Future sensors - planetary prospective

Yoseph Bar-Cohen, JPL/Caltech, Pasadena, CA
818-354-2610, yosi@jpl.nasa.gov
http://ndeaa.jpl.nasa.gov/

National Workshop on Future Sensing Systems

Lake Tahoe, California, August 26-28, 2002.

NDEAA Technologies

- **Advanced Actuators**
  - Ultrasonic/Sonic Driller/Corer (USDC) for planetary exploration
  - Ultrasonic motors (USM), Surface Acoustic Wave (SAW) motors and Piezopump
  - Artificial muscles using electroactive polymers
- **NDE**
  - Materials properties and flaws characterization using leaky Lamb waves (LLW) and polar backscattering
  - In-process and in-service monitoring
- **Ultrasonic Medical Diagnostics and Treatment**
  - High power ultrasound (FMPUL): blood clot lysing, spine trauma and cancer treatment
  - Acoustic Microscopy Endoscope (200MHz)
- **Applications: Radiation sources, Robotics, etc.**
  - Ferrosource for multiple radiation types
  - Noninvasive geophysical probing system (NGPS)
  - Multifunction Automated Crawling System (MACS)
  - Adjustable gossamer and membrane structures
  - MEchanical MIrroring using Controlled stiffness and Actuators (MEMICA) as Haptic interfaces

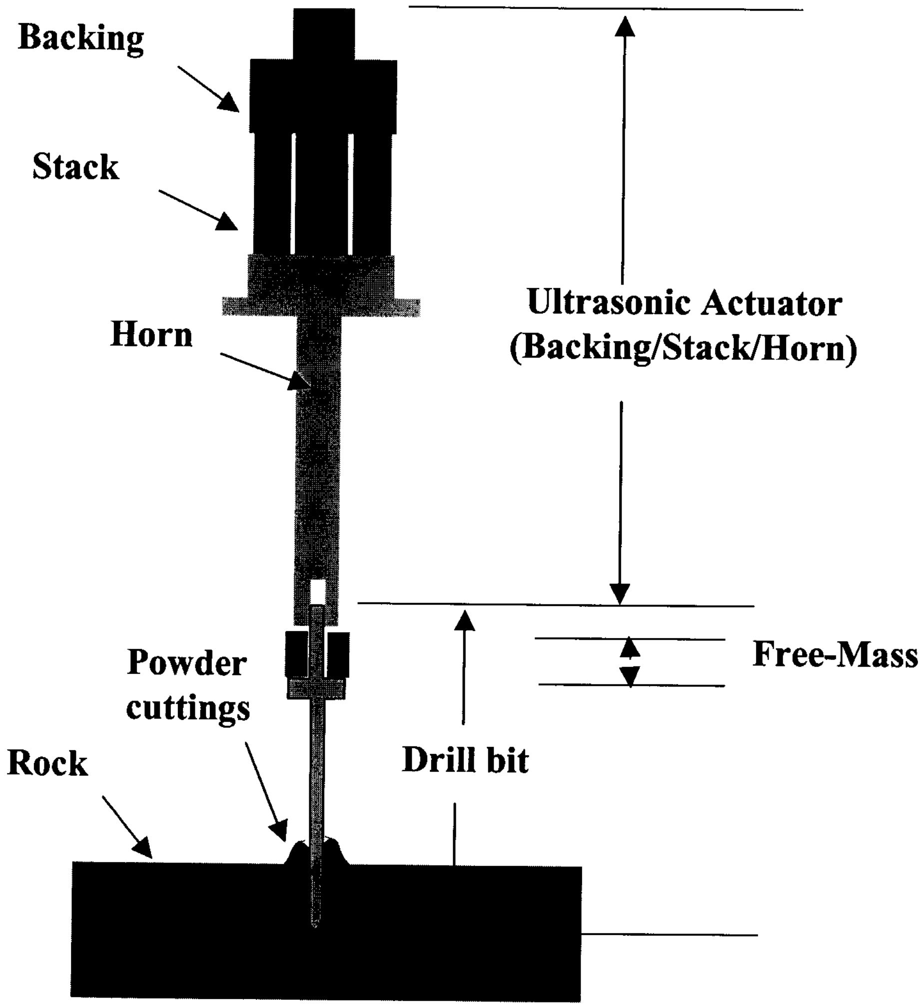
Areas with special sensor needs

- Ultrasonic drill (high temp, sensing, probing, gopher)
- Biomimetics
- EAP
- Gossamer and adjustable shape membranes
- Aerospace structures

