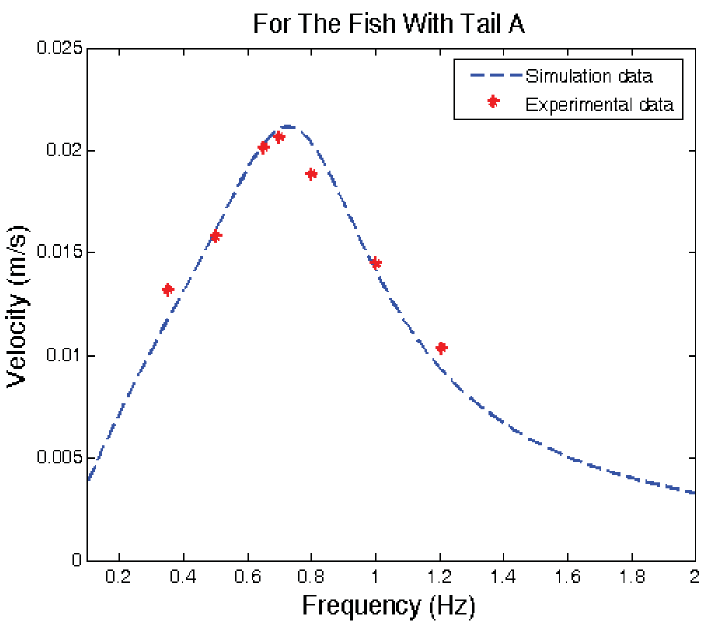
- **Characteristics:**
  - Speed: 2 cm/sec (0.125 BL/sec)
  - Dimension: 15 cm long
- **Advantages:**
  - No motors and gears
  - Low noise
  - Close to biological fish
  - Small size

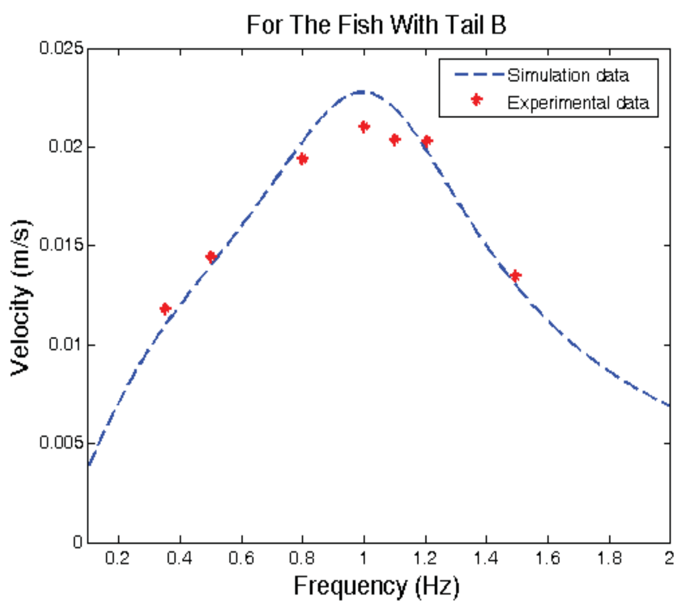
Speed Model of The Robotic Fish

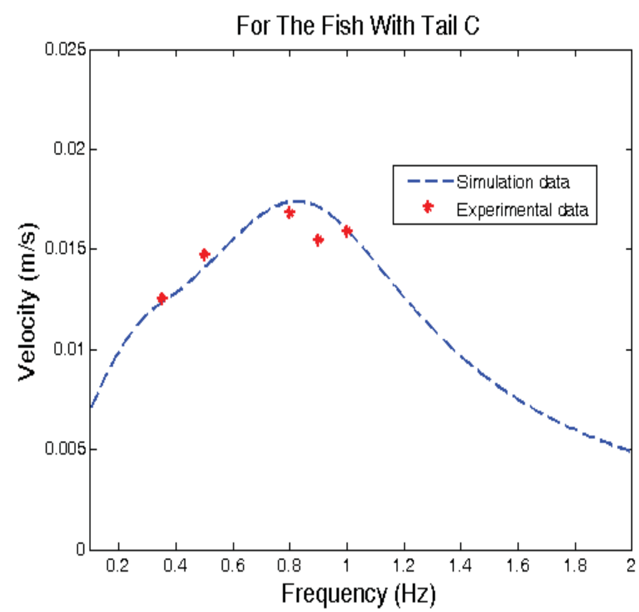
- Steady-state speed under a square wave voltage

