SURGICAL ROBOTICS

Montpellier, France

Pôle Universitaire Européen de Montpellier et du Languedoc-Roussillon

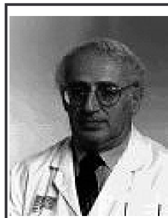
Laboratoire d'Informatique de Robotique et de Microélectronique de Montpellier
LIRMM

Frontiers of Endoluminal Robotics Surgery (Part 3)

Cesare Stefanini

Scuola Superiore Sant'Anna
Pisa, Italy

a lab of inventors and entrepreneurs



Sir Alfred Cuschieri, MD

The operating room of the year 2030 will be a totally different environment than today

MASS Screening and EARLY diagnosis will have a major impact on the type and invasiveness of required surgical procedures

The combination of micro/nano tecnologies and microrobotics will enable to perform active monitoring and diagnostics in advanced and early manners, and will be also one of the key technologies enabling future high quality, early and minimal invasive surgery

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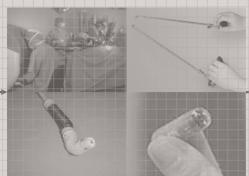
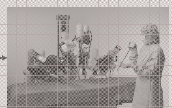
Evolution of surgical robotics

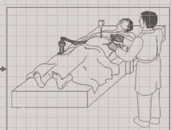
Past



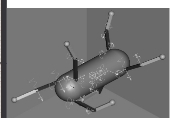
Present



Traditional robots:
- more functional
- less invasive
- novel procedures



Hand-held robots:
- selective use
- more ergonomic
- teleoperated



Endoluminal robots:
- non-invasive
- semi-autonomous

Future

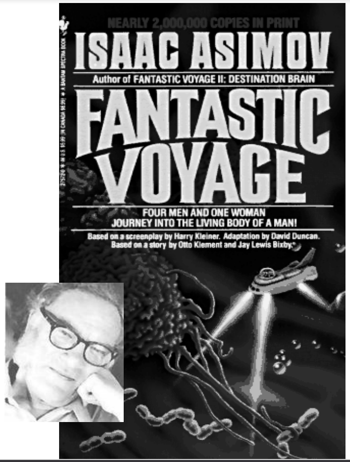
Trends in Computer Assisted Surgery

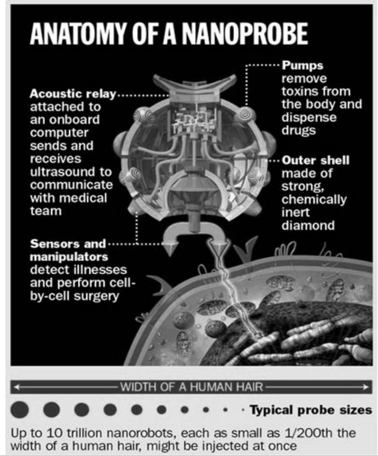
- Observing surgeon's actions and reproducing them by a robot, with the goal of increasing the accuracy and ultimately the quality and predictability of intervention
- Extending surgeon's capabilities in space (teleoperation) and size
- Augmenting surgeon's capabilities by means of hand-held instruments
- **Extending surgeon's capabilities and reducing invasiveness by endoluminal surgery**

The objective of Endoluminal Surgery

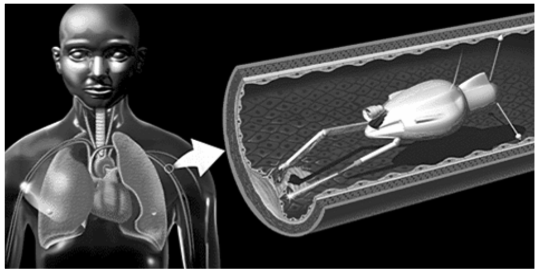
Bringing a set of **miniaturized tools** for **visualization**, **diagnosis**, **therapy**, **surgery**, **measurement**, etc., through a **minimal access** to sites within the human body which are **remote or difficult to reach**

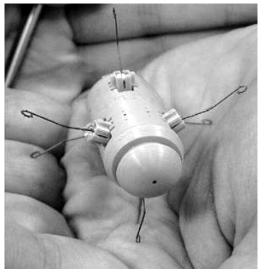
Science Fiction…?





…or Engineering Dream?

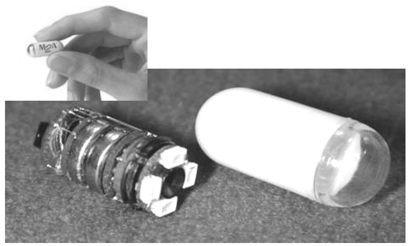




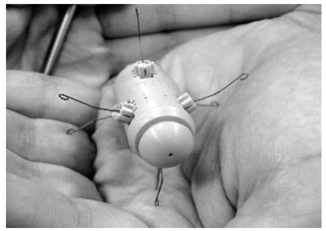
Research on endoluminal microrobotics aims **to define theory and design methods, and to develop suitable fabrication technologies**

Endoscopic Microcapsules

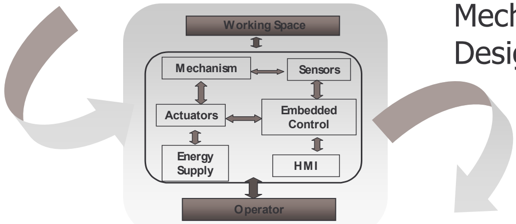
- Autonomous capsules able to navigate within internal lumens of the body
- Able to perform tasks by remote control, in wireless conditions.
- Very low invasiveness.
- Applications: gastroenterology, …



Endoscopic capsule for small bowel diagnosis (Given Imaging Ltd, Israel).

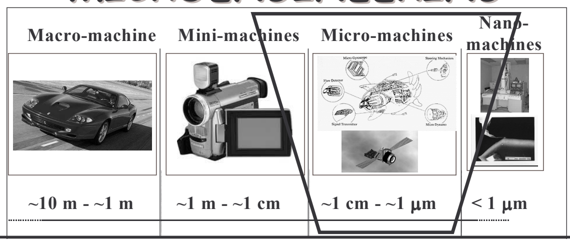


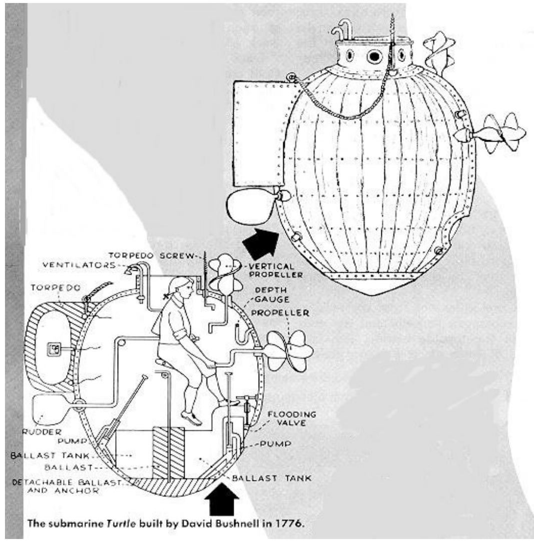
Legged endoscopic capsule able to locmote in the GI tract (Scuola Superiore Sant'Anna, Pisa).



Mechatronics Design Paradigm

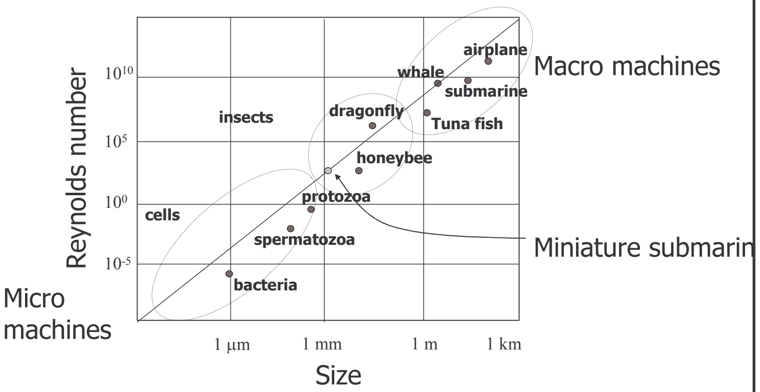
A New Engineering Discipline:
MICROENGINEERING





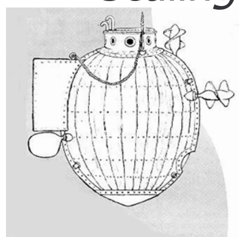
Scaling a Submarine from a diameter of 2.5 m down to a diameter of 1 mm

Reynolds number: $\dfrac{\text{inertial force}}{\text{viscous resistance}}$



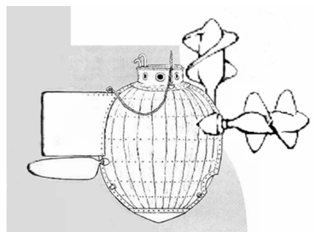
The lesson from nature: viscous resistance is dominant in small biological machines

Technical Sheet
Scaling of Performances



2.5 m

Propulsion type:	*Human*
Speed:	**0.5 m/s**
Engine Power:	**200 W**
Propeller efficiency: 0.9	



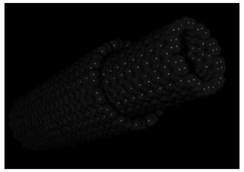
1 mm

Propulsion type:	*Electrical*
Speed:	**0.1 mm/s**
Engine Power:	**1.3 µW**
Propeller efficiency: $3.5\ 10^{-8}$	

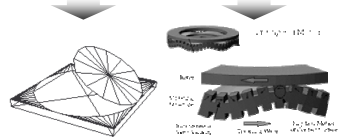
Scaling mechanisms: useful hints

Improving the fabrication accuracy up to the atomic level, thus having actual symmetry and balancing of the Van der Waals forces

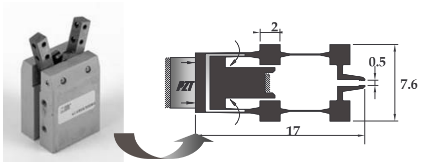
(e.g.: nanotubes fabricated using transmission electron microscope)



Find smart solutions which exploit friction (e.g.: wobble motors, traveling wave ultrasonic motors).