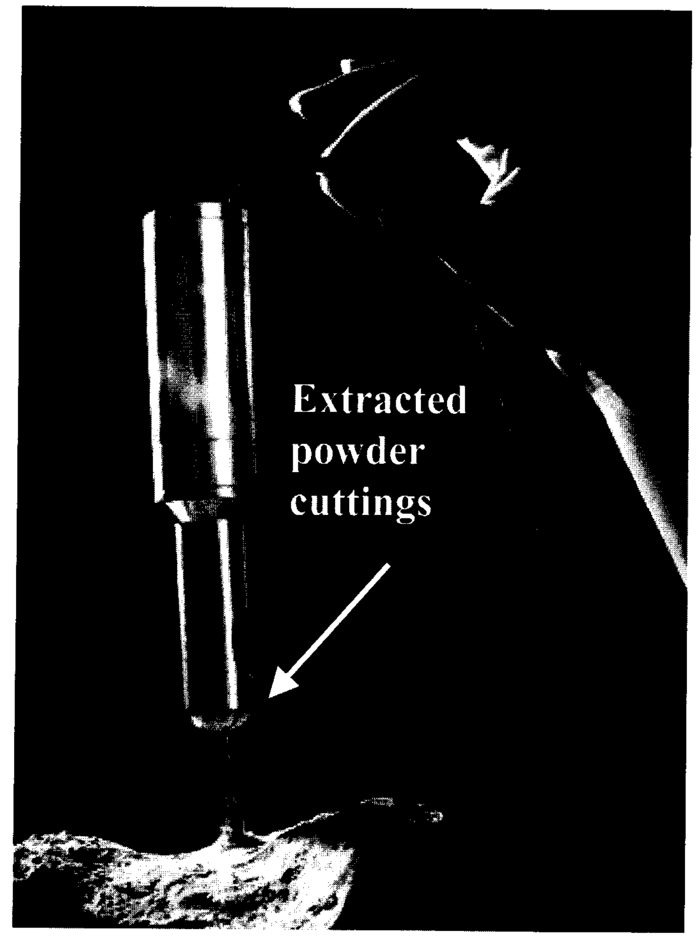
Categories of required sensors

- Imbedded sensors – Fiberoptic, piezoelectric
- Coated - Bruising paint indicator, brittle coating
- Attached sensors - cracking fuse, resistance gauging, strain gage, ultrasonic, eddy current, fiber optics
- Adjacent/inductive - eddy current, ultrasonic, magnetic, visual, etc.
- Remote sensors – Visual, sonic, infrared

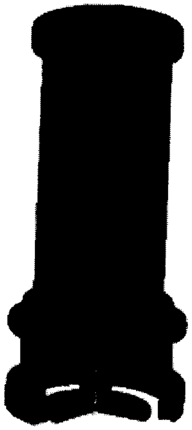
Ultrasonic/Sonic Driller/Corer (USDC)

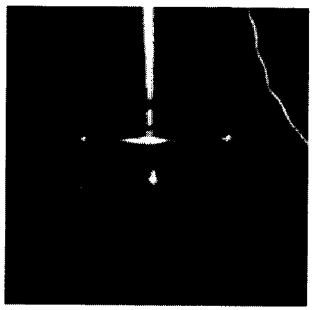


2000 R&D 100 award

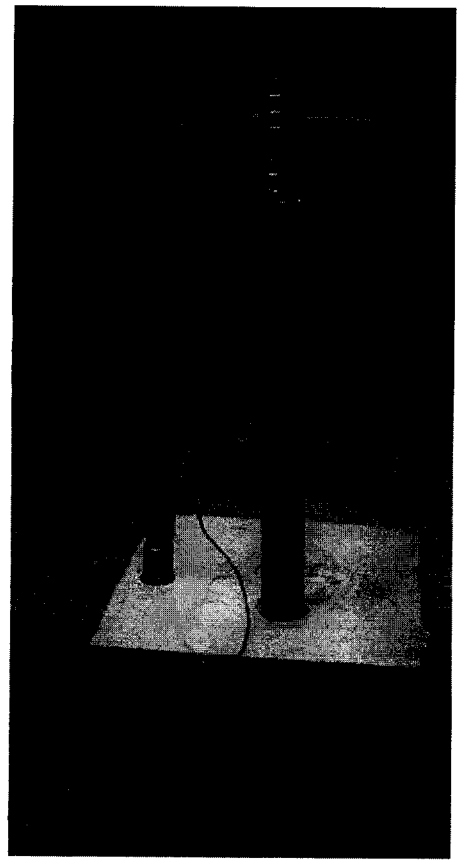


Ultrasonic/Sonic Drill and Corer (USDC)



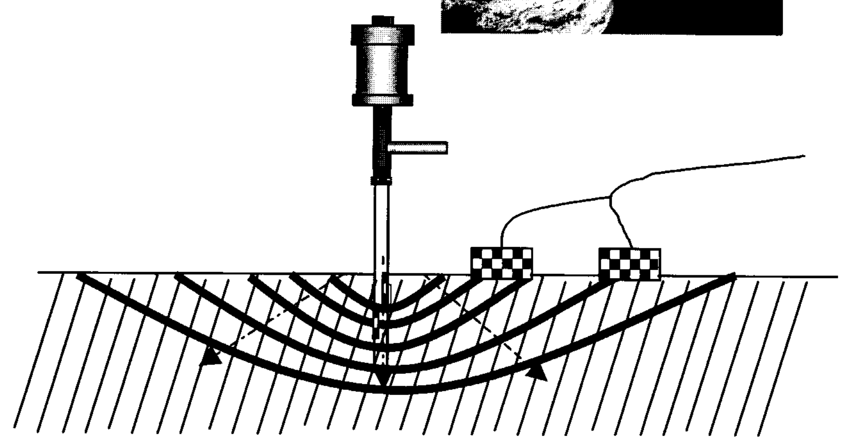


Ultrasonic rock abrasion tool



Ultrasonic Gophers for deep drilling

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

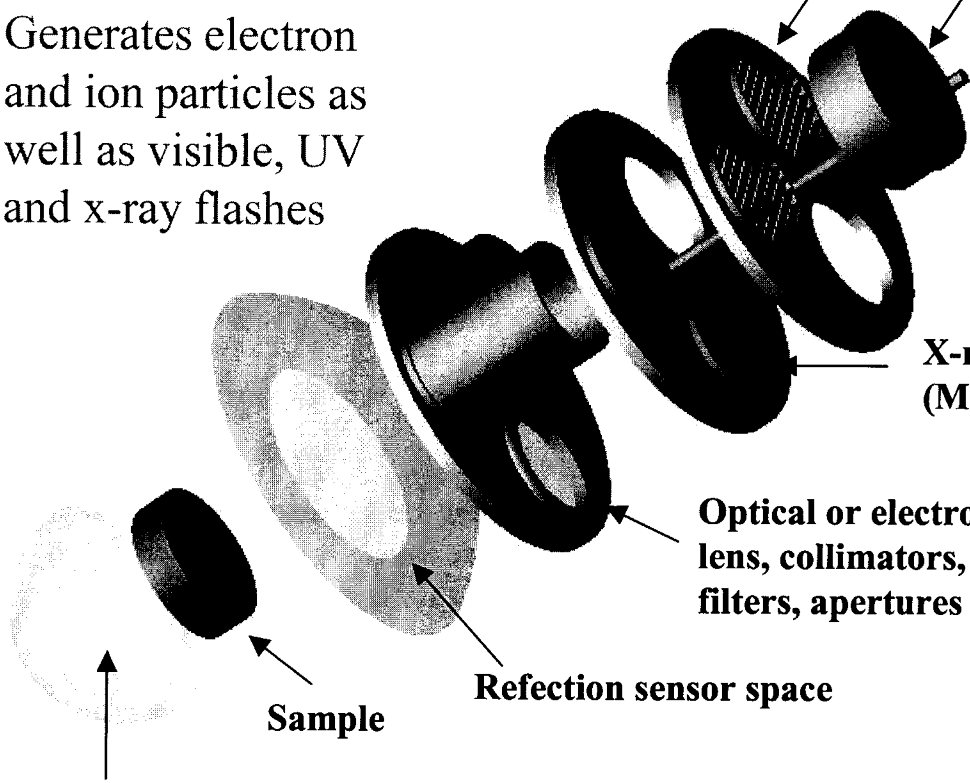
Sensor requirements

The objective of the current research is to develop a USDC that operates as probe, sampler and sensor platform. The characteristics of the required sensors are

