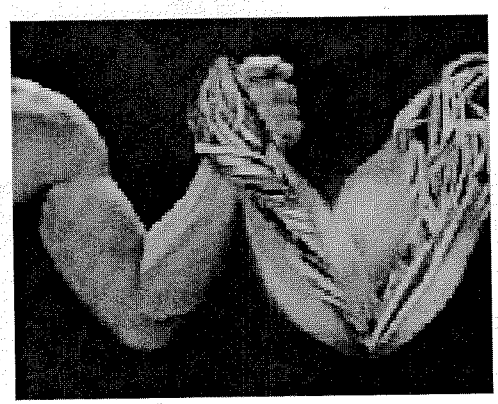
SPIE's 10th Annual International Symposium on Smart Structures and Materials

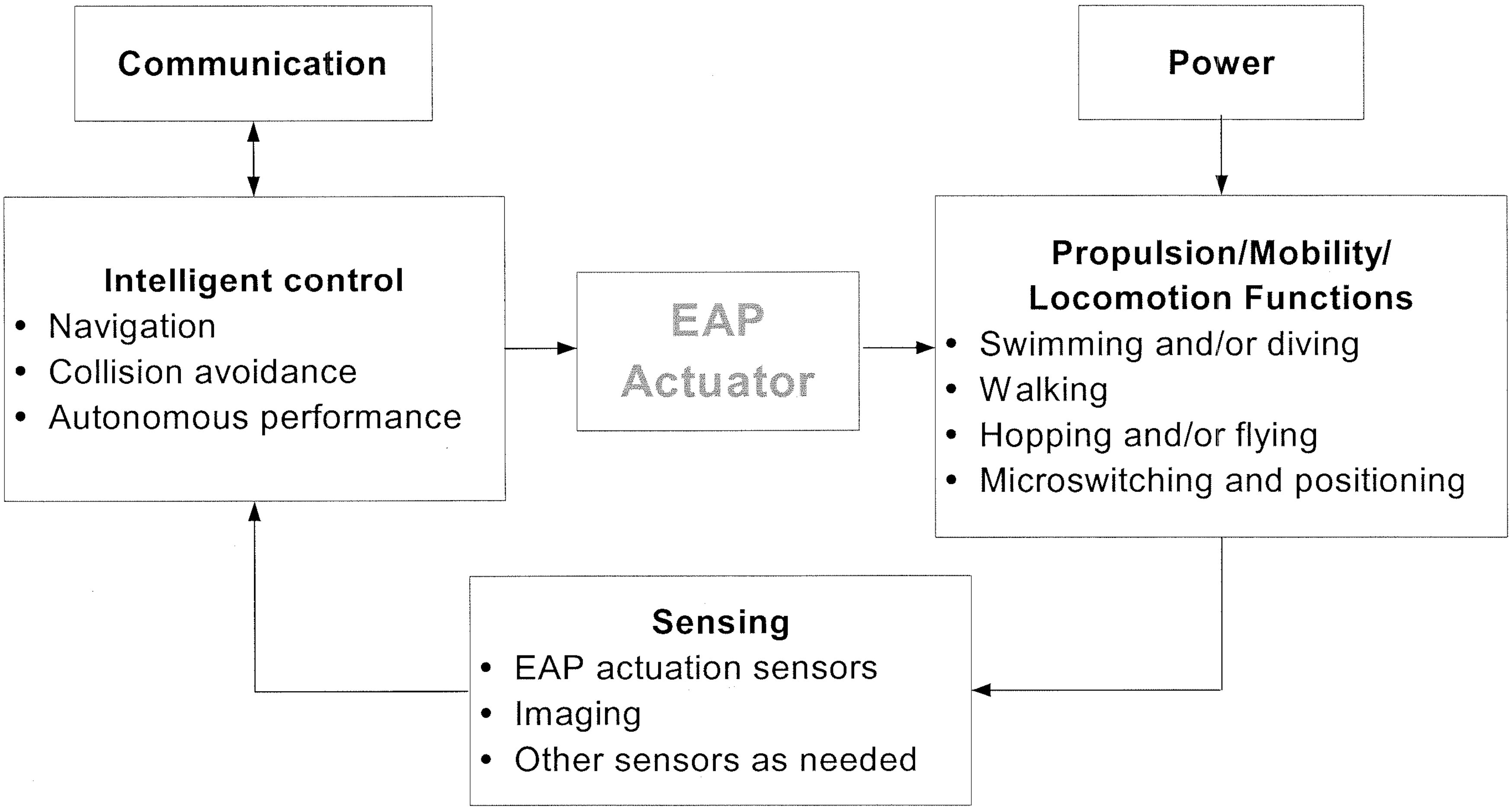
The 5th Electro-Active Polymer Actuators and Devices (EAPAD) Conference #5051



Yoseph Bar-Cohen, EAPAD Conference Chair

San Diego, CA, March 2, 2003

Elements of an EAP actuated robots



EAP AS BIOMIMETIC ACTUATION MATERIALS
Background

- Most conventional mechanisms are driven by actuators requiring gears, bearings, and other complex components.

- Emulating biological muscles can enable various novel manipulation capabilities that are impossible today.

- Electroactive polymers (EAP) are emerging with capability that can mimic muscles to actuate biologically inspired mechanisms.

- EAP are resilient, fracture tolerant, noiseless actuators that can be made miniature, low mass, inexpensive and consume low power.

- EAP can potentially be used to construct 3-D systems, such as robotics, which can be imagined today as science fiction.

Comparison between EAP and widely used transducing actuators

Property	EAP	EAC	SMA
Actuation strain	>10%	0.1 - 0.3 %	<8% short fatigue life
Force (MPa)	0.1 – 3	30-40	about 700
Reaction speed	μsec to sec	μsec to sec	sec to min
Density	1- 2.5 g/cc	6-8 g/cc	5 - 6 g/cc
Drive voltage	2-7V/ 10-100V/μm	50 - 800 V	NA
Consumed Power*	m-watts	watts	watts
Fracture toughness	resilient, elastic	fragile	elastic

* Note: Power values are compared for documented devices driven by such actuators.

Historical prospective

- Roentgen [1880] is credited for the first experiment with EAP electro-activating rubber-band to move a cantilever with mass attached to the free-end
- Sacerdote [1899] formulated the strain response of polymers to electric field activation
- Eguchi [1925] discovery of electrets* marks the first developed EAP
  - Obtained when carnauba wax, rosin and beeswax are solidified by cooling while subjected to DC bias field.
- Another important milestone is Kawai [1969] observation of a substantial piezoelectric activity in PVF2.
  - PVF2 films were applied as sensors, miniature actuators and speakers.
- Since the early 70's the list of new EAP materials has grown considerably, but the most progress was made after 1990.

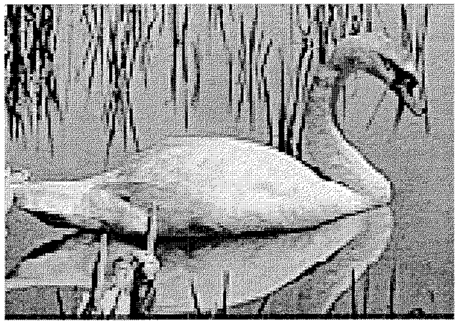
* Electrets are dielectric materials that can store charges for long times and produce field variation in reaction to pressure.

