New trends in robotics for advanced applications including surgery

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IFMA / TIMS / LaMI / UBP
Clermont-Ferrand, France

PAX SOCIETY

September 18-20, 2008
POLYDOME - CLERMONT-FERRAND
(FRANCE)

PAXsociety

VIIIth PAX meeting

The peritoneum is alive during surgery : from pathophysiology to the operative theater

New trends in robotics

- Robots
- Manipulators
- Mobile
- Humanoids
- Modular
- Conclusion

What is a robot

- Etymology: Karel Capek, 1921, **Robotnik** = worker
- A robot is a **mechanical system** under **automatic control** that performs operations such as **handling** and **locomotion** (Source : IFToMM terminology)
- Summary
  - Manipulators
  - Mobile robots
  - Humanoids
  - Modular robots

  ] Classical topics (1950)

  ] Recent topics (1980)
- Robotics = Mecha + tronics + Automatic control
- Industrial automates and milling machines will not be treated

Structure of manipulators

New trends in robotics

- Robots
- Manipulators
  - Structure
  - Modeling
  - Serial
  - Parallel
  - Surgery
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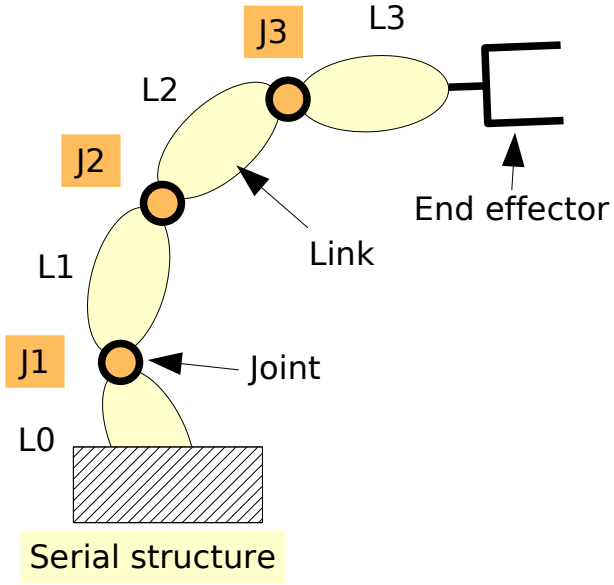
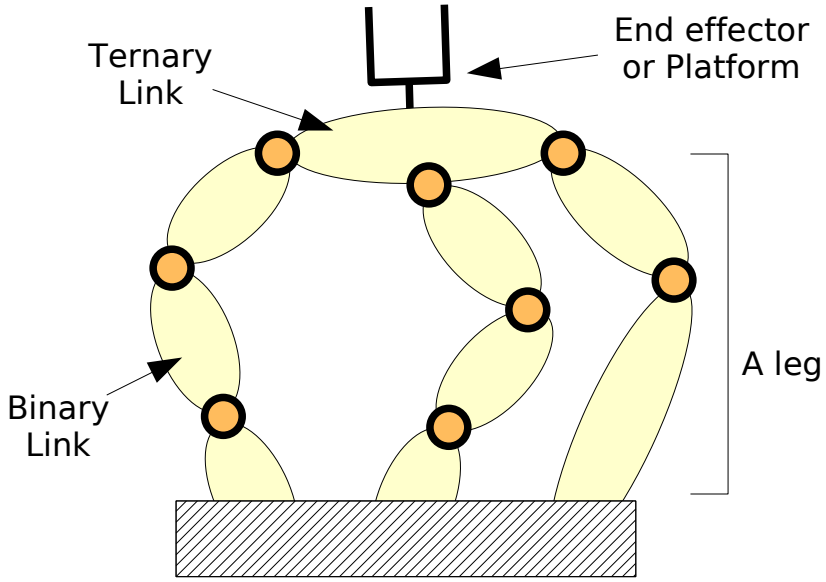


Serial structure



Parallel structure

- ✔ Serial / Parallel / Hybrid structures
- ✔ Kinematical graph
- ✔ Representation of motions : Denavit-Hartenberg, TCS...

Modelling manipulators

- Model

x
Operational coordinates = **position** + **orientation** of end effector

Inverse geometric model

Direct geometric model

q
Articular coordinates = **position** or **orientation** of actuators

$\dot{x}$
Operational speeds

Inverse kinematic model

$$(\dot{x}) = \begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \\ \dot{x}_5 \\ \dot{x}_6 \end{pmatrix} = [J] \begin{pmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \\ \dot{q}_4 \\ \dot{q}_5 \\ \dot{q}_6 \end{pmatrix} = [J](\dot{q})$$

Direct kinematic model

$\dot{q}$
Articular speeds

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- Properties of robots:
  - ✔ Workspace
  - ✔ Singularities (come from conditioning of Jacobian J matrix)
  - ✔ Stiffness and precision
- Can be used for synthesis

Serial Manipulators

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Kuka KR1000 Titan 6R
(L1000kg / R3.2m / r0.2mm)
www.kuka.com

Staubli RS80 Scara 2RPR
(L8kg / R0.8m / r0.01mm)
www.staubli.com

ABB IRB660 4R
(L250kg / R3.1m / r0.05mm)
www.abb.com

- ✔ Specifications :
- ✔ Load L (up to 1000kg)
- ✔ Reach R (up to 3m)
- ✔ Repeatability r (up to 0.01mm)

Serial arms

- ✔ **Virtual Reality** applications
- ✔ Use robot **geometrical model**

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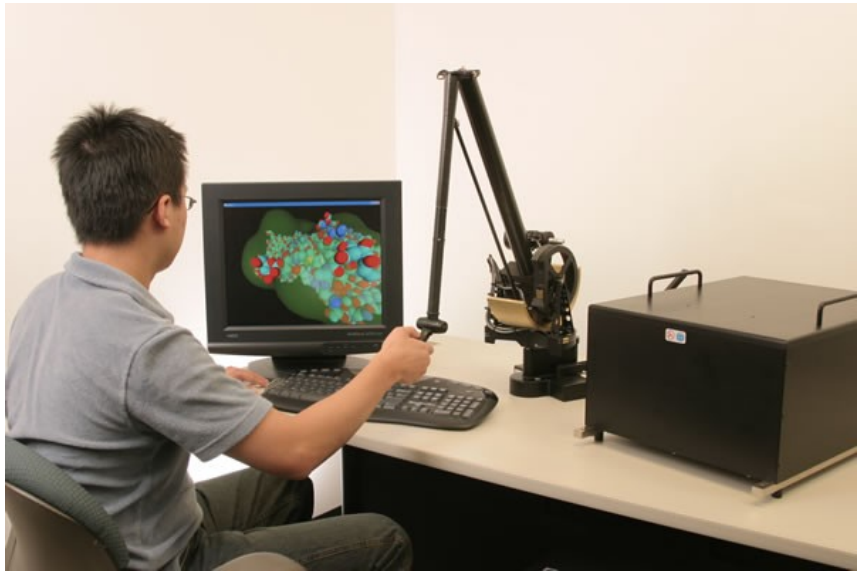
Sigma Measuring Arm
6kg, up to 5m range
Accuracy +/- 25 µm
www.romer.com



