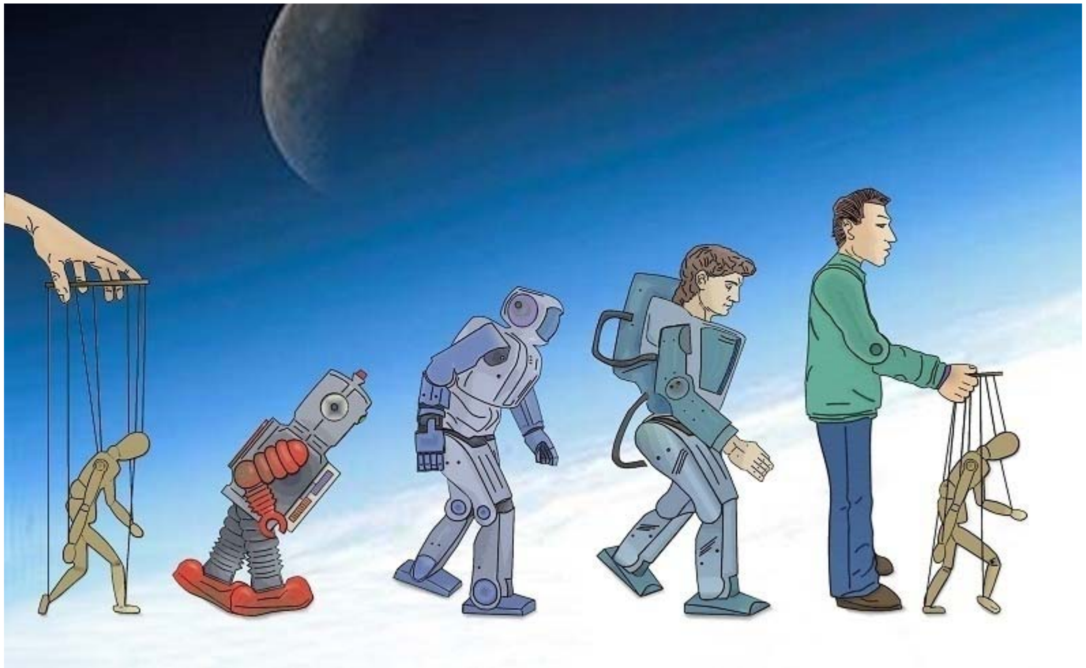
Planetary exploration using bio-inspired technologies



Ref.: Y. Bar-Cohen & D. Hanson "Humanlike Robots" 2009. Courtesy of Adi Marom, Graphics Artist.

Yoseph Bar-Cohen,

Jet Propulsion Laboratory, California Institute of Technology

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

Biology – inspiring human innovation

Flying was enabled using aerodynamic principles

Honeycomb structures are part of almost every aircraft

The fins were copied to significantly improve swimming and diving

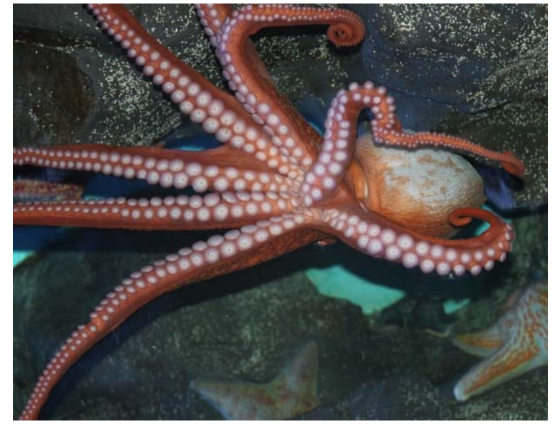
http://www.wildland.com/trips/details/326/new_zealand_itin.aspx

http://www.swimoutlet.com/Swim_Fins_s/329.htm

The spider is quite an "engineer". Its web may have inspired the fishing net, fibers, clothing and others.

The octopus as a model for biomimetics

Adaptive shape, texture and camouflage of the Octopus



Courtesy of William M. Kier, of North Carolina

Courtesy of Roger T. Hanlon, Director, Marine Resources Center, Marine Biological Lab., MA

Camouflage has many forms

The swan puffs its wings to look bigger in an attack posture

Jewel Scarab Beetles - bright colors appear bigger

Leafy seadragon

Butterfly - Color matching

Owl butterfly
Wikipedia freely licensed media
http://en.wikipedia.org/wiki/Owl_butterfly

Lizard - Color matching

Plants use of camouflage

- To maximize the pollination opportunities - flowers are as visible as possible.
- To protect from premature damage – initially, fruits are green, have sour taste, and are camouflaged by leaves.
- Once ripped, fruits become colorful and tasty, as well as have good smell

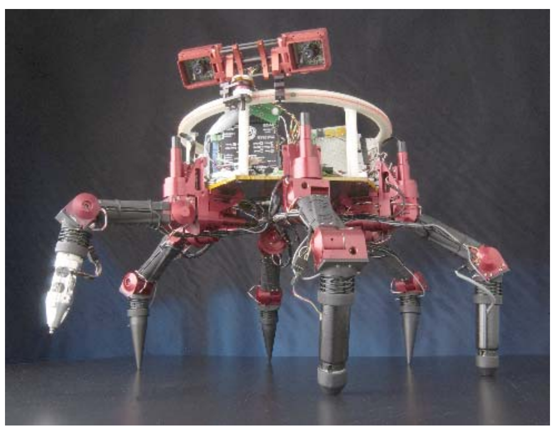


Biomimetic robotic exploration of the universe

The Curiosity rover and the Mars Science Laboratory MSL) landed on Mars in Aug. 2012.

The mountain goat is an inspiring model for all-terrain legged rovers

LEMUR (Limbed Excursion Mobile Utility Robot): 6-legged robot. Courtesy of Brett Kennedy, JPL



A futurist vision of the role of humanlike robots in planetary exploration of the Universe

Courtesy of Adi Marom, graphic artist.

