JPL

Electroactive Polymers (EAP) as Artificial Muscles

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http://ndeaa.jpl.nasa.gov/

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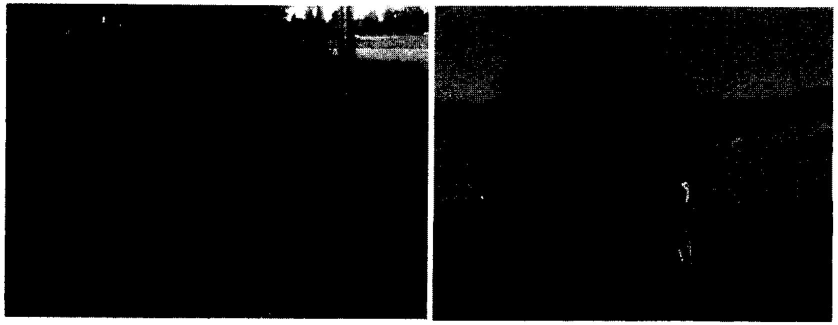
von Karman Auditorium Lecture Series

Nature as a model for robotics engineering



Tumbleweed

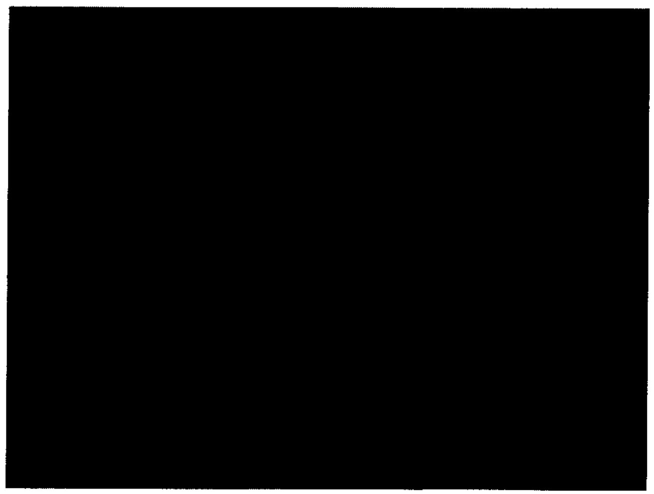
Helicopter
(Tipuana tipu)

Glider
(Alsomitra macrocarpa)

Aerodynamic dispersion of seeds

(Courtesy of Wayne's Word)

Ref: http://waynesword.palomar.edu/plfeb99.htm#helicopters



Courtesy of William M. Kier, of North Carolina

Some octopuses can change their color according to their mood

Octopus adaptive shape, texture and camouflage

Ref: http://www.pbs.org/wnet/nature/octopus/

Six Million Dollar Man

Ref.: http://web.ukonline.co.uk/craig.pierce2/six.html

- The series started in 1974, **Lee Majors** took the role of **Col. Steve Austin,** quite a switch from a cowboy in the wild west series Big Valley.

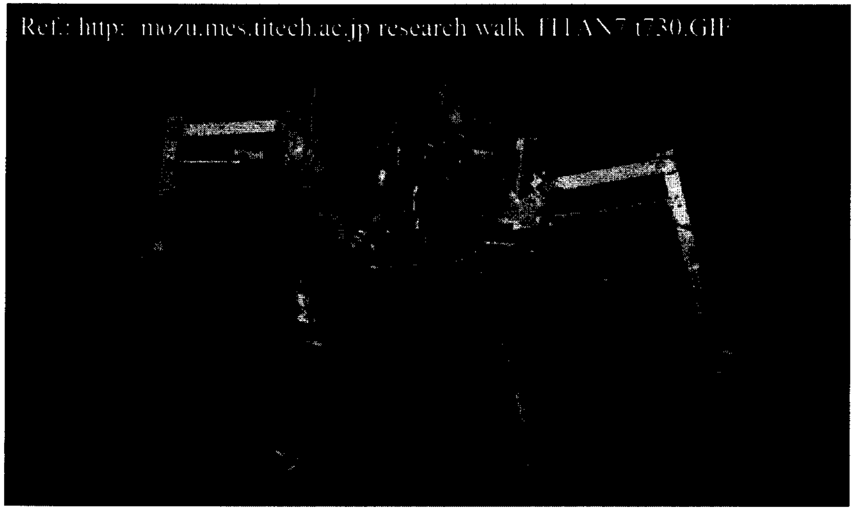
- In the early episodes Steve Austin was portrayed as a man in complete rejection of his situation, he couldn't come to terms with the fact that he had lost the sight in his **left eye,** and had his **right arm** and **both legs** amputated, in the pilot episode he tried to commit suicide, but was stopped by a nurse (Barbara Anderson), this form of Human emotion by the character of Steve Austin led to **critical acclaim** for the series.

- When Steve is told that there is a chance that he can be fitted with new limbs and shown them, he is shocked, but the Doctor explains these are very special and once fitted he would be able to hold a woman's hand and she wouldn't be able to tell that it was bionic, the skin texture, heat, hairs would all match his own original arm.

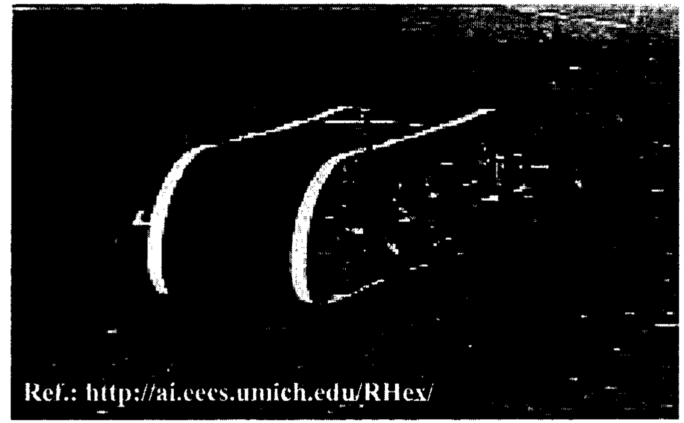
- The surgery goes ahead for many hours and after, the surgical team wait in his room for him to recover. Then success he wakes and attempts to lift his new and approved arm, which as you can see he does, and then the long re-hab road can start.

- The Six Million Dollar Man is based on the **Martin Caidin novel "The Cyborg".**

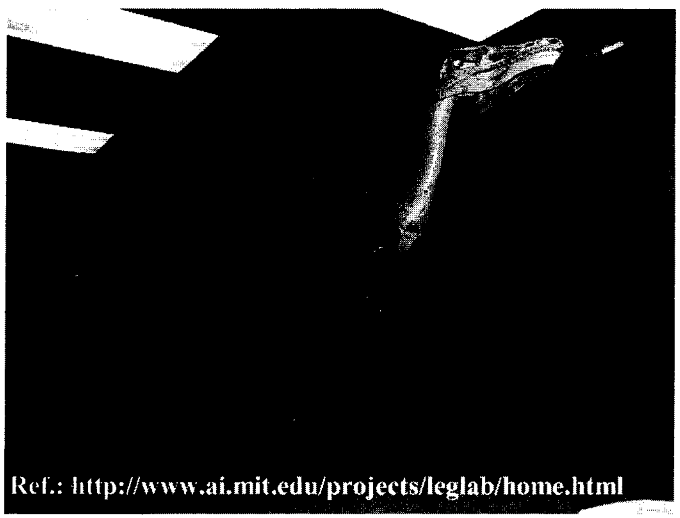
Biologically inspired robots



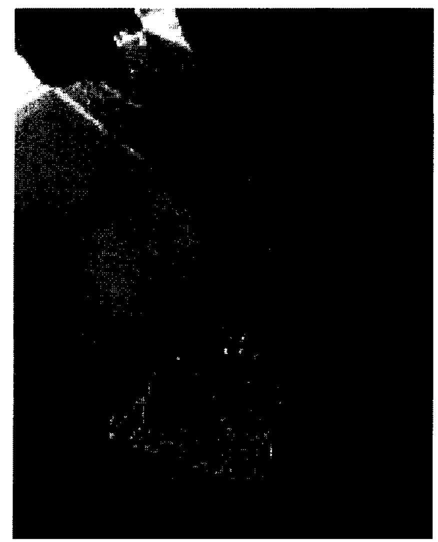
Quadruped Walking Machine to Climb Slopes at the Univ. of Nagoya, Japan