Phantom 3.0
6 DOF, Accuracy 20 µm
Haptic rendering on 3 translations
20 N max, 3N nominal)
www.sensable.com

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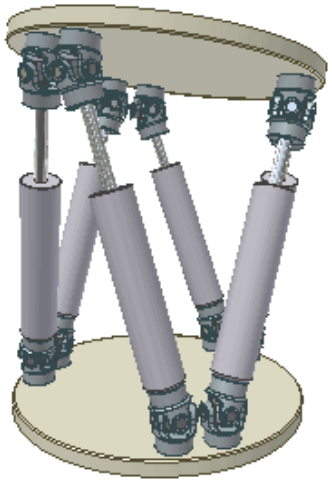
Parallel Manipulators

- ✔ Direct (reverse) geometric model is hard (easy) to solve
- ✔ Recent gain of popularity in industry

ABB IRB360 Delta 3 DOF
(L3kg / R0.4m / r0.1mm)
www.abb.com



Hexapod Gough-Stewart platform
Used for simulators / milling machines

Falcon joystick
3 leg parallel mechanis
www.novint.com

- ✔ Industrial applications are recent (simulator, positioning device, pick and place, milling machine)
- ✔ Small workspace but good precision
- ✔ High accelerations (100g)
- ✔ High precision
- ✔ New structures are synthesized each year
- ✔ Resource on parallel machines: www.parallemic.org

Isoglide 4 T3R1
A Decoupled Parallel Manipulator

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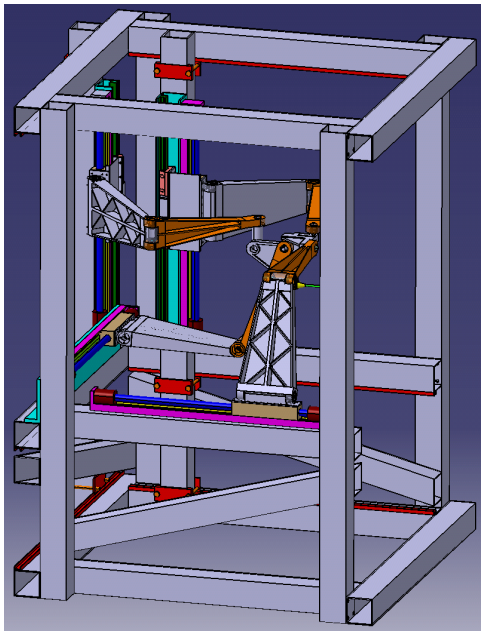
- ✔ Original idea of G. Gogu
- ✔ Isoglide family of robots
- ✔ Isoglide 4 T3R1 decoupled in translation
- ✔ Unitary Jacobian



IFMA INSTITUT FRANÇAIS DE MECANIQUE AVANCEE — LaMI

Isoglide 4 T3R1
www.ifma.fr/lami

Surgery Manipulators

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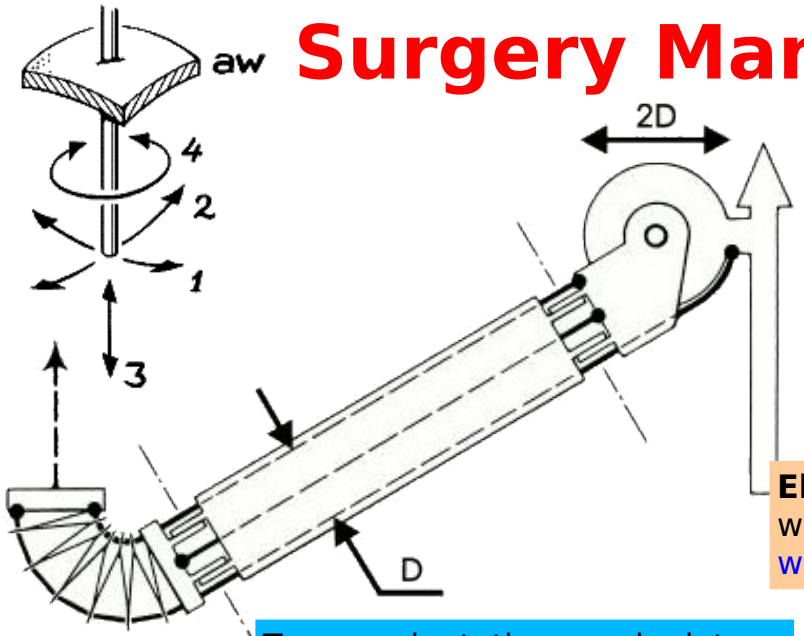
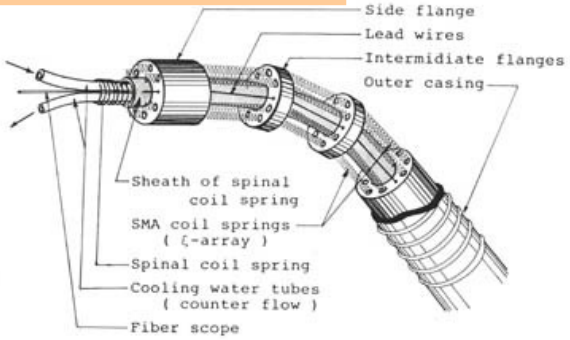
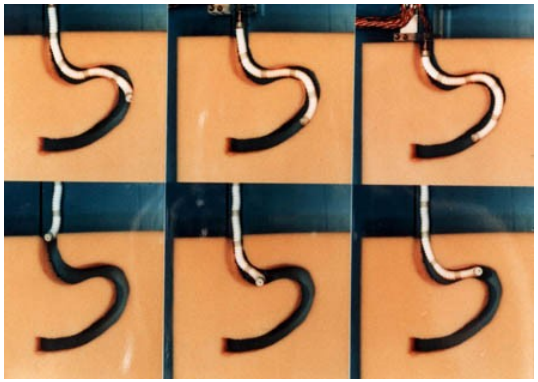