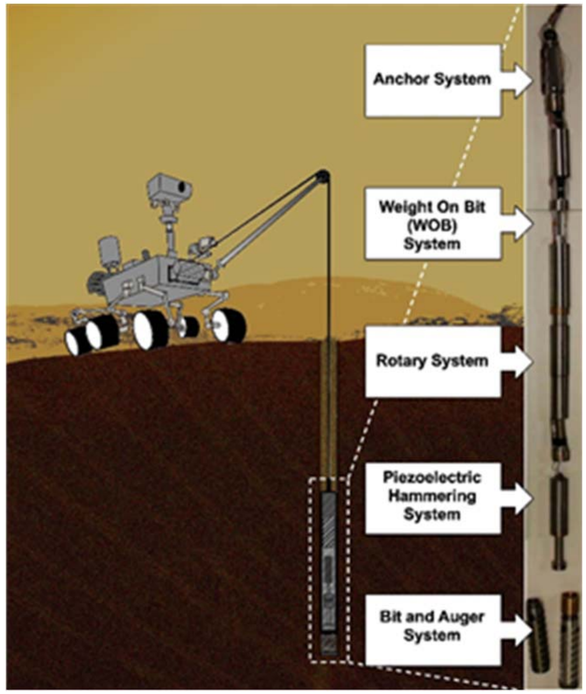
Biomimetics in support of space exploration

- Key objective of the NASA's solar system exploration of planetary bodies is the search for preserved bio-signatures and habitable regions.
- Various biomimetic approaches having a range of technology readiness levels (TRL) are being investigated.
- Examples include:
  - Deep drilling via the biologically inspired Auto-Gopher
  - Artificial muscles as actuators
  - Humanlike robot for planetary exploration
  - Artificial nose that was tested on the International Space Station,
  - Biomimetic optical sensor for real-time measurement of aircraft wing deflection
  - Parallel processing algorithms
  - Snake-like robotics for traversing through narrow openings and passages to conduct maintenance and inspection functions

Inspired by the Gopher's holes making

The gopher makes holes by removing soil along its path to form underground tunnels.

Image reference:
http://www.ancpestsolutions.net/gophers/

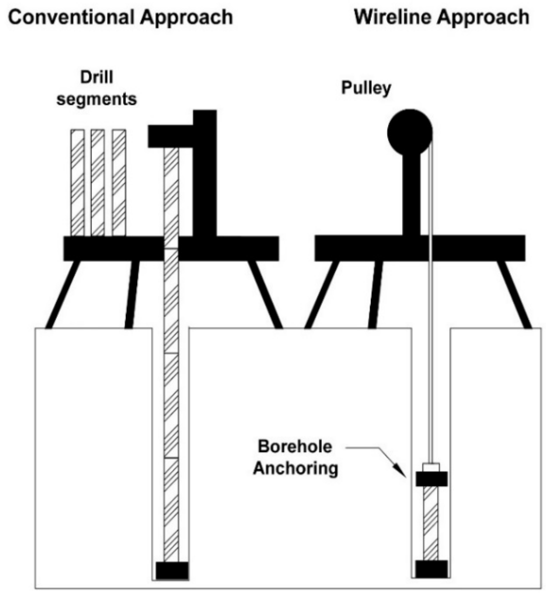


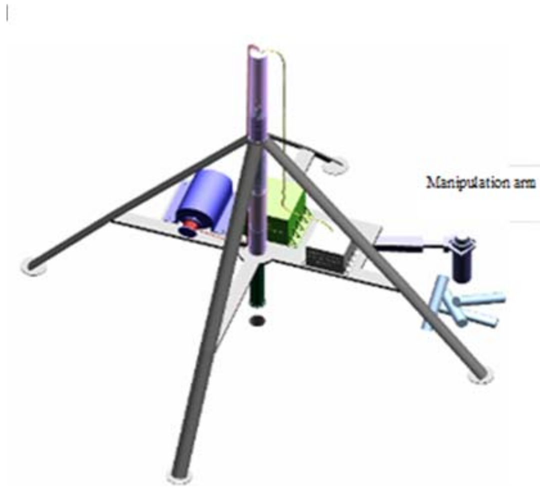
The wireline Auto-Gopher for deep drill and its components.

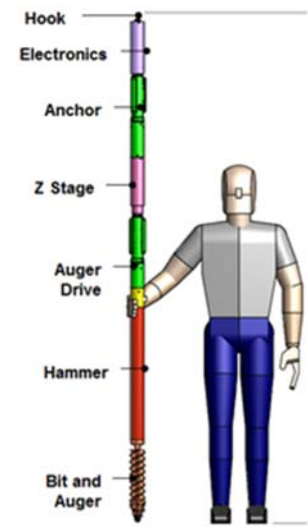
The initial version of the deep drill technology--the Auto-Gopher-1.

The drill is shown with the cores that were acquired from reaching 3 m deep.

The Auto-Gopher is a Wireline drill



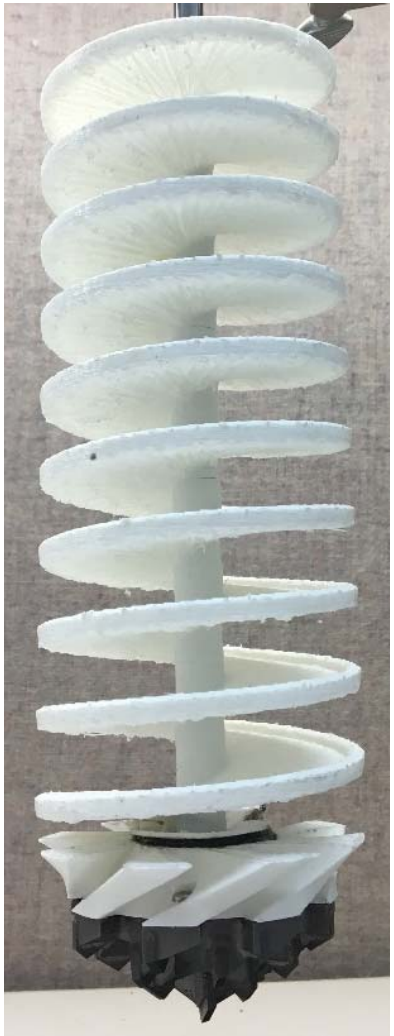




- The Auto-Gopher is a wireline drill that is lowered and raised via a tether.
- It creates fragments and cuttings, then the drill is pulled up to remove them.
- The process is repeated to reach the desired depth.
- It is superior to the conventional drilling approaches since the deployment mechanism is:
  - Lighter
  - Has less complex mechanism of downloading
  - Can reach great depths with a relatively compact system.