BIOLOGICALLY INSPIRED ROBOTICS

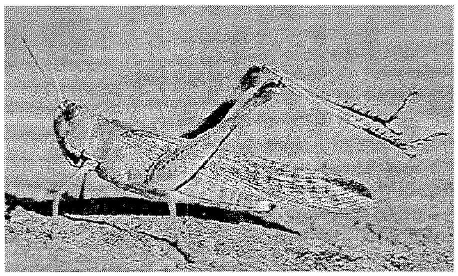
IN-SITU MULTI-TASKING MISSIONS USING SCALABLE AUTONOMOUS ROBOTS FOR COLONIZED EXPLORATION

Multiple locomotion capabilities

Flying, walking, swimming & diving

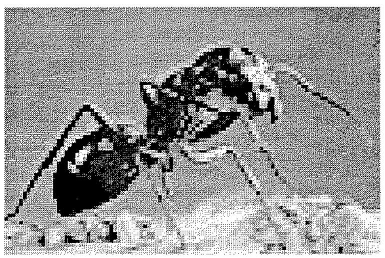


Hopping, flying, crawling & digging

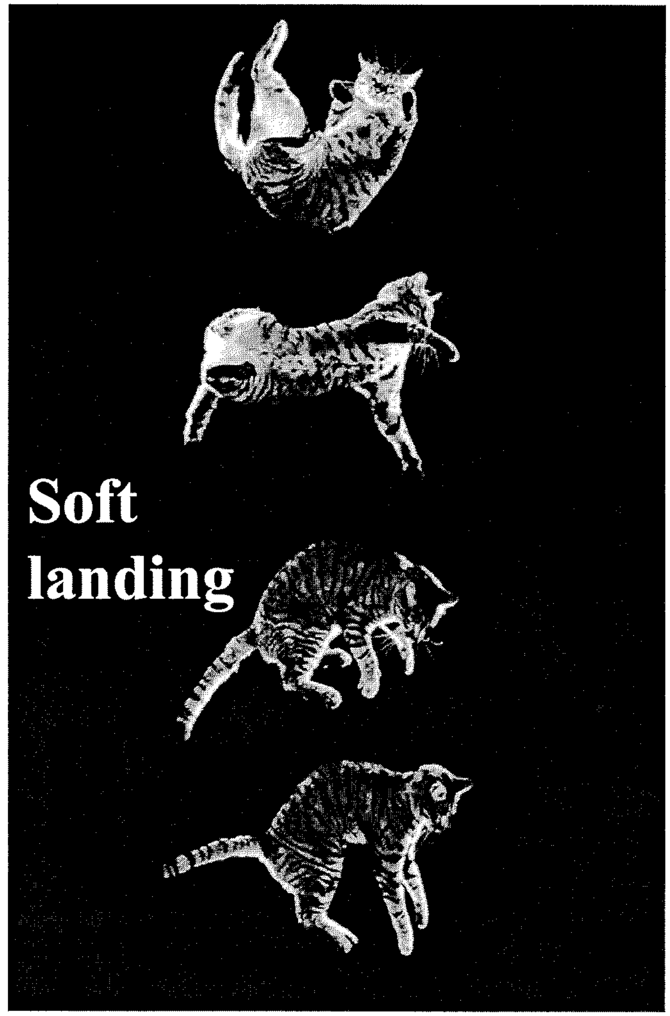


Coordinated robotics

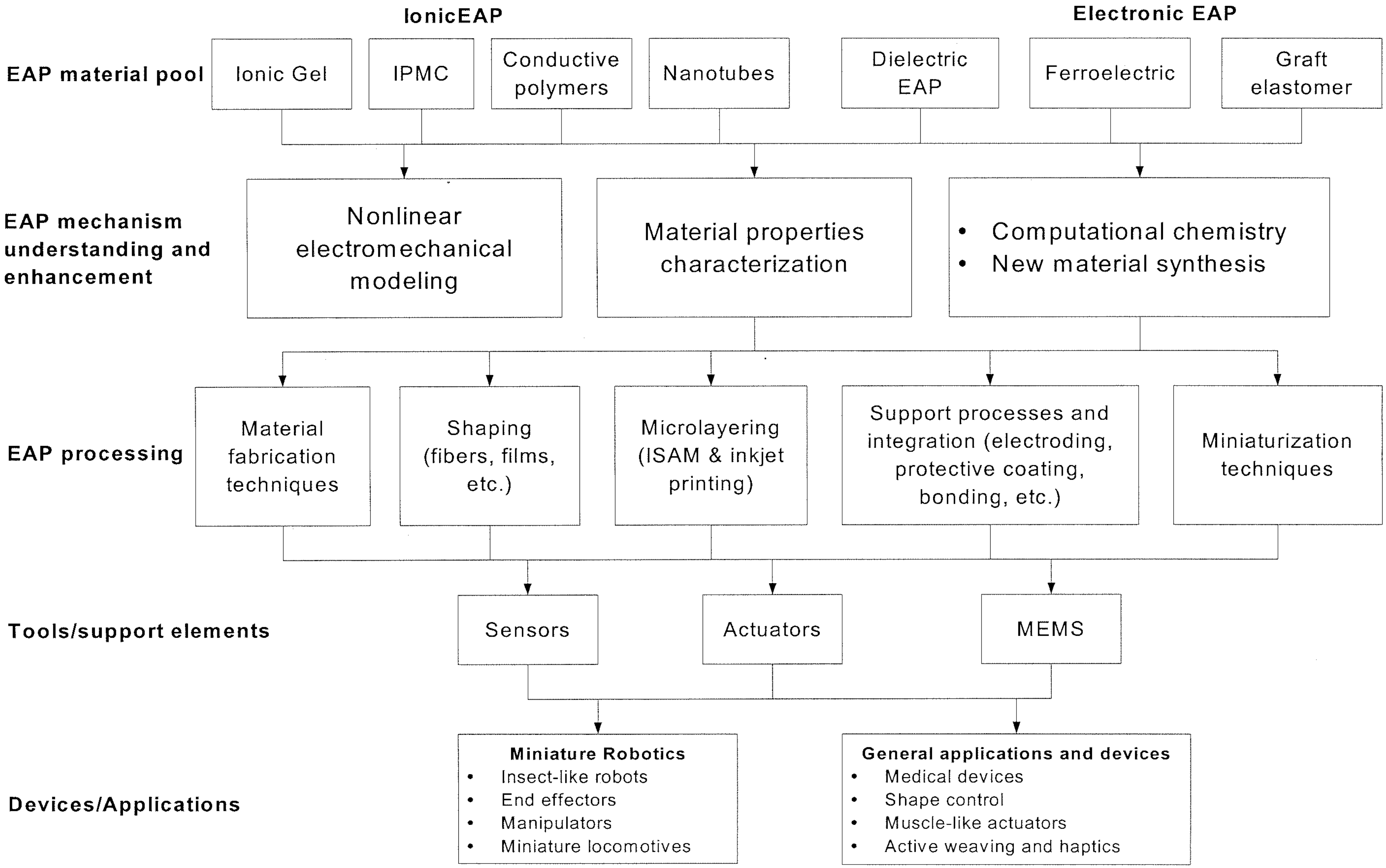
Neural networks & expert systems



Models for EAP Actuated Flexible Robots

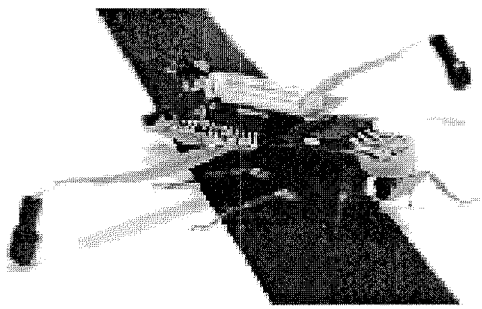


EAP infrastructure

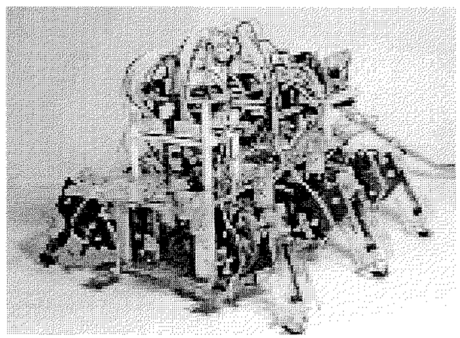


Insects as workhorses and robots

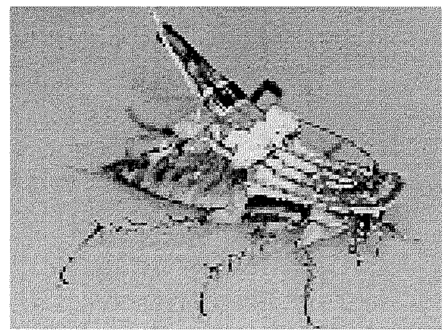
- Insects were used by various researchers (e.g., University of Tokyo, Japan) as locomotives to carry backpack of wireless electronics.
- EAP offers the potential of making insect-like robot to replace the "real thing".