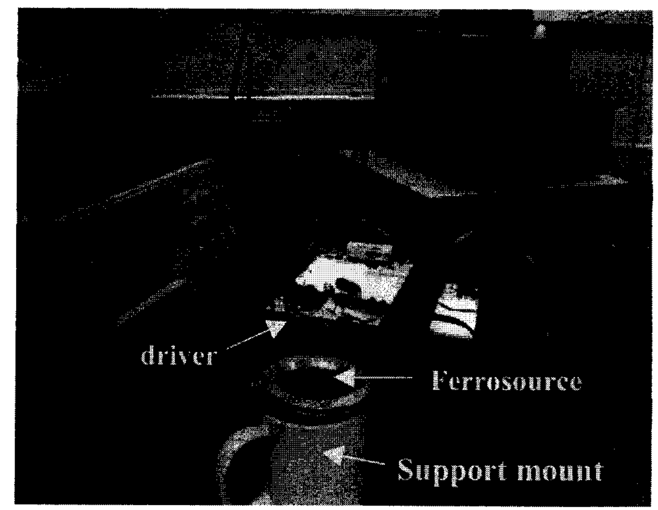
- Small cross-section and low mass
- Require minimal power
- Operational at high (Venus: 460°C) and Low (Titan ~ - 200°C) Temperature
- Durable to harsh environment and cyclic impacts
- Detect life, biological markers and water
- Support analysis of mineralogy, crystallography and/or geological

Ferrosource and fixtures for emission of multiple radiation types

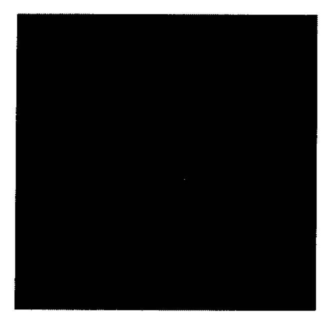
Generates electron and ion particles as well as visible, UV and x-ray flashes

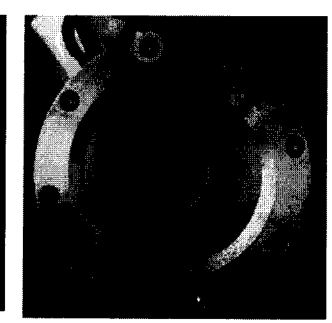


Require: miniature, multi-functional sensors

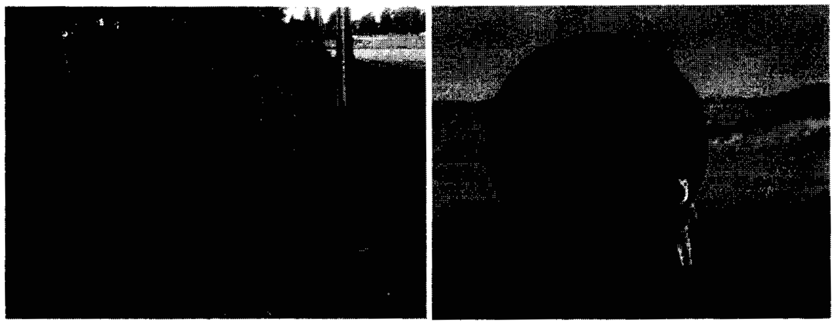


Ferrosource





Nature as a model for robotics engineering



Tumbleweed

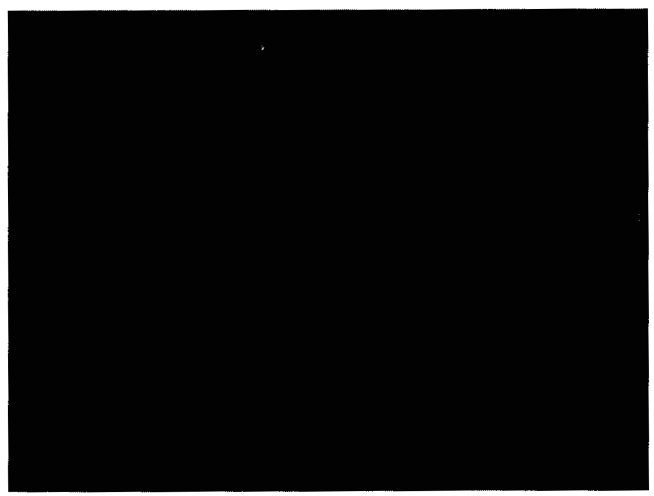
Helicopter
(Tipuana tipu)

Glider
(Alsomitra macrocarpa)

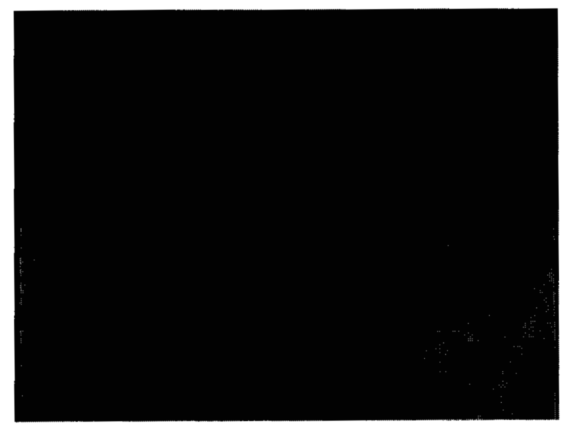
Aerodynamic dispersion of seeds

(Courtesy of Wayne's Word)