Auger mechanism is being developed

3D printed model of the auger design that is currently being investigated



Electroactive Polymers (EAP) as Artificial Muscles

FIELD ACTIVATED (ELECTRONIC) EAP

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

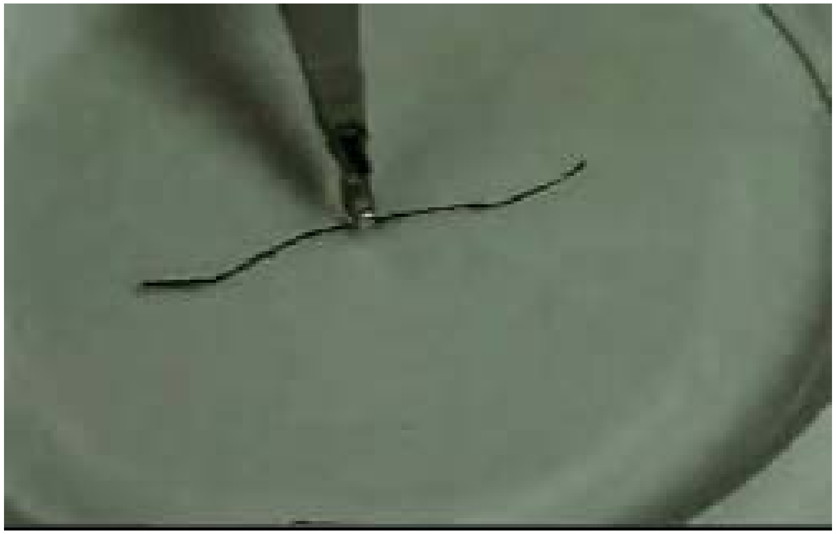
IONIC EAP

- 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
Field Activated (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). Recent development allowed for (~20 MV/m) • Requires compromise between strain and stress • Glass transition temperature is inadequate for low-temperature actuation tasks and, in the case of Ferroelectric EAP, high temperature applications are limited by the Curie temperature • Mostly, producing a monopolar actuation independent of the voltage polarity due to associated electrostriction effect.
Ionic EAP	• Produces large bending displacements • Requires low voltage • Natural bi-directional actuation that depends on the voltage polarity.	• Except for CPs and NTs, 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 requiring • To operate in air requires attention to the electrolyte. • Low electromechanical coupling efficiency.

EAP – as artificial muscles

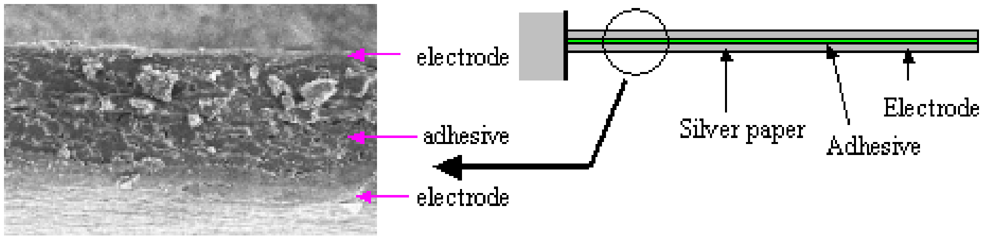


IPMC made by Keizuke Oguro, ONRI, Japan

Ferroelectric EAP made by Qiming Zhang, Penn State University, USA

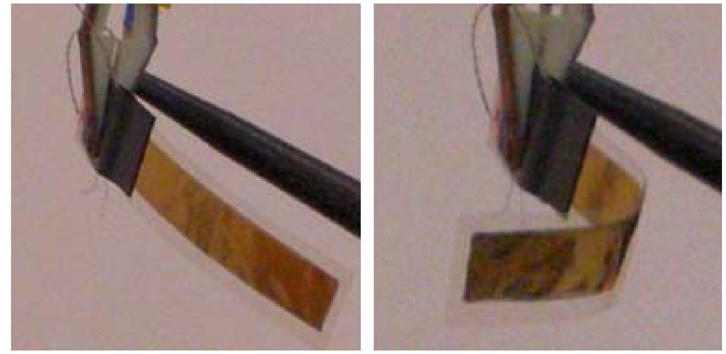
Field Activated (Electronic) EAP

ELECTRIC FIELD OR COULOMB FORCES DRIVEN ACTUATORS



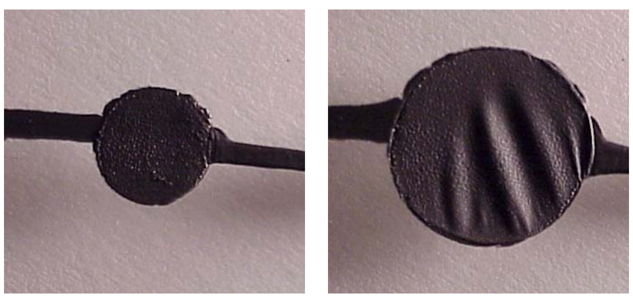
Paper EAP

[J. Kim, Inha University, Korea]



Ferroelectric

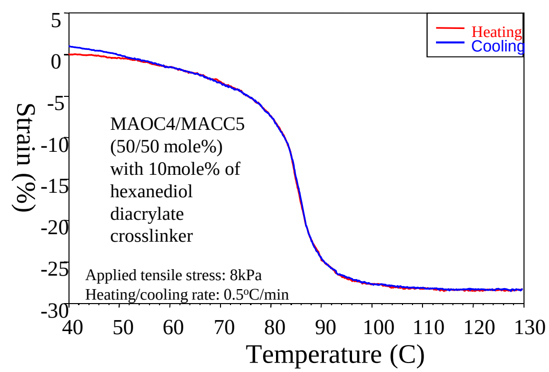
[Photographed at JPL, the material provided from Q. Zhang, Penn State U.]



Voltage Off   Voltage On

Dielectric EAP

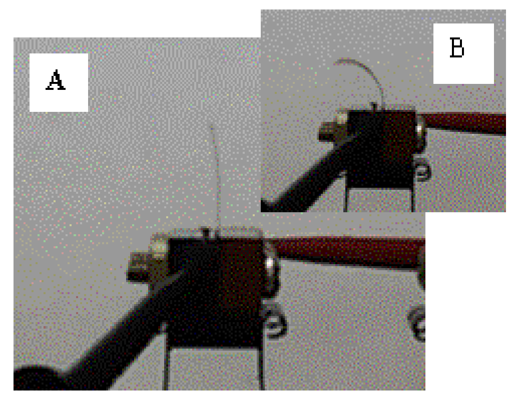
[R. Kornbluh, et al., SRI International]



Liquid crystals

(Piezoelectric and thermo-mechanic)

[B. R. Ratna, NRL]

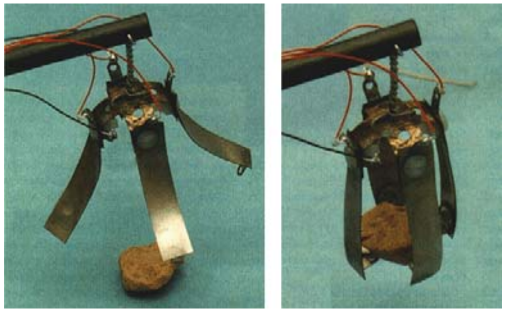


Graft Elastomer

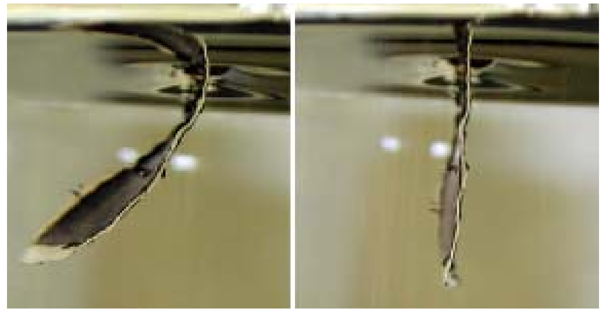
[J. Su, NASA LaRC]