Cricket



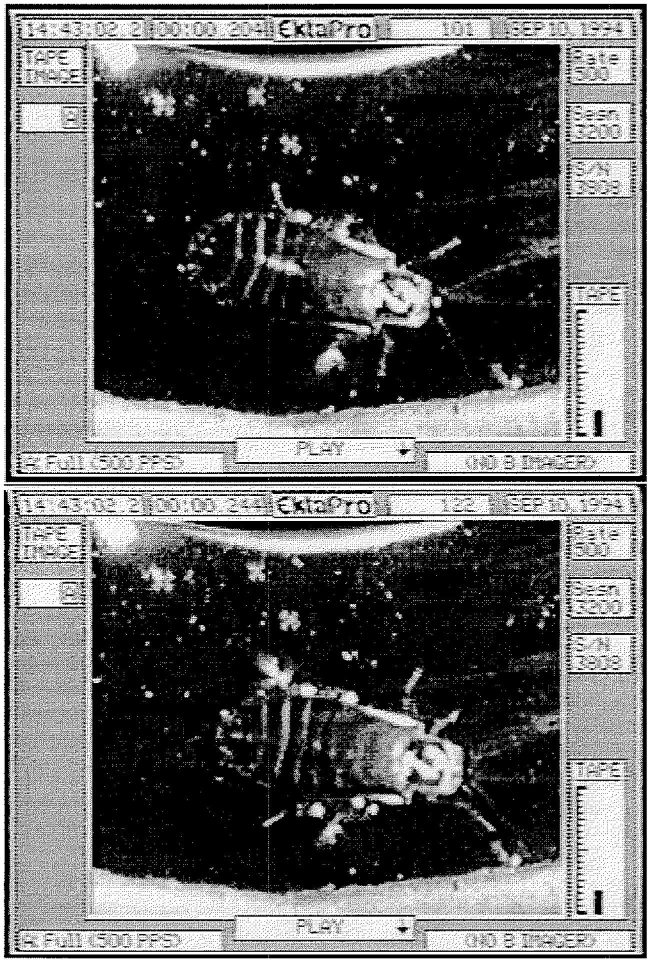
Spider



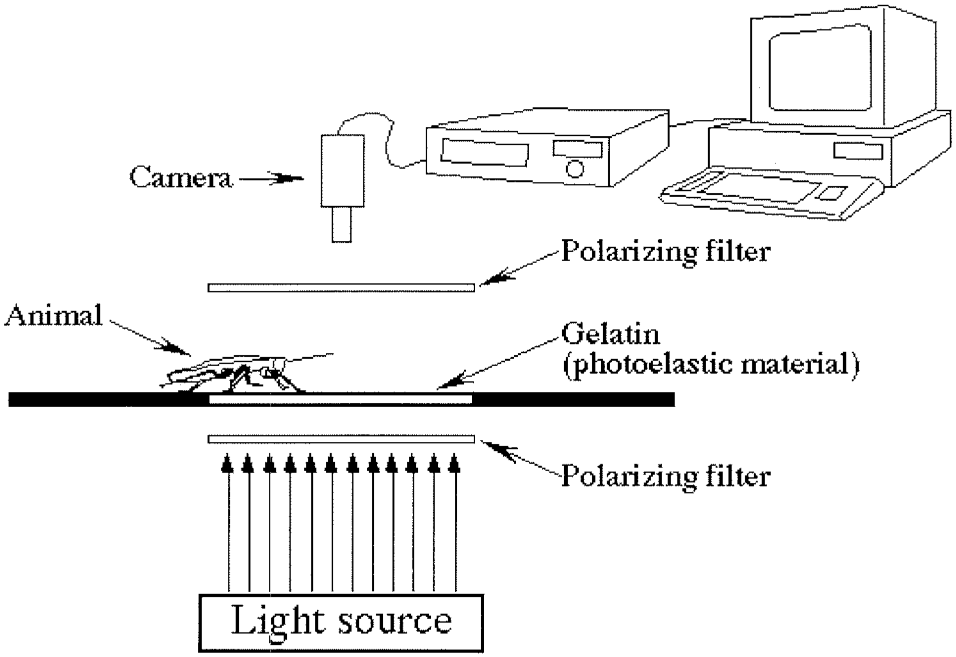
Cockroach

Reference: http://www.leopard.t.u-tokyo.ac.jp/

Insect walking process*



Photoelastic force platform is used at Berkeley to study insect walking mechanism.

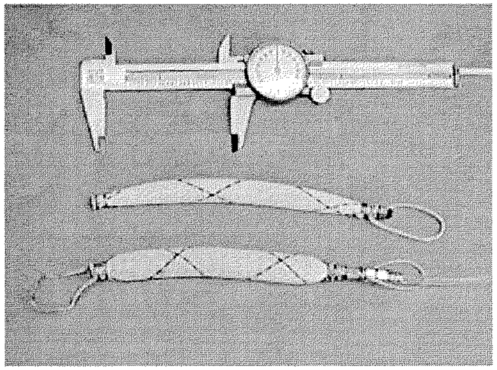


* Robert Full, Berkeley U.
Ref: http://rjf2.biol.berkeley.edu/Full_Lab/FL_Publications/PB_Posters/94ASZ_Turning/94ASZ_Turning.html

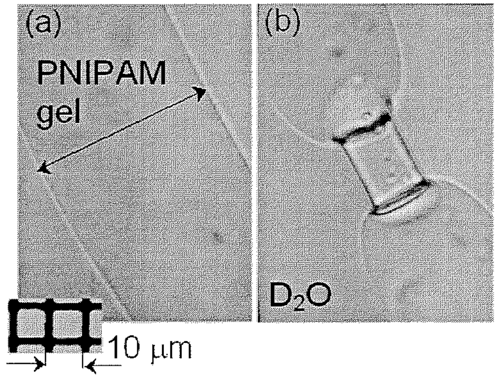
Non-Electro Active Polymers (NEAP)

- Conductive and Photonic Polymers
- Smart Structures and Materials
- Deformable Polymers
  - Chemically Activated
  - Shape Memory Polymers
  - Inflatable Structures
  - Light Activated Polymers
  - Magnetically Activated Polymers

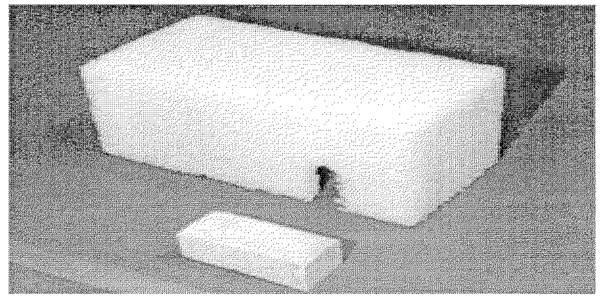
Non-electrical mechanically activated polymers