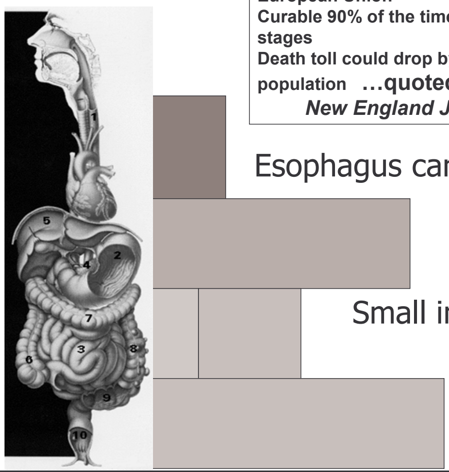
Using parts connected by elastic joints rather than separate moving parts



Surgical and Diagnostic Robots: applications

Type of Interaction	Type of Access: Traditional Access	Minimally Invasive Access	Endocavitary/ endoluminal access
Autonomous systems	ROBODOC CASPAR	Stereotaxis Inc	Endoscopic Microcapsules
Interactive systems	Eye scalpel RinC	AESOP MIAS	Active Catheters
Teleoperated systems	Mammotome PAKY	da Vinci ZEUS	Neuro-endoscopy
Passive systems	PinPoint	HALS (non robotic)	Given Imaging (non robotic)

Colon cancers are one of the deadliest but most preventable malignancies
Kills 437 000 people worldwide each year, 98 500 from the European Union
Curable 90% of the time, if detected and treated in the earlier stages
Death toll could drop by 50 to 75% with mass screening of the population ...quoted from
New England Journal of Medicine (20 March, 2000)



Esophagus cancer

Stomach cancer

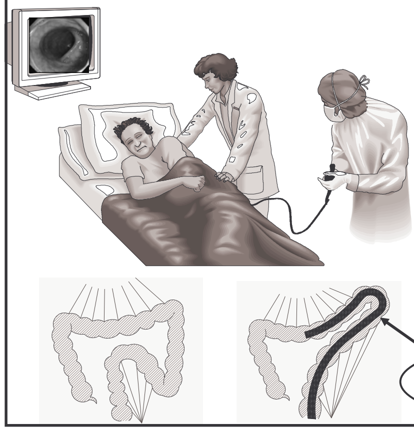
Small intestine pathologies

Colon Cancer

Colon-Rectum Cancer

Drawbacks of Conventional Colonoscopy

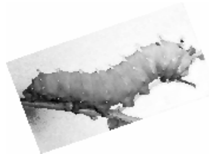
- Pain and disconfort for the patient
- Complex and demanding procedure for the medical doctor



- The active part of the colonoscope is the head incorporates the visualization system (optical fibers or camera, optics, illumination)
- The head must be inserted along the colon by maneuvering and pushing, from outside the body, a relatively stiff shaft
- These actions stretch the colon and originate pain

Robotic endoscopy of the gastrointestinal tract and beyond: a grand challenge

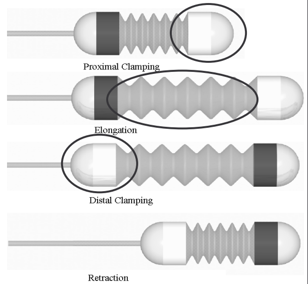
"Inchworm" locomotion for novel PAINLESS colonoscopy



Distal clamper

Central elongator

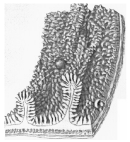
Proximal clamper

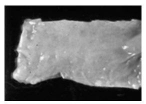


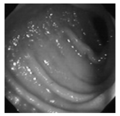
Typical colonoscopy prototype

Diameter : 24 mm
Retracted Length : 115 mm
Elongated Length : 195 mm
Stroke: 80 mm

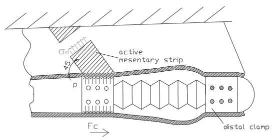
Step 1 - Understanding the colon environment



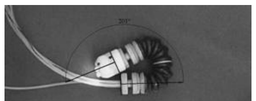




Step 2 - Modeling locomotion: adhesion and motion



Step 3 - Designing appropriate engineering solutions



Elongator:

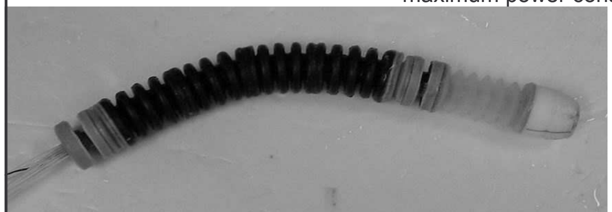
retracted length:	115 mm
stroke length:	115 mm
stiff part length:	13 mm
effective stiff part length:	16 mm
theoretical speed:	≈18 cm/min
elongation ratio:	200 %

Camera:

Size:	ϕ12 mm X 12 mm
Resolution:	200.000 pixels
Illumination:	5 ultrawhite LEDs

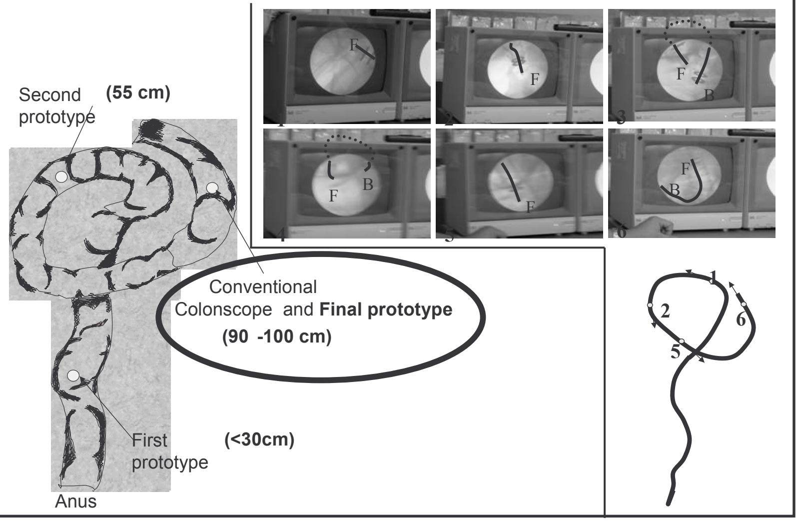
Steering mechanism:

maximum angle:	± 90 °
average response time:	2 s
maximum power consumption:	850 mW

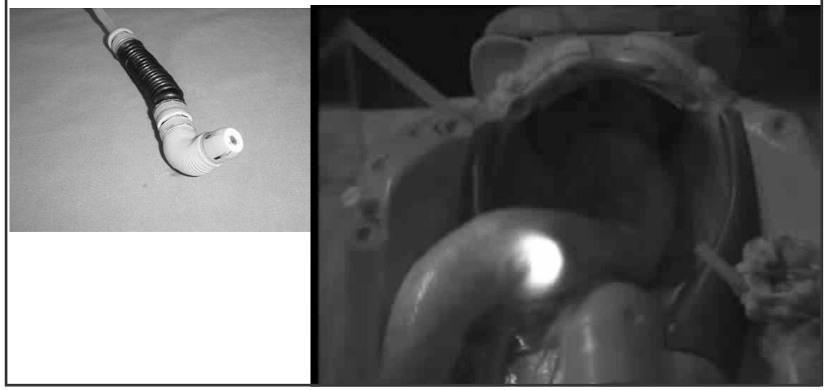


- **Dario P., Carrozza M.C., Pietrabissa A., "Development and in vitro testing of a miniature robotic system for computer assisted colonoscopy", *Computer Aided Surgery, Vol. 4, (1999)***
- **Dario P., Carrozza M.C., Pietrabissa A., Magnani B., Lencioni L. "Endoscopic Robot", *United States Patent No. 5,906,591, May 25, 1999***
- **L. Phee, D. Accoto, A. Menciassi, C. Stefanini, M.C. Carrozza, P. Dario "Analysis and Development of Locomotion Devices for the Gastrointestinal Tract" *IEEE Trans. Biomed. Eng., June 2002***

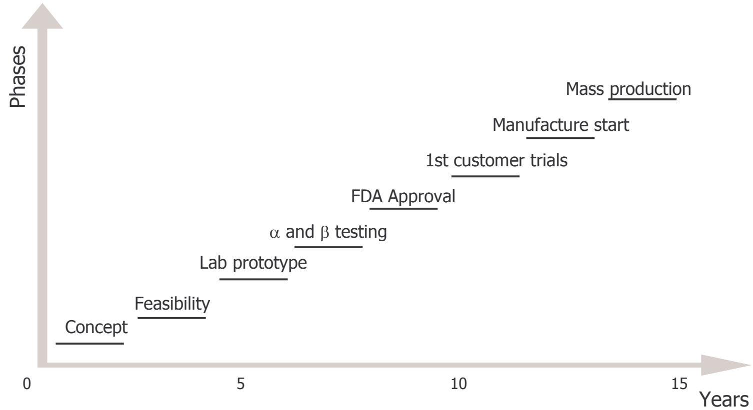
Final results



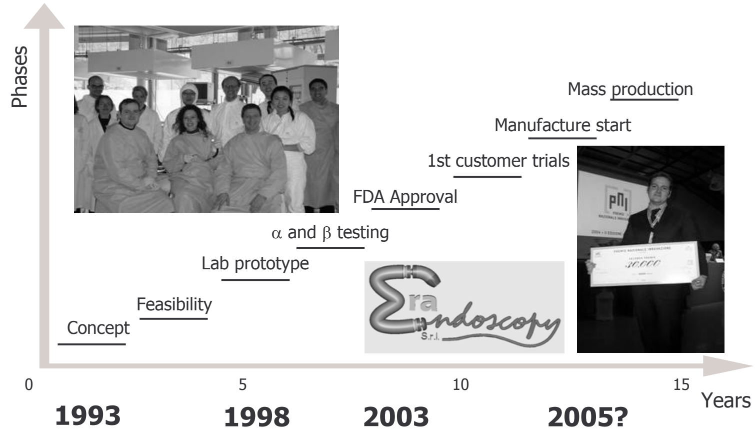
In vitro tests of the final (**teleoperated**) system for painless colonoscopy ("EMIL" Project, funded by IMC, Korea)



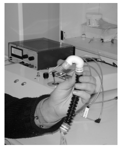
Development phases of a new biomedical device



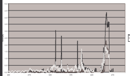
Development phases of the new painless colonoscopy system