Six legged robot at the AI Lab, Univ. of Michigan



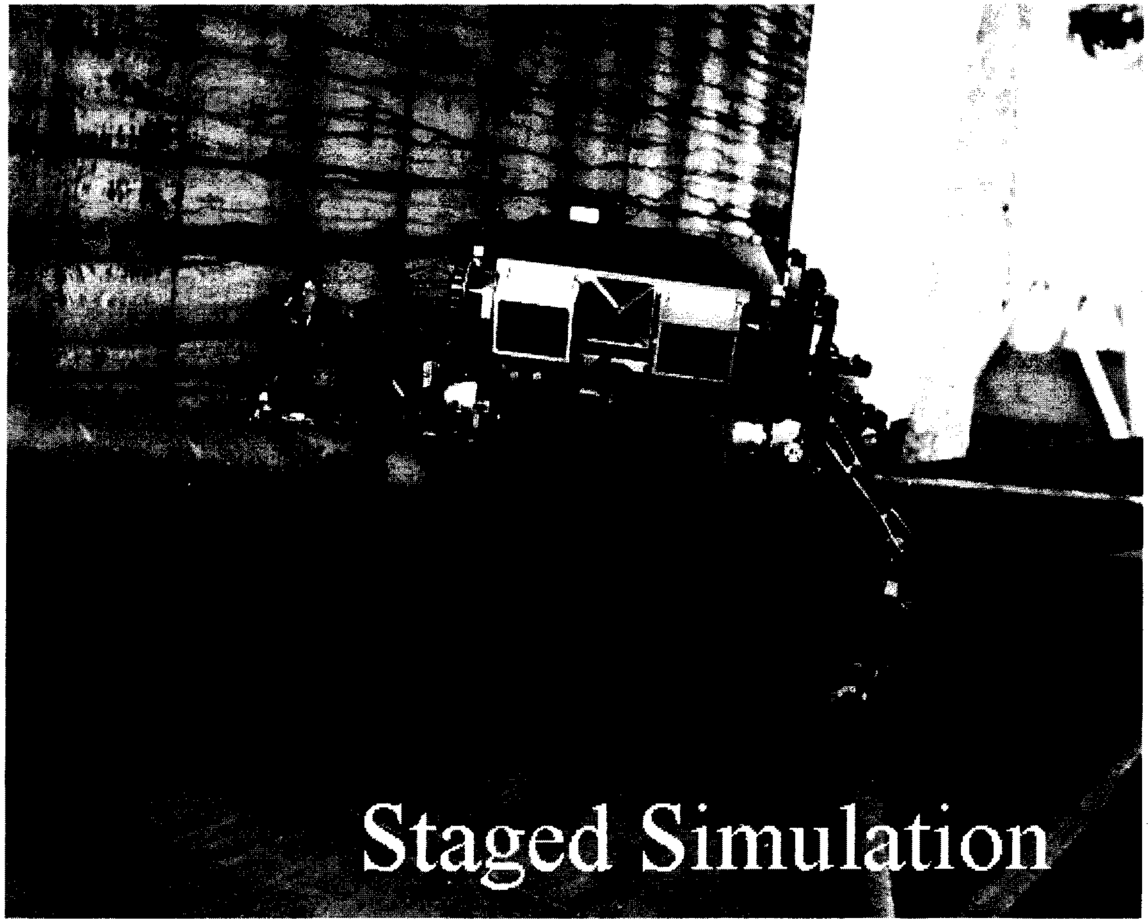
Fully Contained 3D Bipedal Walking Dinosaur Robot at MIT