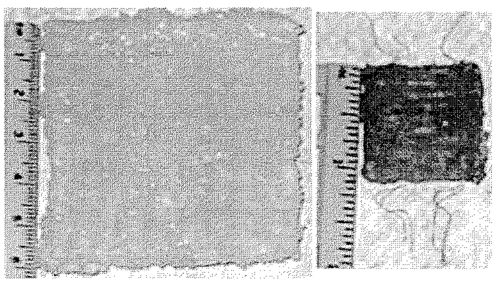
McKibben Artificial Muscles
Air Pressure activation (Hannaford, B.U. Washington)



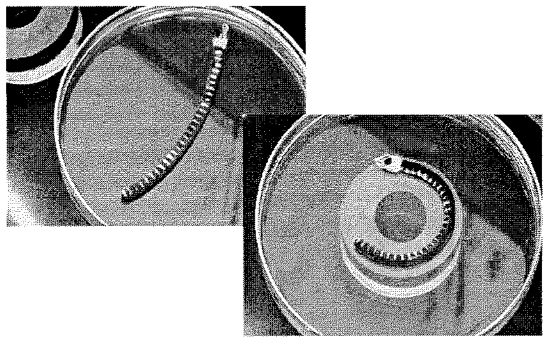
Laser Illuminated Polymer
Light activation (H. Misawa, Japan)



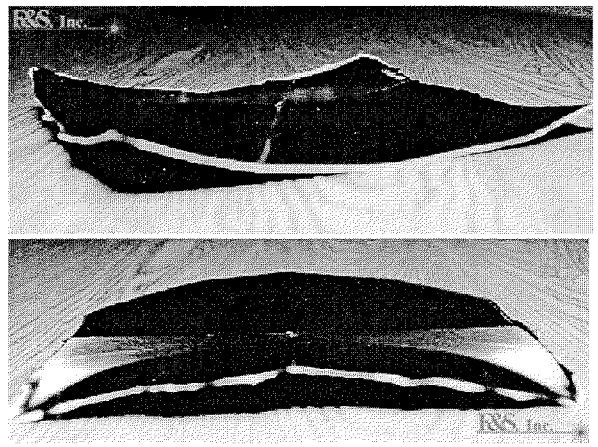
Shape Memory Polymers
Heat/pressure activation (W. Sokolowski, JPL)



Ionic Gel Polymers
Chemical transduction (P. Calvert, UA)



Ferrogel
Magnetic Activation (M. Zrinyi, Hungary)



Smart Structures
Polymers with Stable shapes (S. Poland, Luna Innovations, VA)


Artificial Muscles
EAP
Yoseph Bar-Cohen, Ph.D.
Jet Propulsion Laboratory

Electroactive Polymers (EAP)

ELECTRONIC EAP

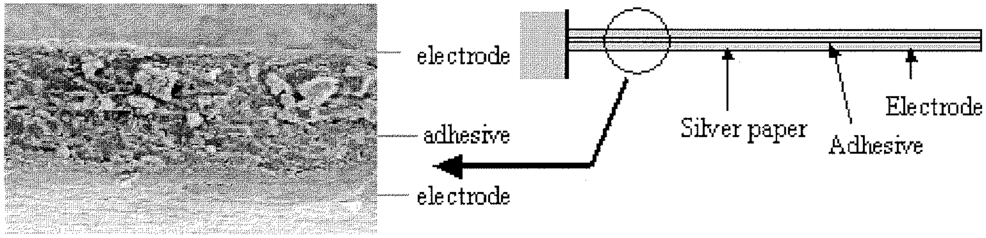
- Dielectric EAP
- Electrostrictive Graft Elastomers
- Electrostrictive Paper
- Electro-Viscoelastic Elastomers
- Ferroelectric Polymers
- Liquid Crystal Elastomers (LCE)

IONIC EAP

- Carbon Nanotubes (CNT)
- Conductive Polymers (CP)
- ElectroRheological Fluids (ERF)
- Ionic Polymer Gels (IPG)
- Ionic Polymer Metallic Composite (IPMC)

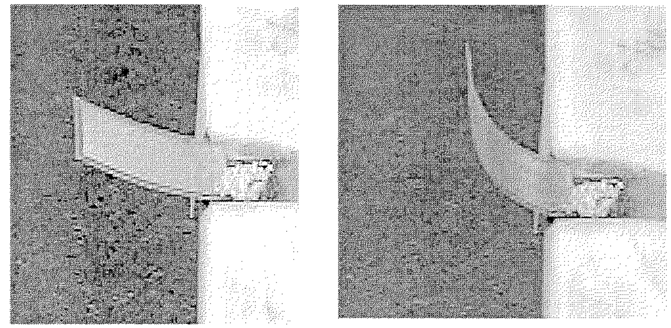
Electronic EAP

ELECTRIC FIELD OR COULOMB FORCES DRIVEN ACTUATORS



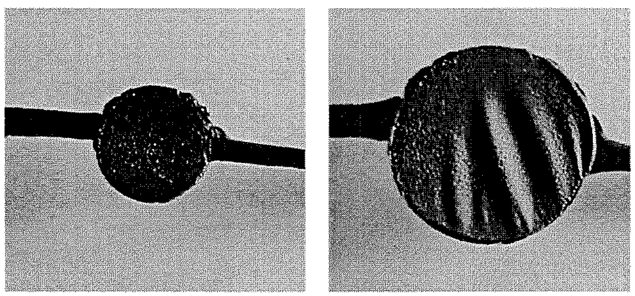
Paper EAP

[J. Kim, Inha University, Korea]



Ferroelectric

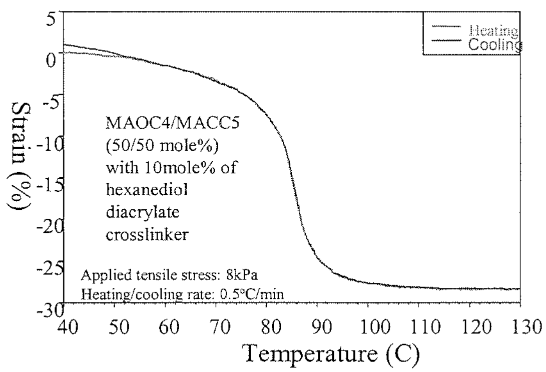
[Q. Zhang, Penn State U.]



Voltage Off **Voltage On**

Dielectric EAP

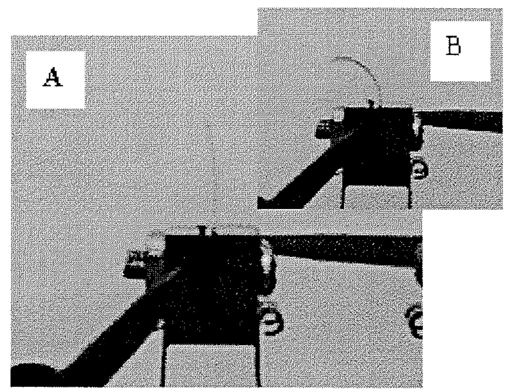
[R. Kornbluh, et al., SRI International]



Liquid crystals

(Piezoelectric and thermo-mechanic)

[B. R. Ratna, NRL]

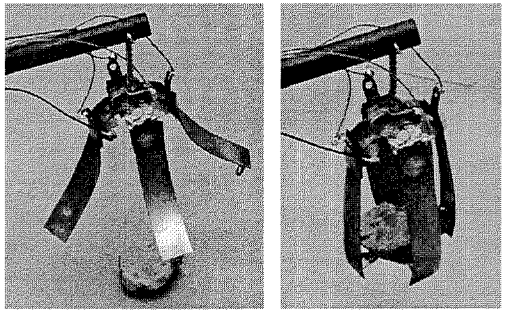


Graft Elastomer

[J. Su, NASA LaRC]