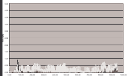


The Product: E² system

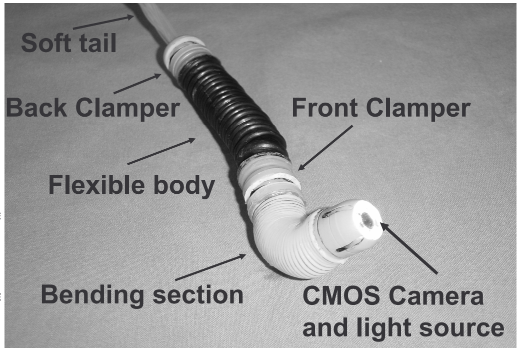


Steering capabilities of the E² system

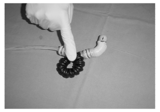




Force profiles during colonoscopy: Traditional colonoscopy Vs E² system



Fully covered by International Patent N°: WO 02/068035 A1



Flexible capabilities of the E² system

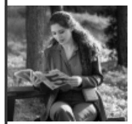
Control rack: it will be possible to integrate the whole control unit in an embodiment, with overall size comparable to the size of a briefcase

The device is composed of a very flexible body, that allows painless locomotion within the human colon. Thanks to the highly technically advanced clamping system, the robot travels along the bowel lumen as an inchworm

Future scenario for endoscopy: miniature/micro endoscopes inside the body

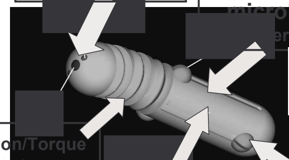
Inside the body

Outside the body



CMOS camera

On-board micro battery (... Supply)



Bellow (Motion/Torque Converter)

On board Energy Converter (minimotor, SMA, EPAM, etc.)

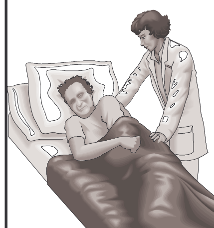
Contact and position sensors

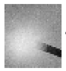
Human monitoring and Diagnosis (Controller)

1. Traditional endoscopy: mechanisms, actuation and control all outside the body

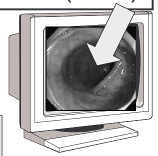
Inside the body

Outside the body

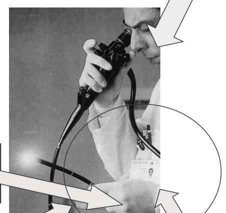




CCD (Sensor)



Human registration and control (Controller)



Hand (Energy Converter)

Human Force (Power Supply)

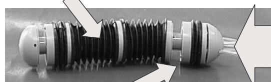
Wrist (Motion/Torque Converter)

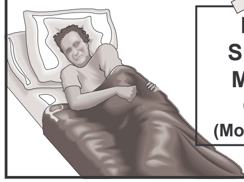
2. New scenario for endoscopy: some components inside the body, some outside

Inside the body

Outside the body

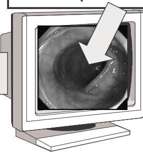
Bellows (Motion Converter)





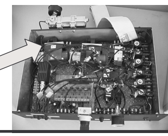
Pressure, Suction and Mechanical Grasping (Motion Converter)

CCD (Sensor)

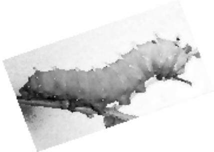


Human control (Controller)

Pneumatic distributor (Power Supply and Energy Converter)



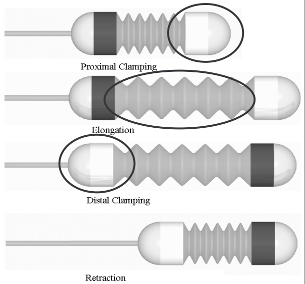
Painless colonoscopy system based on "inchworm" locomotion



Distal clamper

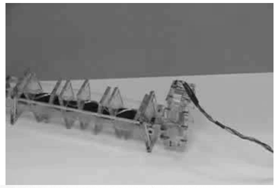
Central elongator

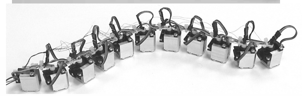
Proximal clamper



Typical colonoscopy prototype
Diameter : 24 mm
Retracted Length : 115 mm
Elongated Length : 195 mm
Stroke: 80 mm

Model and simulation of the *polychaete* locomotion mechanism





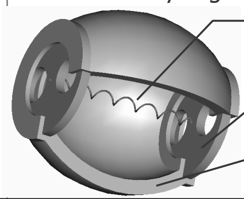
Many DOFs and redundancy BUT implementation with single actuator (pattern generator)

J. Vincent et al., Bath University (2002)

Artificial earthworm design

Main issues

- design of segments with constant volume and ability to contract/enlarge circumferentially by 25% and to contract/enlarge longitudinally by 60%
- no major constraint on segment force: propulsion force is produced by anchoring setae and by peculiar peristaltic waves rather than by segment traction/elongation force



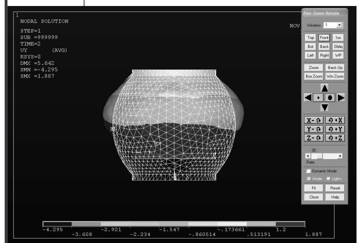
Shape Memory Alloy "agonistic" spring: it contracts when actuated

Brass disk separating the modules and allowing electrical connections

Silicone shell acting as antagonistic structure

According to the analogy with segments of biological earthworms, the artificial module possesses *active* longitudinal muscles and *passive* circular muscles

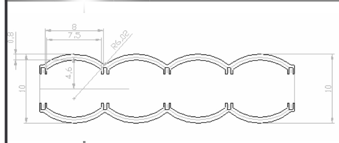
Artificial earthworm design: details



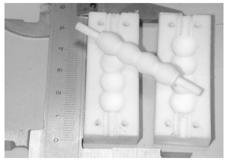
Segment details

- Diameter 1 cm and length 1 cm in rest position
- each segment includes 1 or 3 SMA springs in parallel with diameter ranging between 350 μm and 600 μm. The springs are obtained by SMA wires with diameter of 50 μm, 75 μm or 100 μm, depending on the required performance
- average force generated by one segment: 0.3 N
- silicone shell fabricated by Silastic 3483 (Dow Corning). Based on ANSYS

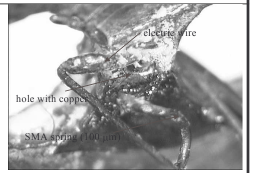
Artificial earthworm fabrication



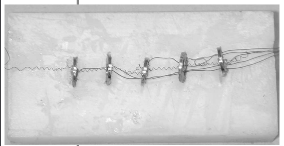
Silicone mould design with 4 segments and 5 disks



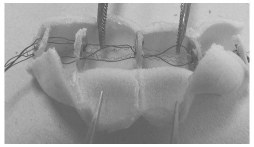
Mould for the silicone shell



Electrical connection between brass disk and SMA spring by copper electrodeposition



Earthworm skeleton

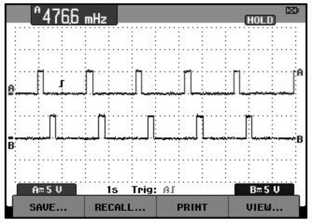


Covering by silicone shell

Final earthworm

Locomotion performance without anchoring legs

The driver produces a sequential contraction of the 4 modules. When 1 module is active the other 3 are at rest.

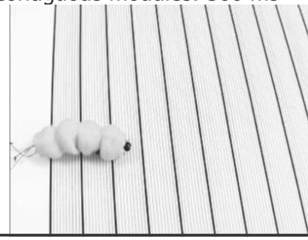


Activation sequence of two contiguous modules

Typical period of one cycle: 2 s (0.5 Hz)

Typical current peak duration: 200 ms

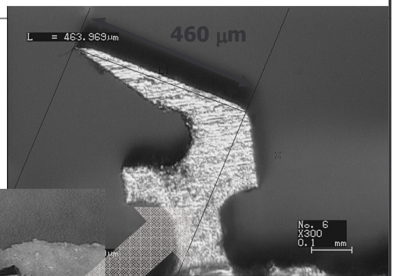
Typical activation delay between contiguous modules: 300 ms

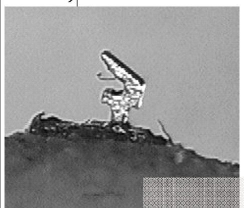


Locomotion performance with anchoring legs

Each segment has been provided with 4 small metal hooks with a specific orientation

(Small polyurethane hooks integrated into the silicone shell are currently developed in our lab)





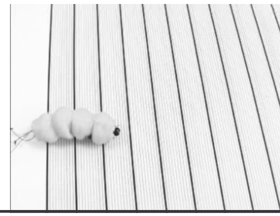
Locomotion performance with anchoring legs on paper substrate

Frequency (mHz)	Current peak duration (ms)	Current (mA)	Energy for module (J)	Velocity on flat surface (mm/s)	Velocity on sloped surface (40°) (mm/s)
330	320	400	0.15	0.7	0.45
530	260	350	0.096	2	1.43
600	130	350	0.05	2.5	1.25

Earthworm with 4 segments and 1 spring for each segment (75 µm in diameter wire, rather than 100 µm. This increases the robot speed)

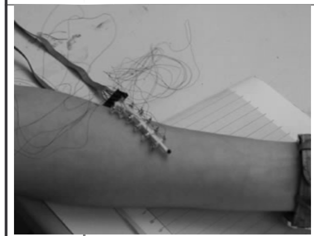
For one complete cycle

V = 2.5 mm/s

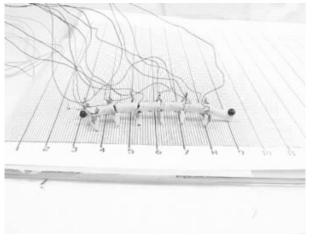


V = 0.22 mm/s

The 5-module SMA artificial polycheata: performance (2/2)



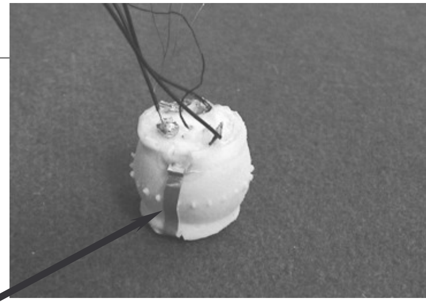
Polycheata with friction enhancement structures (small hooks, as in the earthworm prototype).



