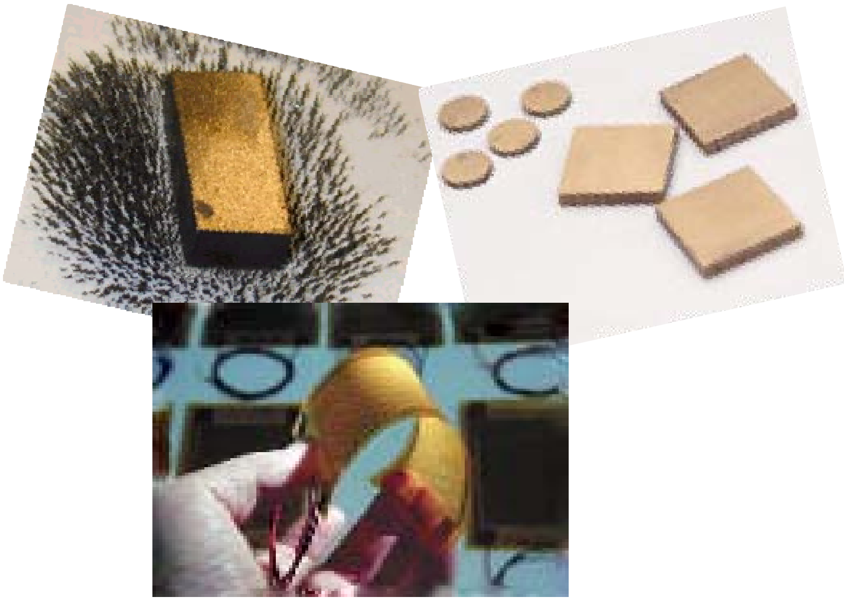
Overview of Smart Materials



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LECTURE 6:

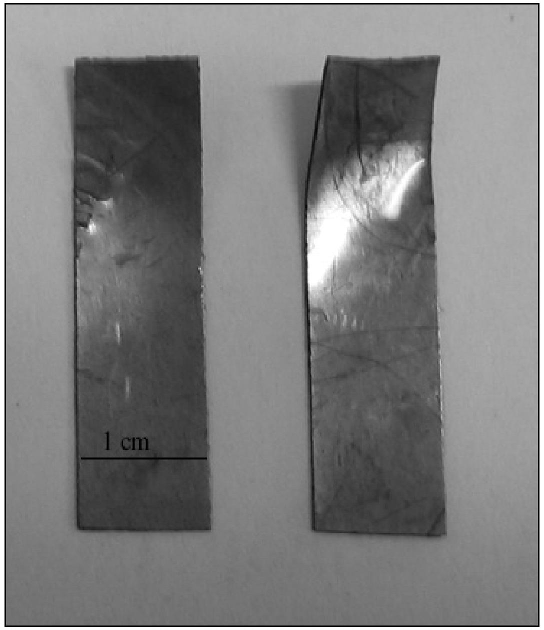
Active Smart Polymers (Part 2)

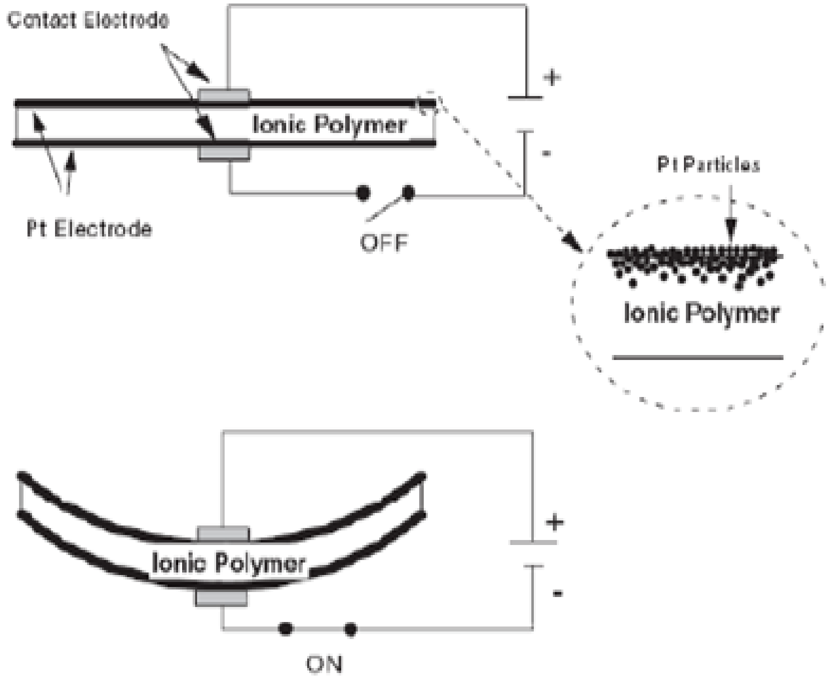
Organization

- Ionic Polymer Metal Composite (IPMC)
- Actuators Developed using IPMC
- Sensors Developed using IPMC
- Future of IPMC