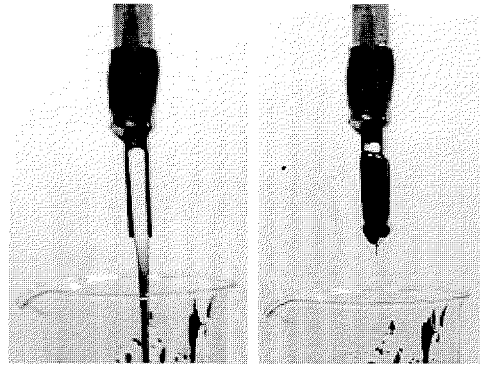
Ionic EAP

Turning chemistry to actuation



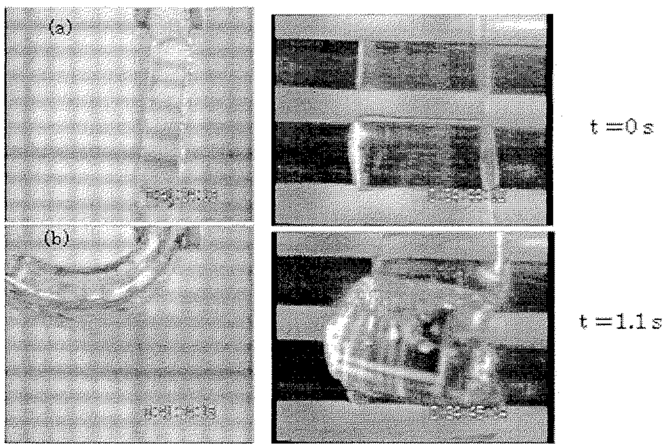
IPMC

[JPL using ONRI, Japan & UNM materials]



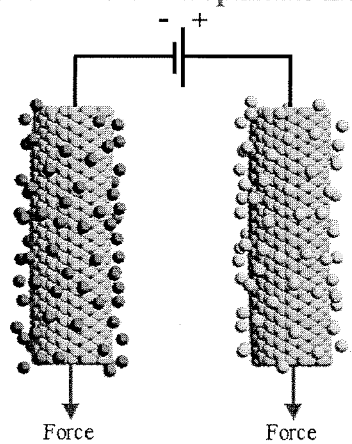
ElectroRheological Fluids (ERF)

[ER Fluids Developments Ltd]



Ionic Gel

[T. Hirai, Shinshu University, Japan]



Carbon-Nanotubes

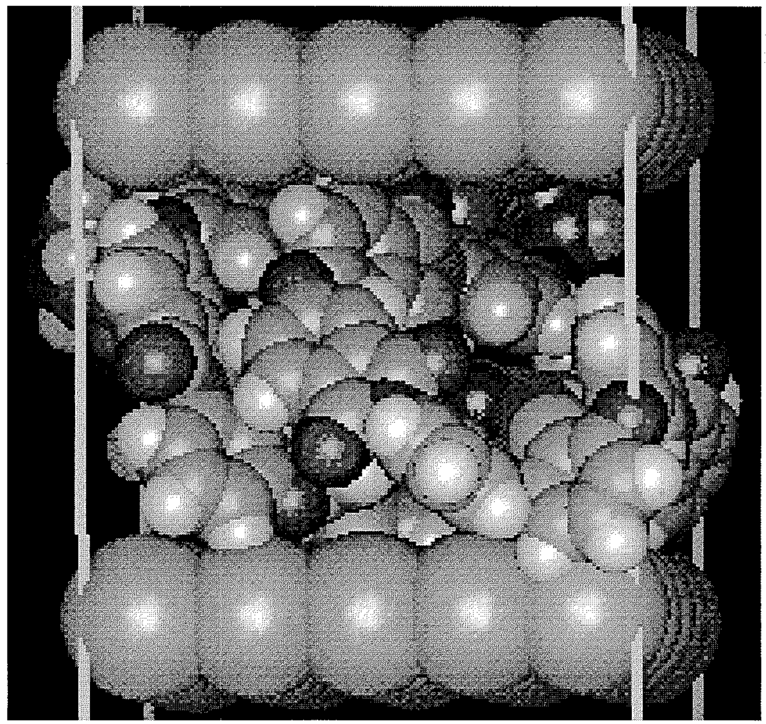
[R. Baughman et al, Honeywell, et al]

Current EAP
Advantages and disadvantages

EAP type	Advantages	Disadvantages
Electronic EAP	▪ Can operate in room conditions for a long time ▪ Rapid response (mSec levels) ▪ Can hold strain under DC activation ▪ Induces relatively large actuation forces	▪ Requires high voltages (~150V/μm) ▪ Requires compromise between strain and stress ▪ Glass transition temperature is inadequate for low temperature actuation tasks
Ionic EAP	▪ Large bending displacements ▪ Provides mostly bending actuation (longitudinal mechanisms can be constructed) ▪ Requires low voltage	▪ Except for CPs, ionic EAPs do not hold strain under DC voltage ▪ Slow response (fraction of a second) ▪ Bending EAPs induce a relatively low actuation force ▪ Except for CPs, it is difficult to produce a consistent material (particularly IPMC) ▪ In aqueous systems the material sustains hydrolysis at >1.23-V

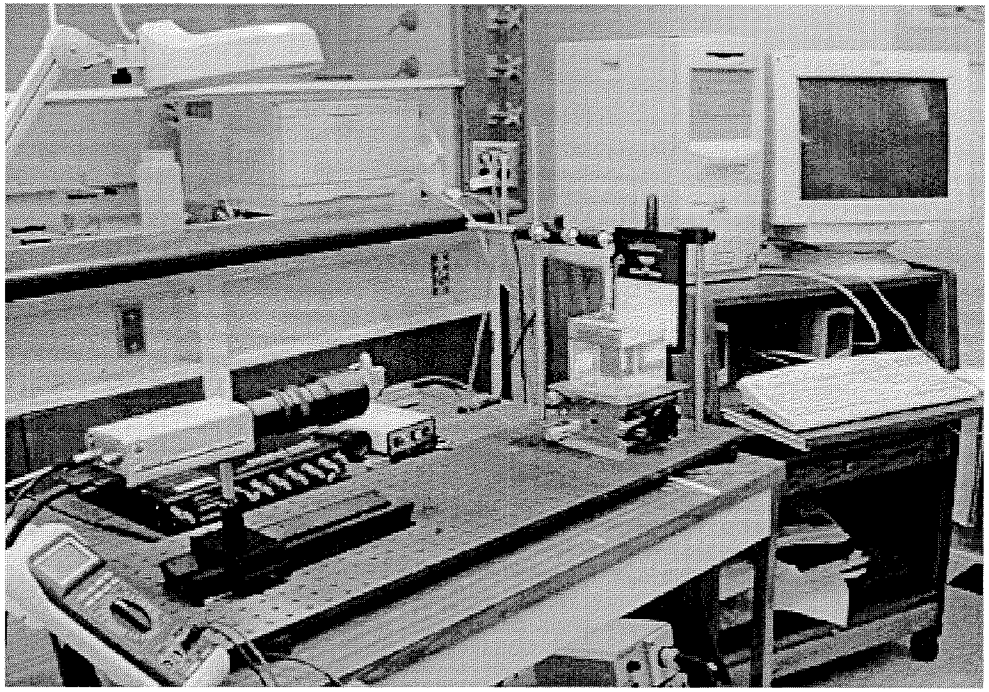
Computational chemistry

Computational chemistry may lead to material design tools using comprehensive modeling to methodically synthesize effective new EAPs