Elastor endoscope
with SMA actuators
www-robot.mes.titech.ac.jp

Trump orientating manipulator for laparoscopy
www-robot.mes.titech.ac.jp





Surgery Manipulators

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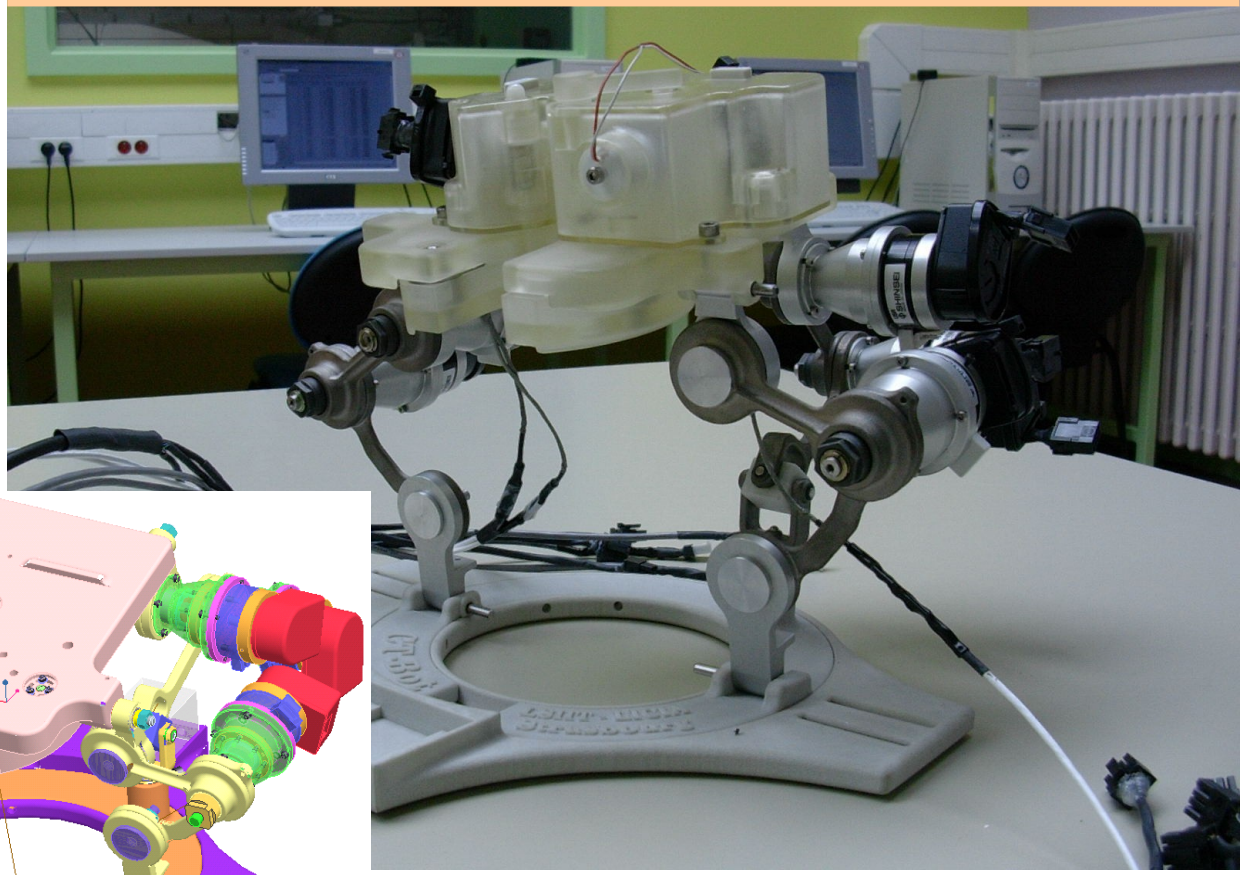
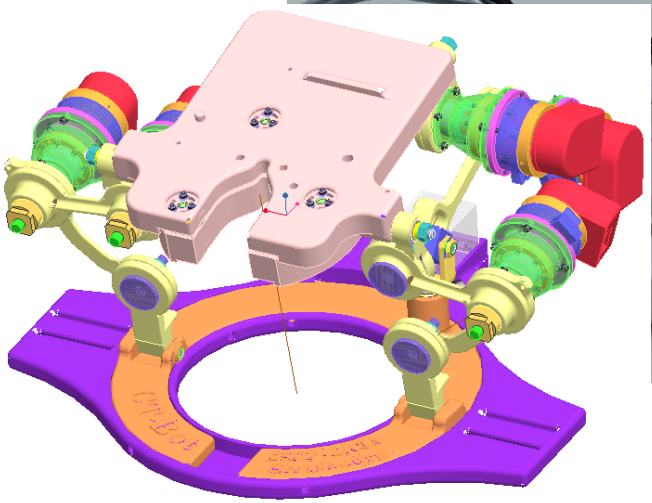
CT-Bot
5DOF parallel robot for needle insertion guided by **C**omputer **T**omography (the surgeon avoids to work among X-Rays)
lsiit.u-strasbg.fr





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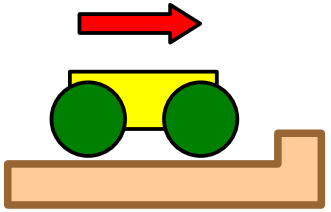
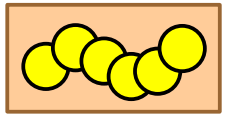
Mobile robots

Terrestrial vehicles

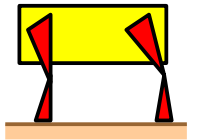


- **Wheeled** vehicles prevail (energetic efficiency ?)
- Blocked on **slope discontinuities** of the ground
- Legs / Tracks regain interest for **climbing**

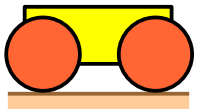
Interface with the ground



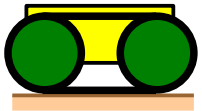
- **Crawler** + multiples contacts, can cross obstacles & rough terrain
  - require high energy, moderate speed, complex control



- **Leg** + can cross obstacles and go fast on rough terrain
  - contact discontinuity, energy cost, stability control



- **Wheel** + fast on smooth surface, energy efficient
  - cannot climb obstacles or run on rough terrain