IONIC POLYMER METAL COMPOSITES

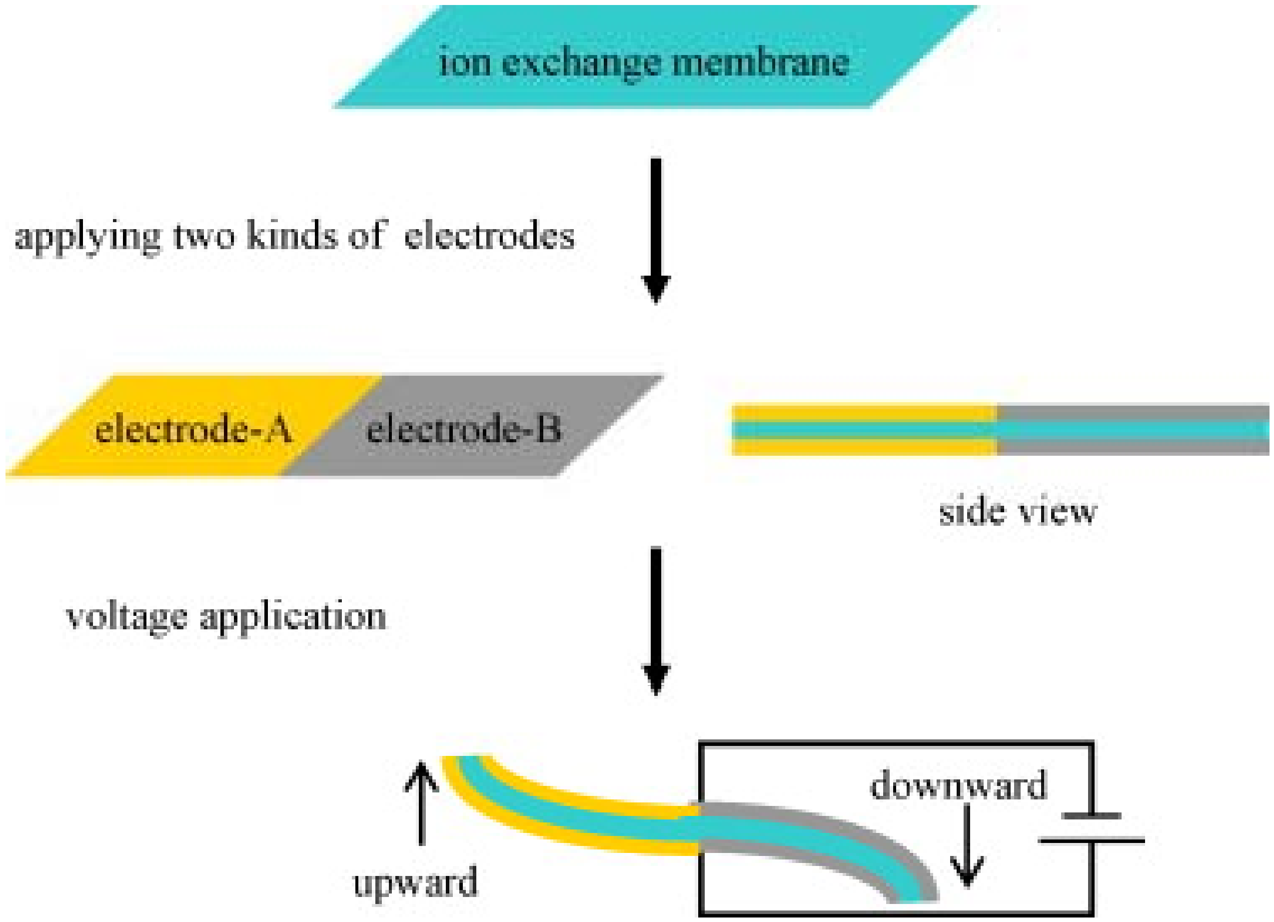
- Ionic electro active polymer
- Large deformation
- Low actuation voltages
- Fast response