Snake-like – by Mark Tilden

Ref: http://www.beam-online.com/Robots/Galleria_other/tilden.html

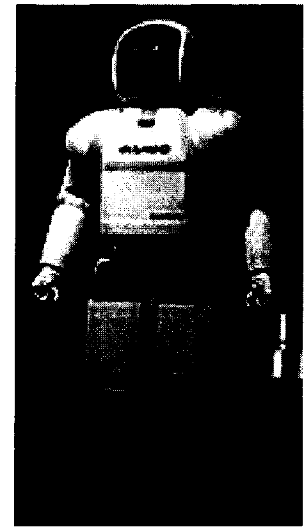
Lemur - 6-legged robots at JPL



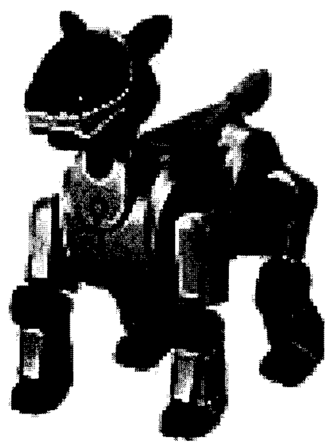
Smart Toys

Sony's SDR3

Honda's Asimo

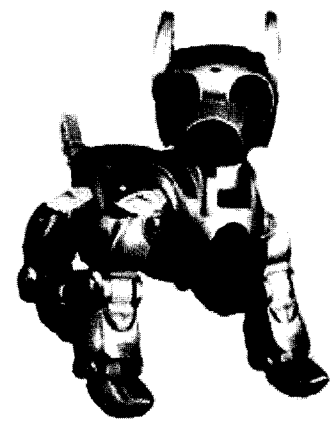


Ref.: http://www.designboom.com/eng/education/robot.html



AIBO - Sony 2nd Generation ERS-210

Ref.: http://www.us.aibo.com/ers_210/product.php?cat=aibo

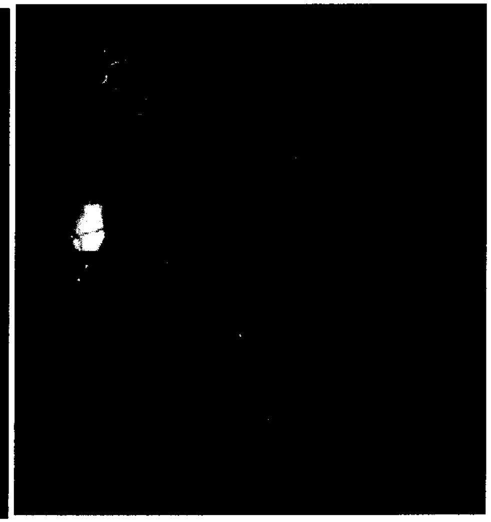


I-Cybie

Ref.: http://www.i-cybie.com

Entertainment industry

Jim Henson's Creature Shop, animatronic creature with skin

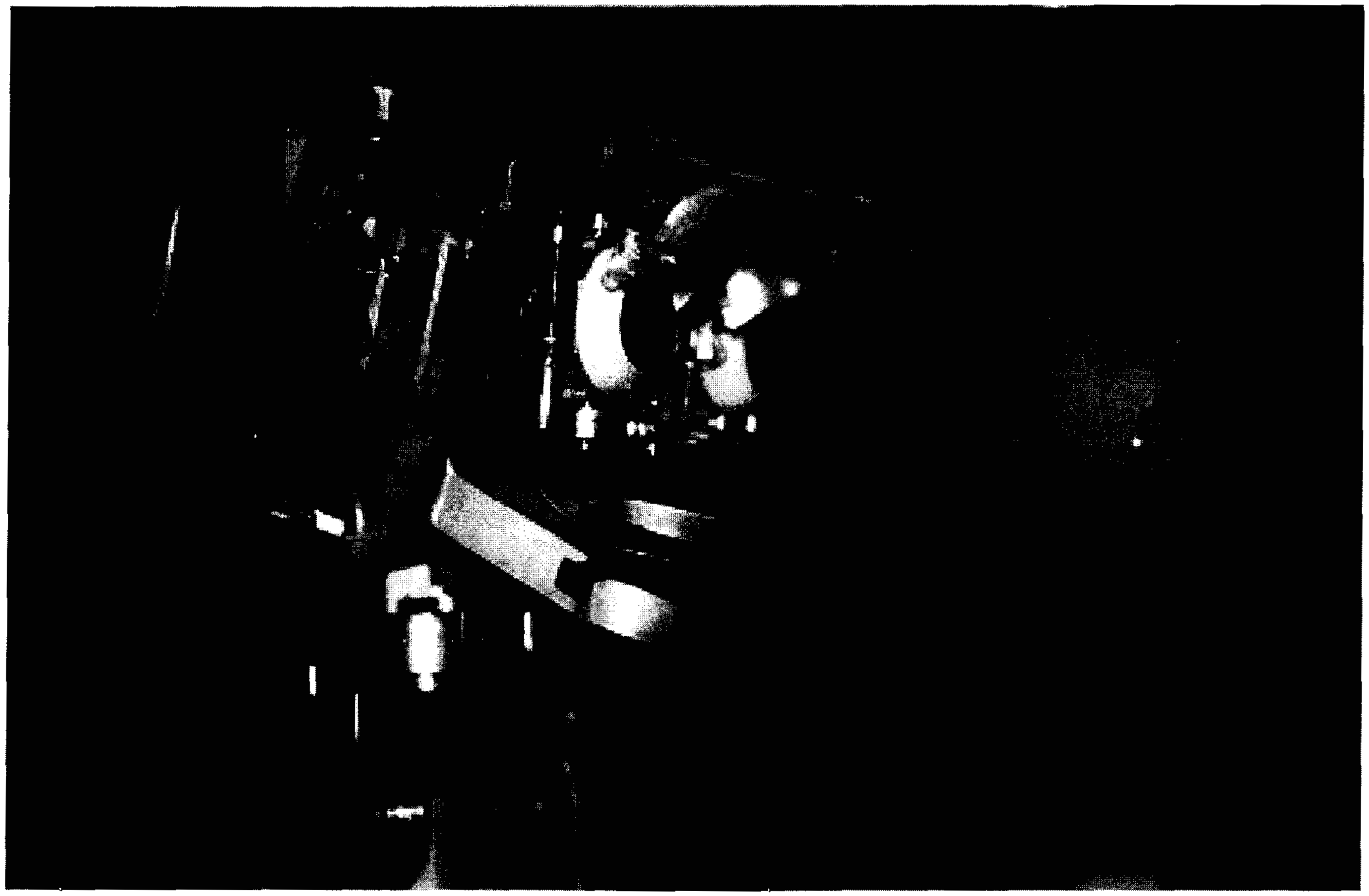


Walt Disney Imagineering "Haunted Mansion© Disney" at Disneyland

Smiling Robot of Hidetoshi Akasaw.

Robot that responds to human expressions

Cynthia Breazeal, MIT, and her robot Kismet



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 only be imagined as science fiction using current capabilities.

Historical prospective

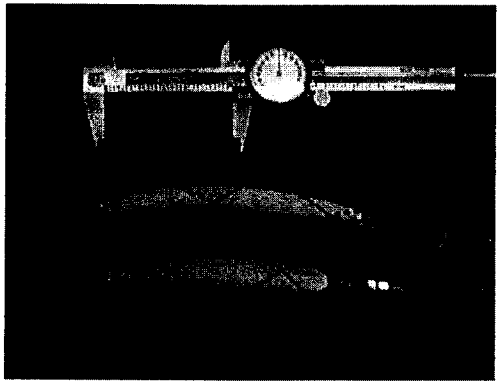
- Roentgen [1880] is credited for the first experiment with EAP electro-activating rubber-band to move a cantilever with mass attached to the free-end
- Sacerdote [1899] formulated the strain response of polymers to electric field activation
- Eguchi [1925] discovery of electrets* marks the first developed 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.

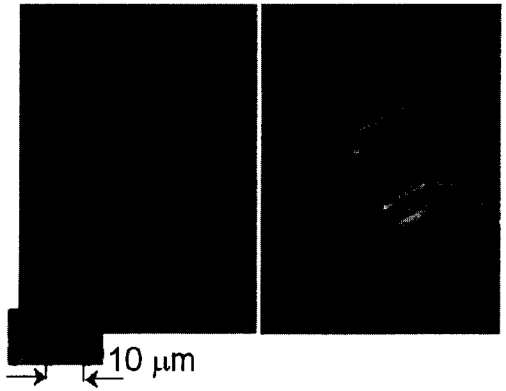
Non-Electro Active Polymers (NEAP)

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

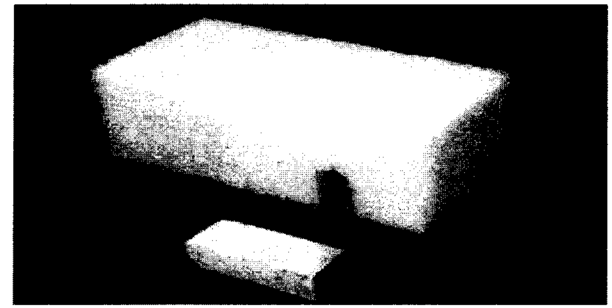
Non-Electrical Mechanically Activated Polymers



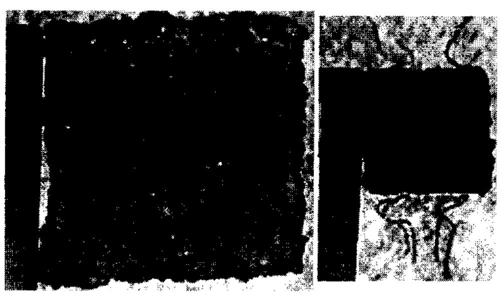
McKibben Artificial Muscles
Air Pressure activation (Hannaford, B.U. Washington)



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)

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

* <u>Note</u>: Power values are compared for documented devices driven by such actuators.