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



Courtesy of William M. Kier, of North Carolina



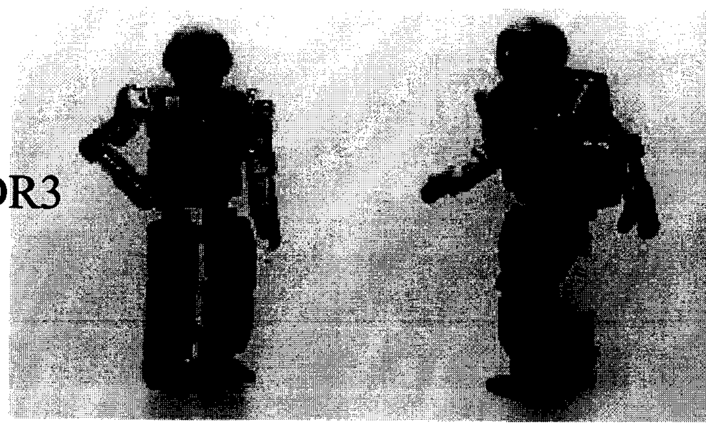
Courtesy of Roger T. Hanlon, Director, Marine Resources Center, Marine Biological Laboratory, Woods Hole, MA

Octopus adaptive shape, texture and camouflage

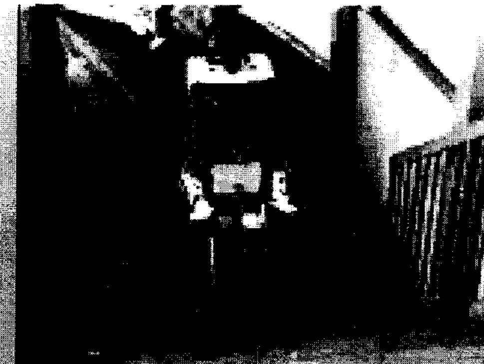
Ref: http://www.pbs.org/wnet/nature/octopus/

Smart Toys

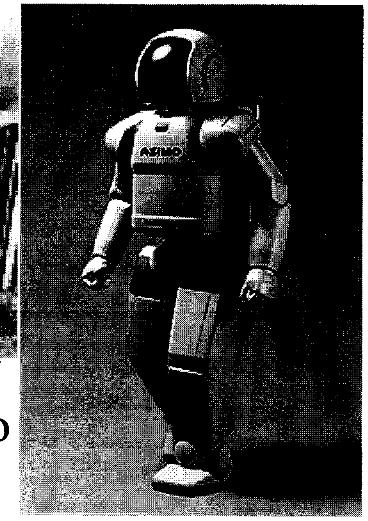
Sony's SDR3



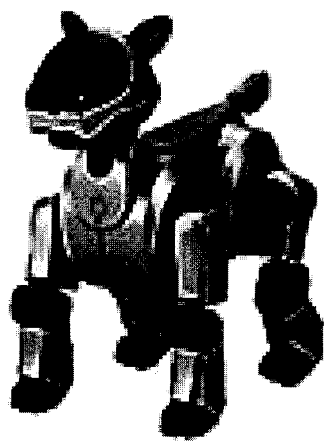
Ref.: http://www.designboom.com/eng/education/robot.html