- **Track** + permanent stability, high traction
  - high friction energy loss, particularly during steering

Steering

- Most of the vehicles have **non holonomic behaviour**

  E.g. a car cannot **go sideways** without a **manoeuvre**
  Going sideways is **non controlable**, although **possible**

- Holonomy is brought by **omnidirectional** propulsion

Crawling mobile robots

- ✔ Several **modes** (slide-pushing, peristaltism...)
- ✔ Suitable for inspection tasks (pipes...)
- ✔ **Solid ground** / **water**

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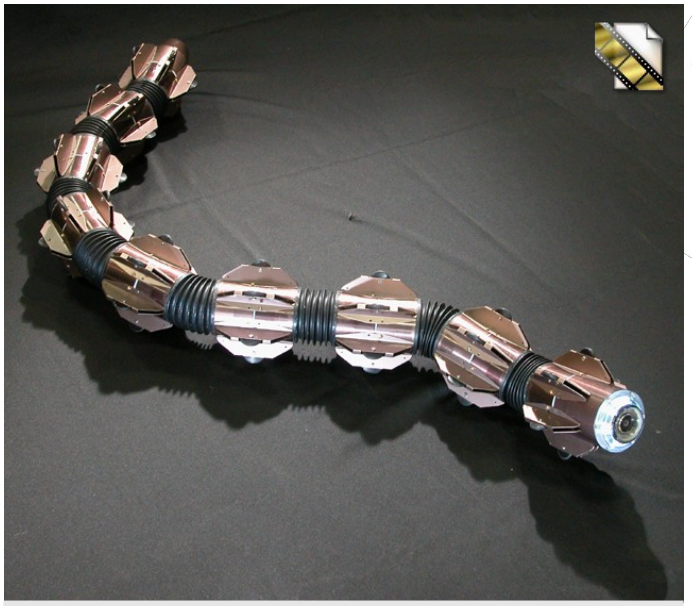

Active Cord Mechanism ACM-R5
7.5kg, 1.7m long, 80mm diameter
Snake propulsion on ground and water
www-robot.mes.titech.ac.jp

Aiko
7kg, 1.5m long, 20 DOF, 2.5 Nm
Obstacle-aided locomotion, slidewinding
www.sintef.no

Mobile robots based on legs

- ✔ Bi / Quadri / Hexa / Octo
- ✔ Gait study based on nature
- ✔ Gait self-teaching

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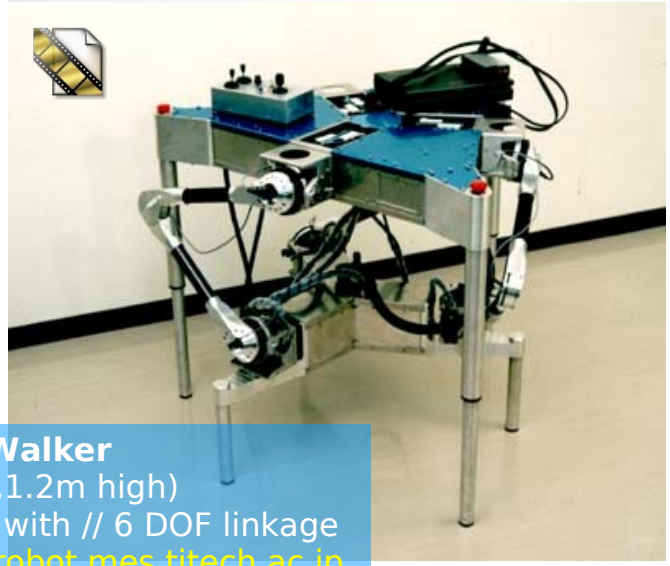
Big Dog (75kg, 1m long, 6km/h, 35° slopes, 150kg payload)
www.bostondynamics.com

Resilient walker
Gait self-teaching
Functional damage compensation
ccsl.mae.cornell.edu



ParaWalker
(50kg,1.2m high)
Biped with // 6 DOF linkage
www-robot.mes.titech.ac.jp

Mobile robots based on legs

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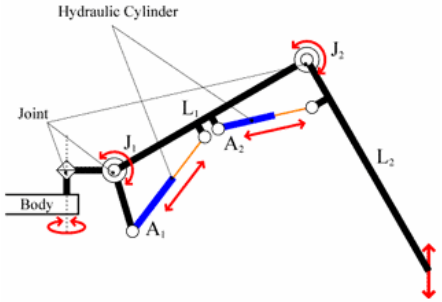
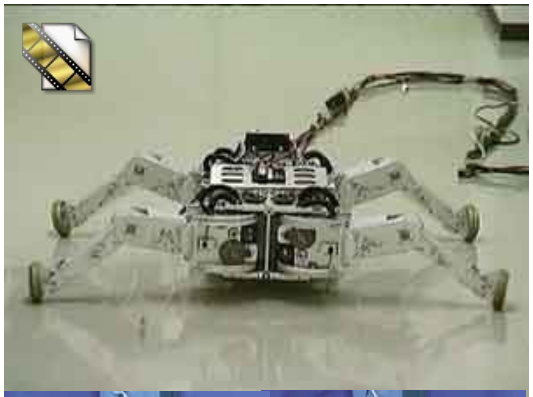
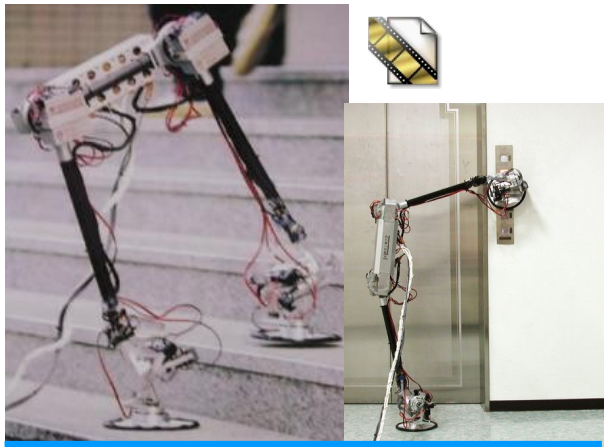
Titan XI
(7000kg, leg 3.7m)
Climbing&heavy drilling
www-robot.mes.titech.ac.jp





Roller-Walker (24kg, 0.5m long) Convertible wheels
Dual locomotion mode: walking / roller-skating
www-robot.mes.titech.ac.jp