Biology - inspiration for robotics

Multiple locomotion capabilities

Flying,
walking,
swimming &
diving

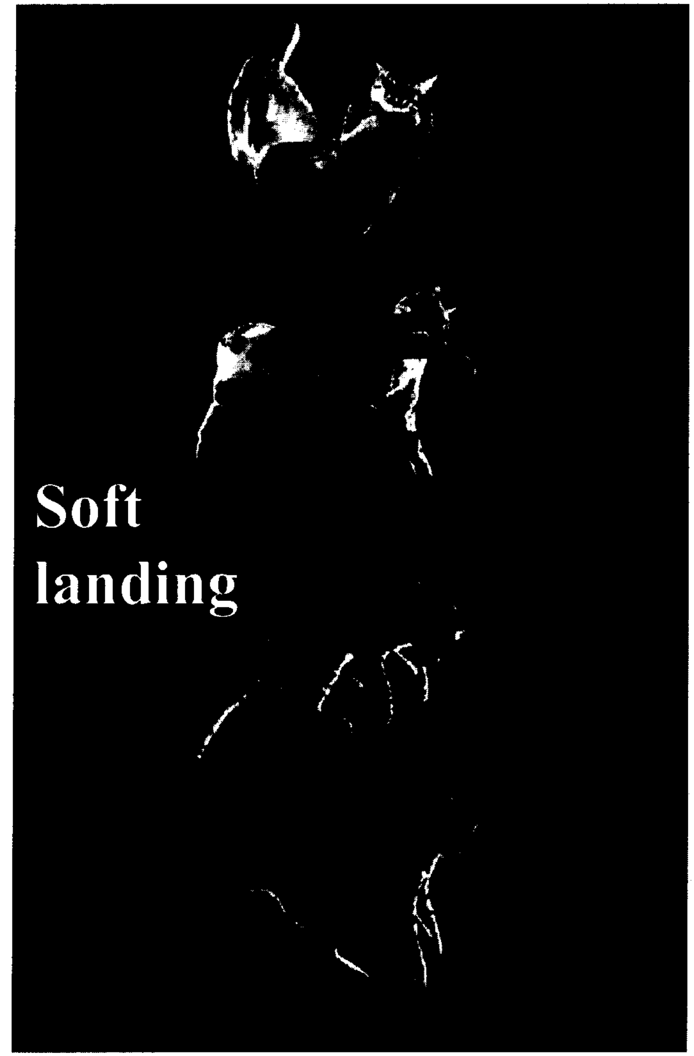
Hopping,
flying,
crawling
& digging

Coordinated robotics

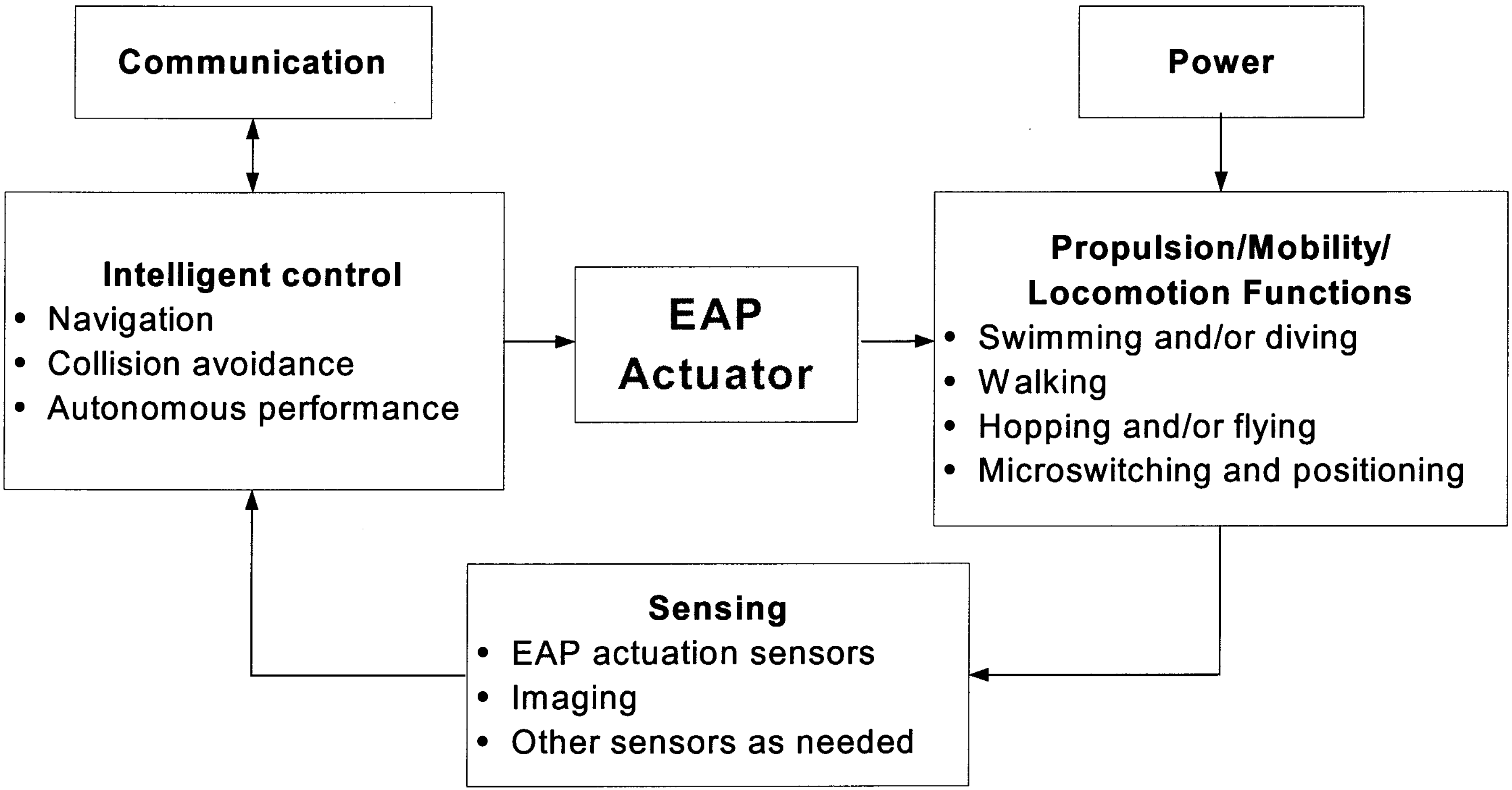
Neural networks
& expert systems

Models for EAP Actuated Flexible Robots

In-situ multi-tasking missions using scalable autonomous robots for colonized exploration