$$\bar{U} = \sqrt{\frac{m \cdot \frac{2\omega^2 A_m^2}{\pi^2} \sum_{n=1,3,5\cdots}^{\infty} \left| H_3(jn\omega) \right|^2}{C_D \rho_w S + m \cdot \frac{2A_m^2}{\pi^2} \sum_{n=1,3,5\cdots}^{\infty} \frac{\left| H_{3d}(jn\omega) \right|^2}{n^2}}}$$

- Model validation







Z. Chen, et al., IEEE/ASME Trans on Mechatronics, 2010

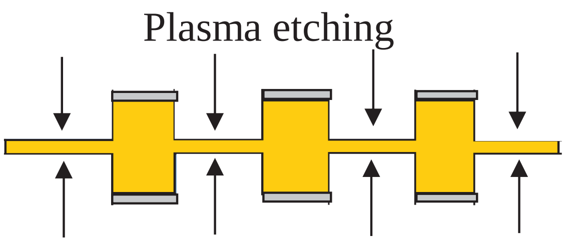
IPMC Powered Robotic Manta Ray

- Bio-inspiration

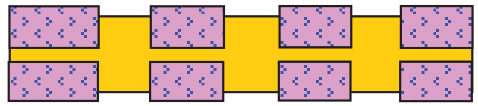
Movie Courtesy from ARKIVE

- 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

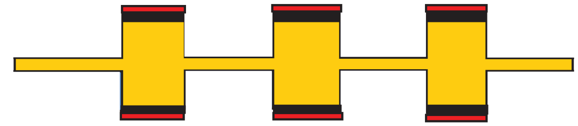
Micro-fabrication of Pectoral Fin



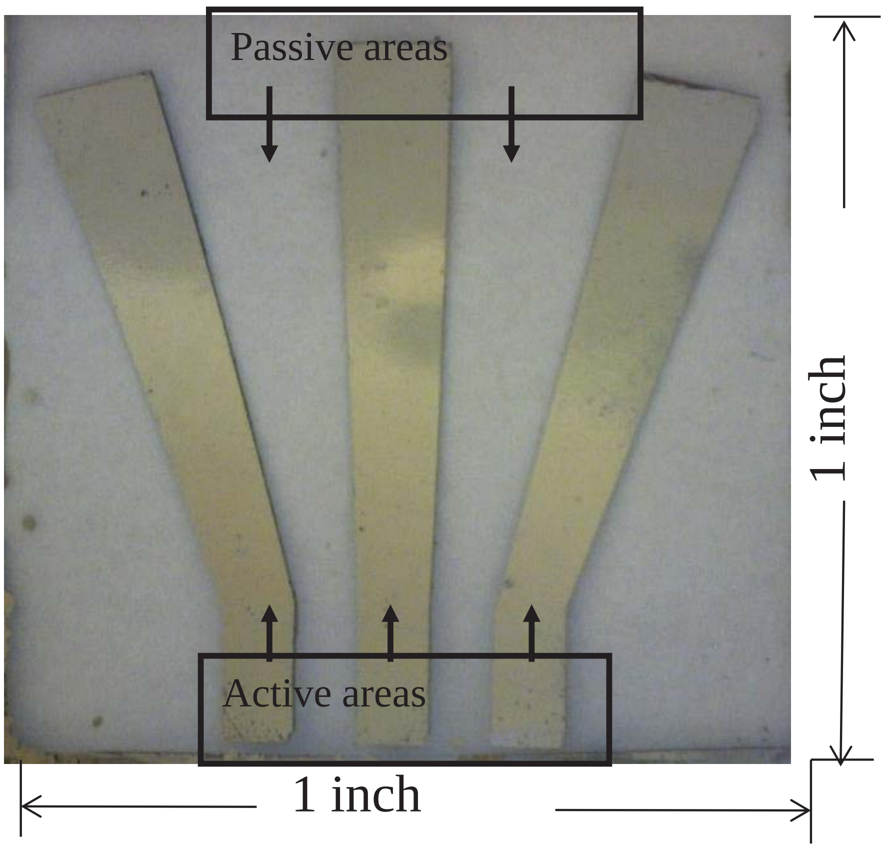
(a) Selectively thin down passive area with plasma etch