Frequency (Hz)	Current peak duration (s)	Current (mA)	Energy for module (J) - (R = 10 ohm)	Velocity on flat surface (mm/s)
0.5	**0.2**	**170**	**0.06**	**1.3**

Next steps: Sensing Element for the SMA module

PVDF film used to detect internal contraction and elongation and external contact



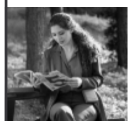
- 3 PVDF strips (3 mm x 30 mm) partially embedded into the polyurethane disks
- PVDF films positioned along both lateral surface and top of the unit

Additional silicone applied over the PVDF strips at the end of the fabrication process

Sensing elements embedded into the shell

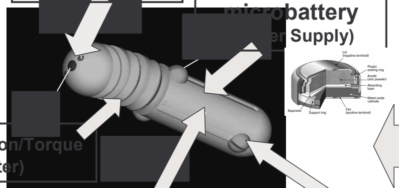
3. Future scenario for endoscopy: miniature/micro endoscopes inside the body

Inside the body



CMOS camera

On-board micro battery ([redacted]er Supply)



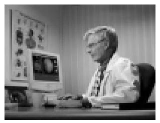
Bellow (Motion/Torque Converter)

On board Energy Converter (minimotor, SMA, EPAM, etc.)

Contact and position sensors

Outside the body

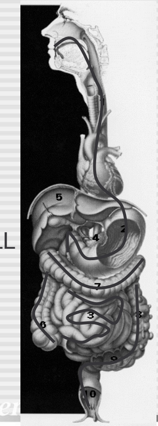
Human monitoring and Diagnosis (Controller)



From EMIL to EMILOC

Smoothly…from inchworm to legged locomotion

Suitable forFULL GI endoscopy



The concept: REVERSING the POINT of VIEW: Instead of forcing the tissue onto the adhesion/clamping area, the adhesion/clamping area is pushed against the tissue, by mounting it at the end of deployable micro-legs/arms

Analysis of legged locomotion

Advantages

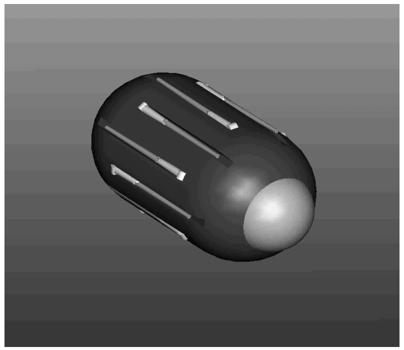
- **Effectiveness**: brachiation mode reduces the ”accordion effect”
- **Fast locomotion**: legs extension enables lever effect and therefore motion amplification
- **Avoiding pathological areas in the gut**: critical areas of gut tissue (e.g.: ulcers, polyps, …) can be bypassed because capsule body is suspended on legs and doesn’t slide over the tissue
- **Adaptability** to different gut diameters (small intestine, colon…), thanks to legs extension
- **Dexterity**: the capsule can turn, rotate, propel, etc., that is perform the 6 DOF of a free body
- **Legs as probes: legs can bring a set of tools enhancing capsule functionalities**
  - **Biopsy tool**
  - **Drug delivery modules**

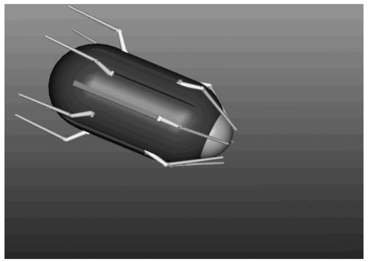
Analysis of legged locomotion

Limitations:

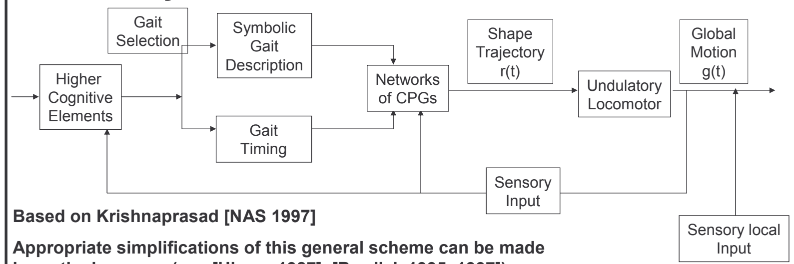
- **Mechanical complexity**: all listed advantages pose significant technological challenges
- **Control complexity**: actuating cooperatively multiple legs and degrees of freedom is difficult to achieve by pure onboard control. Multi-level control architecture (external/internal) should be implemented
- **Energy consumption**: legged locomotion requires several miniature actuators, that may be rather inefficient

Concept of legged microcapsule for endoscopy in the gastrointestinal tract





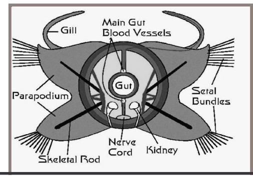
Undulatory locomotion: Motion Control Architecture



Based on Krishnaprasad [NAS 1997]

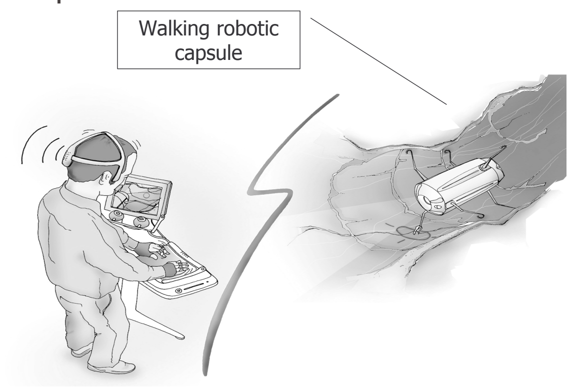
Appropriate simplifications of this general scheme can be made in particular cases (e.g. [Hirose 1987], [Burdick 1995, 1997])

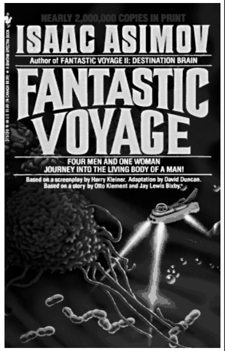
Undulatory creature:
setal sensors and segmented actuators



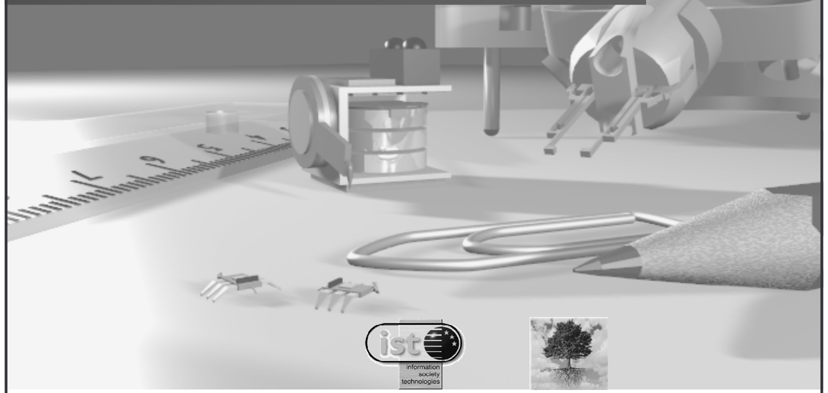
Global motion can be “locally” modified by a single segment sensing and actuating. Every seta is equipped with sense organs (touch receptors) connected to segmented muscle actuators

Guiding a robotic endoscope inside the human body





The **I-SWARM** project: Intelligent Small World Autonomous Robots for Micro-manipulation

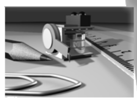


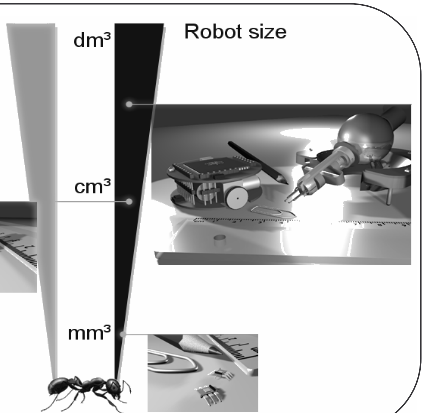
Centre for Research in Microengineering
Scuola Superiore di Studi Universitari e Perfezionamento Sant'Anna

I-Swarm Project Overview

Robot capabilities

- Mimic *some* aspects of ants
- Create a simple ~1 mm³ robot with manipulation capabilities
- Swarm behavior can arise from simple agents
- First mass-produced swarm of (up to 1,000) micro robots
- Easily observable robot swarm
- Freely programmable for swarm experiments
- MST (MEMS) approach: "chip with legs and feelers"



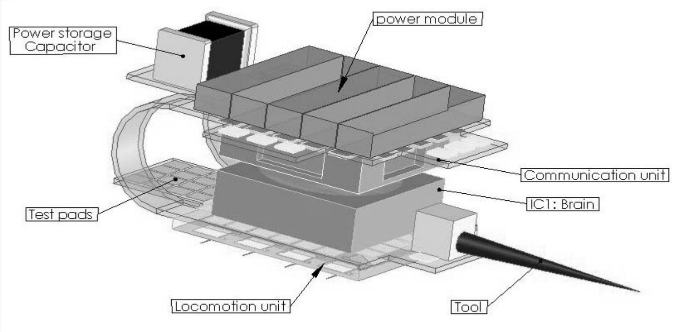


First-year activity presentation

Beyond robotics project **I-SWARM** - IST 507006

I-SWARM - Intelligent Small World Autonomous Robots in Micro-manipulation

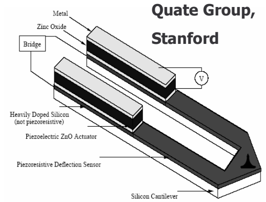
I-Swarm Robot Concept
Year 1

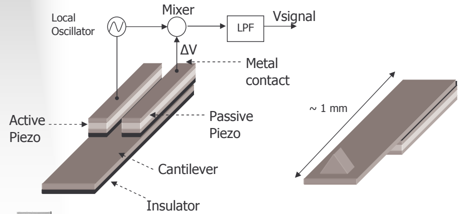


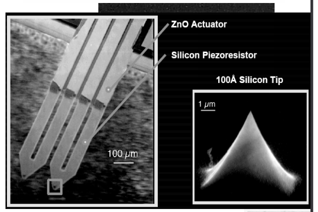
The vibrating needle

- **tactile antenna**: simple and automatic control of the robot to approach small object
- **transport feedback system**: robot aware if it is still carrying an object (additional mass makes the vibration go out of resonance).
- **electrostatic attractor**: in the grasping/releasing phase the cantilever can be polarized (+ or -) to attract/release charged particles, without neutralizing them → insulating layer avoids charge sharing between robot and object. Combined vibration+electrostatic repulsion to release charged particles. For neutral particles only vibration can be used for releasing.