Ionic EAP

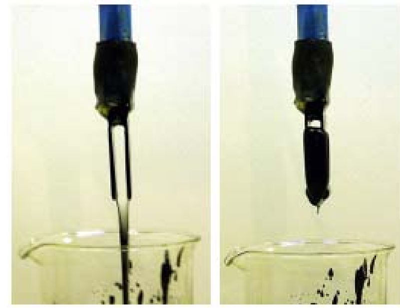
Turning chemistry to actuation



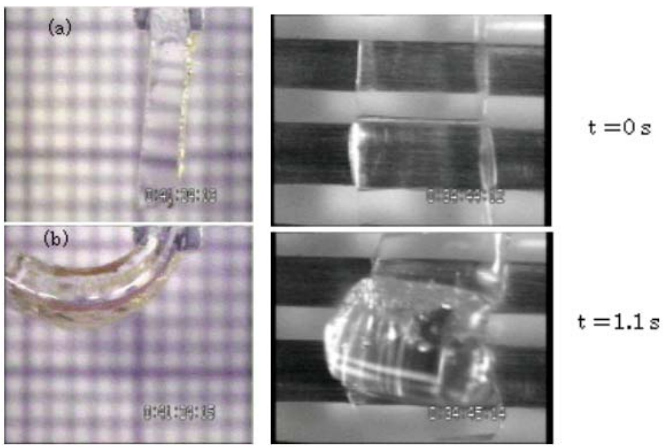
IPMC
[JPL using ONRI, Japan & UNM materials]



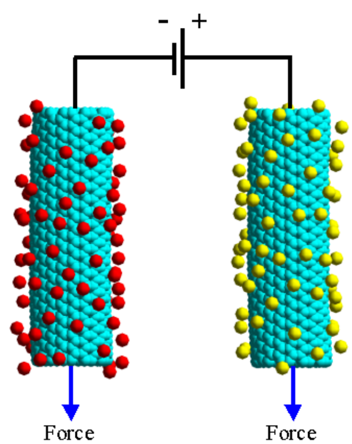
Conductive Polymers
[Made and photographed at JPL]



ElectroRheological Fluids (ERF)
[ER Fluids Developments Ltd]



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



Carbon-Nanotubes
[R. Baughman et al, UTD]

Exploration of planetary applications

Dust wiper

Sample
handling
robotics

The grand challenge for EAP as

Artificial Muscles

The First Arm-wrestling Contest

March 7, 2005

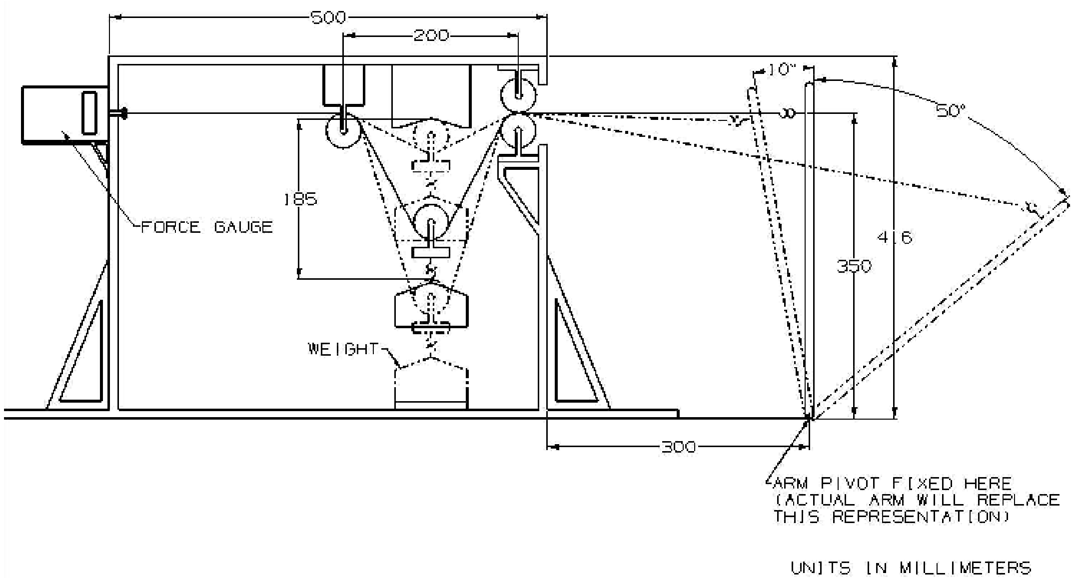
EMPA, Dubendorf, Switzerland used dielectric elastomer in 4 groups of multi-layered scrolled actuators– this arm lasted 4-sec.

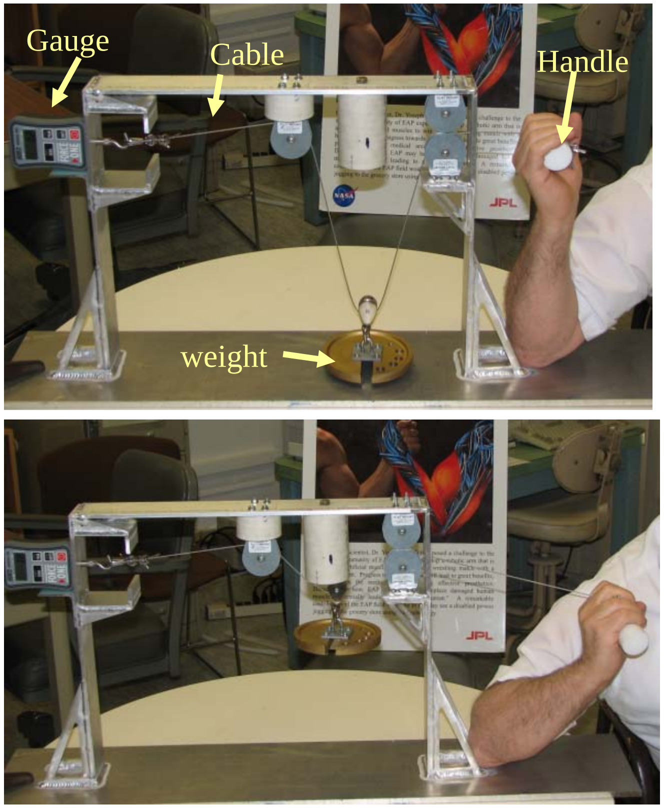
Students from VT used PAN gel fibers and an electrochemical cell – this arm lasted 3-sec.

Environmental Robots Inc. (ERI), Albuquerque, NM, used shape memory polymer strips.

The 2006 Arm-wrestling Contest

- The strength and speed of the competing arms was measured using a test fixture and the data was compared with the performance of the female student who wrestled in 2005.
- The student's strength and speed were two orders of magnitude higher.