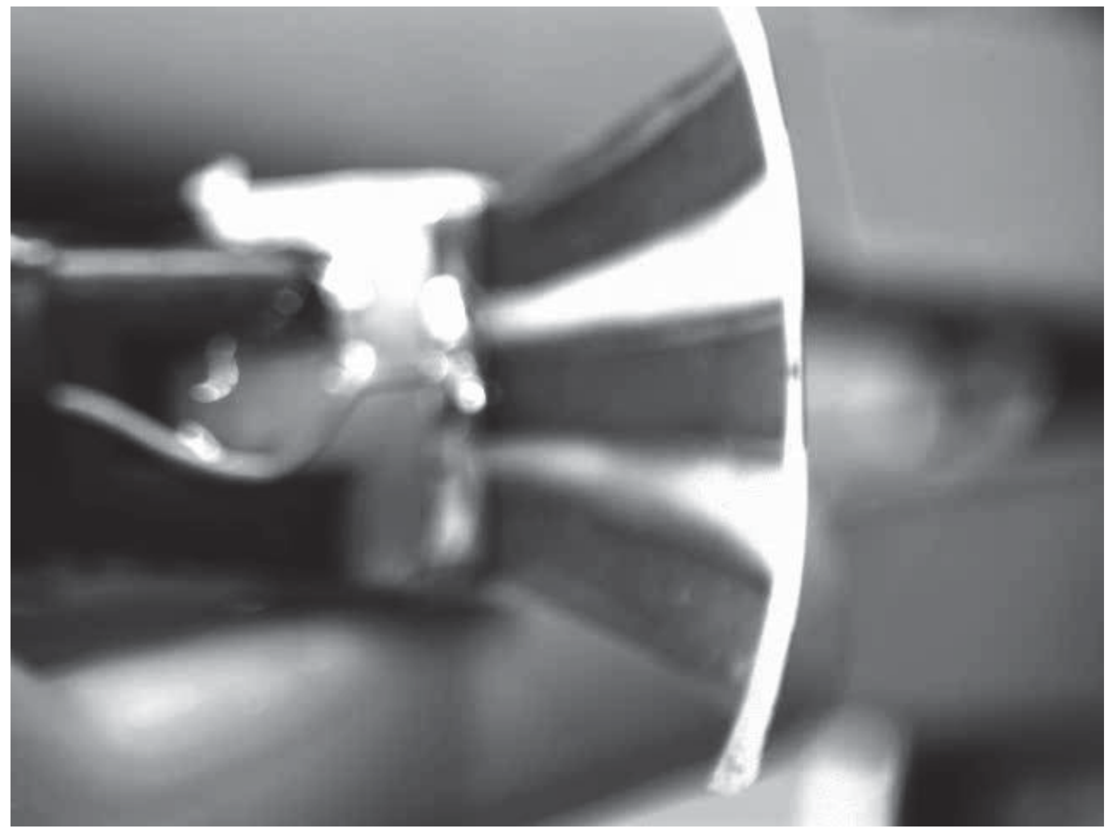


(b) Deposit PR and then pattern PR through lithography



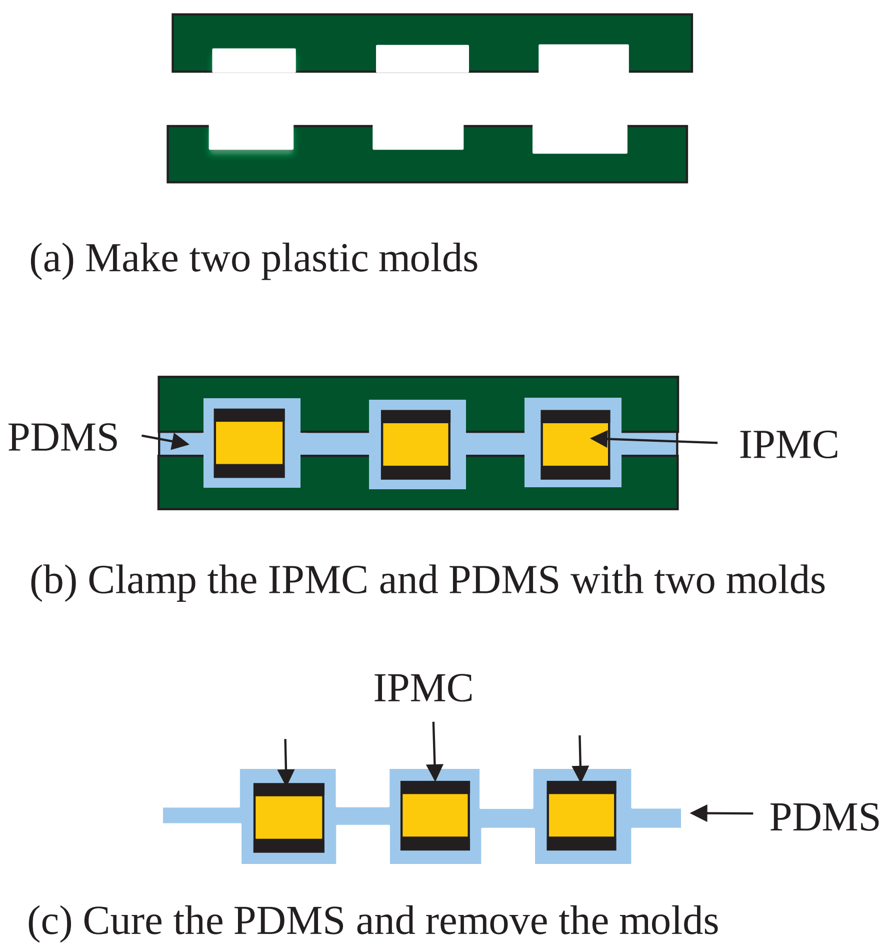
(c) Perform electroless plating of platinum and final treatment