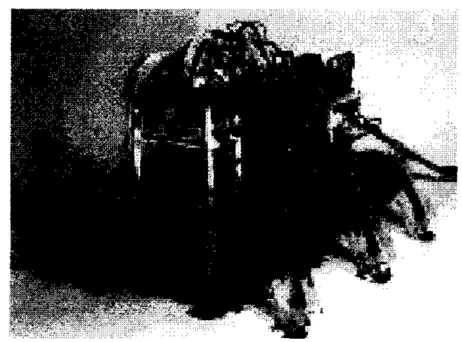
Elements of EAP actuated robots



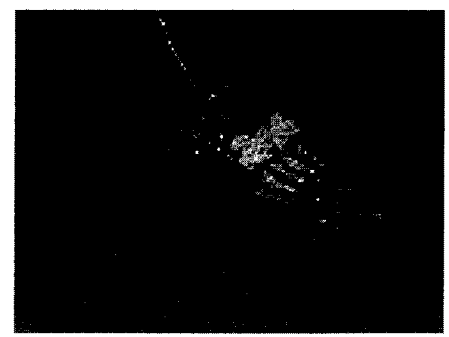
Insects as workhorses and robots

- 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



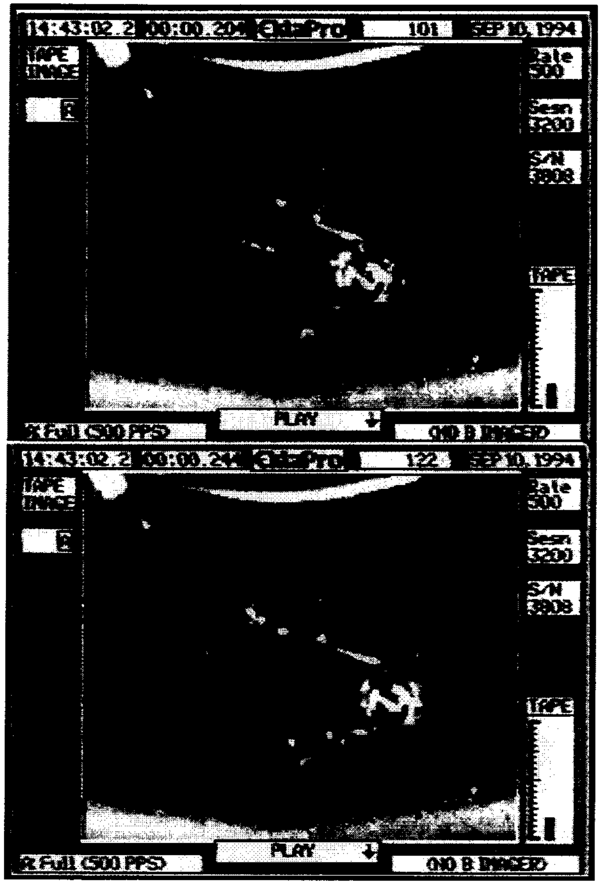
Spider



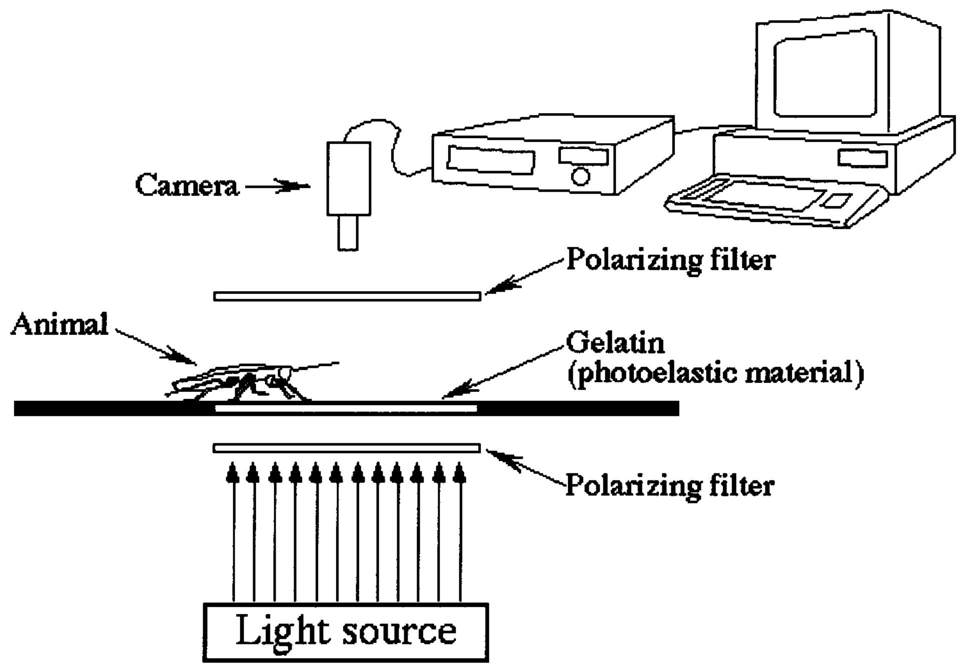
Cockroach

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

Insect walking process*

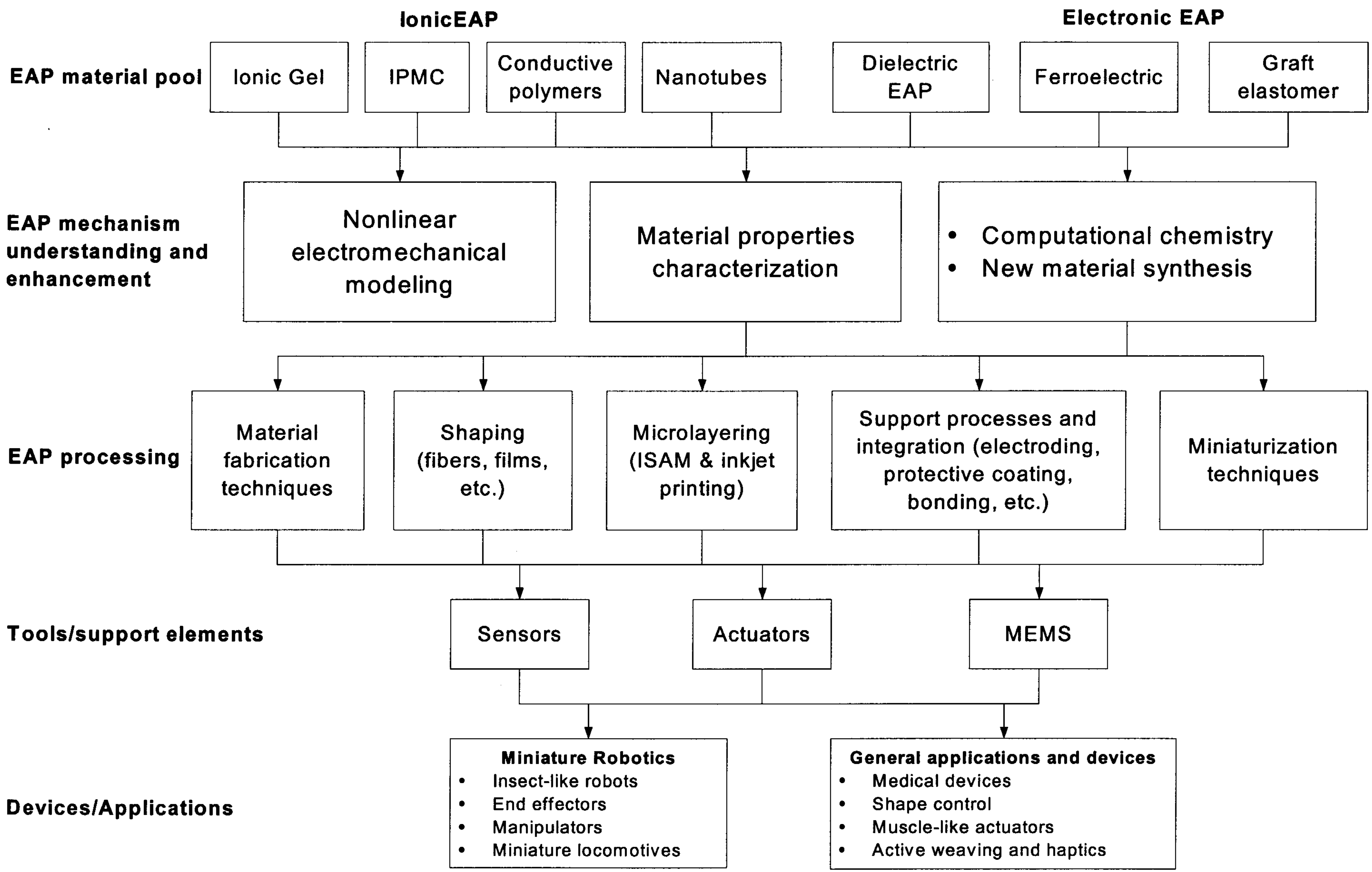


Photoelastic force platform was used at Berkeley to study insect walking mechanism.



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

EAP infrastructure



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)

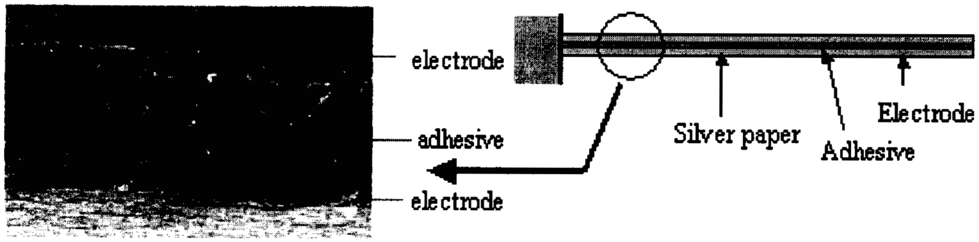
Current EAP

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 (~150 MV/m) · 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 Electrolysis at >1.23-V

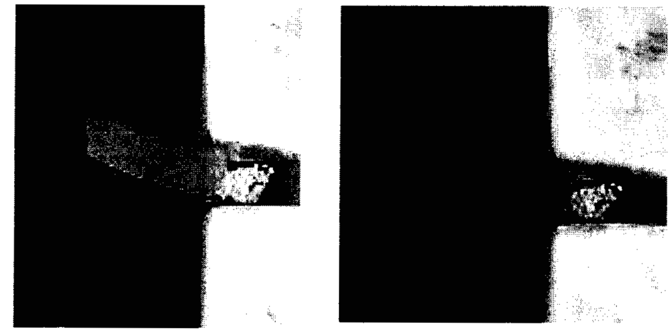
Electronic EAP

ELECTRIC FIELD OR COULOMB FORCES DRIVEN ACTUATORS



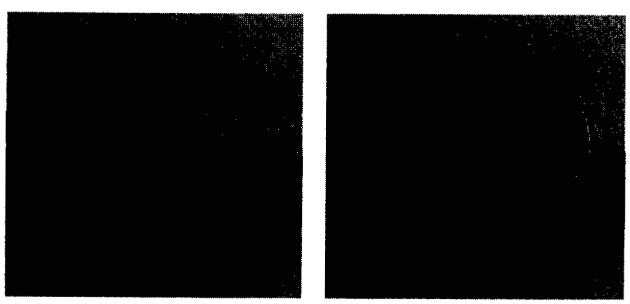
Paper EAP

[J. Kim, Inha University, Korea]



Ferroelectric

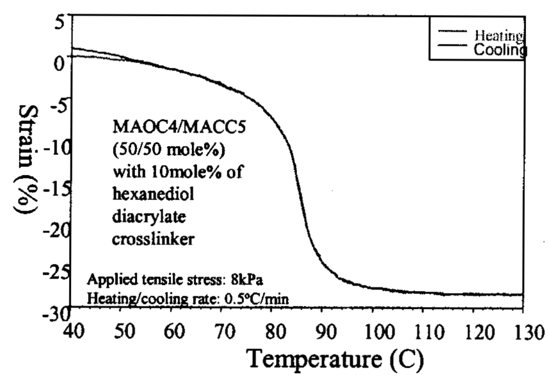
[Q. Zhang, Penn State U.]