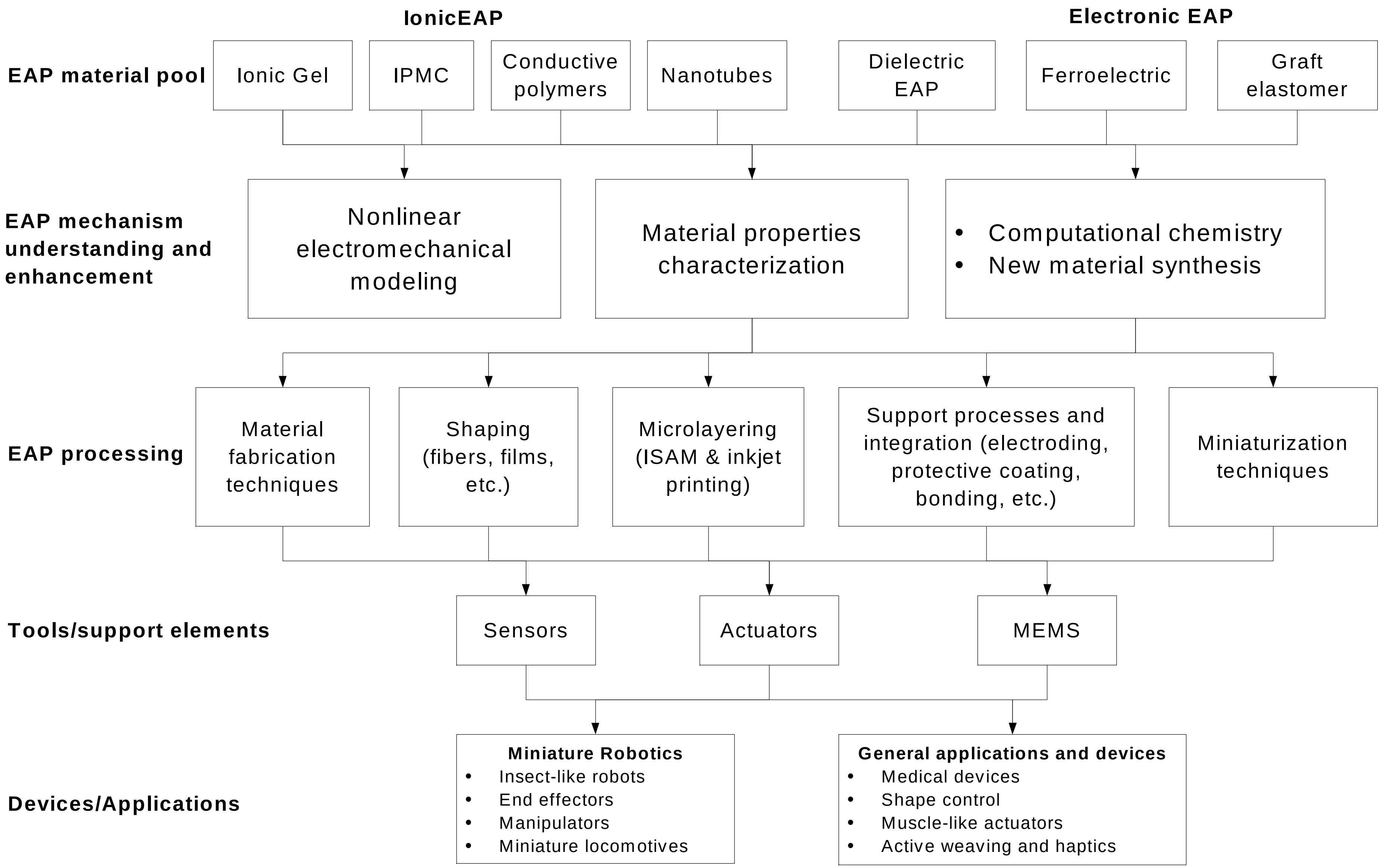


Recent advances

Thermally activated nylon torsional actuators

UT Dallas demo in March 2014

EAP infrastructure – need development in many areas



Making intelligent humanlike robots

There are three key possibilities of making a humanlike robot operate intelligently:

- Telepresence - where a remote operator controls the robot.
- Fully autonomous – Potentially, future humanlike robots will be equipped with cognition capability.
- Cyborg – The ultimate in prosthetics would be a humanlike robot with natural live human brain installed onboard. The technology is too far from today's capability.

The NASA JSC's Valkyrie Robot

Sociable Robots

Respond to human facial and verbal expressions

Cynthia Breazeal and her team at MIT talking to her robot Kismet

Ref: C. Breazeal, Designing Sociable Robots. MIT Press, Cambridge, MA (2002)

Humanoids – robots with human appearance

The PINO humanoid has a machine appearance with human characteristics
Courtesy of Kitano Symbiotic Systems, Japan

The Fujitsu's "enon" robot
Courtesy of Fujitsu Frontech Limited and Fujitsu Laboratories Ltd., Japan

Female Type (FT)
Courtesy of Tomotaka Takahashi, Robo-Garage, Kyoto, Japan

The Robo-Garage's Chroino
Photographed by the author

Realistic looking humanlike robots (HLR)

Courtesy of Hiroshi Ishiguro and his group at Osaka University jointly with Korkoro Co., Ltd.

The Cyber-receptionist Ms. Saya
Courtesy: Hiroshi Kobayashi, Tokyo University of Science.

EveR-2 Muse
Courtesy of KITEC (Korea Institute of Industrial Technology).

The roboticists Zou Renti, China, and his clone robot at Nextfest 2007.

“Beauty contest” of humanlike robots

Potential candidates for future robotic beauty pageant

Actroid-DER 01(made by Kokoro, Inc.)

Actroid-DER 02 (made by Kokoro, Inc.)

Replee Q2 facing the graduate student Motoko Noma in Tokyo

Courtesy of Osaka University

Dion is a humanlike robot made in China.

Full size robot with expressive head

- Humanlike head of Einstein (Hanson Robotics) and Hubo Robot body (KAIST) is the first ever expressive humanlike face on an untethered walking robot.
- This robot was made in celebrations of the 100 years anniversary of the theory of relativity.

Courtesy of David Hanson, Hanson Robotics

The USA's DARPA (Defense Advanced Research Projects Agency) Robotics Challenge (DRC)

- In an effort to promote significant advances in humanoids technology and making society more resilient, the DARPA posed in 2012 a Robotic Challenge to produce such robots that operate in disaster scenarios.
- The challenge was focused on the requirements that were needed after the Fukushima accident in Japan, where there was limited access to emergency responders as a result of the extremely high radiation around the failed nuclear plant.
- In response, various humanoids were developed that participated in the DARPA Robotics Challenge (DRC) contests that were held in 2013 and 2015.
  - The 2013 contest was called the Trials
  - The 2015 contest was called the Finals

WHY THE DARPA ROBOTICS CHALLENGE TASKS?

The story of the DARPA Robotics Challenge (DRC) begins on March 12, 2011, the day after the Tohoku, Japan earthquake and tsunami struck the Fukushima-Daiichi nuclear power plant. On that day, a team of plant workers set out to enter the darkened reactor buildings and manually vent accumulated hydrogen to the atmosphere. Unfortunately, the vent team soon encountered the maximum level of radiation allowed for humans and had to turn back. In the days that followed, with the vents still closed, hydrogen built up in each of three reactor buildings, fueling explosions that extensively damaged the facility, contaminated the environment and drastically complicated stabilization and remediation of the site.