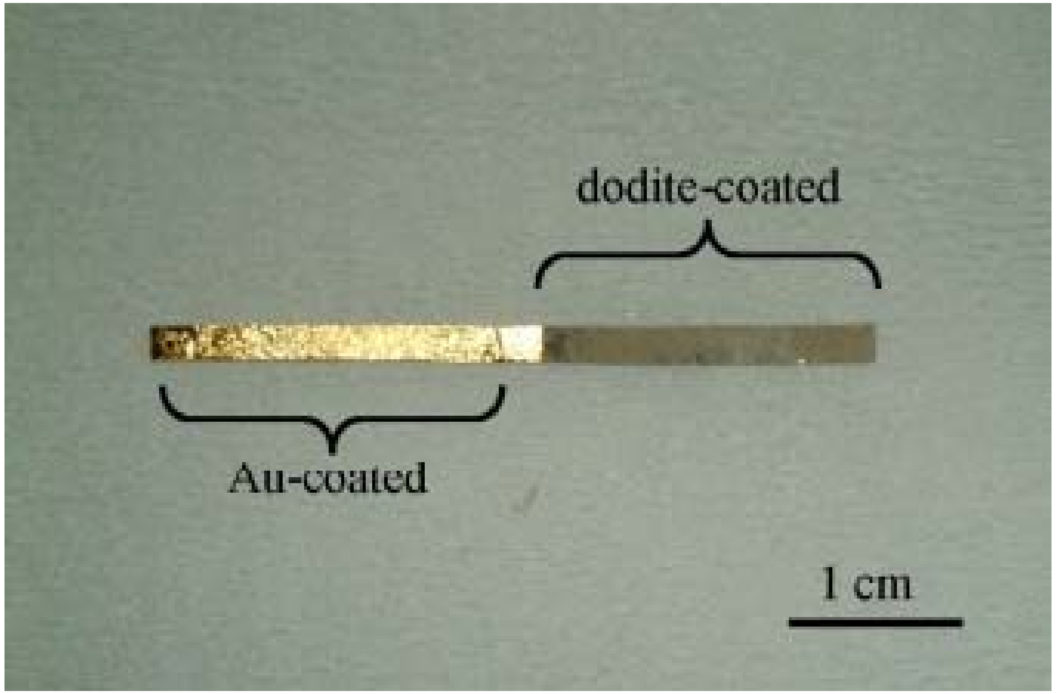


Schematic Diagram of IPMC

Developing Double Curvature using IPMC



Double Bending in Selemion

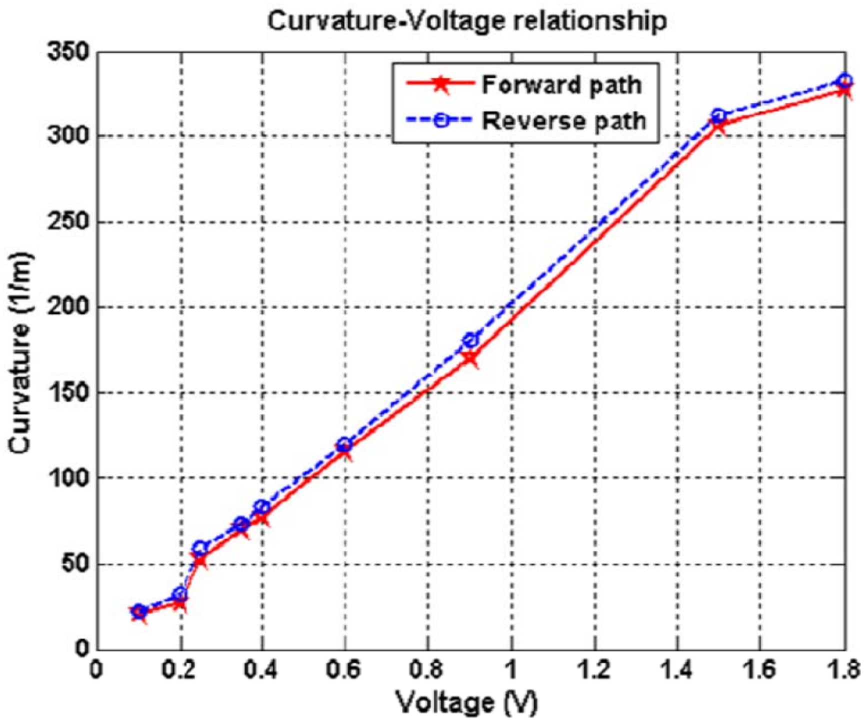


This IPMC consisted of Selemion and the left half of its top and bottom surfaces coated with Au foils using a paste, and the right half of its top and bottom surfaces coated with Dotite.
Dotite is an electrically conductive adhesive containing silver powder manufactured by Fujikura Kasei Co., Ltd. (Tokyo)

Selemion is a generic name of ion exchange membranes manufactured by Asahi Glass

MODELLING OF IPMC AS ACTUATOR

- Phenomenological modelling
- Equivalent circuit model
- Based on thermodynamics and mechano-chemical relationships

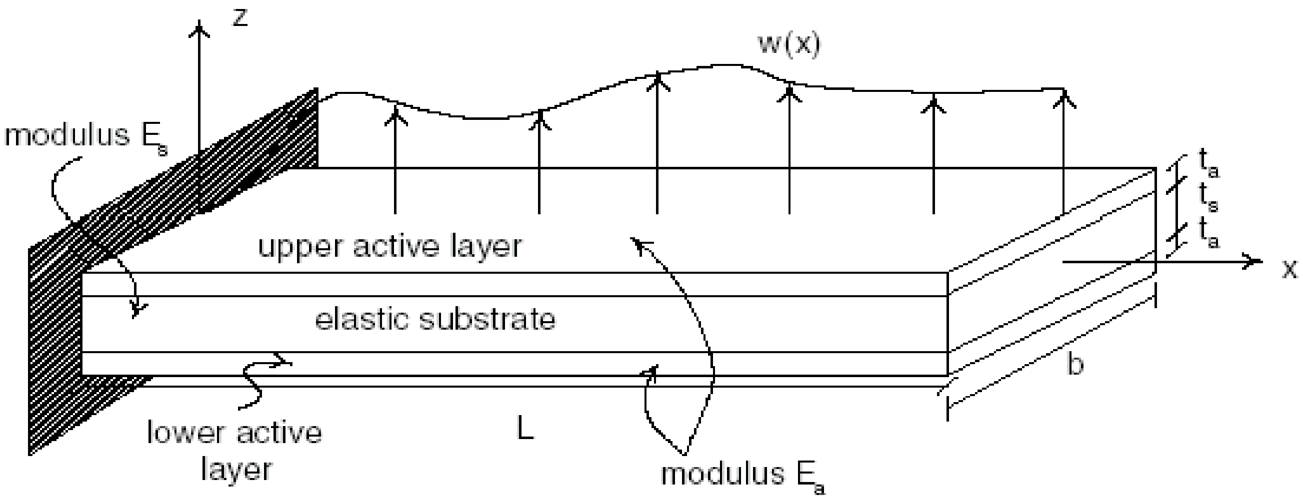


Curvature –voltage relationship from experiments

$$\kappa = K \times V - 0.05$$

$$M_o = K \times V \times E \times I$$

Bimorph Geometry



A Bimorph Actuator Configuration

Constitutive Equation

S: strain

T: Stress

t: layer thickness

E: Modulus of Elasticity

V: App. Voltage

d: Elect-Mech. Coeff.