Voltage Off **Voltage On**

Dielectric EAP

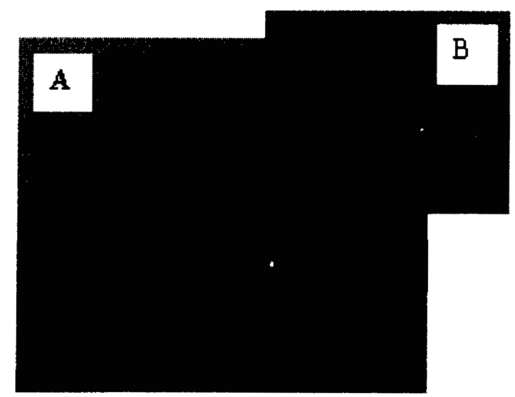
[R. Kornbluh, et al., SRI International]



Liquid crystals

(Piezoelectric and thermo-mechanic)

[B. R. Ratna, NRL]

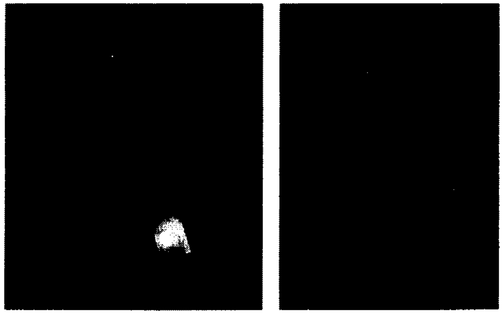


Graft Elastomer

[J. Su, NASA LaRC]

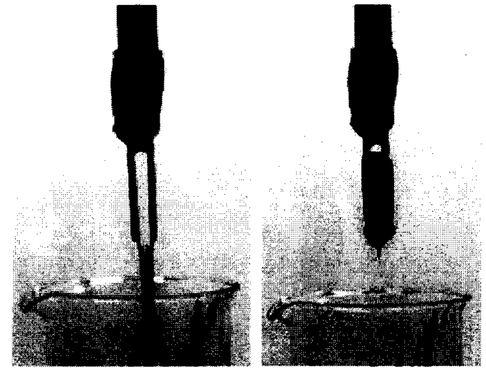
Ionic EAP

Turning chemistry to actuation



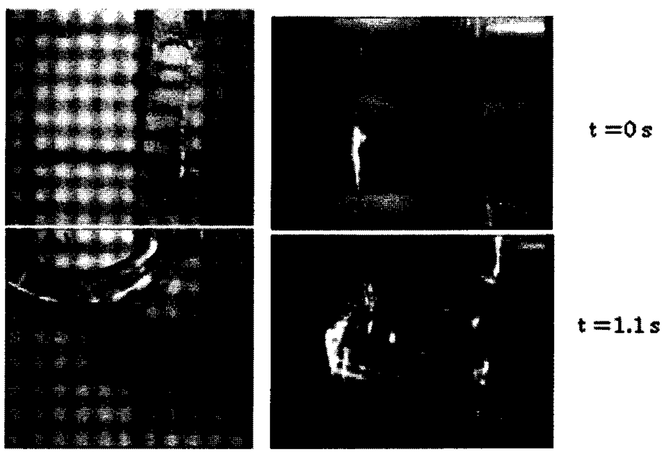
IPMC

[JPL using ONRI, Japan & UNM materials]



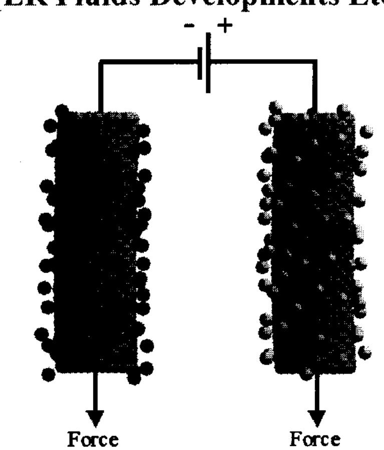
ElectroRheological Fluids (ERF)

[ER Fluids Developments Ltd]



Ionic Gel

[T. Hirai, Shinshu University, Japan]



Carbon-Nanotubes

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

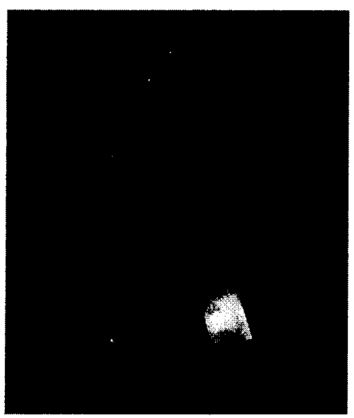
Planetary application considered at JPL

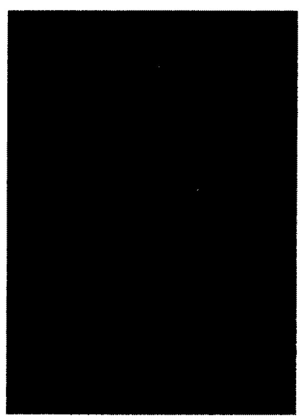
Dust wiper

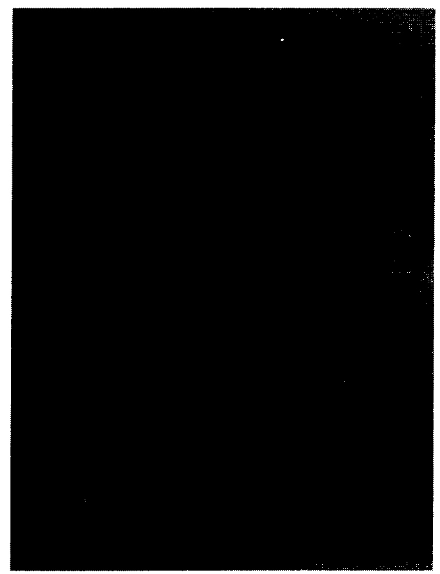
Bending EAP is used as a surface wiper

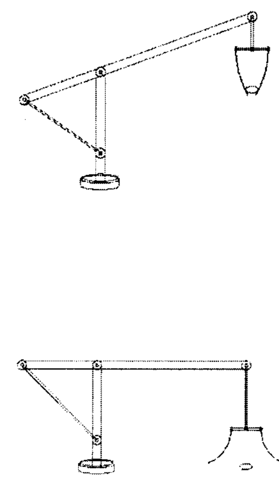
Sample handling robotics

Extending EAP lowers a robotic arm, while bending EAP fingers operate as a gripper