Ref: http://world.honda.com/robot/movies/

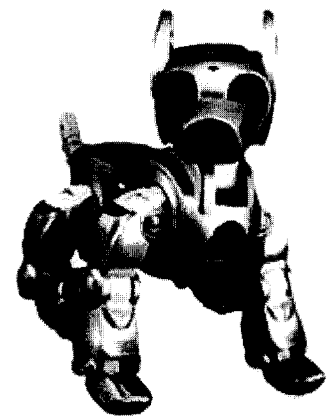


Honda's Asimo



AIBO - Sony 2nd Generation ERS-210

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

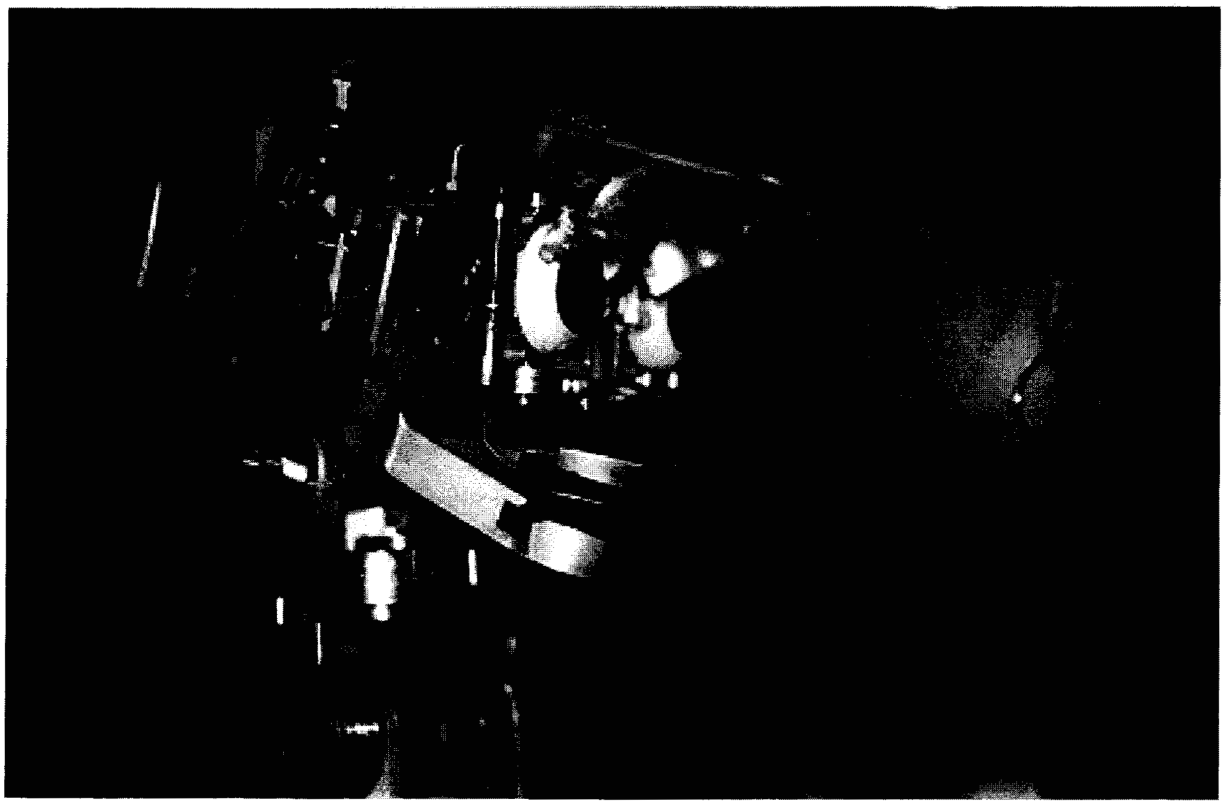


I-Cybie

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

Robot that responds to human expressions

Cynthia Breazeal, MIT, and her robot Kismet



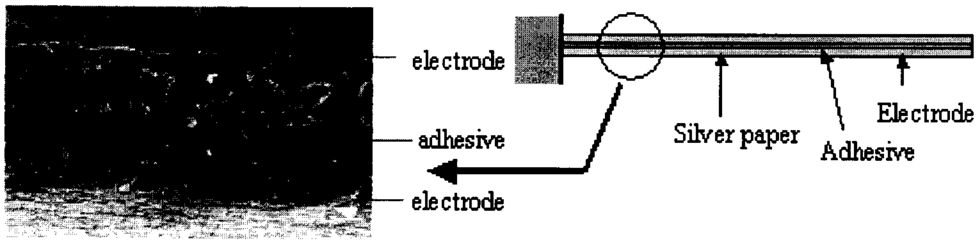
COMPARISON BETWEEN EAP AND WIDELY USED TRANSDUCING ACTUATORS

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.

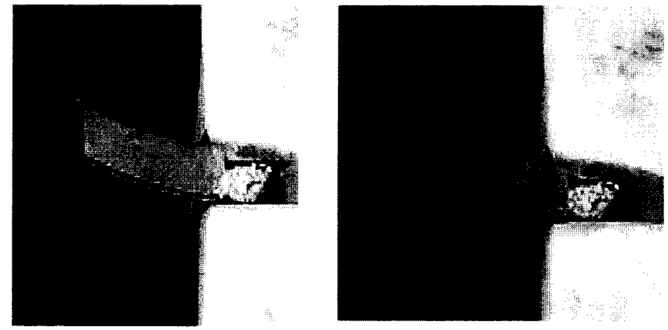
Electronic EAP

Electric field or coulomb forces driven actuators



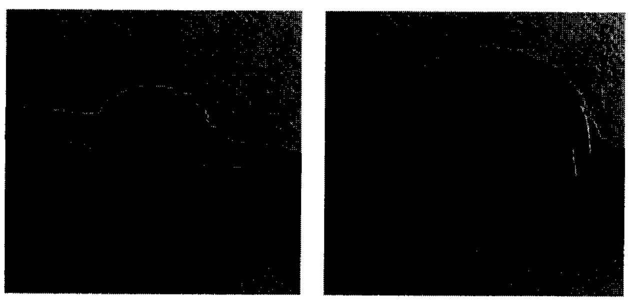
Paper EAP

[J. Kim, Inha University, Korea]



Ferroelectric

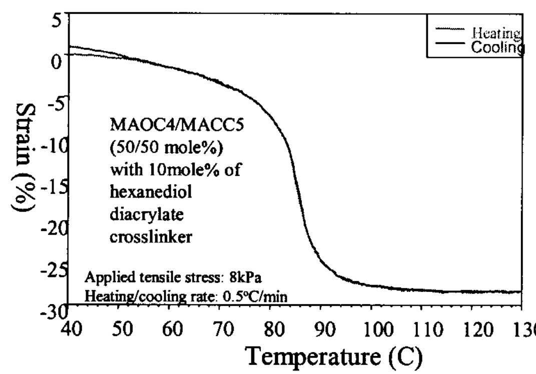
[Q. Zhang, Penn State U.]



Voltage Off **Voltage On**

Dielectric EAP

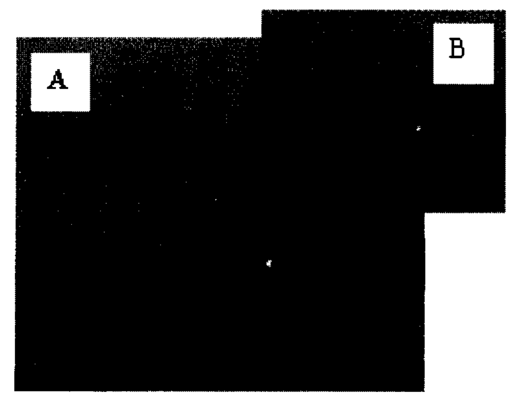
[R. Kornbluh, et al., SRI International]



Liquid crystals

(Piezoelectric and thermo-mechanic)

[B. R. Ratna, NRL]

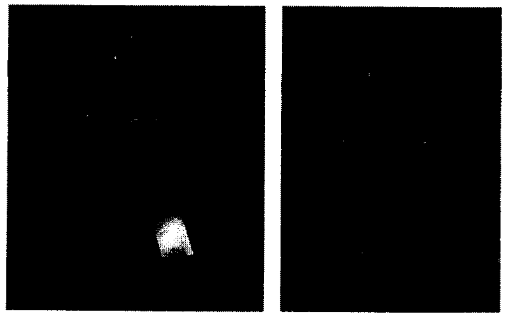


Graft Elastomer

[J. Su, NASA LaRC]