$$S_s = \frac{T_s}{E_s}$$

$$S_u = \frac{T_u}{E_u} + d\frac{V}{t_u}$$

$$S_l = \frac{T_l}{E_l} - d\frac{V}{t_l}$$

Useful Model

$$x = a_{11} f + a_{12} v$$

$$q = a_{21} f + a_{22} v$$

x: displacement

f: force

v: voltage

U: Total strain energy

$$a_{11} = \frac{\partial^2 U}{\partial f^2}$$

$$a_{12} = a_{21} = \frac{\partial^2 U}{\partial f \partial v}$$

$$a_{22} = \frac{\partial^2 U}{\partial v^2}$$

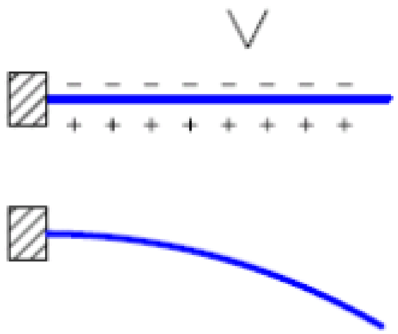
IPMC based Actuators

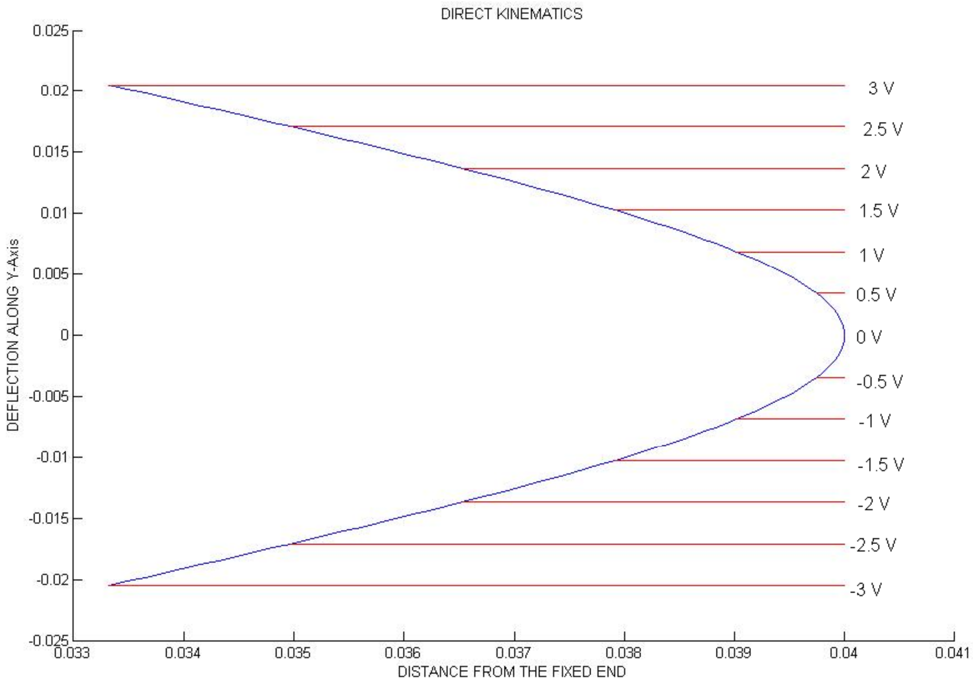
- Single Link Manipulator
- Multi-link Gripper
- Vibration Generation and Control
- 4-bar Manipulator
- Bio-mimetic Systems