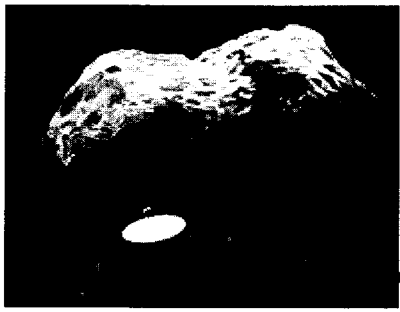




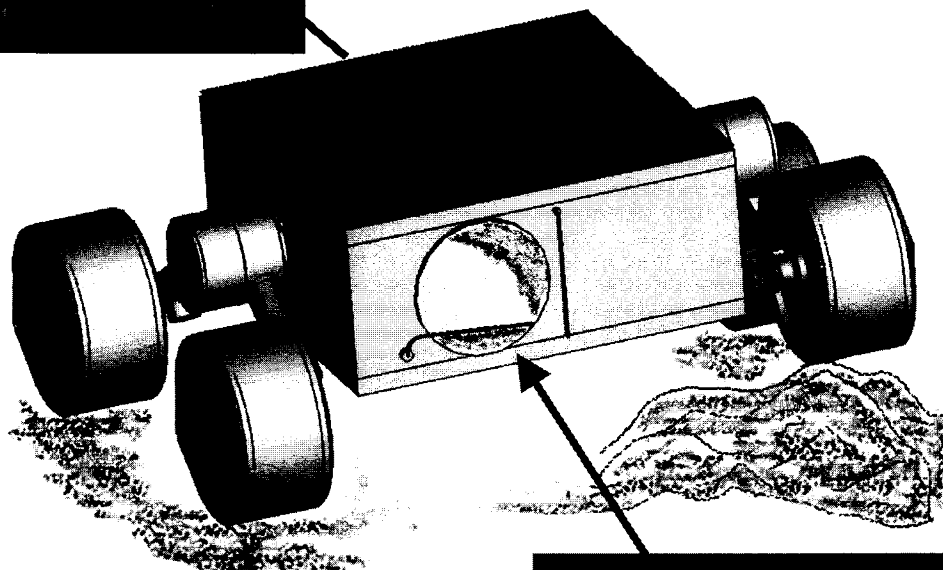


EAP Dust Wiper

Baselined in the MUSES-CN Nanorover



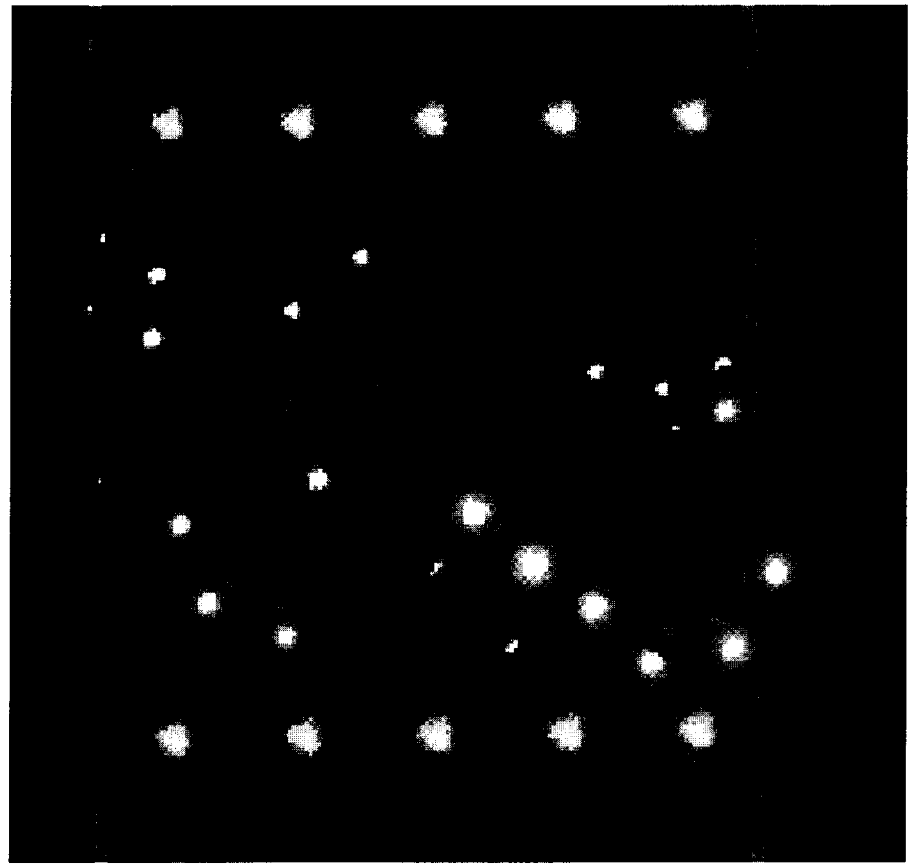
MUSES-CN mission was a joint NASA and NASDA (National Space Development Agency of Japan) mission scheduled for launch in Jan. 2002, from Kagoshima, Japan, to explore the surface of a small near-Earth asteroid. Due to budget constraints, this mission was cancelled in Nov. 2000.



- An IPMC actuated wiper was selected as a baseline for the dust removal from the visual/IR window.
- The technical challenges were beyond the technology readiness requirements

Computational chemistry

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

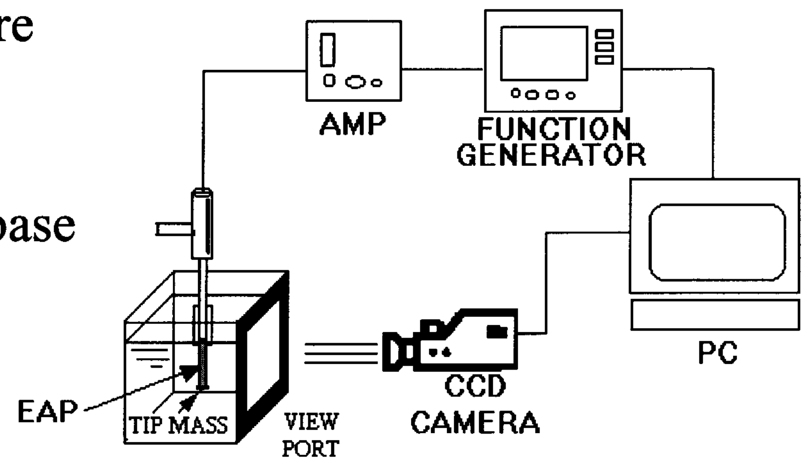


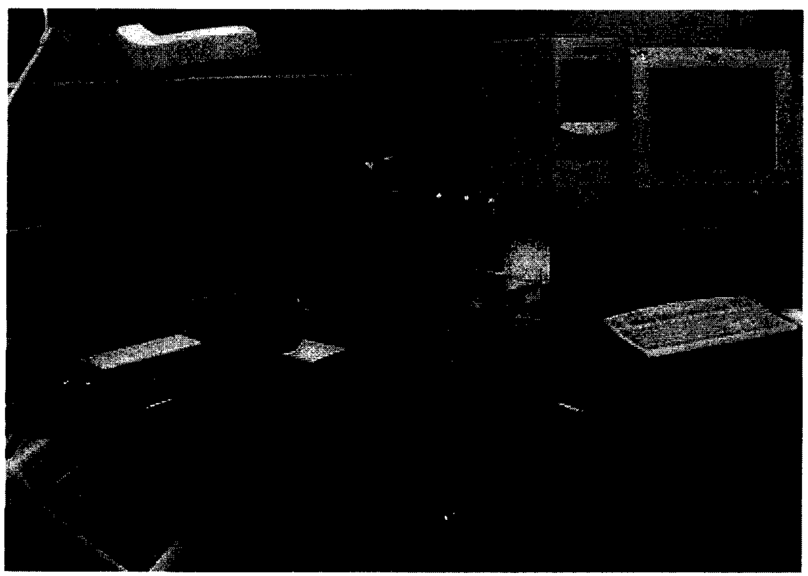
(NASA-LaRC)

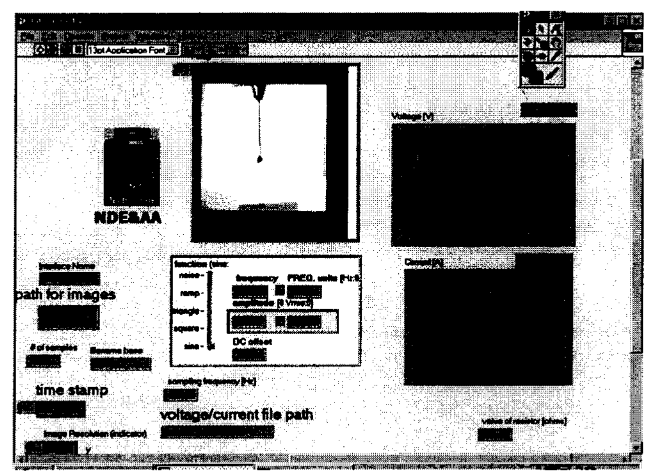
EAP Material Characterization

- Different methods of characterization are needed for the various types of EAP.

- Efforts are underway to develop a database that allows comparing the properties of EAP with other material-base actuators