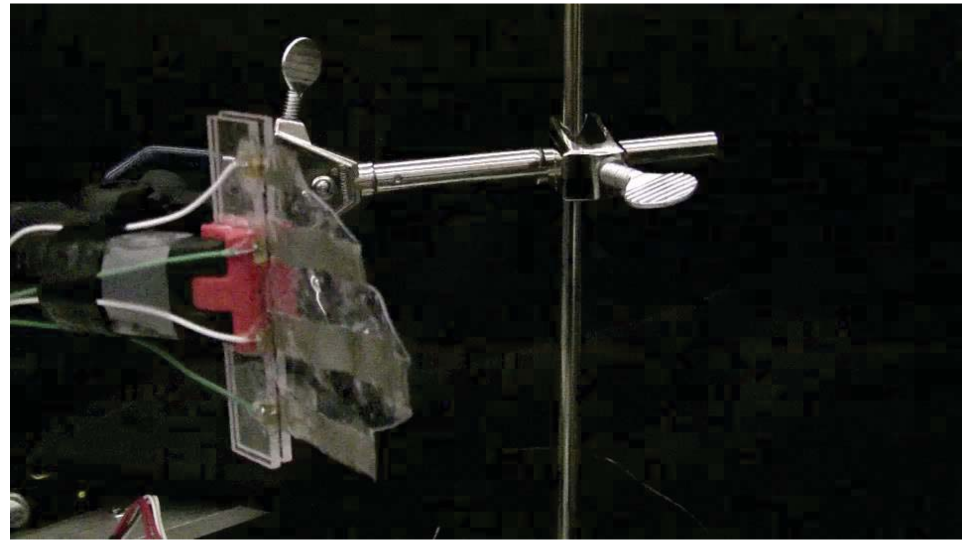


Z. Chen, et al., Sensors and Actuators A: Physical, 2010

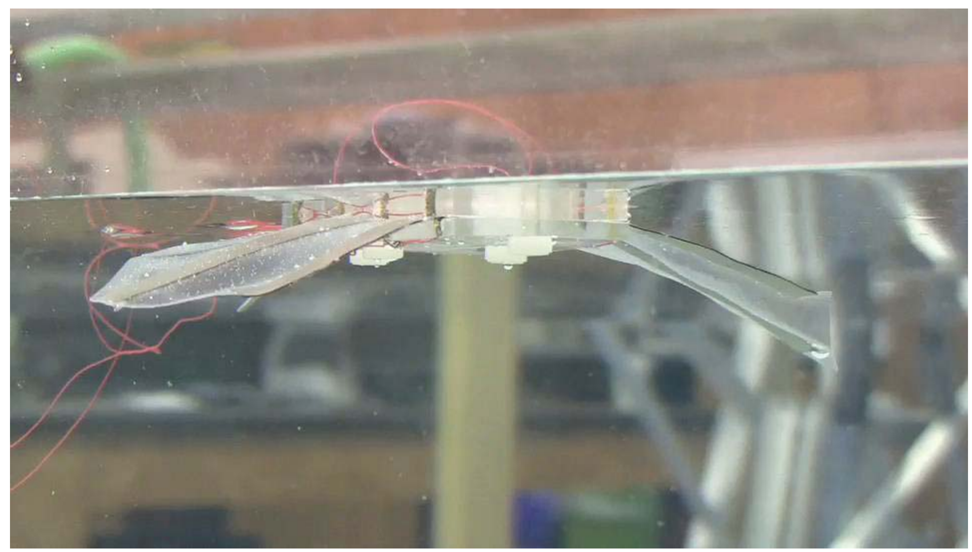
PDMS Molding Based Fabrication of Pectoral Fin