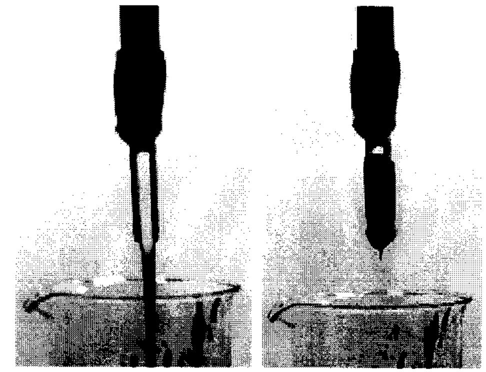
Ionic EAP

Turning chemistry to actuation



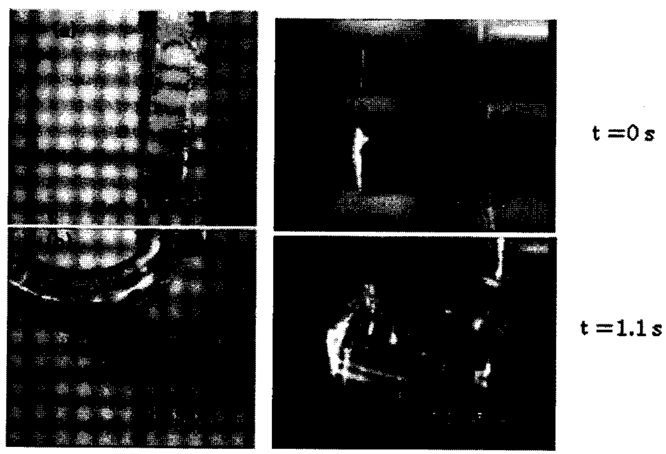
IPMC

[JPL using ONRI, Japan & UNM materials]



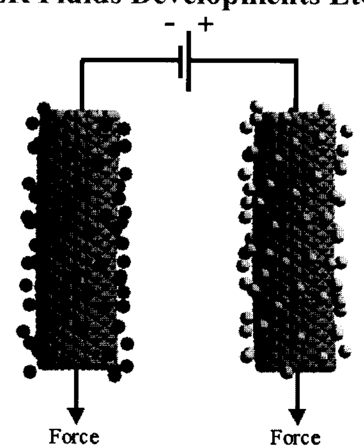
ElectroRheological Fluids (ERF)

[ER Fluids Developments Ltd]



Ionic Gel

[T. Hirai, Shinshu University, Japan]



Carbon-Nanotubes

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

Applications

Underway or under consideration

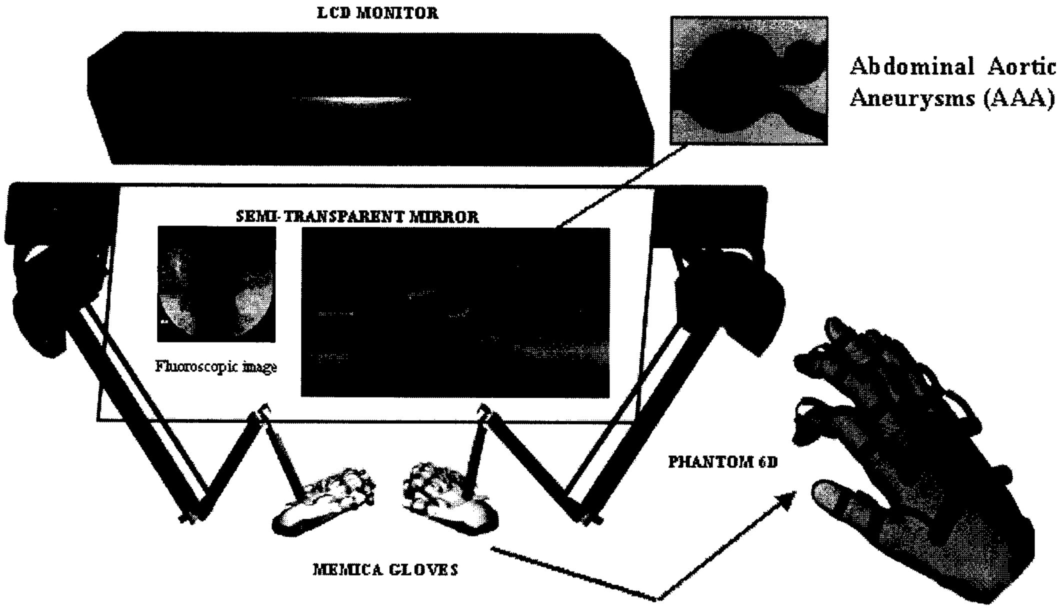
- **Mechanisms**
  - Lenses with controlled configuration
  - Mechanical lock
  - Noise reduction
  - Flight control surfaces/Jet flow control
  - Anti G-suit
- **Robotics, Toys and Animatronics**
  - Biologically-inspired robots
  - Toys and Animatronics
- **Human-Machine Interfaces**
  - Haptic interfaces
  - 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**

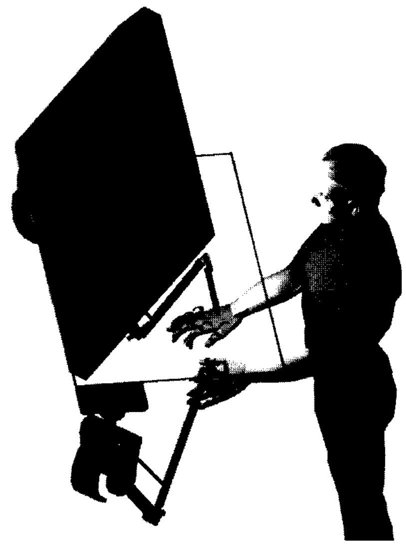
Required sensors

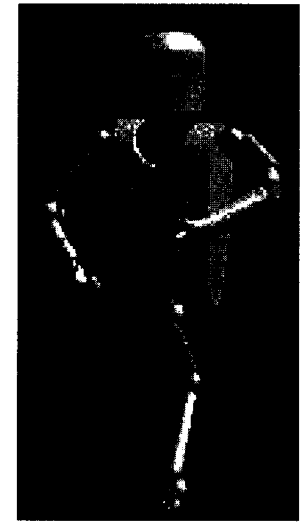
- Flexible
- Light weight
- Imbeddable
- Miniature distributable
- Easy to multiplex
- Easy to connect and integrate