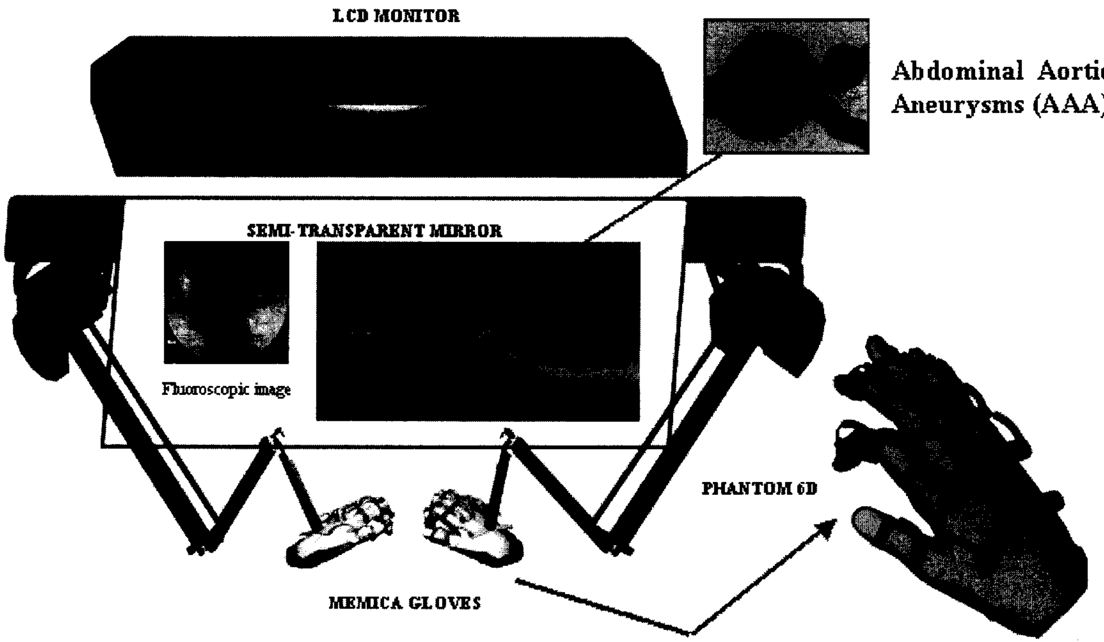
Applications

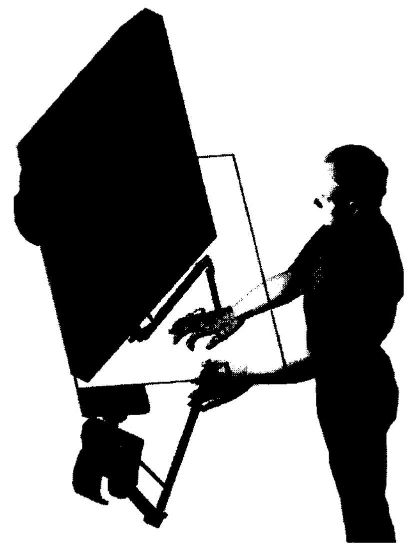
Underway or under consideration

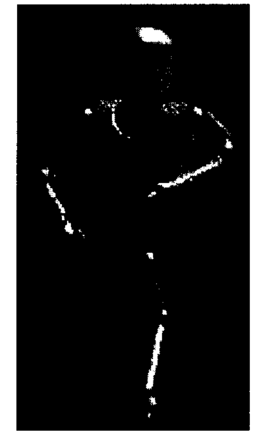
- **Mechanisms**
  - Lenses with controlled configuration
  - Mechanical lock
  - Noise reduction
  - Flight control surfaces/Jet flow control
  - Anti G-suit
- **Robotics, Toys and Animatronics**
  - Biologically-inspired robots
  - Toys and Animatronics
- **Human-Machine Interfaces**
  - Haptic interfaces
  - Tactile interfaces
  - Orientation indicator
  - Smart flight/diving suits
  - Artificial nose
  - Active Braille display
- **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**

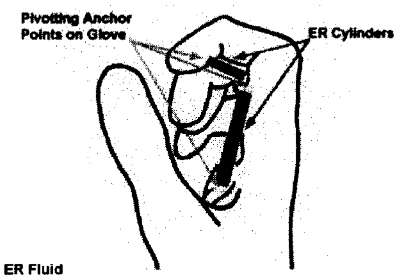
MEMICA

(MEchanical MIrroring using Controlled stiffness and Actuators)

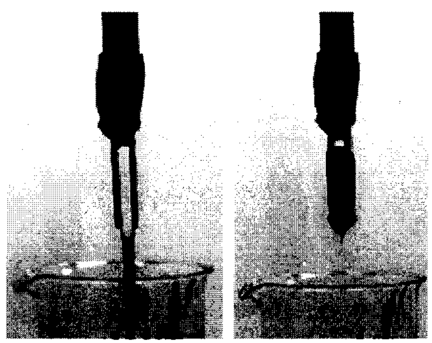


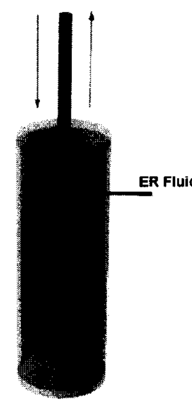




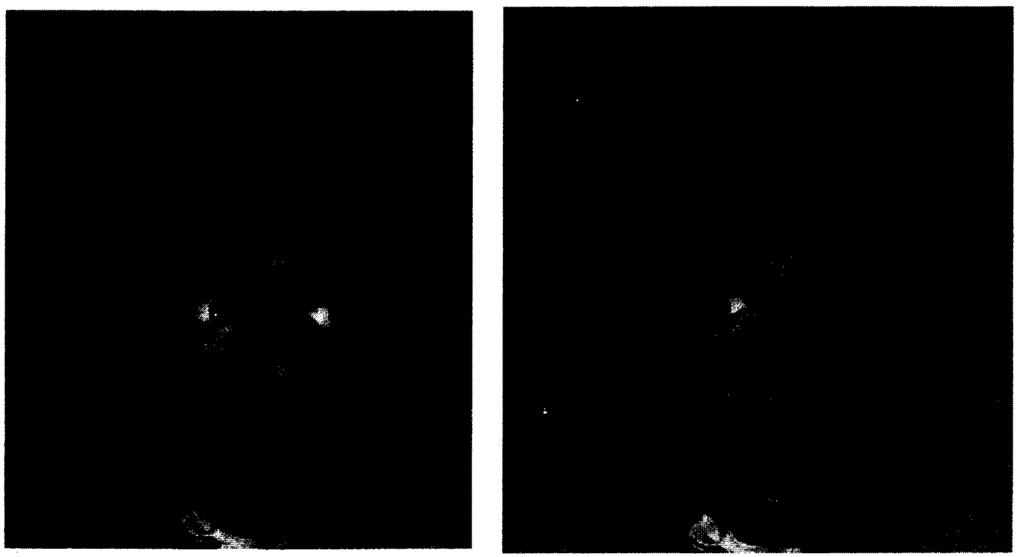


Electro-Rheological Fluid at reference (left) and activated states (right). [ER Fluid Developments Ltd, UK]



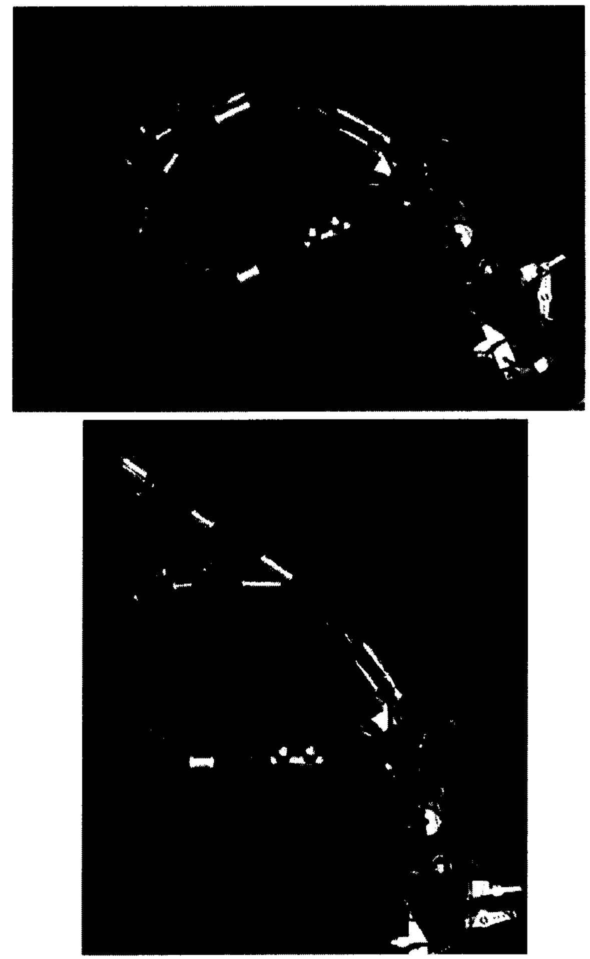


Platforms for EAP Implementation



Android making facial expressions

[G. Pioggia, et al, University of Pisa, Italy]



Robotic hand platform for EAP

[G. Whiteley, Sheffield Hallam U., UK]

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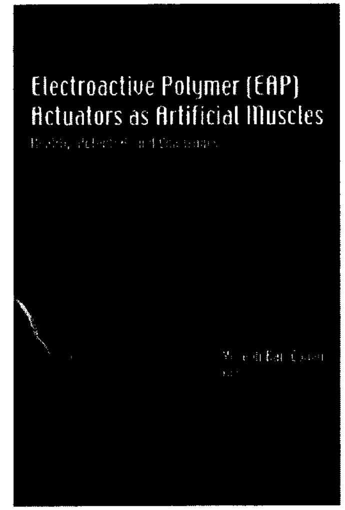

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The grand challenge for EAP as
ARTIFICIAL MUSCLES

SUMMARY

- Artificial technologies (AI, AM, and others) for making biologically inspired devices and instruments are increasingly being commercialized.
  - Autonomous robotics, wireless communication, miniature electronics, effective materials, powerful information technology are some of the critical support technologies that have have emerged and enhanced enormously in recent years.
- Materials that resemble human and animals are widely used by movie industry and animatronics and they have been advanced to become highly effective.
- 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 enables biologically inspired robotic applications.
- Science fiction ideas are increasingly becoming technology reality.