Yanboo III
(13kg,0.7m high)
Biped with suction/rolling effectors
Legs are manipulators
www-robot.mes.titech.ac.jp

Wheeled & tracked robots

- ✔ Wheel: energy efficient even when steering
- ✔ Only exception : **skid steering**

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Pioneer P3-AT
Skid steering simple robot
www.mobilerobots.com

Nomad
Dual Ackermann steering strategy
www.frc.ri.cmu.edu/projects/lorax

Wheeled & tracked robots

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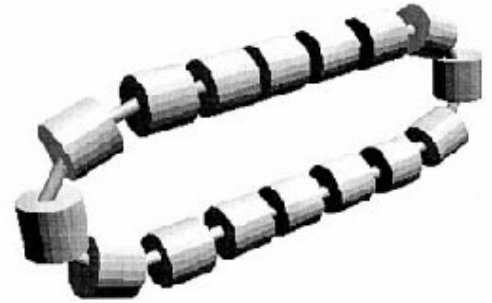
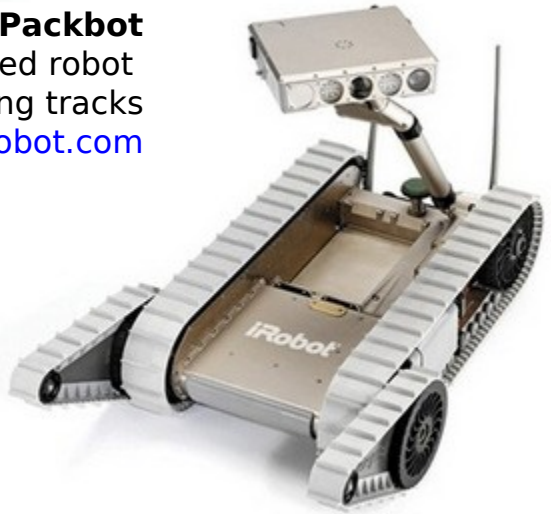
- ✔ Tracks: good traction but steering generates wear

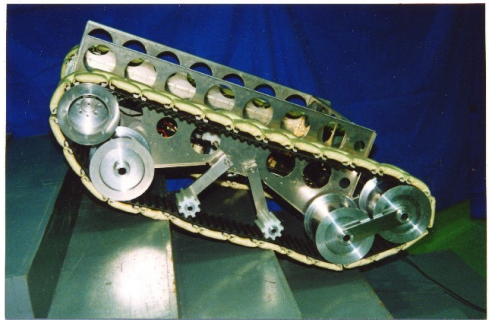


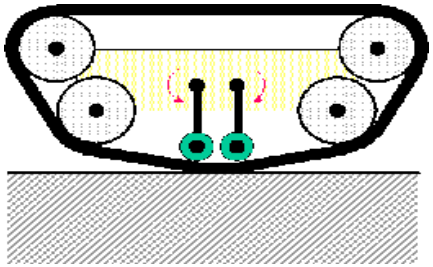
Vuton
4 Omnidirectional tracks
Holonomic vehicle
www-robot.mes.titech.ac.jp

Packbot
Tracked robot
with auxilliary climbing tracks
www.irobot.com



Xevius
Tracked robot
with reconfigurable polygon
www-robot.mes.titech.ac.jp





Adaptative Wheeled Robots

- ✔ **Minimally actuated frame**, energy efficiency
- ✔ Simple control

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Rocky 7
Adaptative rocker-bogie structure
www-robotics.jpl.nasa.gov

Micro5
Climbing abilities via 5 wheels
www.mit.edu/~ykuroda

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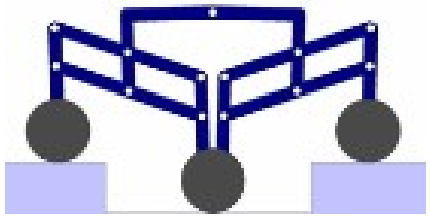
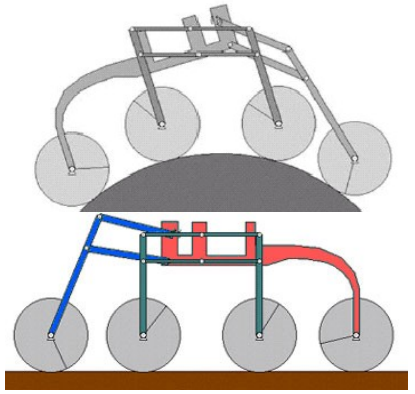
Crab I
Adaptative parallel bogies
Obstacle climbing abilities
www.asl.ethz.ch



Shrimp
6 wheels on 2 // bogies
and 1 front linkage
www.asl.ethz.ch



Hybrid multi-mode robots

- ✔ Highly **actuated** frame
- ✔ **Orientable tracks** for special modes of displacement

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Azimut
4 orientable tracks
www.gel.usherbrooke.ca/laborius

Helios VII
2 articulated tracks + 1 manipulating arm with hybrid grip/wheel end effector
www-robot.mes.titech.ac.jp

Hybrid multi-mode robots

- ✔ **Highly actuated** frame
- ✔ Displacement modes: **peristaltic** crossing, obstacle **climbing**

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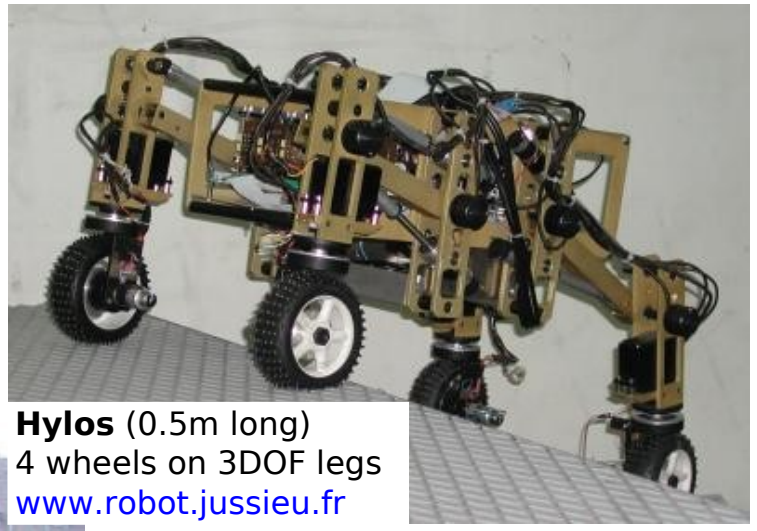
RobuROC 6 (150 kg, 1.5m long)
3 tiltable axles with passive warping
Able to turn on itself
Can climb obstacles
www.robosoft.fr