At Fukushima, having a robot with the ability to open valves to vent the reactor buildings might have made all the difference. But to open a valve, a robot first has to be able to get to it. The DRC tasks test some of the mobility, dexterity, manipulation and perception skills a robot needs to be effective in disaster response.

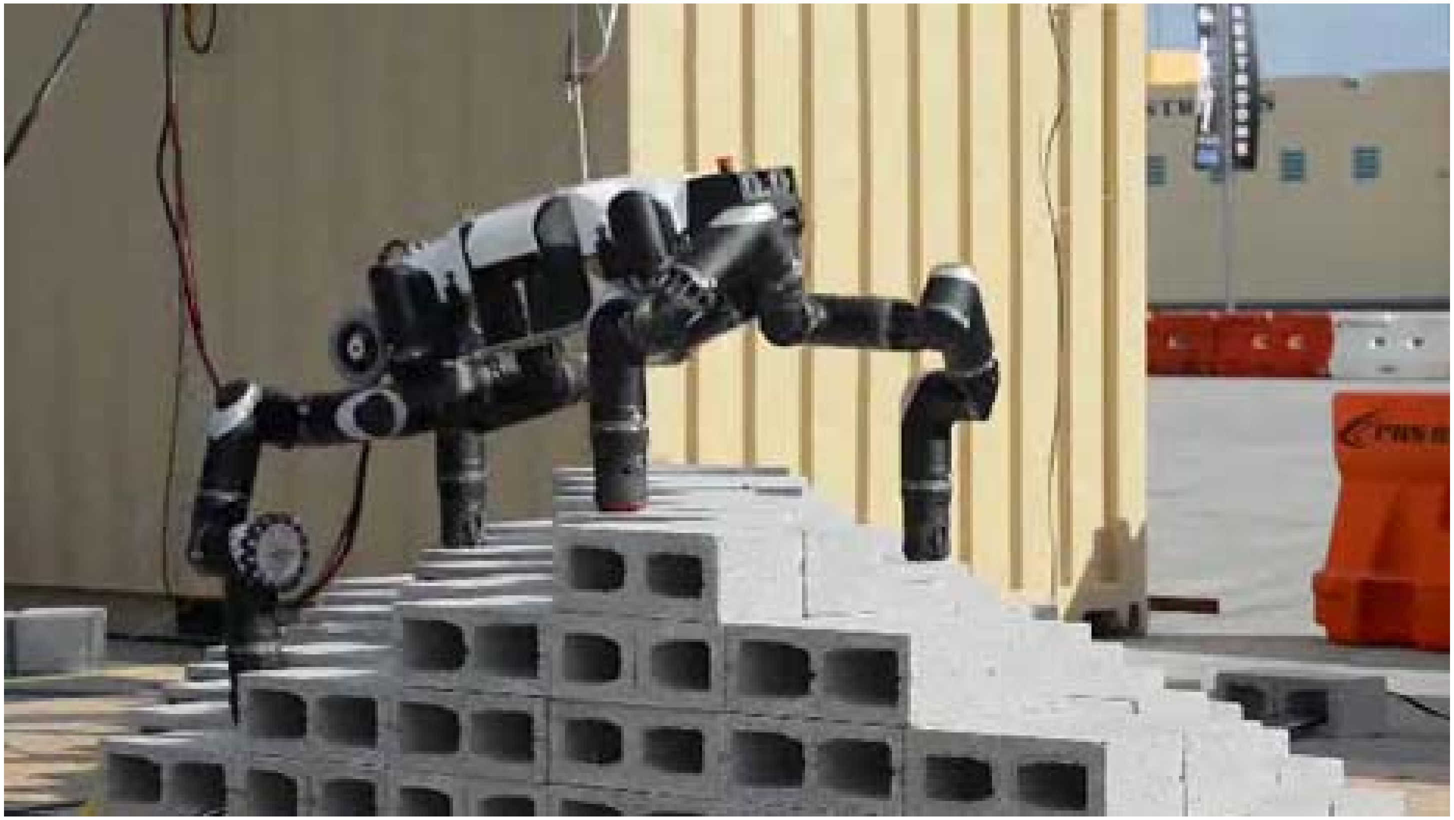
KEY
- Perception
- Mounted Mobility
- Dexterity
- Decision-making
- Dismounted Mobility
- Strength

DARPA

ROBOTICS CHALLENGE 2013 TRIALS

#DARPADRC

The JPL's RoboSimian robot climbing a rough terrain during the DARPA competition (Dec. 2013)



Credit: NASA/JPL-Caltech.

The winners of the Trial Contest that was held on December 20-21, 2013

SCHAFT Inc.

Robot: S-One
Schaft Inc.
1st
Bipedal; based on existing SCHAFT HRP-2 robot
http://theroboticschallenge.org/node/58

IHMC Robotics

Robot: Atlas-Ian
IHMC Robotics
2nd
Bipedal; 28 hydraulically actuated joints; modular wrists accept 3rd-party hands; based on Petman robot
http://theroboticschallenge.org/node/61

Carnegie Mellon University

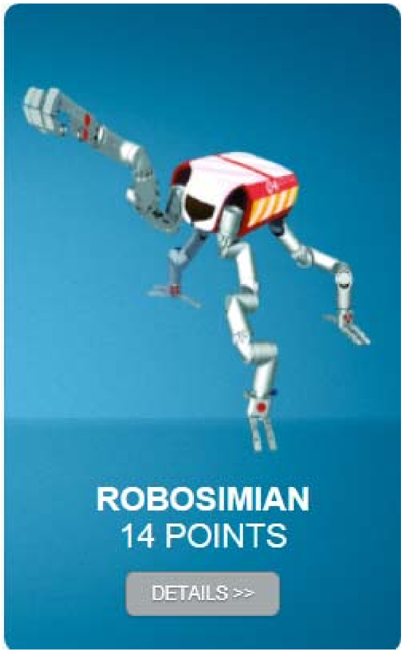
Robot: CHIMP
Tartan Rescue
3rd
Quadrapedal but can stand bipedally; tank treads on feet and forearms to maximize stability over uneven terrain
http://theroboticschallenge.org/node/48

MIT

Robot: Atlas-Helios
Team MIT
4th
Bipedal; 28 hydraulically actuated joints; modular wrists accept 3rd-party hands; based on Petman robot
http://theroboticschallenge.org/node/64

The winners of the Trial Contest that was held on December 20-21, 2013

JPL



Robot: RoboSimian
JPL
5th
Quadrapedal but can stand bipedally; four general-purpose limbs and hands capable of both mobility and manipulation
http://theroboticschallenge.org/node/60

TRACLabs, Inc.