(NASA-LaRC)

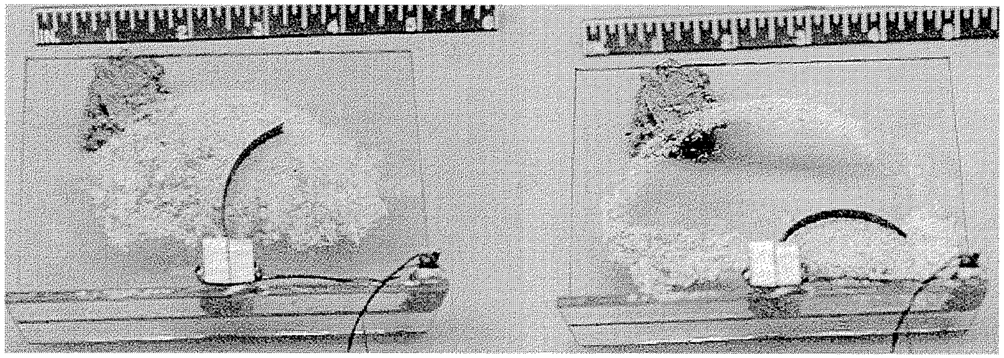
EAP Material Characterization



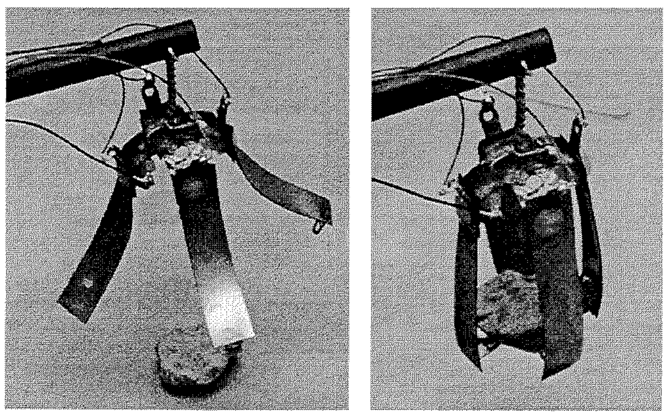
- Different methods of characterization are needed for the various types of EAP.
- Efforts are underway to develop a database that allows comparing with properties of other actuators

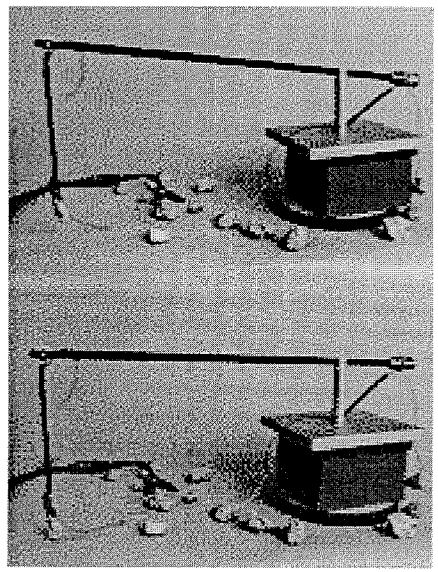
Exploration of planetary applications

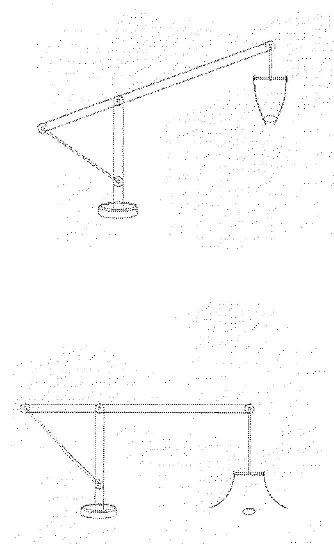
Dust wiper



Sample handling robotics

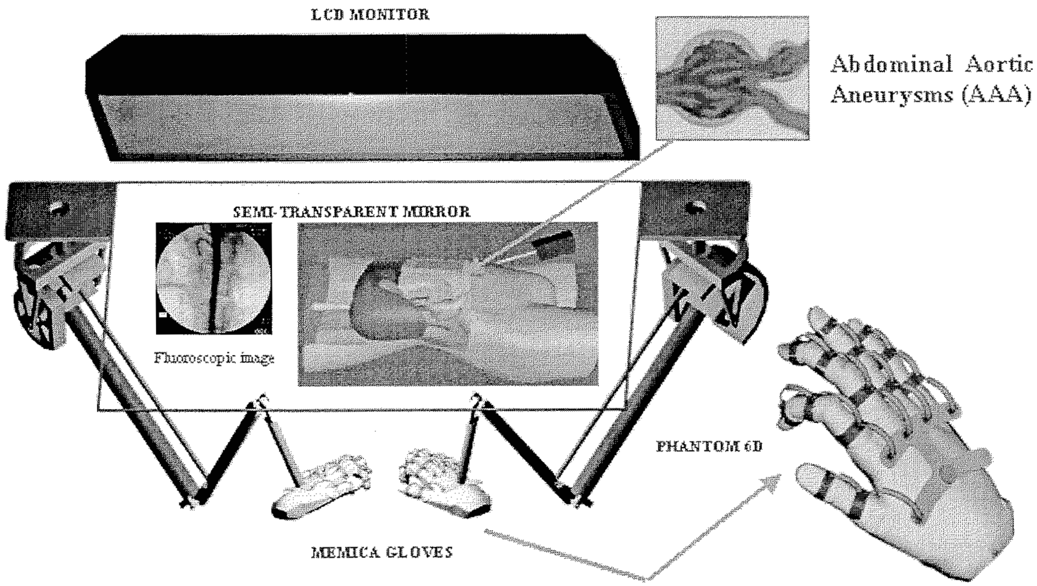


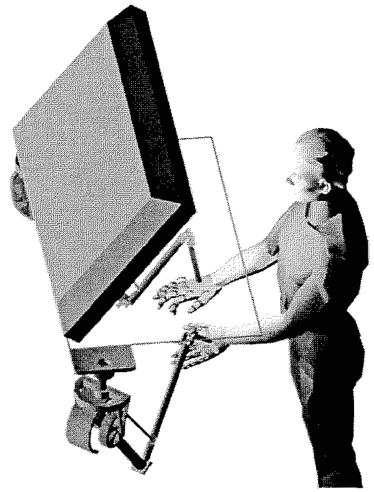


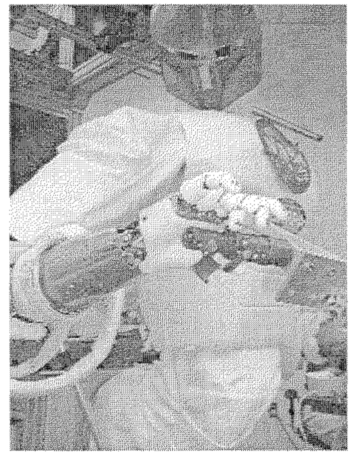


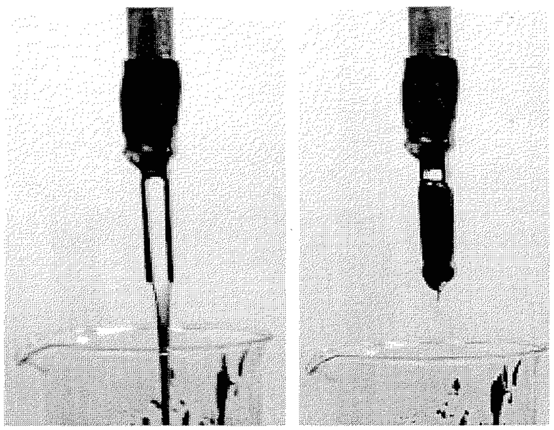
MEMICA

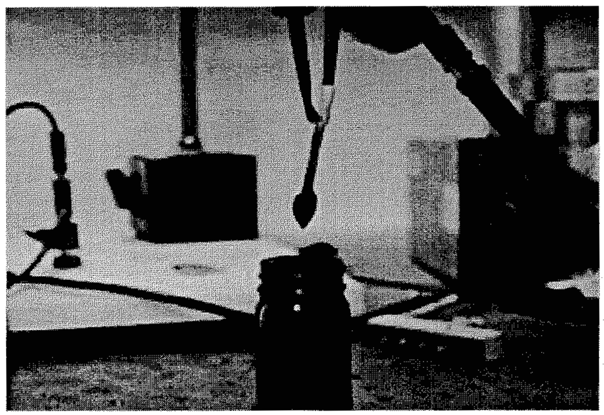
(MEchanical MIrroring using Controlled stiffness and Actuators)