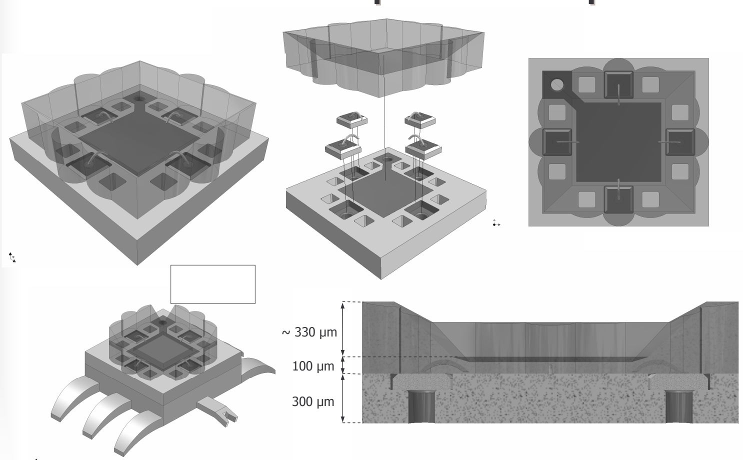
Quate Group, Stanford





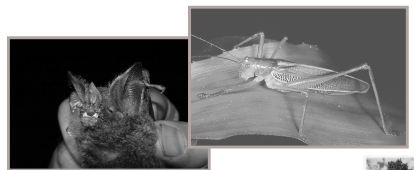


The photonic chip



The LED strategy was proposed to achieve „clustering“

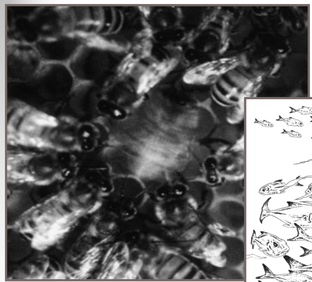
- **Reaching the cluster**
  - **Undirected communication (e.g., pheromone)**
    - **In most cases persistent in the environment**
  - **Directed communication (flashes to/from identified neighbors)**
    - **In most cases non-persistent**
- **Communication within the cluster**
  - **Problem: crowd, noise, …**
  - **Selective attention**
  - **jam avoidance**

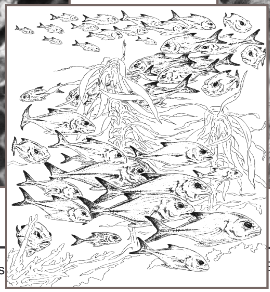


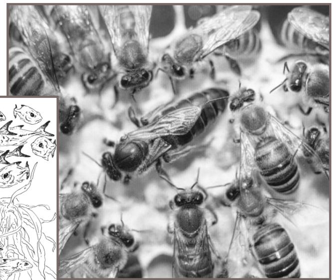
How?
Where?
Why?

Forms of aggregation/clustering

- Moving clusters and swarms:







First-year activity pres... Beyond robotics project **I-SWARM** - IST 507006

Endoscopic Capsules: State of the Art (1/2)

Given Imaging – M2A

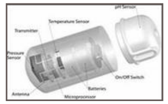
- ❖ Dimension: L = 27 mm, D = 11 mm (children versions under testing)
- ❖ CMOS technology
- ❖ RF trasmission data
- ❖ Powered by internal battery

SmartPill Diagnostic

Measurable Variables
- ❖ Peristaltic pressure evaluation
- ❖ Temperature
- ❖ pH level
- ❖ Transit time

Effectiveness only in the small bowel

In all the GI tract



www.givenimaging.com **www.smartpilldiagnostics.com**

Over 250,000 patients worldwide have experienced the advantages of painless and effective M2A® Capsule Endoscopy for diagnose diseases of the small intestine including: Crohn's Disease, Celiac disease and other malabsorption disorders, benign and malignant tumors, vascular disorders and medication related small bowel injury

Endoscopic Capsules: State of the Art (2/2)

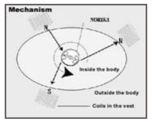
Olympus (Dec. 2004)

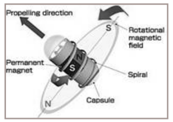
- ❖ Electromagnetic fields to freely control the capsule's movements
- ❖ For Esophagus, Stomach and Intestine
- ❖ Wireless energy supply: **battery free**

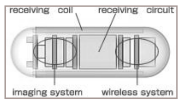
Norika 3

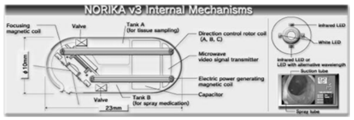
- ❖ Dimensions: L = 23 mm, D =10 mm
- ❖ CCD technology
- ❖ Wireless energy supply: **battery free**
- ❖ RF data trasmission

www.olympus.co.jp **www.rfnorika.com**

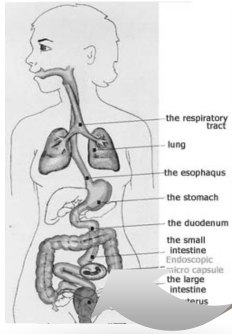


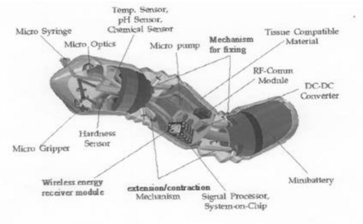






The microcapsule for gastrointestinal diagnosis and therapy (IMC, Korea)





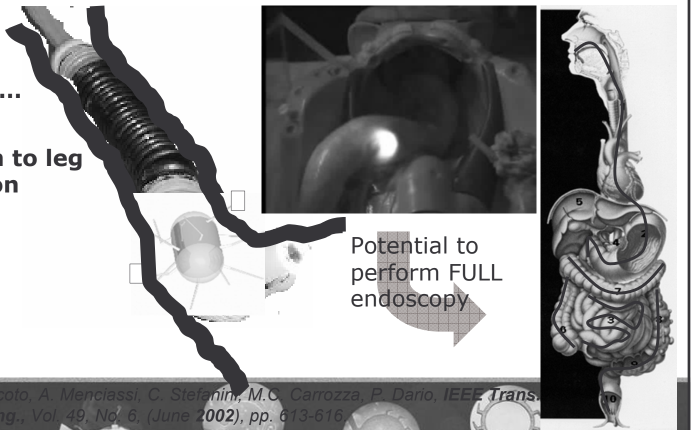
"ALL INSIDE" WIRELESS MICROCAPSULE

microgripper
microsyringe
microoptics
temperature sensors
pH sensors
chemical sensors
microbattery
locomotion and fixing mechanisms
RF module
drug-delivery microsystem

Bio-inspiration and endoscopic locomotion

Smoothly…

…from inchworm to leg locomotion



Potential to perform FULL endoscopy

L. Phee, D. Accoto, A. Menciassi, C. Stefanini, M.C. Carrozza, P. Dario, ***IEEE Trans. on Biomed. Eng.,*** *Vol. 49, No. 6, (June* ***2002****), pp. 613-616.*

A. Menciassi, J.H. Park, S. Lee, S. Gorini, P. Dario, J.O. Park, Proc. IEEE/RSJ ***Int. Conf. On Intelligent Robots and Systems, 2002****, Lausanne, pp. 1379-1384.*

Theoretical modeling **and experimental simulation**

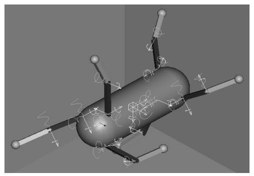
Steps of the theoretical model

Numerical code for the determination of capsule interaction with tissue (based on tissues properties derived experimentally)

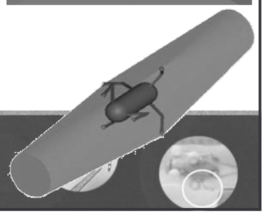
```
%DETERMINAZIONE DELLE FORZE DI ATTRITO SULLE ZAMPE

%Si calcola il coefficiente di attrito come funzior
%della deformazione epsilon e quindi si moltiplica
normale
mod_fatt = [];
mu = [];
for i = [1:6]
    MU = 0.4208*epsilon(i)^2-0.2413*epsilon(i)+0.0
    mu = [mu; MU];
    fatt = FORZA(i)*MU;
    mod_fatt = [mod_fatt; fatt];
end
```

Robotic modeling of the capsule with 6 DOF for the body and 3 DOF for each leg (more than in the experimental capsule, where DOFs are limited by mechanical complexity)

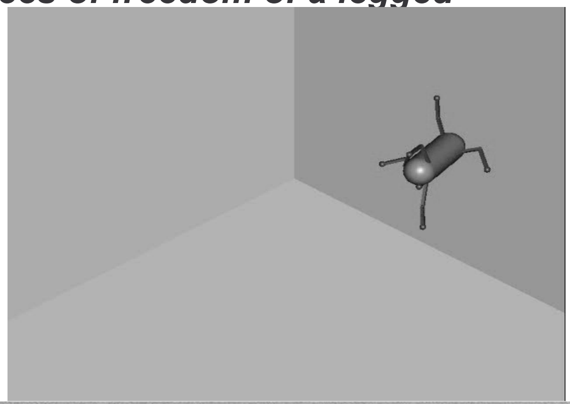


3D animated combination of tissue deformation and capsule motion.