Types of actuation

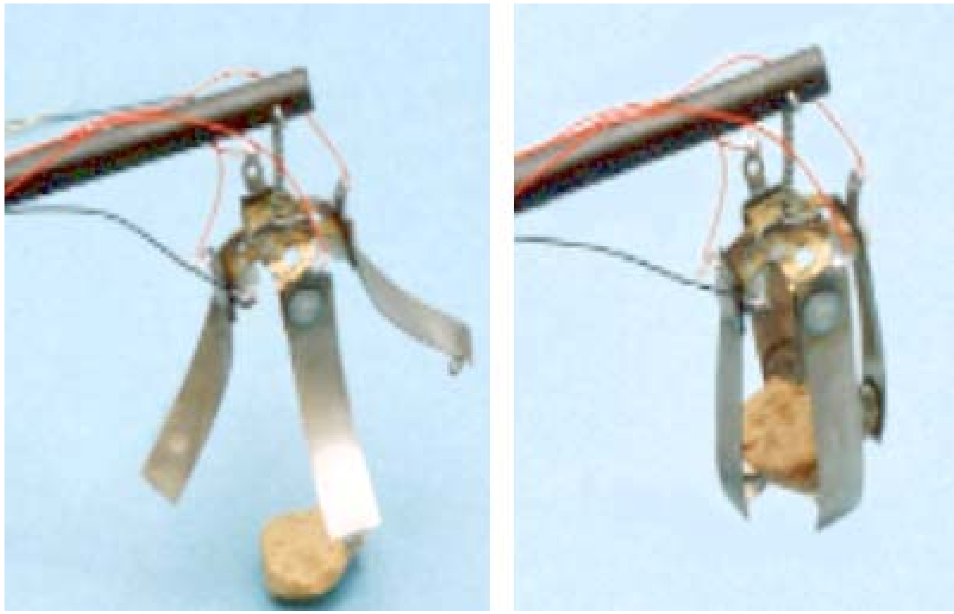
1. **Single electrode(1 DOF)**

The end point can be moved on a curve





Combination of Single-links to form Gripper

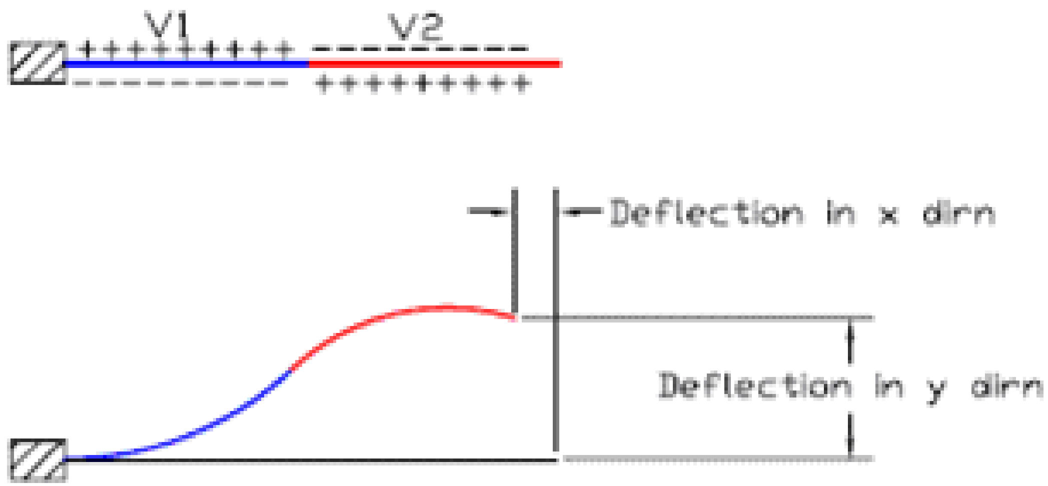


Ref. electrochem.cwru.edu

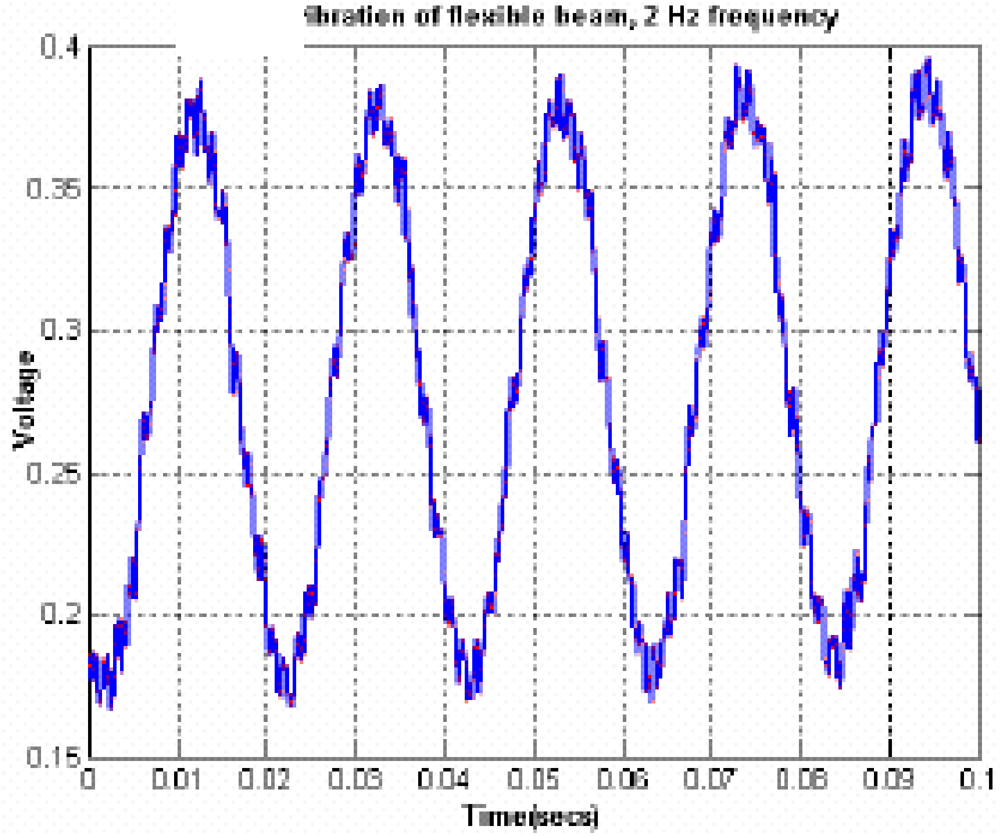
2. **Two or more patches**

The end point can be moved on a planar work-volume

- **A small object can be manipulated in the work-volume**
- **DOF available will depend on the number of patches**