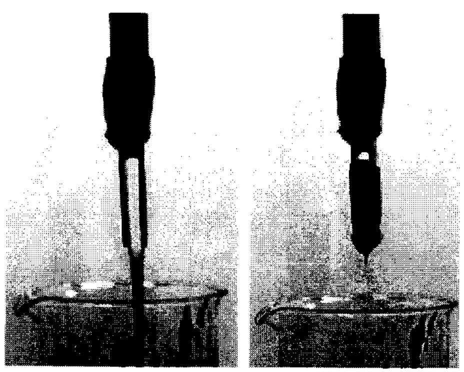
Haptic Interfacing – MEMICA System

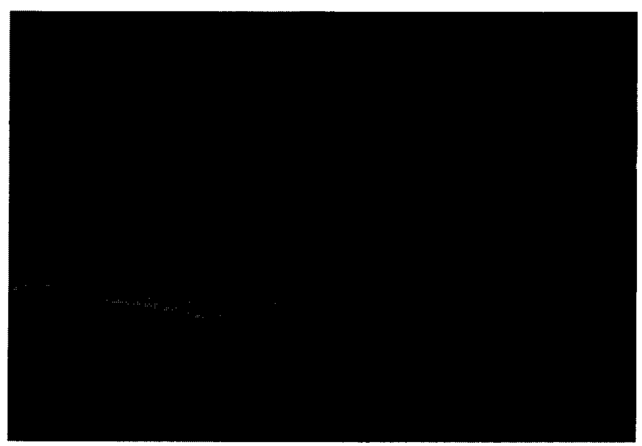
(MEchanical MIrroring using Controlled stiffness and Actuators)

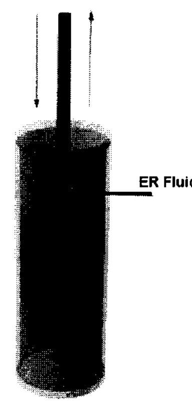


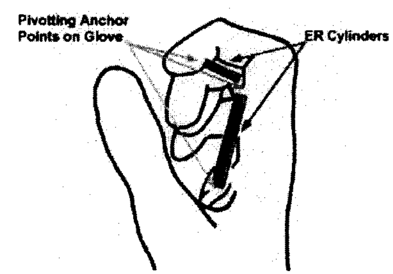










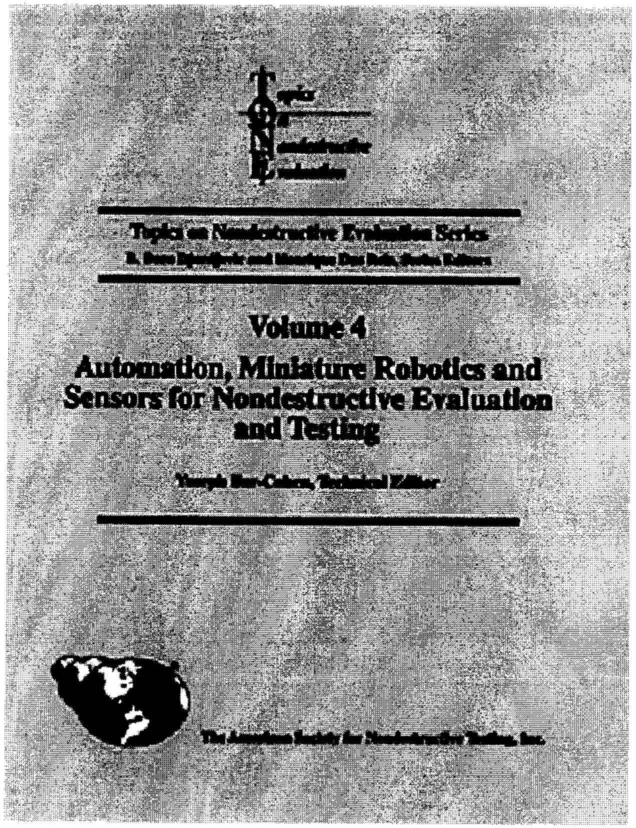


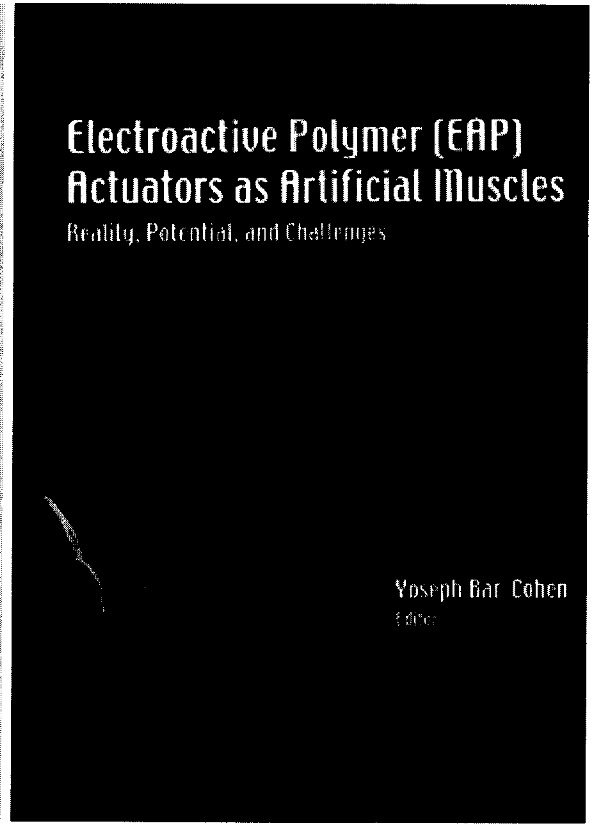
Electro-Rheological Fluid at reference (left) and activated states (right).
[Smart Technology Group, UK]