Robot: Atlas-Hercules
TRACLabs, Inc.
6th
Bipedal; 28 hydraulically actuated joints; modular wrists accept 3rd-party hands; based on Petman robot
http://traclabs.com/

Worcester Polytechnic Institutes

Robot: Atlas-Warner
WPI
7th
Bipedal; 28 hydraulically actuated joints; modular wrists accept 3rd-party hands; based on Petman robot
http://www.prweb.com/releases/2013/12/prweb11421359.htm

Lockheed Martin Advanced Technology Laboratories

Robot: Atlas-Rocky
Lockheed Martin
8th
Bipedal; 28 hydraulically actuated joints; modular wrists accept 3rd-party hands; based on Petman robot
http://theroboticschallenge.org/node/69

The final DRC was held in Pomona, CA, from June 5 to 6, 2015

Examples of the successes

https://www.youtube.com/watch?v=xCC4_VJ36-A#t=26819

Examples of the failures

https://www.youtube.com/watch?v=g0TaYhjpOfo

DRC FINALS TEAM STANDINGS

TEAM	SCORE	TIME
TEAM KAIST	8	44:28
TEAM IHMC ROBOTICS	8	50:26
TARTAN RESCUE	8	55:15
TEAM NIMBRO RESCUE	7	34:00
TEAM ROBOSIMIAN	7	47:59
TEAM MIT	7	50:25
TEAM WPI-CMU	7	56:06
TEAM DRC-HUBO AT UNLV	6	57:41
TEAM TRAC LABS	5	49:00
TEAM AIST-NEDO	5	52:30
TEAM NEDO-JSK	4	58:39
TEAM SNU	4	59:33
TEAM THOR	3	27:47
TEAM HRP2-TOKYO	3	30:06
TEAM ROBOTIS	3	30:23
TEAM VIGIR	3	48:49
TEAM WALK-MAN	2	36:35
TEAM TROOPER	2	42:32
TEAM HECTOR	1	02:44
TEAM VALOR	0	00:00
TEAM AERO	0	00:00
TEAM GRIT	0	00:00
TEAM HKU	0	00:00

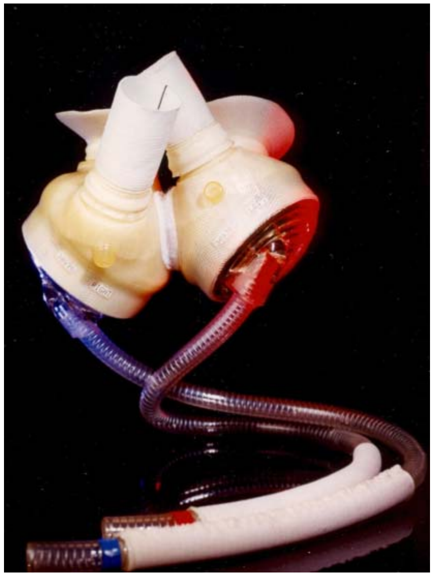
Benefits of the technology

Jesse Sullivan is the world's first person to have a robotic prosthetic arm driven by his own nerve impulses from his brain.
Courtesy of the Rehabilitation Institute of Chicago (RIC).

A motorless exoskeleton using variable damping in a passive system.
Courtesy of Hugh Herr, Media Lab, MIT.

Artificial Organs

Augmenting or replacing body organs with artificial mechanisms and devices is increasingly enabled as a result of significant advances in bio-compatible materials, powerful microelectronics, and efficient miniature actuators. Examples include augmenting or replacing body organs with:



– Artificial organs such as heart, lung, kidney, liver, hip, and others.

– Smart limbs with various degrees of sophistication.

Advances prosthetics

London 2012 Olympics: Games legend Michael Johnson believes Oscar Pistorius has an 'unfair advantage'

The 400-metre world record holder, Michael Johnson, believes disabled athletes who use prosthetic limbs should not be allowed to compete in able-bodied races, as it has not been disproved whether or not it provides them with an "unfair advantage".

http://www.telegraph.co.uk/sport/olympics/athletics/9405113/London-2012-Olympics-Games-legend-Michael-Johnson-believes-Oscar-Pistorius-has-an-unfair-advantage.html

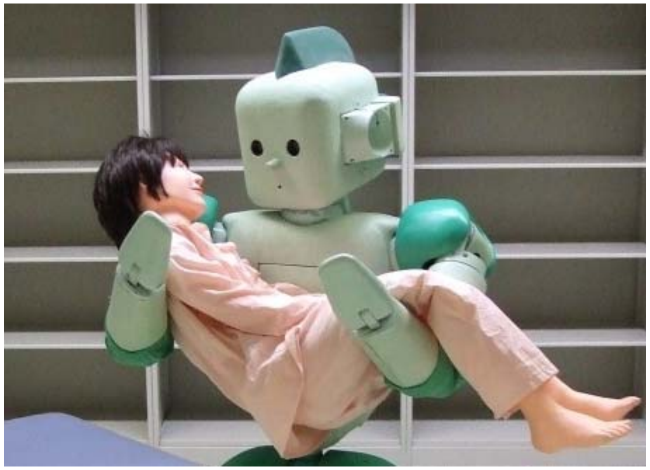
The technology of prosthetics is now competitive with human capability.

- During the 2008 Olympics games in China, the South African athlete Oscar Pistorius (having two prosthetic legs) sought to participate as a runner in a race against able-bodied athletic runners with natural legs.
- In the London Olympics 2012 Oscar Pistorius made history in the 400 meters by his participation in this race.

Potential applications of HLR

Humanoids and HLRs are already being made to look like and operate as receptionists, guards, hospital workers, guides, dancers, toys, and more.

- High risk jobs - Filling need for employees to perform dangerous, and physically demanding jobs.
- Entertainment – movies, toys, partner in sport (tennis, etc.).



The RI-MAN robot carries a manikin as a simulated patient.
Courtesy: RIKEN Bio-Mimetic Control Research Center, Japan.

- Medical – Perform surgeries, support healthcare staff, assist in rehabilitation and perform psychological therapies including phobia (e.g., treatment of autism, fear of speaking in public, etc.) and provide smart prosthetics.
  - For elderly, disabled or patients in rehabilitation, HLRs robots may provide assistance, monitoring, and emergency treatment 24-hours 7-days a week at their own home.

Courtesy – Adi Marom, Graphic Artist.