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;

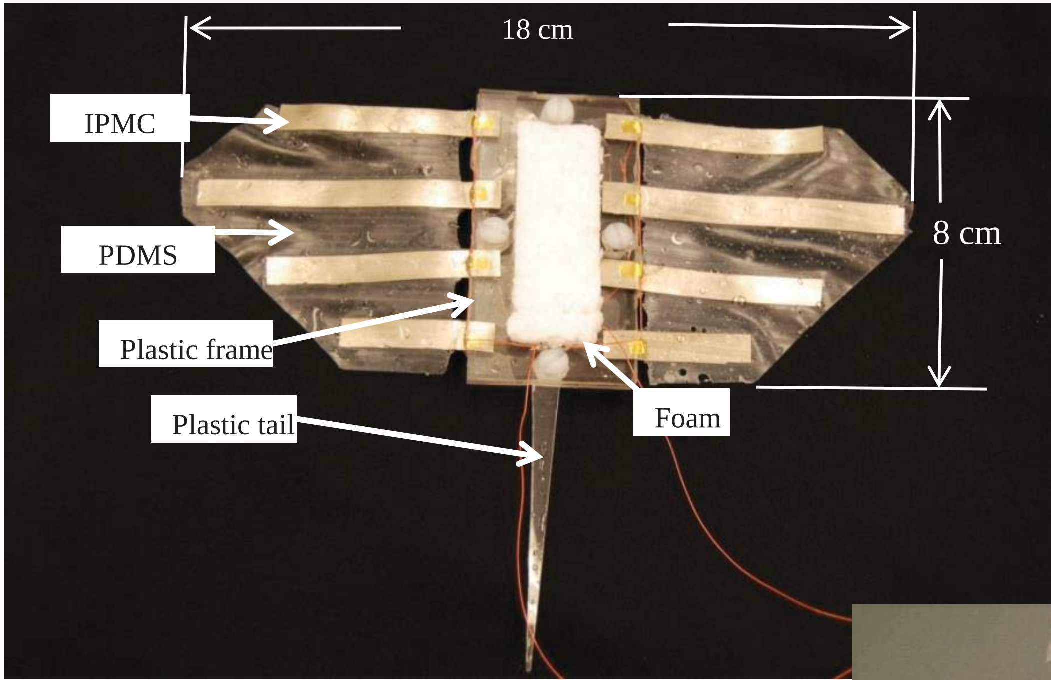
Disadvantages: Unable to select soft material in passive region;
Time consuming and expensive;