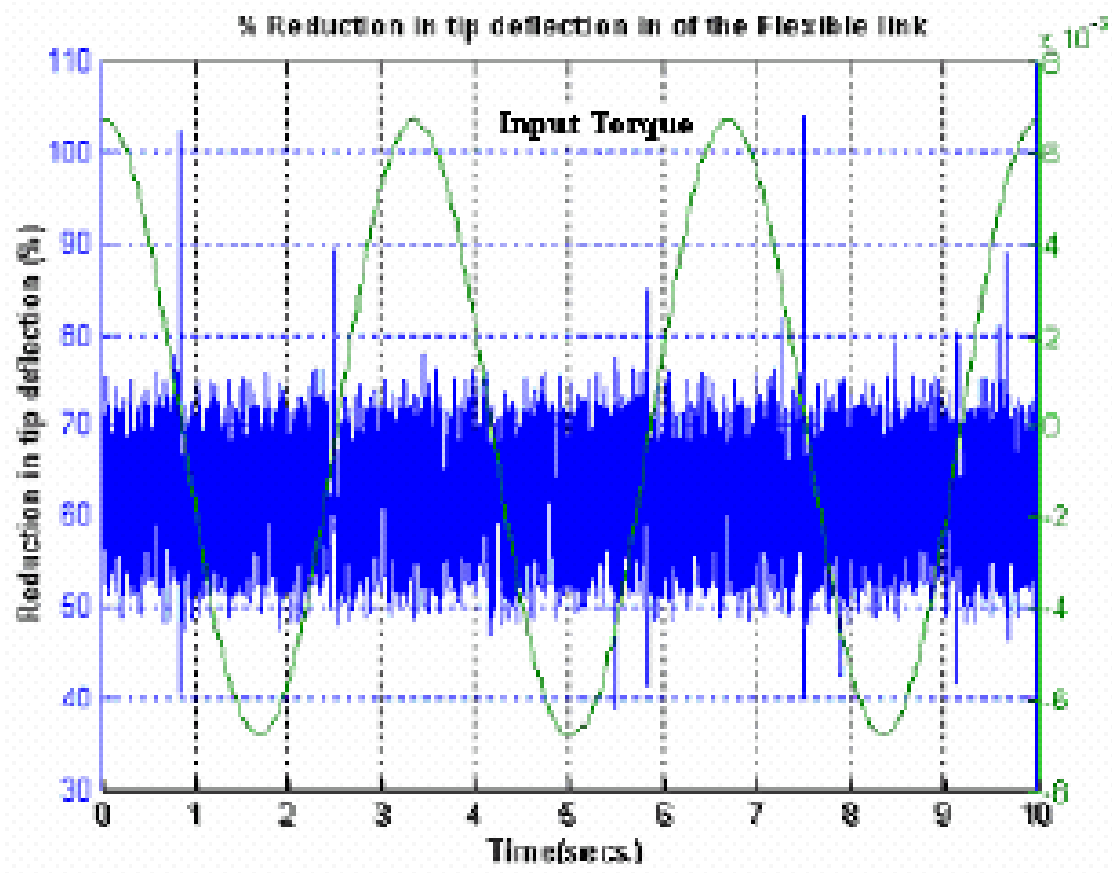


3. IPMC induced vibration of Flexible Beam

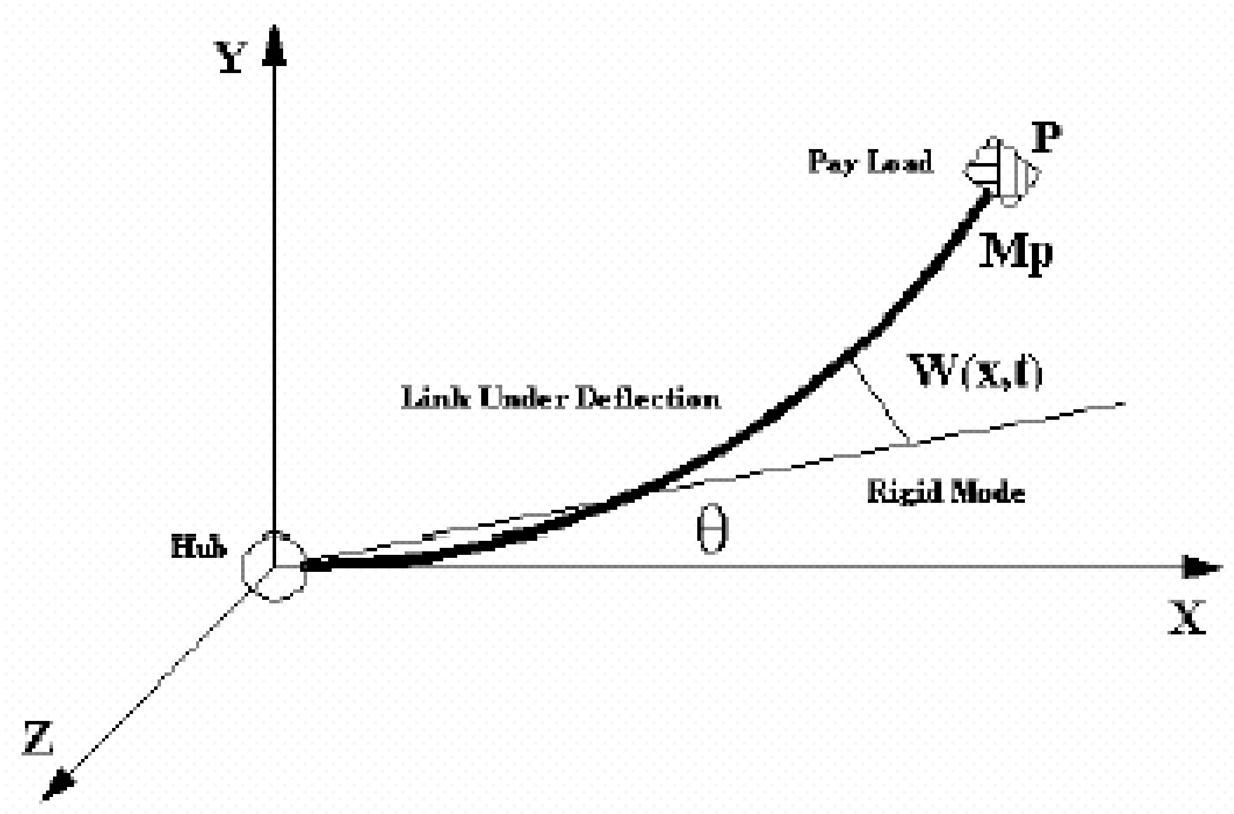


vibration of flexible beam, 2Hz frequency

Reduction in Tip Deflection of the Flexible Beam



Application to Flexible Manipulator



System Parameters of the Flexible Beam

Position vector of any point P on the link as shown (Fig. 4) is given by

$$\begin{aligned} p_x &= x\cos(\theta) - w(x,t)\sin(\theta) \\ p_y &= x\sin(\theta) + w(x,t)\cos(\theta) \end{aligned} \tag{9}$$

Where, θ = Hub angle with respect to the inertial X-axis.

Now total kinetic energy of the link with payload is given by

$$T = T_{link} + T_{payload} =$$

$$\frac{1}{2}\rho_b A_b \frac{l^3}{3}\dot{\theta}^2 + \frac{1}{2}\int_0^l \rho_b A_b \phi(x)^2 \dot{q}(t)^2 dx +$$

$$\frac{1}{2}\int_0^l \rho_b A_b \phi(x)^2 q(t)^2 dx + \frac{1}{2}\int_0^l 2x\dot{\theta}\phi(x)\dot{q}(t)dx + \tag{10}$$

$$\frac{M_p}{2}\left[l^2\dot{\theta}^2 + \dot{w}(l,t)^2 + w(l,t)^2\dot{\theta}^2 + 2l\dot{\theta}\dot{w}(l,t)\right]$$

Potential Energy of the System

$$P = \frac{1}{2}\int_0^l E_b(x) I_b(x) \left(w''(x,t)\right)^2 dx \qquad (11)$$

Where, $E_b(x)$ =Young's modulus of elasticity of the beam at point P, $I_b(x)$ = Area moment of inertia of the beam at point P, $w''(x,t)$ = Double differentiation of w with respect to x

Virtual Work on the System

$$\delta w = \sum_{i=1}^{n} \delta w_i = U(t)\delta\theta + \sum_{i=1}^{n} M_i(t)\delta\theta + \sum_{i=1}^{n} M_i(t)\left[H(x - x_i) - H(x - x_{i+1})\right] \times \left[\phi'(x_{i+1}) - \phi'(x_i)\right]\delta \dot{q} \, \mathbf{sin}^2(i\pi / 2) \tag{13}$$

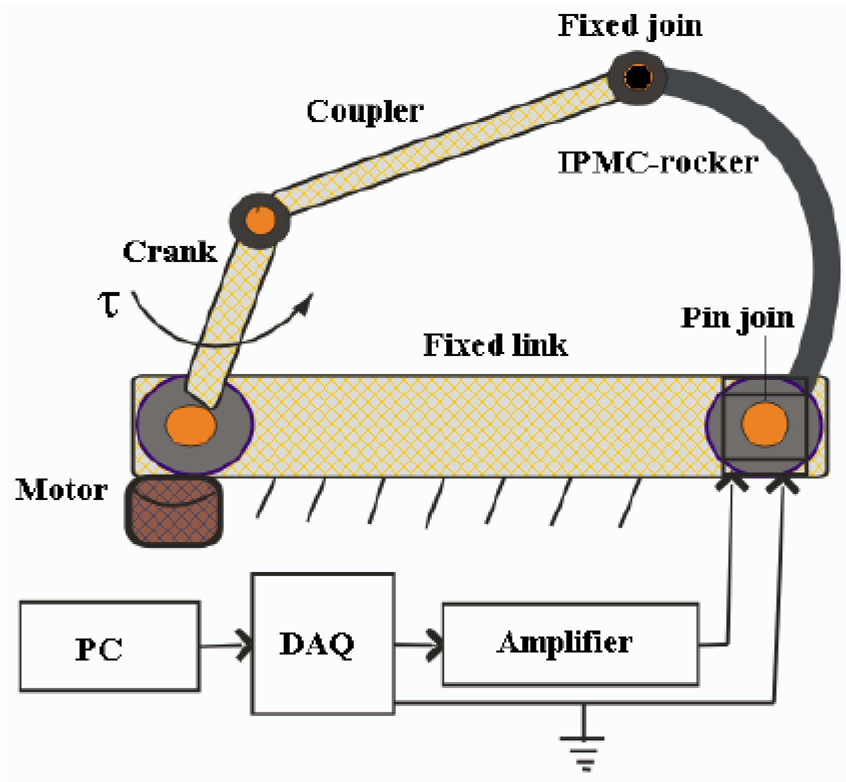
Where, $M_i(t)$ is the bending moment generated by the IPMC active layer assuming fully ion transport rate. $\left[H(x - x_i) - H(x - x_{i+1})\right]$ is the **Heaviside** function with value one or zero according to the discontinuity of the actuator placement. $\left[H(x - x_i) - H(x - x_{i+1})\right]$ = 1 for continuous patch and 0 for areas without patches. The