Fears and potential dangers

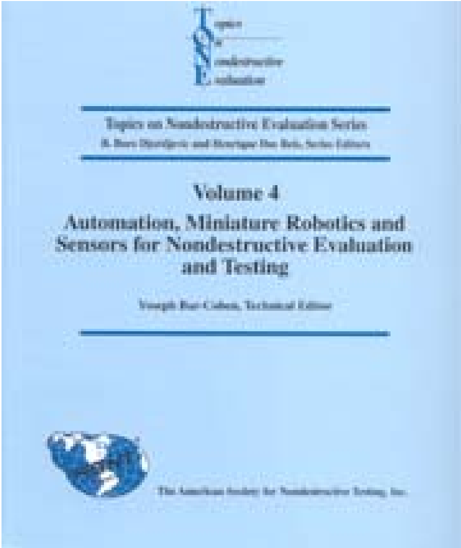
- There is a growing concern that HLR will be used to perform improper or unlawful acts.
  - Rapid prototyping of specific humans may become the ultimate identity theft.
  - Issues related to non-obedient robots or unacceptable behavior need attention.
- Preferably, HLR will be designed to interact with humans in master-slave relations possibly following the laws of the well-known science fiction writer, Isaac Asimov.
  - Roboticists are already working on establishing rules of ethics for the developers and operators of HLR.
- Some of the phobia of HLR may be reduced once we find them more useful in our households and businesses.
- The issue that would be most difficult to address is the like that such robots are going to be making some people unemployable.

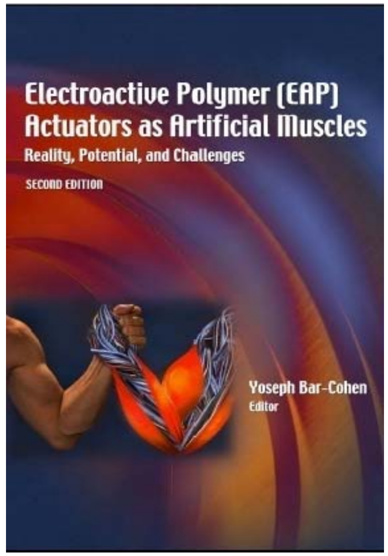
Futurist vision of one of the risks of an HLR being equipped with artificial cognition

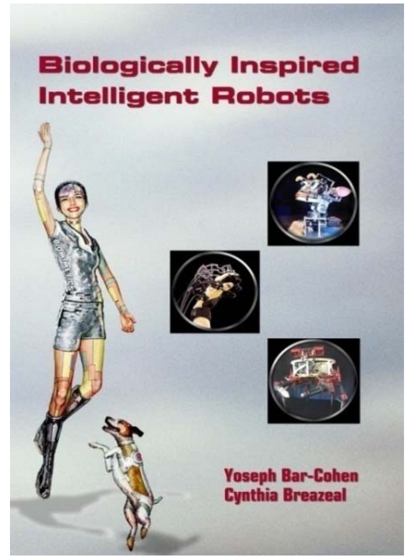
Courtesy – Adi Marom, Graphic Artist.

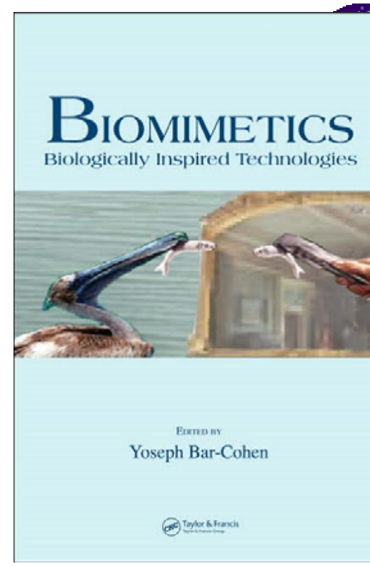
Summary

- Artificial technologies (AI, AM, and others) are increasingly becoming practical tools for making biologically inspired devices and instruments with enormous potential applications.
- The enabled technologies are taking increasing roles in the world around us and making science fiction ideas closer to engineering reality.
- Biomimetic technologies are being investigated for application in potential future NASA missions.
- These technologies include Electroactive polymers (EAP) as artificial muscles, deep drilling via the piezoelectric actuated Auto-Gopher, humanlike robotics and others.







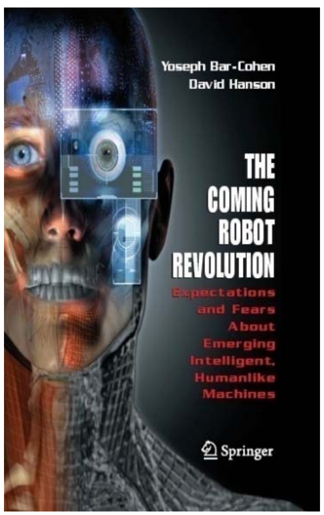


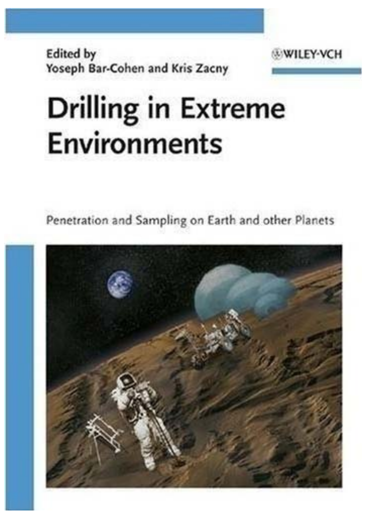
2000

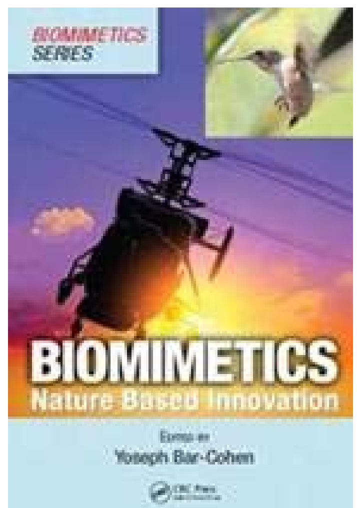
1st Ed. (2001)
2nd Ed. (2004)

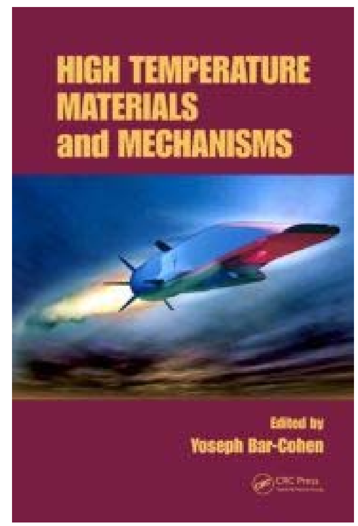
2003

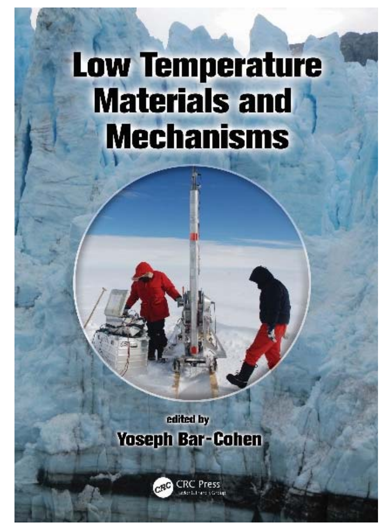
2005











2009

2009

2011

2014

2016

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

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