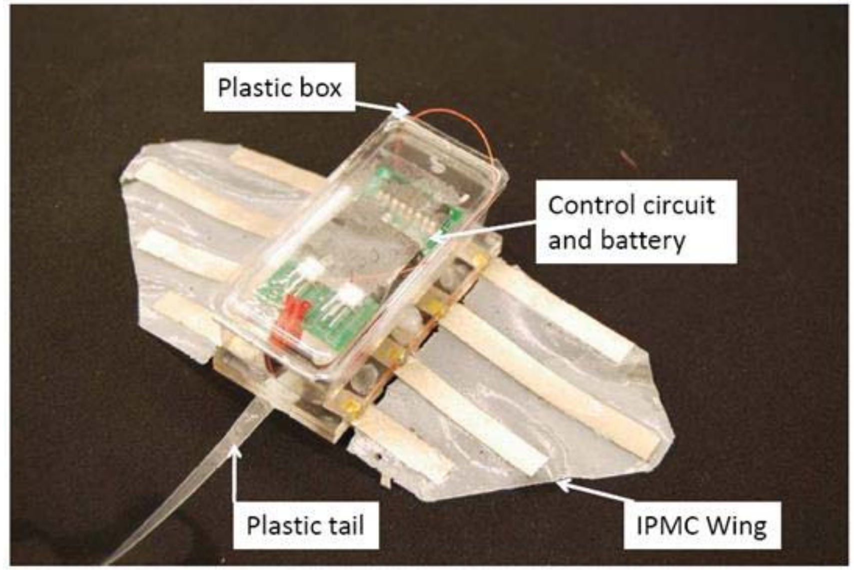
- Based on PDMS molding method:

Advantages: Able to select soft material in passive region;
Easy and cheap;

Disadvantages: Unable to fabricate in micro/meso scale;
Incapable of batch production;