(Free motion) demonstration of the full set of degrees of freedom of a legged capsule

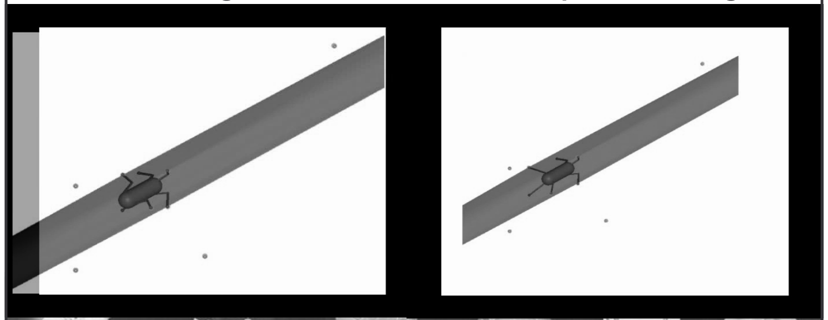
Modeled degrees of freedom: 3 (body trans.) + 3 (body rot.) + 3n (legs)



Comparing different gait patterns

front / rear phase:	0°	front / rear phase:	180°
period:	3 sec	period:	3 sec
full interval:	12 sec	full interval:	12 sec
traveled distance:	23 mm	traveled distance:	144 mm

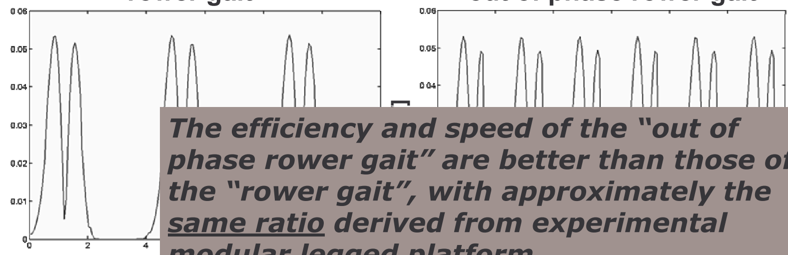
"rower gait" **"out of phase rower gait"**



Comparing different gait patterns

mean cycle power:	17 mW	mean cycle power:	30 mW
time interval:	12 sec	time interval:	12 sec
traveled distance:	23 mm	traveled distance:	144 mm
energy / distance:	8.9 J/m	energy / distance:	2.5 J/m

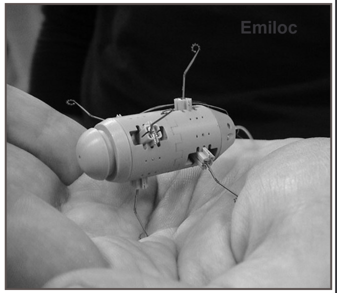
"rower gait" **"out of phase rower gait"**

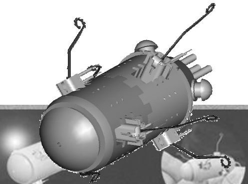


The efficiency and speed of the "out of phase rower gait" are better than those of the "rower gait", with approximately the <u>same ratio</u> derived from experimental modular legged platform

Objective:

A modular, **adjustable** experimental capsule is important in order to vary and **<u>verify, in parallel with virtual simulation,</u>** the best locomotion parameters for a given theoretical architecture

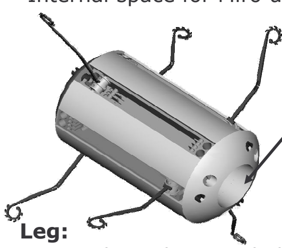




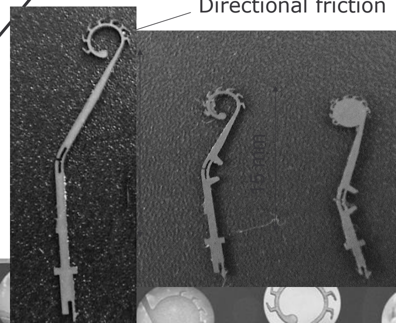
- Dimensions: L = 40 mm, D = 20 mm
- Material: PEEK (poly-ether-ether-ketone)
- Legs: interchangeable
- External (reliable) actuation by push-pull cables
- Modular intraluminal space creation system

Legged Capsule

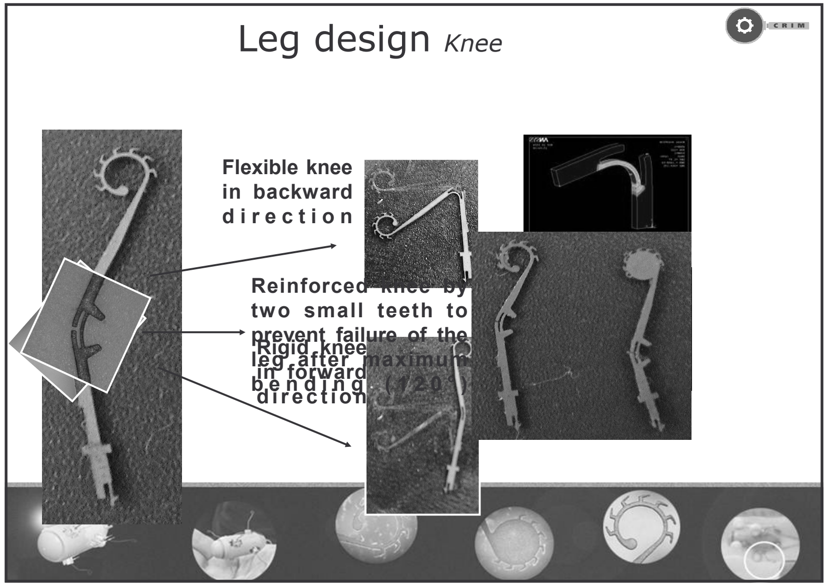
Legged Capsule Final Prototype:
•Diameter: 17 mm
•Lenght: 32 mm
•Internal space for Miro unit D 8 mm x L 28 mm

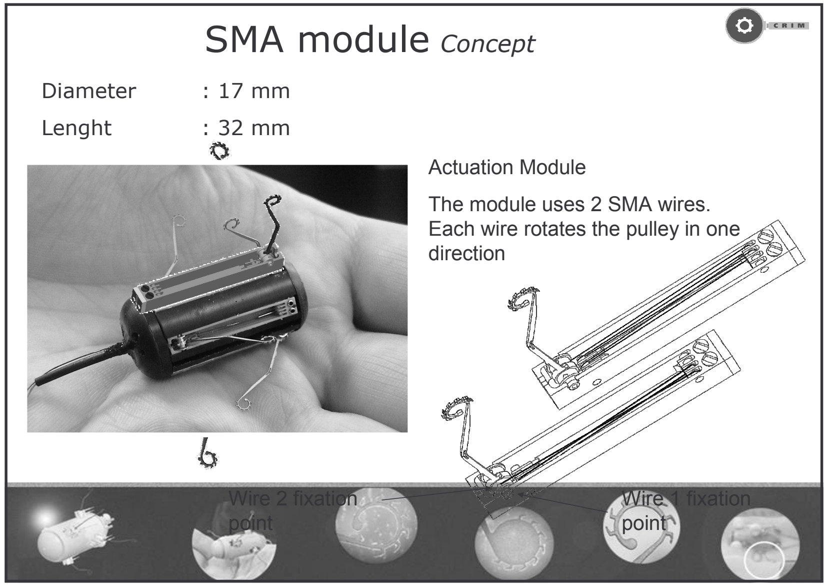


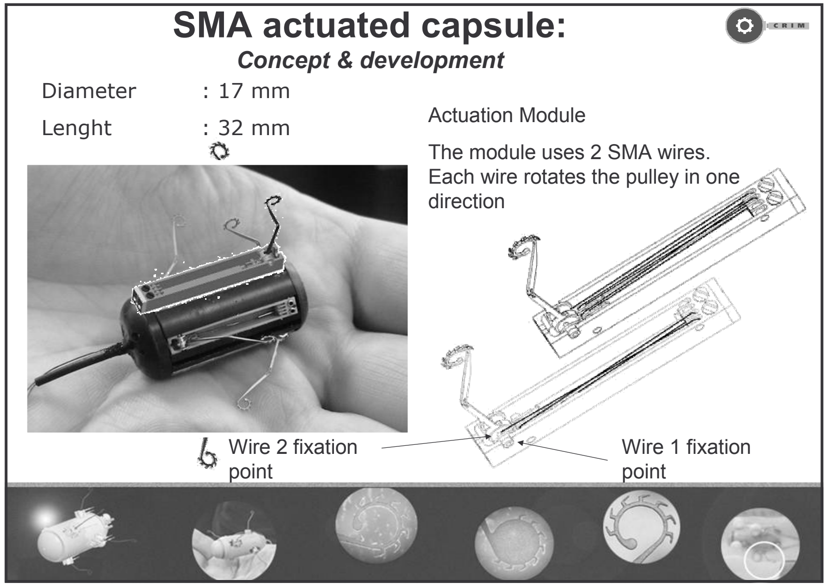
Directional friction

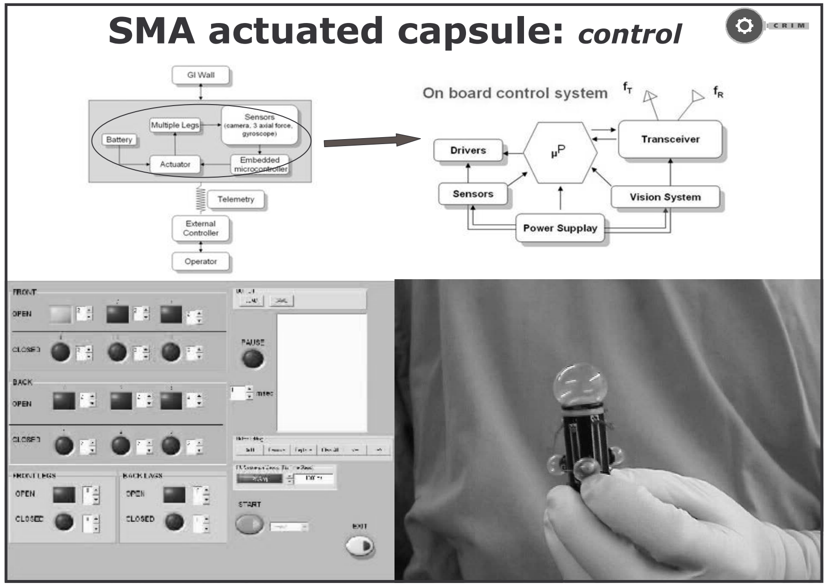


Leg:
•Superelastic legs made by W-EDM machining.
•Length from 15 mm to 20 mm in order to reach the intestine wall
•Thickness 0.25 - 0.5 mm

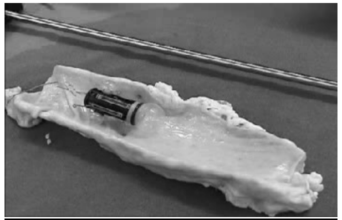

Leg design Knee
Flexible knee in backward direction
Reinforced knee by two small teeth to prevent failure of the leg after maximum bending (120°)
Rigid knee in forward direction

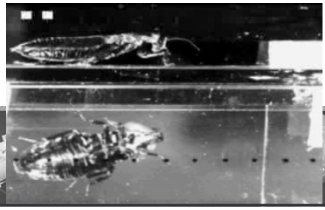

SMA module Concept
Diameter : 17 mm
Lenght : 32 mm
Actuation Module
The module uses 2 SMA wires. Each wire rotates the pulley in one direction
Wire 2 fixation point
Wire 1 fixation point


SMA actuated capsule:
Concept & development
Diameter : 17 mm
Lenght : 32 mm
Actuation Module
The module uses 2 SMA wires. Each wire rotates the pulley in one direction
Wire 2 fixation point
Wire 1 fixation point

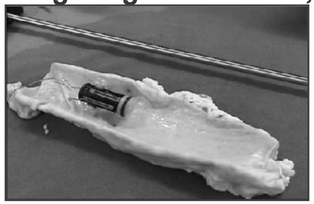

SMA actuated capsule: control
GI Wall
Multiple Legs
Sensors (camera, 3 axial force, gyroscope)
Battery
Actuator
Embedded microcontroller
Telemetry
External Controller
Operator
On board control system
Drivers
μP
Transceiver
Sensors
Vision System
Power Supply
FRONT
OPEN
CLOSED
BACK
PAUSE
FRONT LEGS
BACK LEGS
START
EXIT

Is the capsule like an artificial insect which is able to navigate effectively in a tubular, compliant environment?....





