Piezoelectric Mechanisms and Device

- Ultrasonic motor (USM)
- Piezopump
- Ferrosource
- Ultrasonic/Sonic Driller/Corer (USDC)
Ultrasonic motors are driven by traveling flexure waves induced by a ring-shape sequentially-poled piezoelectric wafer(s).
Piezopump

peristaltic pump with no physically moving parts

- Piezopump is a peristaltic pump that is driven by traveling flexural elastic waves
  - Water pumping rate \( \sim 4.5\text{-cc/min} \)
  - highest-pressure of 1100 Pascal
Piezopump

Ultrasonic/Sonic Driller/Corer (USDC)

Backign
Stack
Horn
Powder cuttings
Rock
Drill bit

Ultrasonic Actuator (Backign/Stack/Horn)

Free-Mass

Extracted powder cuttings

2000 R&D 100 award
USDC Based UGopher

PI: Dr. Yoseph Bar-Cohen

http://indeaa.jpl.nasa.gov
Ultrasonic/Sonic Drill and Corer (USDC)

USDC is a drill that uses low axial force and does not require bit sharpening.

Smart-USDC: A drill with integrated probing and sensing capability.

Ultrasonic rock abrasion tool

Two Ultrasonic Gophers for deep drilling
Biologically inspired technologies

- Electroactive polymers (EAP)
- Artificial muscles driven robotics
- Biomimetic devices
- MEMICA
- On-demand operated exoskeleton
Nature as a model for robotics engineering

Helicopter
(Tipuana tipu)

Glider
(Alsomitra macrocarpa)

Aerodynamic dispersion of seeds
(Courtesy of Wayne's Word)
Ref: http://waynesword.palomar.edu/plfeb99.htm#helicopters

Tumbleweed

Octopus adaptive shape, texture and camouflage
(Courtesy of William M. Kier, of North Carolina)
Ref: http://www.pbs.org/wnet/nature/octopus/

(Courtesy of Roger T. Hanlon, Director, Marine Resources Center, Marine Biological Laboratory, Woods Hole, MA)
Smart Toys

Sony’s SDR3


Honda’s Asimo

AIBO - Sony 2nd Generation ERS-210


I-Cybie

Ref.: http://www.i-cybie.com
## COMPARISON BETWEEN EAP AND WIDELY USED TRANSDUCING ACTUATORS

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

*Note: Power values are compared for documented devices driven by such actuators.*
Biology as inspiration for robotics

Multiple locomotion capabilities

Flying, walking, swimming & diving

Hopping, flying, crawling & digging

Coordinated robotics

Models for EAP Actuated Flexible Robots

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

Neural networks & expert systems

Soft landing
Elements of EAP actuated robots

Communication

Intelligent control
- Navigation
- Collision avoidance
- Autonomous performance

EAP Actuator

Power

Propulsion/Mobility/Locomotion Functions
- Swimming and/or diving
- Walking
- Hopping and/or flying
- Microswitching and positioning

Sensing
- EAP actuation sensors
- Imaging
- Other sensors as needed
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”.

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

EAP material pool
- Ionic Gel
- IPMC
- Conductive polymers
- Nanotubes
- Dielectric EAP
- Ferroelectric
- Graft elastomer

EAP mechanism understanding and enhancement
- Nonlinear electromechanical modeling
- Material properties characterization
- Computational chemistry
- New material synthesis

EAP processing
- Material fabrication techniques
- Shaping (fibers, films, etc.)
- Microlayering (ISAM & inkjet printing)
- Support processes and integration (electroding, protective coating, bonding, etc.)
- Miniaturization techniques

Tools/support elements
- Sensors
- Actuators
- MEMS

Devices/Applications
- Miniature Robotics
  - Insect-like robots
  - End effectors
  - Manipulators
  - Miniature locomotives
- General applications and devices
  - Medical devices
  - Shape control
  - Muscle-like actuators
  - Active weaving and haptics
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]

Ionic Gel
[T. Hirai, Shinshu University, Japan]

ElectroRheological Fluids (ERF)
[ER Fluids Developments Ltd]

Carbon-Nanotubes
[R. Baughman et al, Honeywell, et al]
## Current EAP
### Advantages and disadvantages

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

**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
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**
Electro-Rheological Fluid at reference (left) and activated states (right).
[ER Fluid Developments Ltd, UK]
MEMICA-based exoskeleton for countermeasure of astronauts bones and muscles loss in microgravity. It has potential application as:

- Assist patient rehabilitation
- Enhance human mobility
Platforms for EAP Implementation

Android making facial expressions
[Sculptured by D. Hanson, U. of Texas, Dallas, and instrumented by G. Pioggia, et al, University of Pisa, Italy]

Robotic hand platform for EAP
[G. Whiteley, Sheffield Hallam U., UK]
Robot that responds to human expressions
Cynthia Breazeal, MIT, and her robot Kismet
Related recent and upcoming books

- **Electroactive Polymer (EAP) Actuators as Artificial Muscles**
  - Reality, Potential, and Challenges
  - Editors: Yoseph Bar-Cohen
  - Publisher: SPIE Press

- **Biologically-Inspired Intelligent Robots**
  - Editors: Yoseph Bar-Cohen, Cynthia Breazeal
  - Publisher: SPIE Press

Transducing materials play an important role in our daily life being responsible for the functionality of many instruments and devices that are commonly used. New materials are emerging, such as polymer actuators and devices (EAPAD) (ss03).
Summary

- Time dependent elastic motion can be harnessed for diagnostics and actuation capabilities that enable many novel technologies.
- The JPL's NDEAA team exploited these potential capabilities to support planetary sampling, robotics, NDE, medical, haptic interfaces, etc.
- Finite element modeling tools and experimental capabilities were developed to support this effort.
- The actuators and devices that were developed include:
  - USM that can operate in vacuum and cryogenic temperatures
  - Piezopump that operates peristaltically with no physically moving parts
  - Ultrasonic drill for rock sampling using very low axial load with no lubricants and the bit does not require sharpening.
  - Conceived a haptic interface system that enables virtual operations, telepresence and on-demand exoskeleton.
  - Electroactive polymers as actuators that are compact, low mass, and low power. These EAP actuators are considered for gossamer structures, wiper of sensors, biologically inspired mechanisms, etc.
The grand challenge for EAP as ARTIFICIAL MUSCLES