Hylos (0.5m long)
4 wheels on 3DOF legs
www.robot.jussieu.fr

Lama
Peristaltic crossing
of sandy areas
www.laas.fr

A Hybrid multi-mode robot OpenWHEEL i3R

- ✔ OpenWHEEL **i3R** robot
- ✔ **Stable** obstacle climbing with **only 4** wheels
- ✔ Only one supplemental **central actuator**

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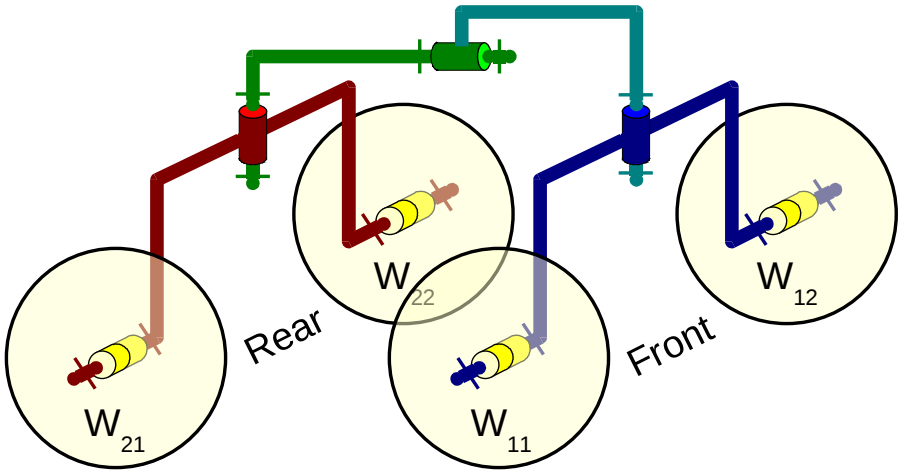
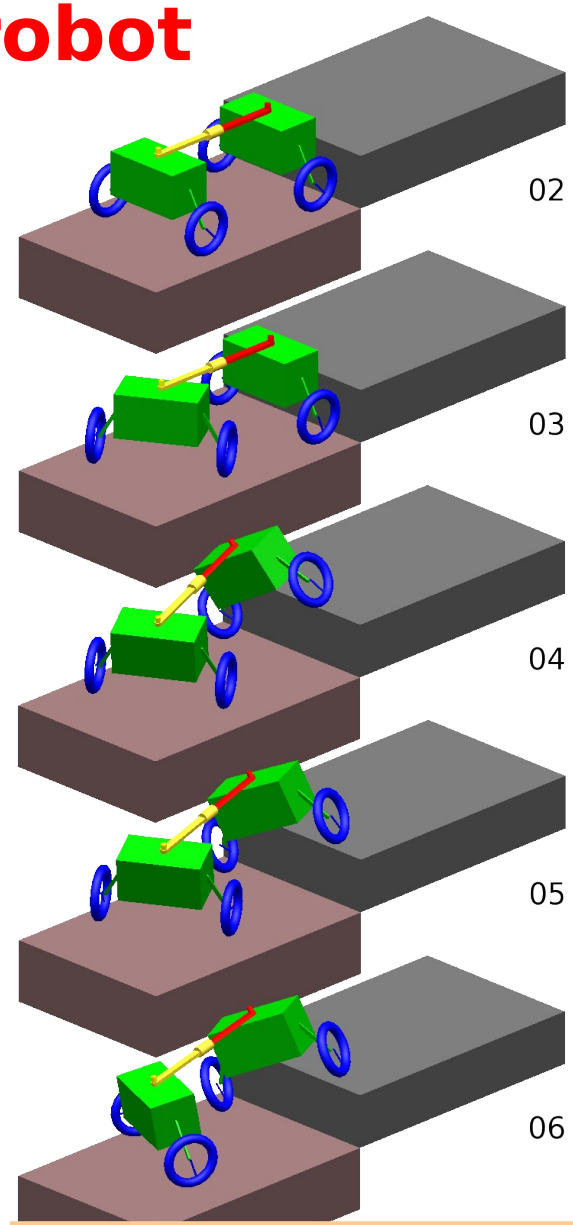
OpenWHEEL i3R
A big central actuator for warping





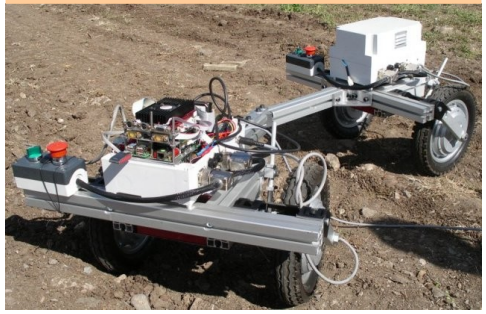
OpenWHEEL i3R
jc.fauroux.free.fr
www.ifma.fr/lami

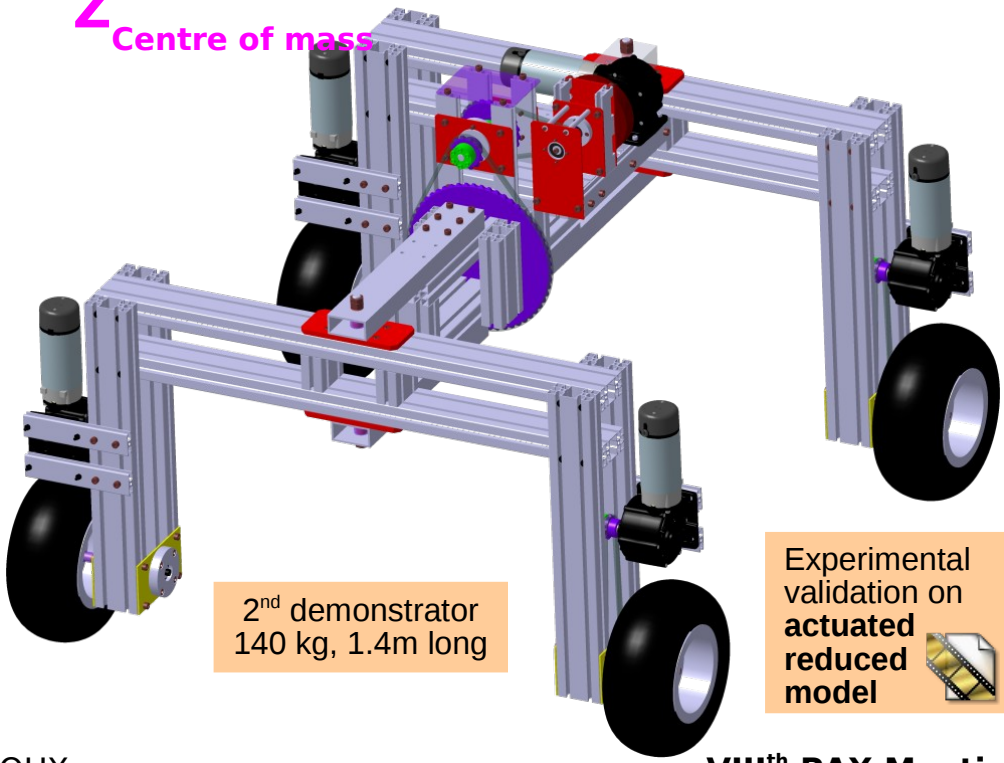
A stable **climbing process**
Multibody validation (Adams)