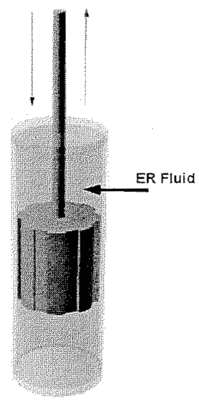


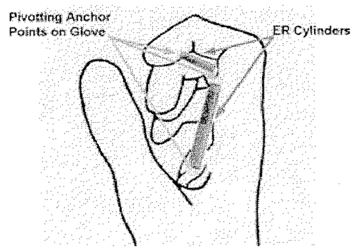












Electro-Rheological Fluid at reference (left) and activated states (right). [Smart Technology Ltd, UK]

Applications

Underway or under consideration

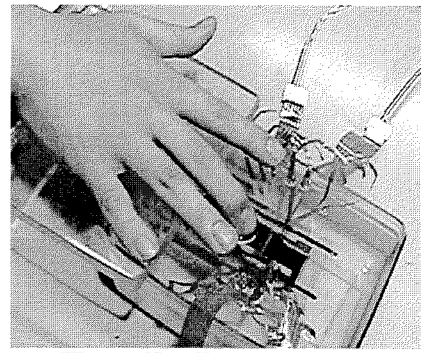
- **Mechanisms**
  - Lenses with controlled configuration
  - Mechanical Lock
  - Noise reduction
  - Flight control surfaces/Jet flow control
  - Anti G-Suit
- **Robotics, Toys and Animatronics**
  - Biologically-inspired Robots
  - Toys and Animatronics
- **Human-Machine Interfaces**
  - Haptic interfaces
  - Tactile interfaces
  - Orientation indicator
  - Smart flight/diving Suits
  - Artificial Nose
  - Braille display (for Blind Persons)
- **Planetary Applications**
  - Sensor cleaner/wiper
  - Shape control of gossamer structures
- Medical Applications
  - EAP for Biological Muscle Augmentation or Replacement
  - Miniature in-Vivo EAP Robots for Diagnostics and Microsurgery
  - Catheter Steering Mechanism
  - Tissues Growth Engineering
  - Interfacing Neuron to Electronic Devices Using EAP
  - Active Bandage
- Liquid and Gases Flow Control
- Controlled Weaving
  - Garment and Clothing
- MEMS
- EM Polymer Sensors &Transducers

Human-Machine Interfaces

- Interfacing human and machine to complement or substitute our senses would enable important medical applications.

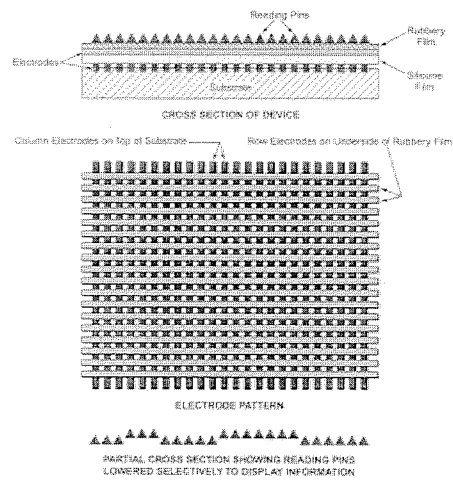
- Researchers at Duke U. connected electrodes to a brain of a money and were able to control a robotic arm. This breakthrough opens the possibility that the human brain would be able to operate prosthetics that are driven by EAP.

- Feedback is required to “feel” the environment around the artificial limbs. Currently, researchers are developing tactile sensors, haptic devices, and other interfaces.



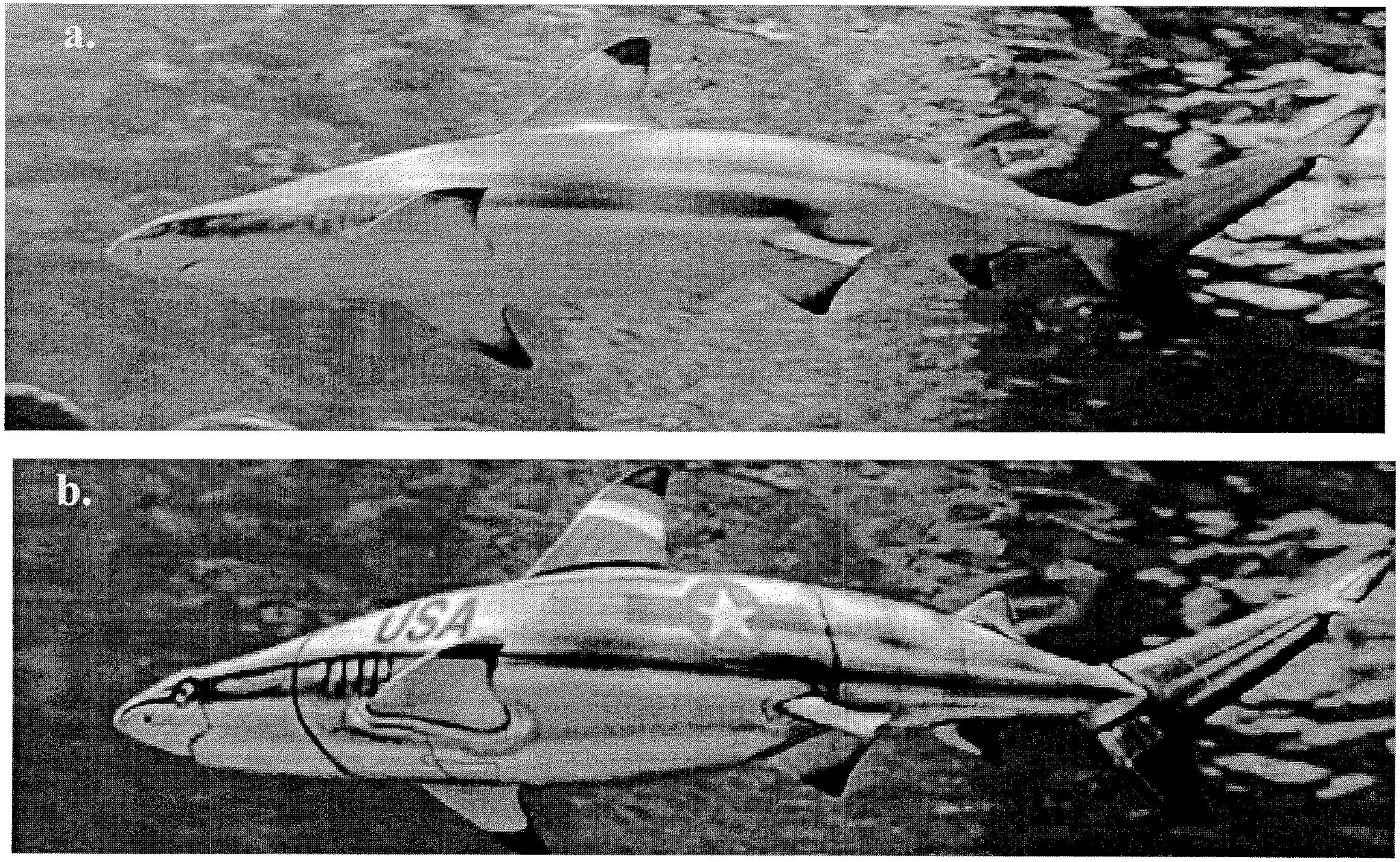
Tactile Interface

(S. Tadokoro, Kobe U., Japan)