Dynamical EOM

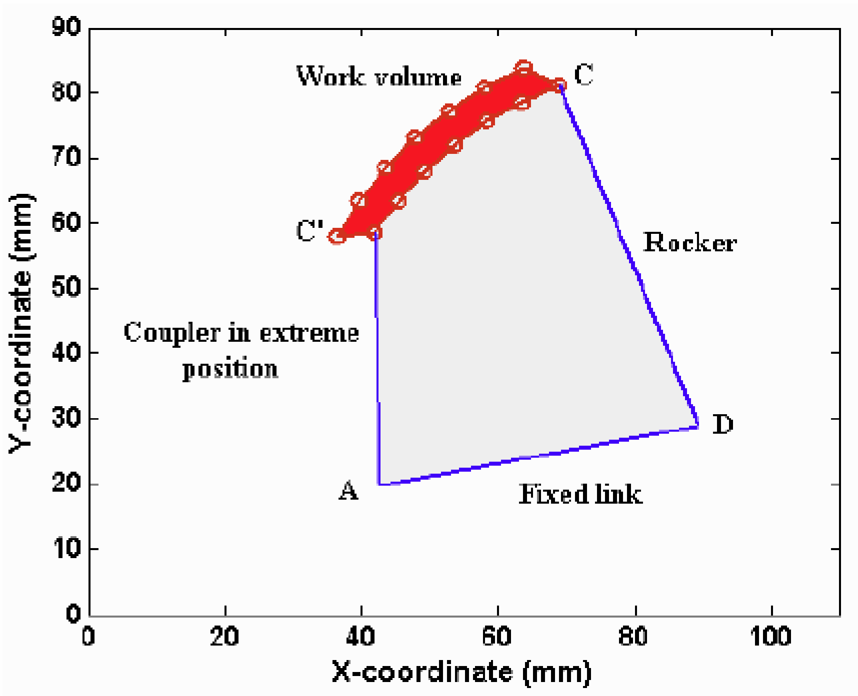
$$\begin{bmatrix} Mtt + q^T M_{gg} q & M_{tg} \\ M_{tg} & M_{gg} \end{bmatrix} \begin{bmatrix} \ddot{\theta} \\ \ddot{q} \end{bmatrix} +$$

$$\begin{bmatrix} M_{gg}\dot{q} & M_{gg}\dot{\theta} \\ -M_{gg} q \dot{\theta} & 0 \end{bmatrix} \begin{bmatrix} \dot{\theta} \\ \dot{q} \end{bmatrix} + \begin{bmatrix} 0 \\ K_q q \end{bmatrix} = \begin{bmatrix} U(t) + M(t) \\ 0 \end{bmatrix}$$