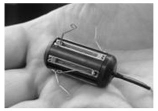
...Is the capsule like an artificial insect effectively navigating in a tubular, compliant environment?....



Not yet.
Work is in progress along the following directions:

- **Length and flexibility of the superelastic leg** are two of the most critical parameters for an effective locomotion in the GI tract. Shorter, stronger legs generate a larger force, but longer, more elastic legs could cope better with changing diameters;
- The **footprint of the legs should be optimized**: a wider contact surface could promote the opening of the lumen during advancement and simplify the adhesion of the leg with the tissue.
- The **individual step should be increased** (research on actuators!). This may help dealing with the elasticity of the tissue wall, which can reduce the effective propulsion significantly.

Centimeter robot | **Millimeter robot** | **Micro-nano robot**



Industrial Product for Clinical Application

Inchworm locomotion

Legged locomotion

Colonoscopic robot

Endoscopic μcapsule

2000

2003-2004

INDUSTRIAL PRODUCT: Active Endoscopic Microcapsule

Capsular Endoscopy: roadmaps by Olympus

(presented by Mr. Shymoiama, President – MicroMachine Summit 2005)

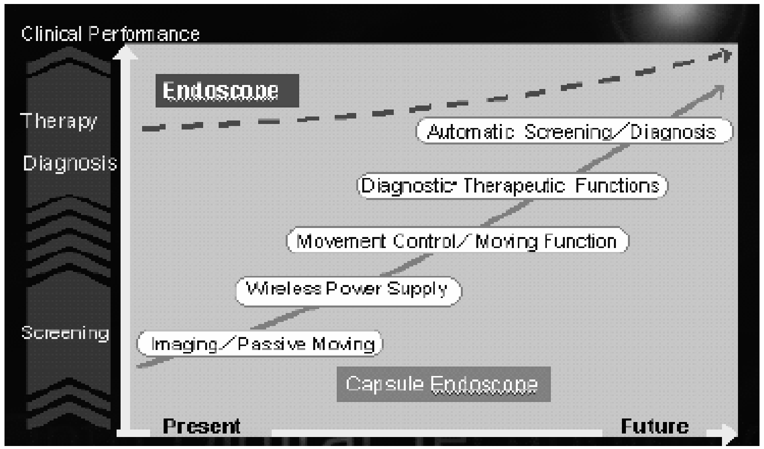
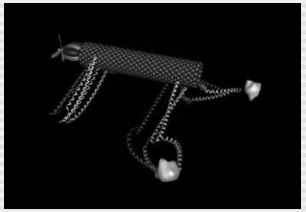


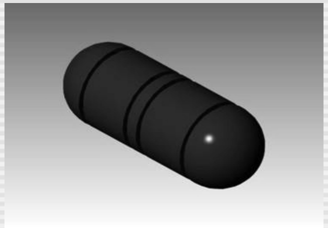
Figure 2. Technological challenge of a future versatile capsule endoscope

IMC

Long Term Goals



Biomolecular machine components that can form multi d.o.f. nanodevices that will be able to apply forces and manipulate objects in the nanoworld (*Rutgers University Bio-Nano project)*



Possible future EMILOC-based nano-devices released by swallowable capsule.

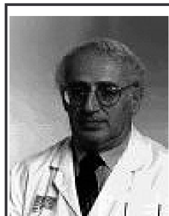
Intelligent Microsystem Center

2nd Fiscal Year Goals | Goals during the total Project Years | Long Term Goals

Future of Robotics Surgery

Challenges for Robotics for Diagnosis and Surgery

- Problems to be solved for further acceptance
  - Real application domains and procedures that benefit
  - Cost/benefit clearly proved
  - Time of intervention
  - Time and complexity for set up



Sir Alfred Cuschieri, MD

The operating room of the year 2030 will be a totally different environment than today

MASS Screening and EARLY diagnosis will have a major impact on the type and invasiveness of required surgical procedures

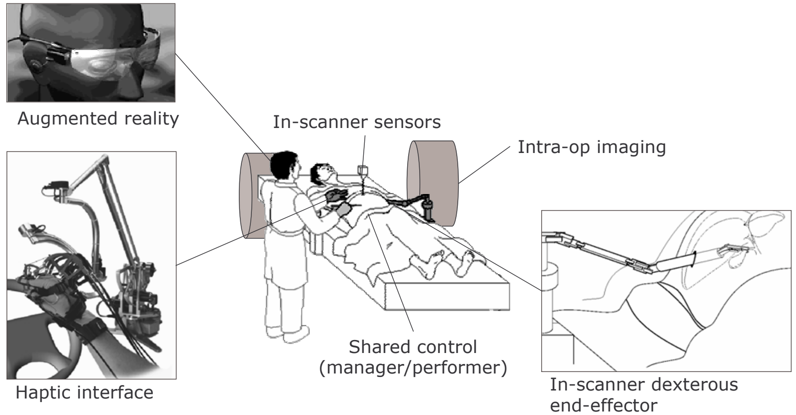
The combination of micro/nano tecnologies and microrobotics will enable to perform active monitoring and diagnostics in advanced and early manners, and will be also one of the key technologies enabling future high quality, early and minimal invasive surgery

The new challenge for surgeons and engineers

*The real challenge for the future of robotics in surgery (and perhaps for surgery in general) is to go **beyond the mere imitation and substitution by a robot of conventional procedures and surgical gestures**, and rather to explore completely novel procedures that are possible only by means of robotic/ mechatronic tools and NOT for human surgeons*

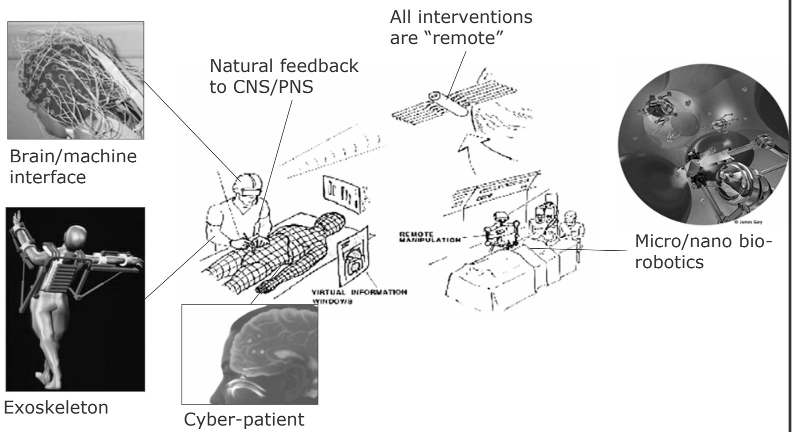
Robotic Surgery in 10 years

- Hands-on robotics paradigm



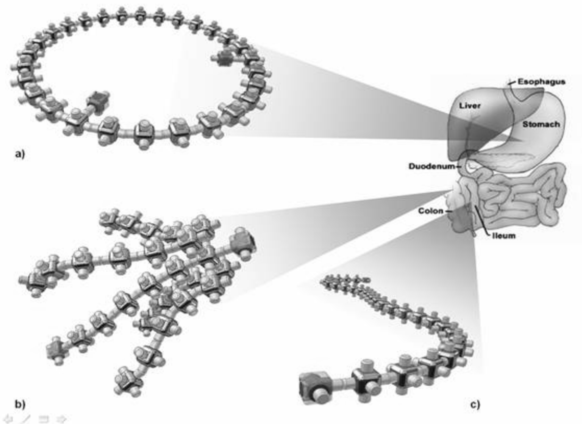
Robotic surgery in 25 years

- Remote robotics paradigm



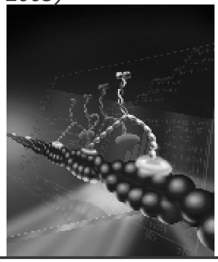
Assembling Reconfigurable Endoluminal Surgical system *(NEST Program of EU 6 FP)*

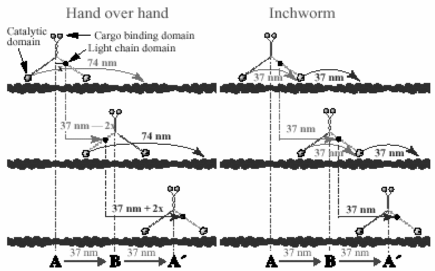
…Surgical and diagnostic procedures of the future will evolve to extremely targeted, localized and high precision endoluminal techniques. New surgical tools capable of entering the human body through natural orifices or very small incisions and of configuring themselves into complex kinematic structures at the specific site of intervention …



Nanorobots with "chemical power supply": a frontier for micro- and nano-mechanisms

Myosin V is a biomolecular motor that moves in nanometer-size steps on actin (red), by transporting cargo within cells. By placing a fluorophore near one foot (rainbow colored oval), and following the motion of a single myosin V, we are able to determine that myosin V "walks," placing one foot over the other, and does not "crawl." - *(P. Selvin et al., Science, Vol. 300, 27 June 2003)*