A Hybrid multi-mode robot OpenWHEEL i3R

- Climbing process in **19 stages**
- Climbs obstacles as high as **66%** of $Z_{\text{Centre of mass}}$

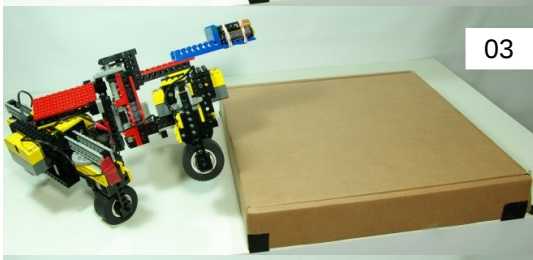
First demonstrator at scale 1:1

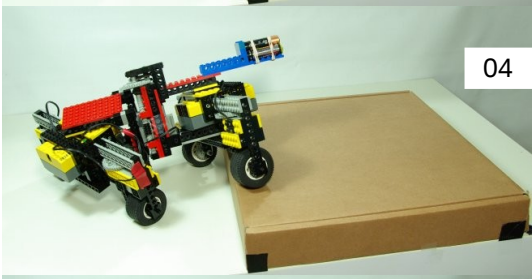




2nd demonstrator
140 kg, 1.4m long

Experimental validation on **actuated reduced model**





New trends in robotics

- Robots
- Manipulators
- Mobile
  - Crawler
  - Leg
  - Wheel-Track
  - Hybrid
  - Special
- Humanoids
- Modular

Special robots

- ✔ Flying **drones** become popular
- ✔ Aero-terrestrial **cooperation**
- ✔ **Underwater** drones

New trends in robotics

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Dragonfly Nanodrone
120mg, 6cm wide, 80mW
SMA actuators on the wings
www.silmach.com

Minidrone
www.bertin.fr

Alistar 3000
5m long, 2800kg
Depth 3000m
www.eca.fr

Seaglider
1.8m long, 52kg
Range 1000km
Depth 1000m
www.irobot.com

New trends in robotics

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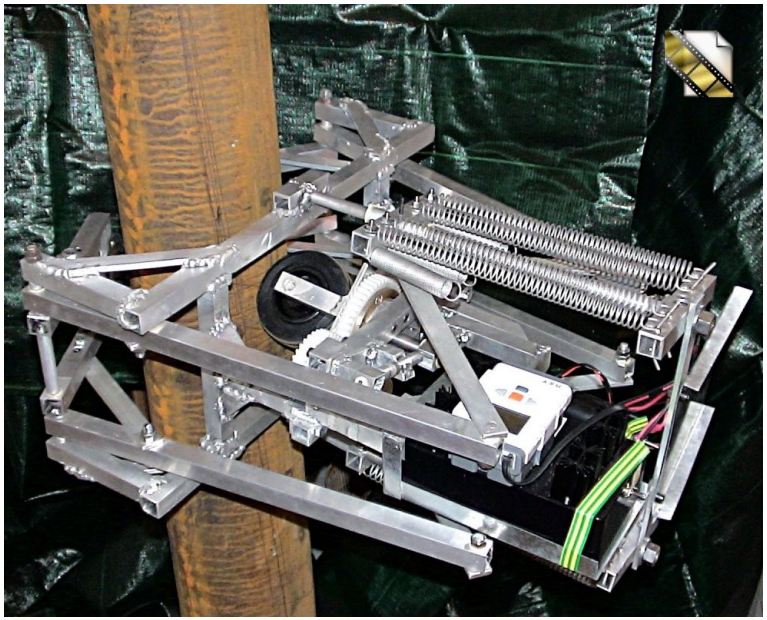
Special robots

✔ Pole climbing



Pobot V2
Pole climbing robot
Cannot fall, can turn around the pole
jc.fauroux.free.fr
www.ifma.fr/lami

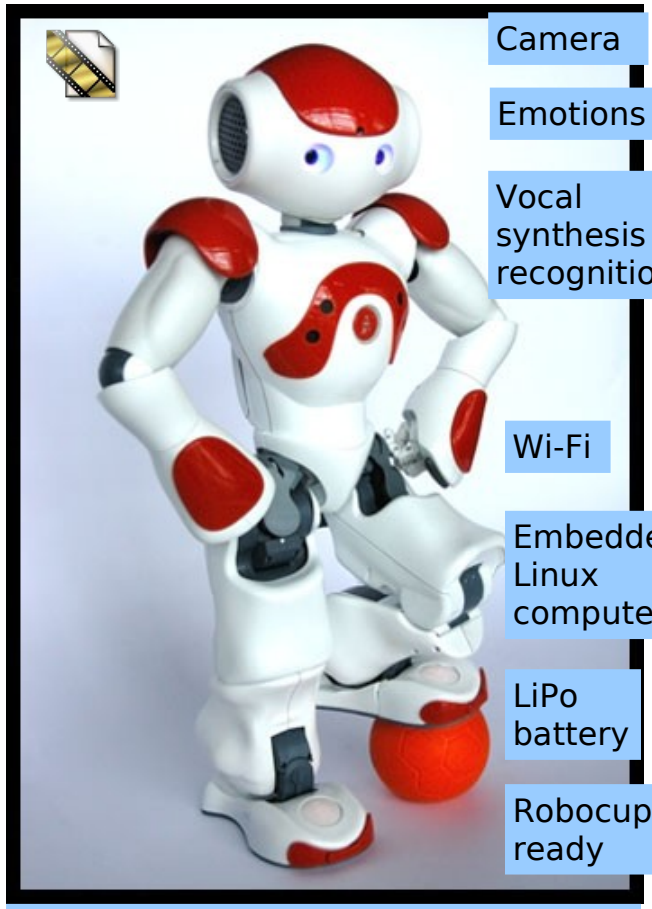
✔ Pipe exploring

MagneBike
2 magnetic wheels with anti-locking rollers
www.asl.ethz.ch

Human-like robots

- ✔ Humanoid = 1 **walking** robot + 2 **manipulators**
- ✔ New applications : **companion** robots