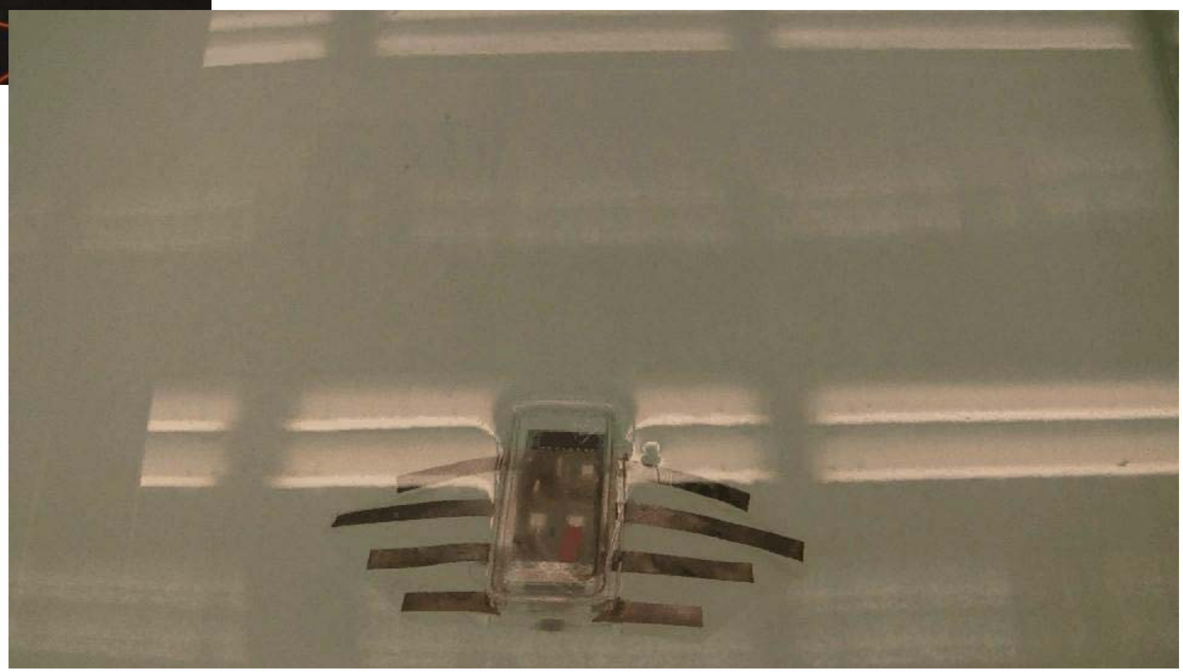
IPMC Powered Robotic Manta Ray





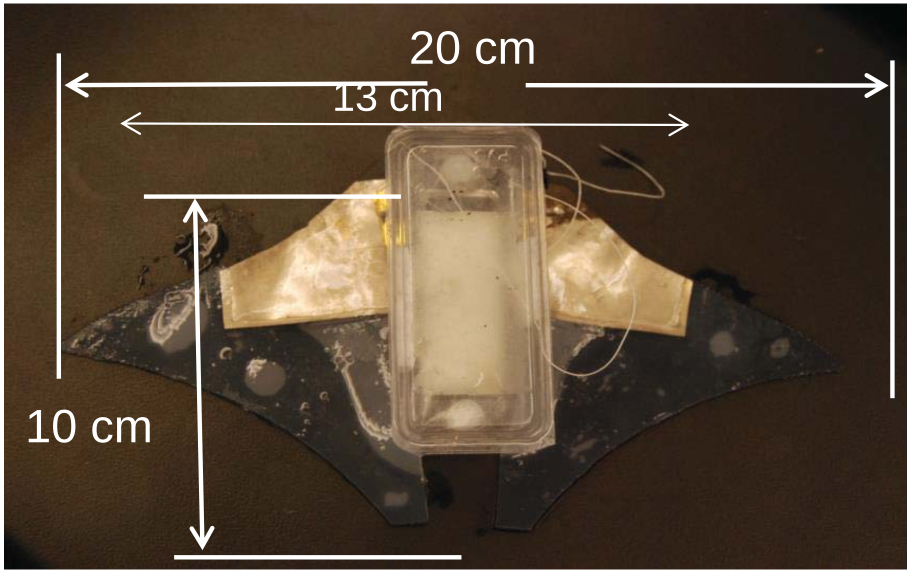
- Characteristics
  - Total mass: 55 grams
  - Maximum speed: 0.053 BL/S
  - Power consumption: < 1W