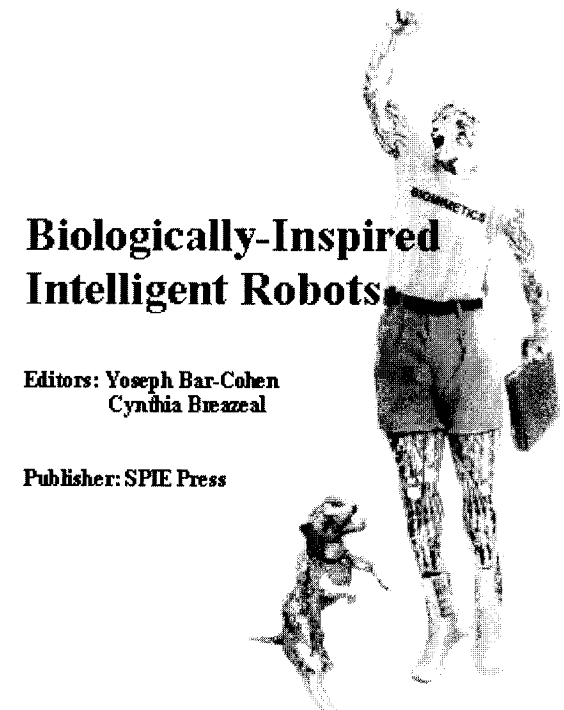
MEMICA-based exoskeleton for countermeasure of astronauts bones and muscles loss in microgravity. It has potential application as:

- Assist patient rehabilitation
- Enhance human mobility

Related recent and upcoming books







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

The grand challenge for EAP as
ARTIFICIAL MUSCLES

Sensors as a part of a system

Location

- Imbedded
- Attached
- Remote
- Remotely interrogatable

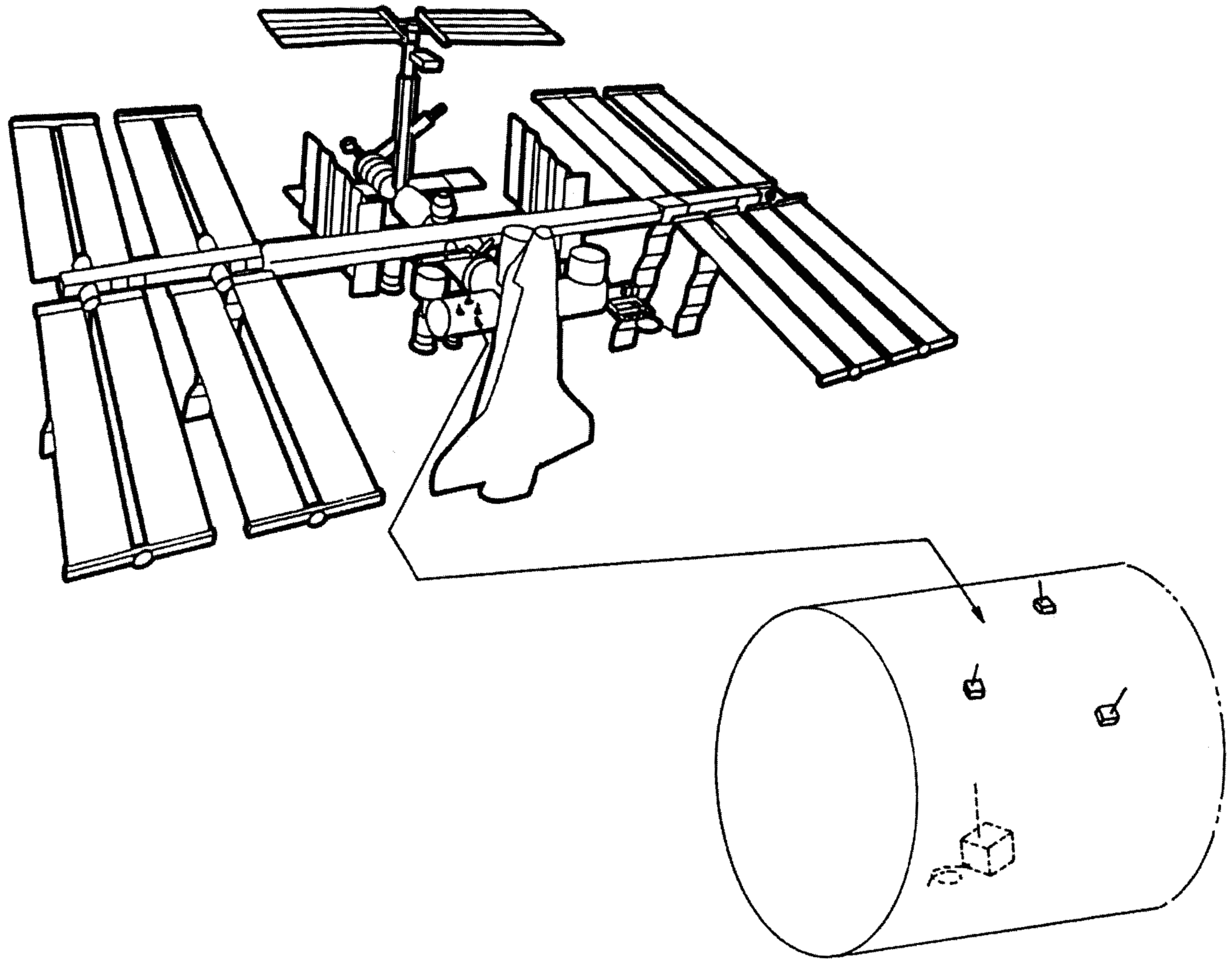
Types

- End-effector of a system
- Stand alone gauge with accumulative indication

Interrogation characteristics

- Real-time in-process (cure, service, active operation) monitoring
- Periodically interrogatable

Tele-stick-on sensor system



Summary

There is a need for sensors that can:

operate at

- Harsh environments
- Extreme conditions
- None linear behaviors
- Areas that are beyond reach

perform

- Distributed sensing
- Test large-areas at high-speeds
- Real-time operation from cradle to retirement.

be

- Reliable and robust
- Scalable
- Miniaturizable to nano levels
- Multifunctional