Asimo
24 DOF, 52 kg, 1.2m high
world.honda.com/ASIMO



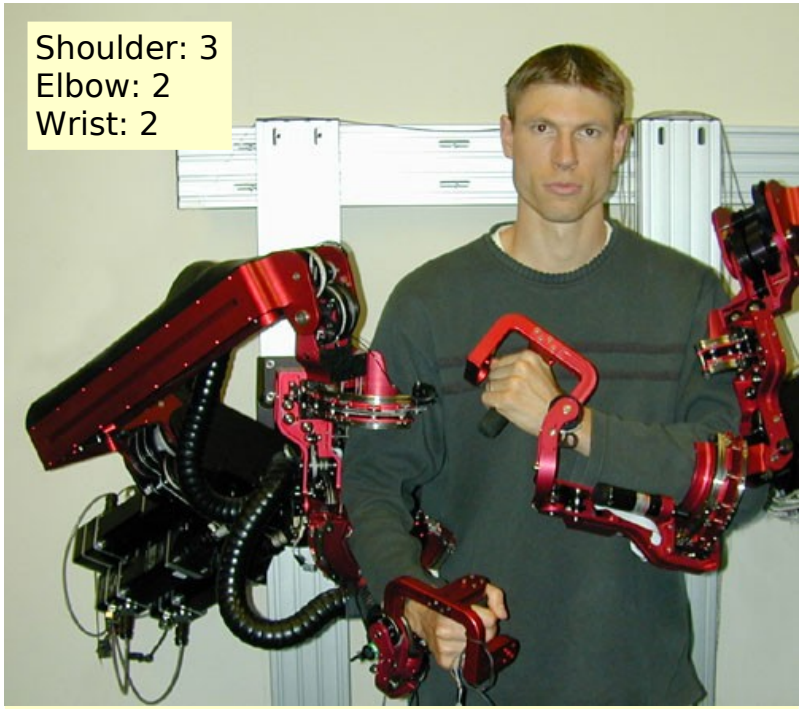
Nao
25 DOF, 0.58m high, 3k€
www.aldebaran-robotics.com

Exo-skeletons

- ✔ Bio-compatible
- ✔ **Haptic** device + Force **amplifier**
- ✔ Specialized on a limb (arm/leg)

New trends in robotics

- Robots
- Manipulators
- Mobile
- Humanoids
  - Human-like
  - Exo-skeletons
- Modular
- Conclusion



Wearable robotics - Exoskeleton
7DOF, Neural control
brl.ee.washington.edu

ReWalk robotic suit
For walking / lifting from seat
www.argomedtec.com

Modular Robotics Kits

- ✔ From toys to industry
- ✔ Cost-effective / maintainability

New trends in robotics

- Robots
- Manipulators
- Mobile
- Humanoids
- Modular
  - • Kit approach
  - • Self-reconfig.
- Conclusion

Mindstorms NXT
Control box, Bluetooth,
3 actuators 2W 50Ncm
Sensors (contact / sound / US / light / ...)
mindstorms.lego.com

Bioloid
Servomotors AX12 150 Ncm
Sensors (distance / light / heat / ...)
www.robotis.com

Ranked 1st and 2nd in France 2007. Source : www.robopolis.com

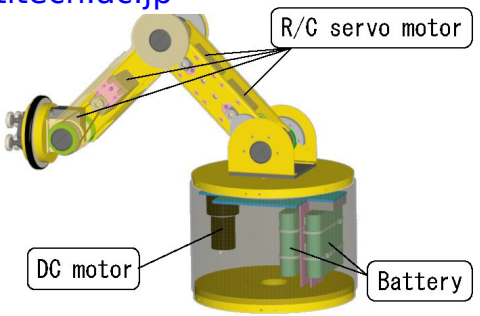
Self-reconfigurable robots

New trends in robotics

- Robots
- Manipulators
- Mobile
- Humanoids
- Modular
  - Kit approach
  - Self-reconfig.
- Conclusion

- ✔ Robot with detachable limbs

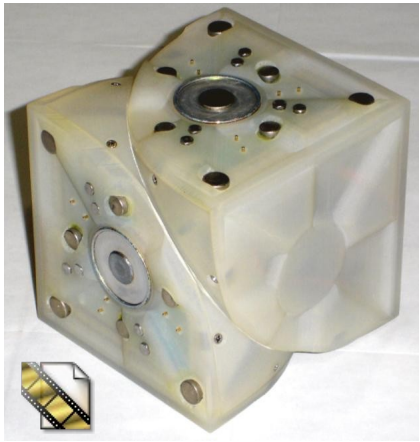
SMC Rover and **UniRover**
6 wheels on detachable legs
www-robot.mes.titech.ac.jp



- ✔ Self-attaching modules
- ✔ Towards auto-replication / cloning

M-TRAN III
Self reconfigurable robot
Locomotion and Adaptation
unit.aist.go.jp/is

The next step:
robot **breeding**



Molecube
Auto-cloning
ccsl.mae.cornell.edu

New trends in robotics

- Robots
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Conclusion

- Manipulators
  - ✔ **Serial** manipulators reached industrial **maturity**
  - ✔ **Parallel and hybrid** architectures may improve **dynamics** and **precision**
- Mobile robots
  - ✔ No locomotion mode is perfect
  - ✔ Improved architectures: engines **distributed** on the wheels, **wheels on legs**
  - ✔ Innovative architectures already exist (e.g. for **spatial** robots)
- Humanoids
  - ✔ **Realism** and **energetic autonomy**
  - ✔ Companion robots with improved **interaction** and **expressivity**
- Modular robots
  - ✔ Modularity for **reliable** and **cost-effective** building of **anything**
  - ✔ Control via portable software development kits, limb and behavior libraries