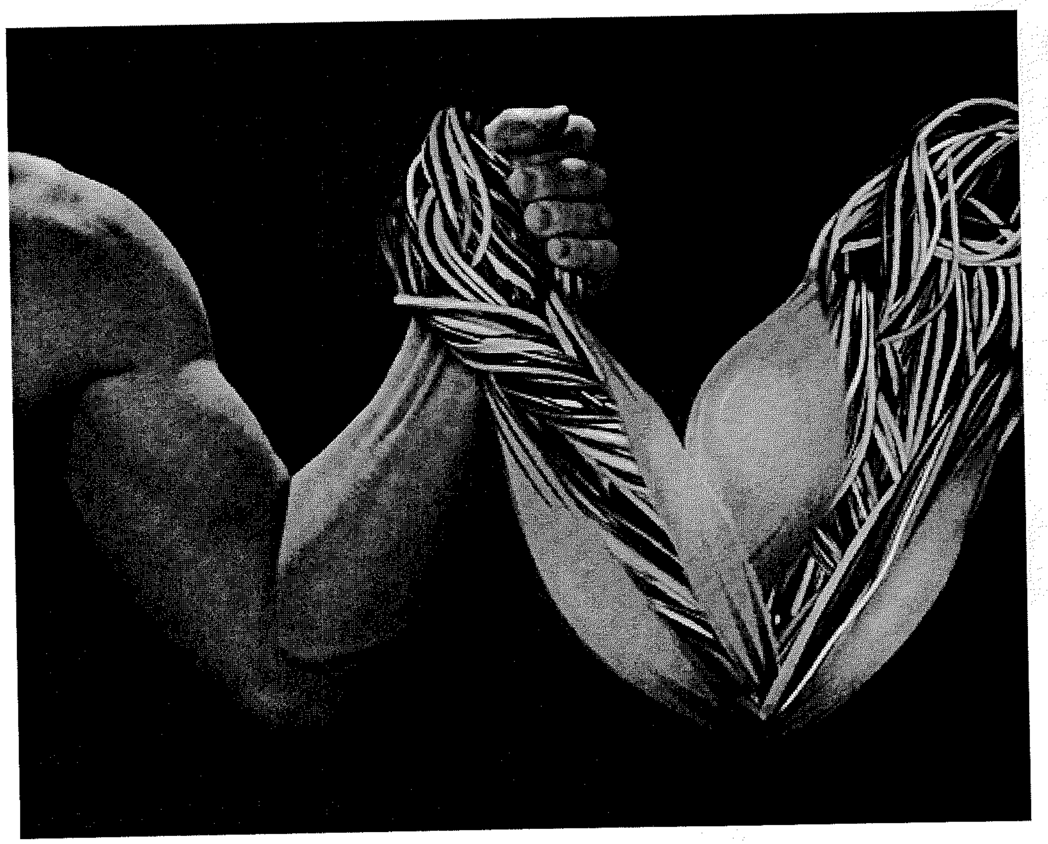


Active Braille Display

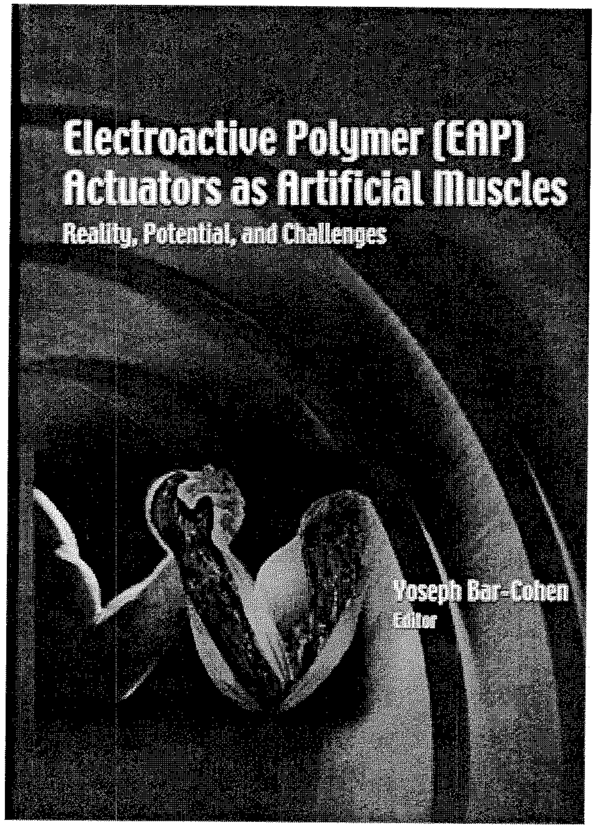
Rapid biomimetic prototyping reality

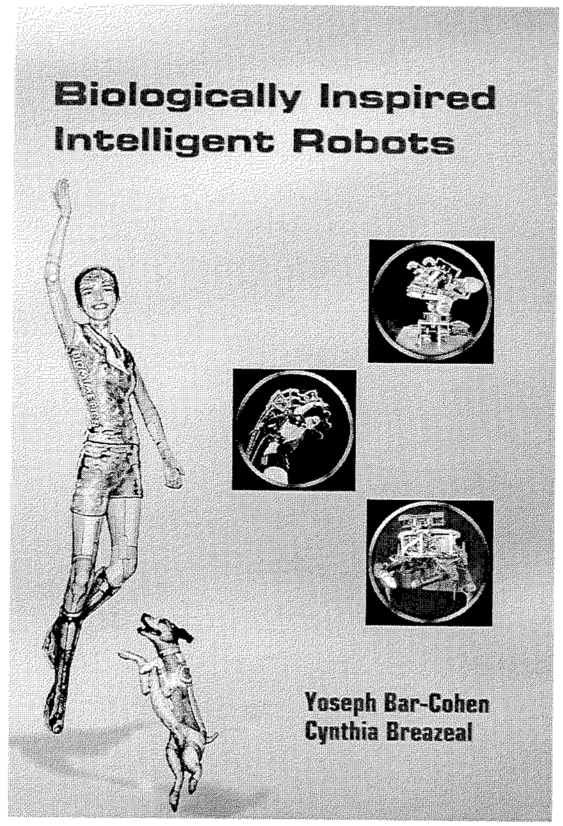


The grand challenge for EAP as Artificial Muscles



Related recent and upcoming books





http://ndeaa.jpl.nasa.gov/nasa-nde/yosi/yosi-books.htm

SUMMARY

- Artificial technologies (AI, AM, and others) for making biologically inspired devices and instruments are increasingly being commercialized.

- Materials that resemble human and animals are widely used by movie industry and animatronics have advanced to become powerful tools.

- Electroactive polymers are human made actuators that are the closest to resemble biological muscle potentially enabling unique robotic capabilities.

- Technology has advanced to the level that biologically inspired robots are taking increasing role making science fiction ideas closer to an engineering reality.