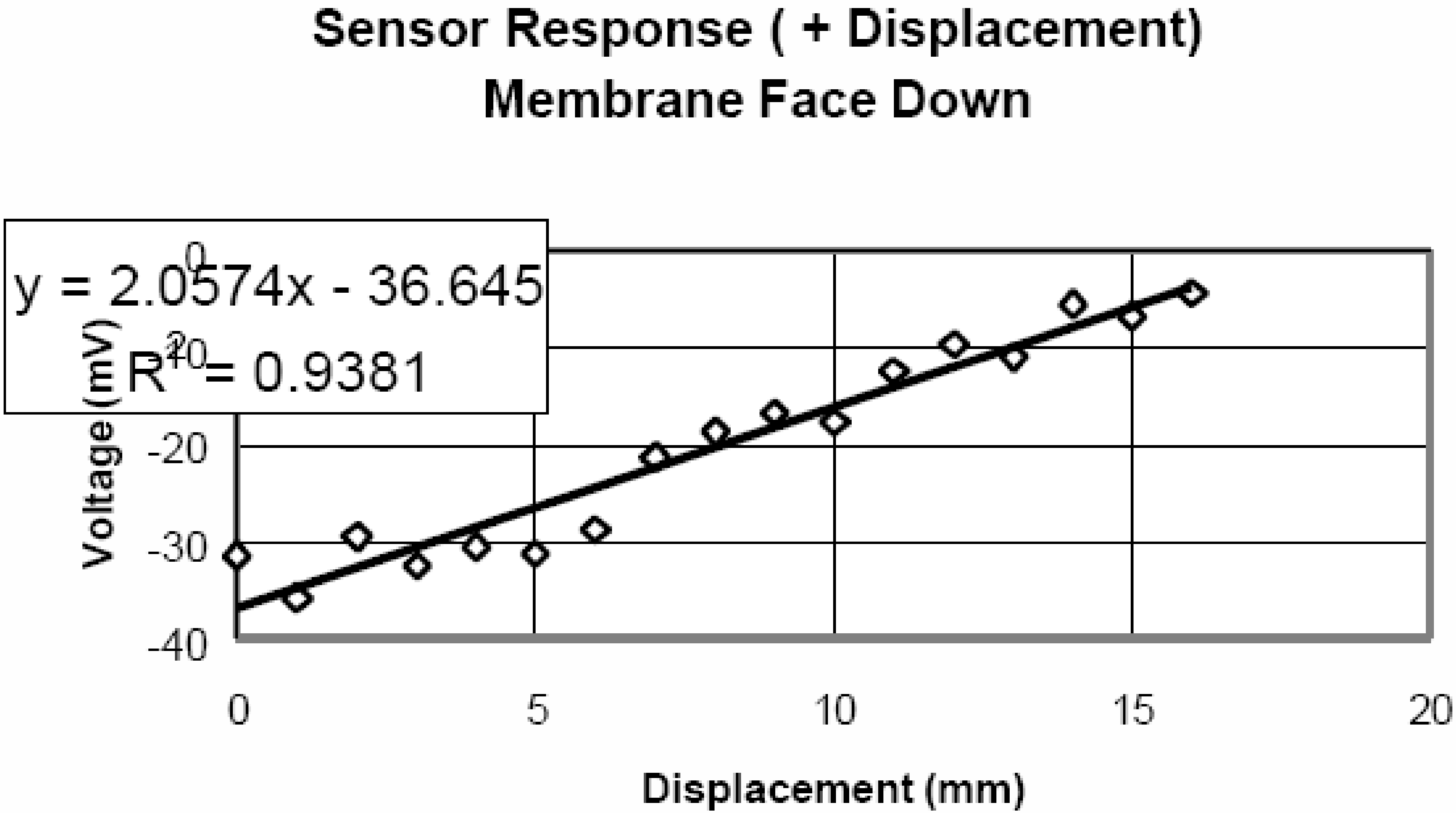
IPMC based 4-bar mechanism



Generation of work-volume using 4-bar IPMC



Inverted IPMC film Sensor

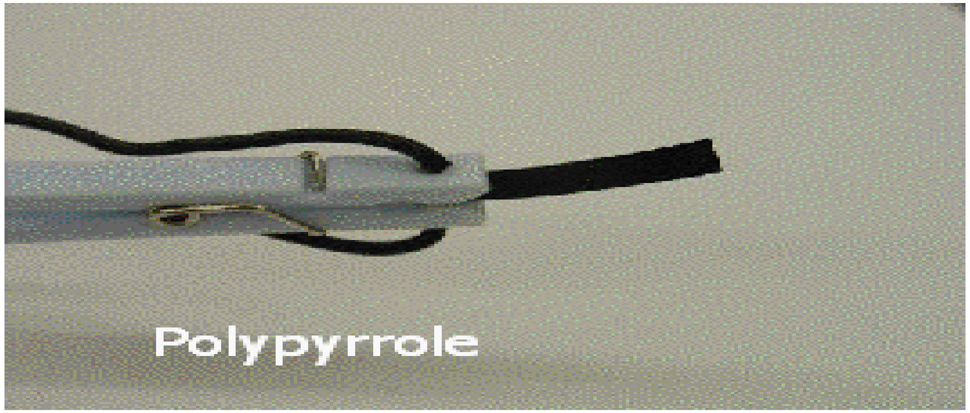


Sahinpoor and Bar Cohen 1998

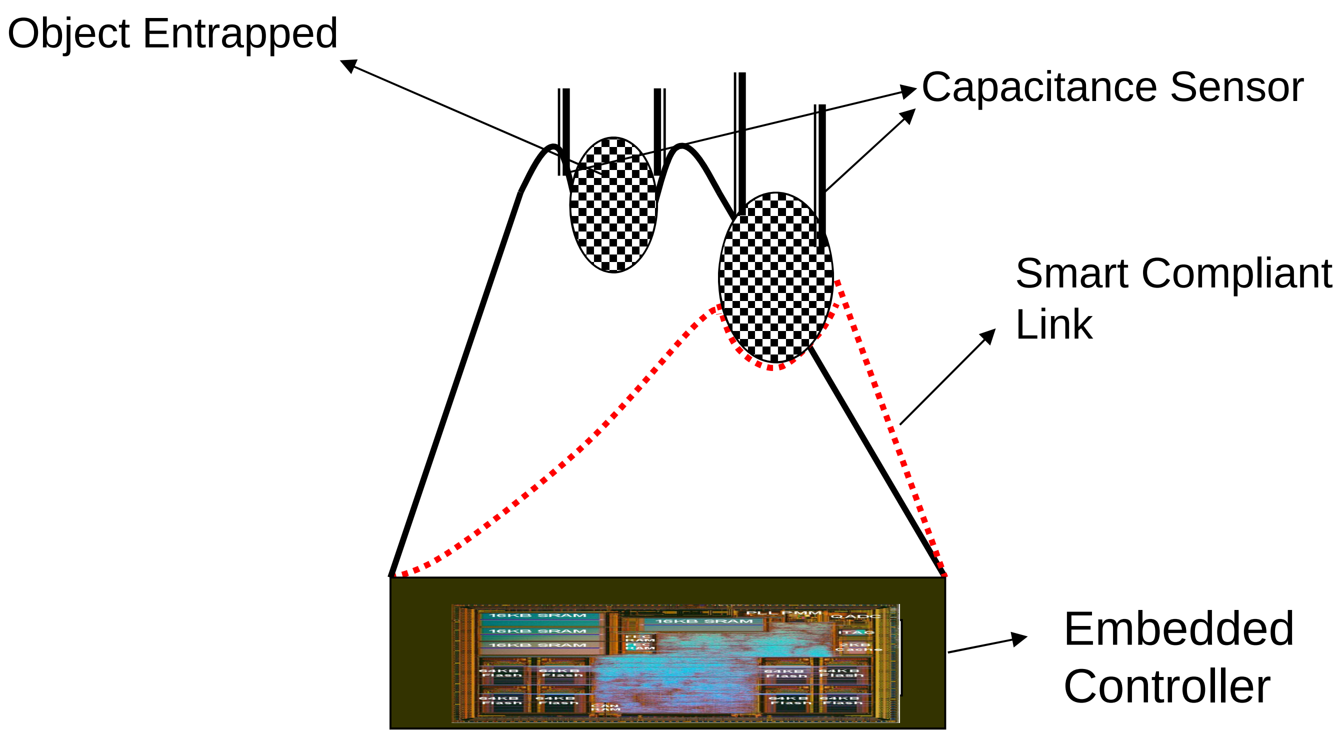
Future of Smart Polymers

- Higher ‘IQ’ – ‘responsiveness’ –larger actuation corresponding to smaller stimulation, ‘agility’ – faster response – increasing the bandwidth of the existing smart materials
- Higher order ‘functionality’- self-sensing, self-actuation, self-healing, auto-phagous, energy harvesting, energy scavenging
- Exploit the success in ‘nano -technology’ and develop more ‘varied’, ‘complex’ and ‘intelligent systems’

Gold/Polypyrrole : A new IPMC



Concept of an Integrated Gripper-Manipulator



Lips: Design of Biomimetic System

References

- Electroactive Polymers for Robotics Applications – Kim and Tadokoro
- Smart Structures – Paolo Gaudenzi

END OF LECTURE 6