Z. Chen, et al., Sensors and Actuators A: Physical, 2011

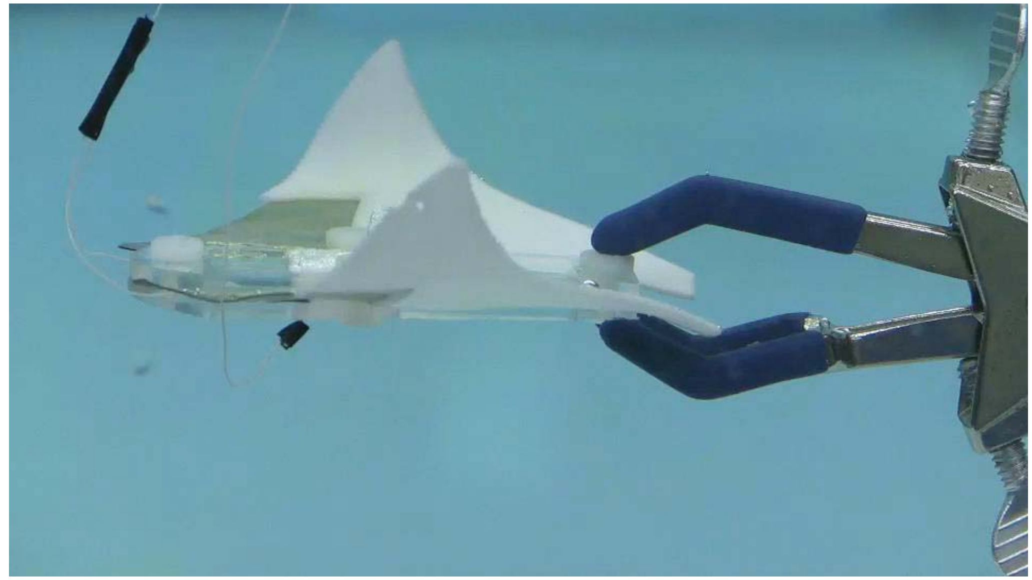


Free swimming test

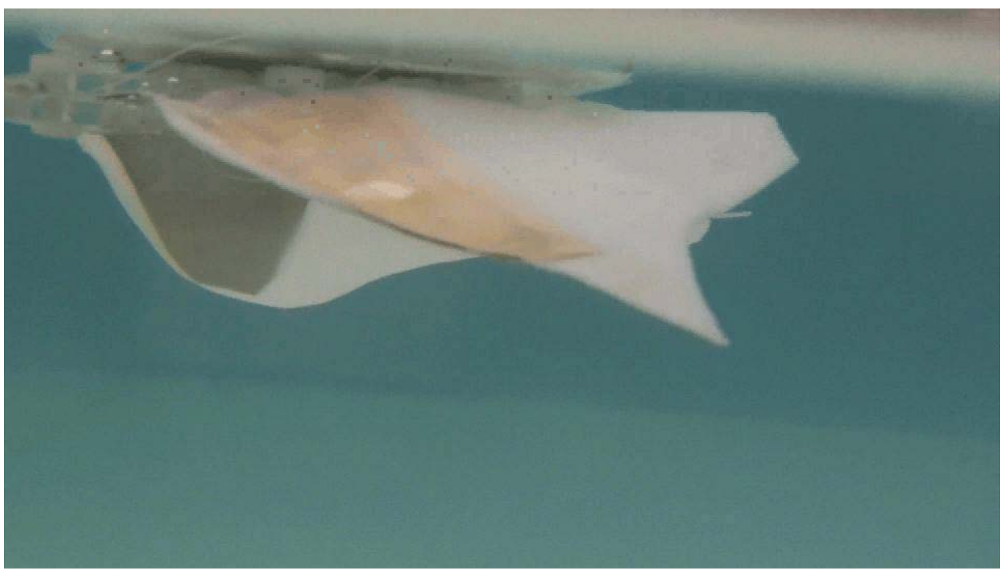
Re-Design of the Pectoral Fin and Robot



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**

1. **Z. Chen**, T. Um, and H. Bart-Smith, "Bio-inspired Robotic Manta Ray Powered by Ionic Polymer-Metal Composite Artificial Muscles", the International Journal of Smart and Nano Materials, Vol. 3, No. 4, pp. 296-308, 2012
2. **Z. Chen**, T. Um, and H. Bart-Smith, “A Novel Fabrication of Ionic Polymer-Metal Composite Capable of 3-Dimensional Kinematic Motions”, Sensors and Actuators A: Physical, Vol. 168, No. 1, pp 131-139, 2011
3. **Z. Chen** and X. Tan, “Monolithic Fabrication of Ionic Polymer Metal Composite Actuators for Complex Deformation”, Sensors and Actuators A: Physical, Vol. 157, No. 2, pp 246-257, 2010
4. **Z. Chen**, S. Shatara, and X. Tan, “Modeling of Biomimetic Robotic Fish Propelled by an Ionic Polymer-Metal Composite Actuator”, IEEE/ASME Transactions on Mechatronics, Vol. 15, No, 3, pp 448-459, 2010
5. **Z. Chen**, and X. Tan, “A Control-oriented, Physics-based Model for Ionic Polymer-Metal Composite Actuators”, IEEE/ASME Trans on Mechatronics, Vol. 13, No. 5, pp 519-529, 2008

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