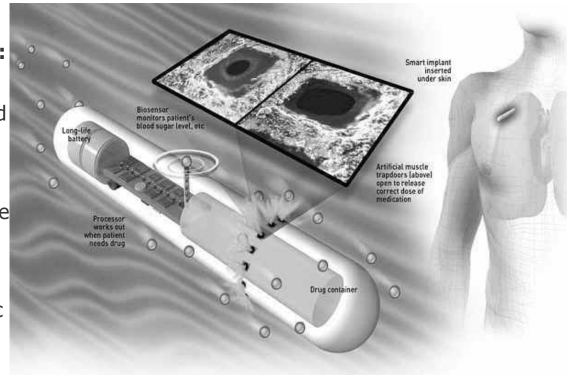




Applications of **nano-**, **bio-**, and **MEMS-technologies** in surgery, therapy and diagnosis

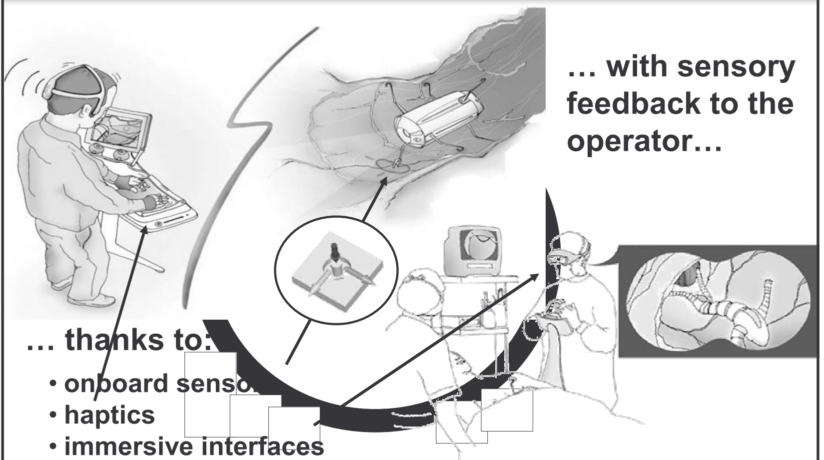
A concrete bio-MEMS research development:

A pill is surgically implanted in the body and a biosensor monitors the insuline level. When this level drops down, an electrical signal causes the *artificial muscles membrane* to shrink and the insuline reservoir to open through microscopic holes. When the insuline level is fine, an electrical signal causes the artificial muscle membrane to relax



http://www.sun-sentinel.com/graphics/news/smartpill/

Robotic capsules inside the human body…



… with sensory feedback to the operator…

… thanks to:

- onboard senso
- haptics
- immersive interfaces

Examples of Challenges for Robotics for Diagnosis and Surgery

- Main scientific and technical challenges
  - Mechanisms
  - Sensing
  - Actuators
  - Control
  - Models of tool-tissue interaction
  - Haptic feedback
  - More functions on board
  - Image based control
  - Miniaturization (towards nanorobots)

Challenges for Robotics for Diagnosis and Surgery

- Problems to be solved for further acceptance
  - Real application domains and procedures that benefit
  - Cost/benefit clearly proved
  - Time of intervention
  - Time and complexity for set up

Biomedical Robotics

Robotics for Diagnosis and Surgery

- Micro-robotic systems for minimally-invasive endoscopic diagnosis
- Robotic and mechatronic tools which improve the quality of surgery, in terms of accuracy, reduced invasiveness, predictability of results

Rehabilitation Robotics

Robots and mechatronic tools for clinical therapy in neuro-motor rehabilitation

Assistive Robotics

Robots and machines which improve the quality of life of disabled and elderly people, mainly through increased personal independence

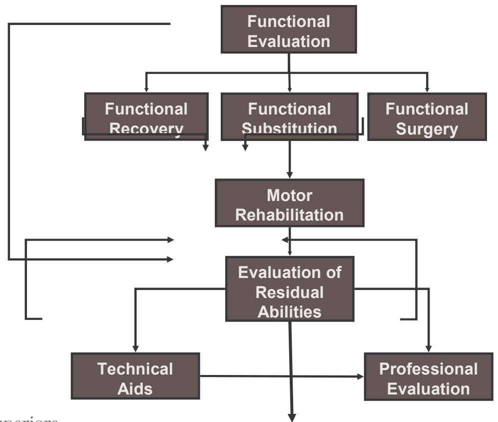
Neuro-Robotics

Anthropomorphic robots as tools for neuroscience, for studying the human brain and better understanding human physiology and pathologies

Bionics

- Biomechatronic prostheses
- Bio-mechatronic components for sensory and motor augmentation
- Hybrid bionic systems

The Rehabilitation Process

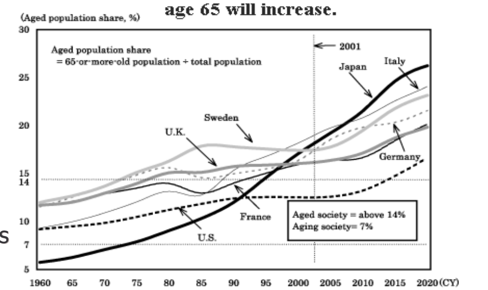


Re-entry into daily life

Main Motivations for the Development of Assistive Robots

- ✓ **Increased need for personal assistance due to:**
  - elongation of life expectations, with increased prevalence of debilitating conditions and diseases
  - increased risks of traumas, in car accidents and hazardous sports
  - increased survival rates from traumatic injury

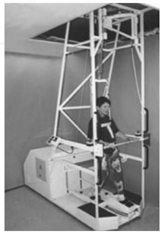
From 2000 to 2020, the percentage of the population age 65 will increase.



Sources: Population Census, Ministry of Public Management, Home Affairs, Posts and Telecommunications; Estimated Future Population of Japan (in January 1997), National Institute of Population and Social Security Research; World Population Prospects (1998), United Nations Population Division.

Systems for physical therapy to patients with muscle-skeletal disorders

- Machines for physical exercise (passive role of patient)
- Isokinetic and isotonic machines (active role of patient for matching the performance set by the machine)
- Machines for physical exercise (cognitive involvement of patient)

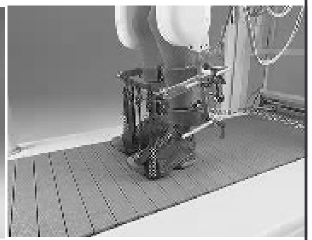



Lokomat

✓ Recent studies have confirmed that a regular exercise with a mobile mat can enhance walking capabilities in patients with incomplete spinal lesions

✓ An orthesis for a guided locomotion has been developed (DGO, Driven Gait Orthesis). Such system can move the spinal lesioned patient's legs in a physiological manner on a mobile mat

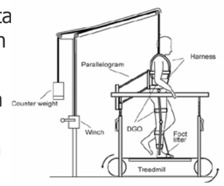

Lokomat


Lokomat, is a support machine for paraplegic patients' locomotion and is implemented and experimented at the Balgrist Hospital of Zurich. It is in a clinical experimentation phase.

A motorized orthosis is fixed around the thorax, at the waist and at the upper and lower part of each leg. It guides knee and hip movement in the sagita plane while the patient is walking on mobile mat.

The patient is suspended through a counterbalanced system. A parallelogram shaped mechanism with a gas spring sustains the orthesis weight for the guided walk. (DGO, Driven Gait Orthosis)



Classification

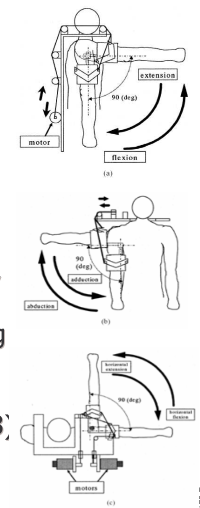
- ✓ **Exoskeleton-like machines:**
  - Application to patients with severe disabilities (when single joint control is required, absence/very few motor sinergies)
  - **Class I**
    - Mechanical/Hydraulic/Pneumatic actuation
    - High power, very precise
    - Heavy, non-portable
  - **Class II**
    - Wearable, portable systems
    - Low power, limited precision
- ✓ **Operational-type machines:**
  - Application to patients with moderate disabilities (when the patients feature a sufficient level of natural motor sinergies)
  - **Class I (e.g. MIT-MANUS)**
    - Low mechanical inertia/friction
    - High back-driveability
    - Fine tuning of viscoelastic properties for force fields generation and measurement of the impedance of the human arm
  - **Class II (e.g. MEMOS)**
    - Simple mechanical structure, no back-driveability
    - Active compensation of inertia/friction

Exoskeleton-like machines:

The machine is designed so that the trajectories of its end-effector AND of ALL its joints are equal to that of the natural limb in the operational space AND in the joint space

State of the art

- ✓ ***Upper limb neurorehabilitation systems (exoskeleton like)***
  - MULOS system developed at Scuola Superiore Sant'Anna, Italy (Bergamasco et al., 1994)
  - System developed at Salford University, UK (Tsagarakis e Caldwell, 1999)
  - GENTLE system developed at Reading Univesity, UK (Werry et al., 2001)
  - System developed at Nagoya University, Japan (Kiguchi et al., 2003)

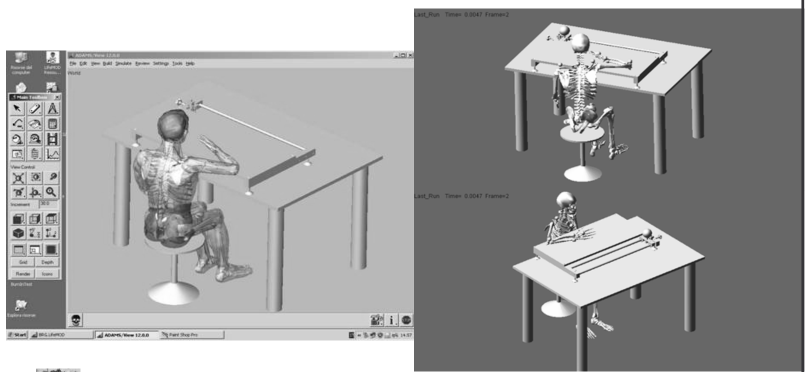


NEUROBOTICS exos

In the framework of the Neurobotics Project, SSSA is currently developing a new exoskeleton

Biomechanical model

Catching task simulation

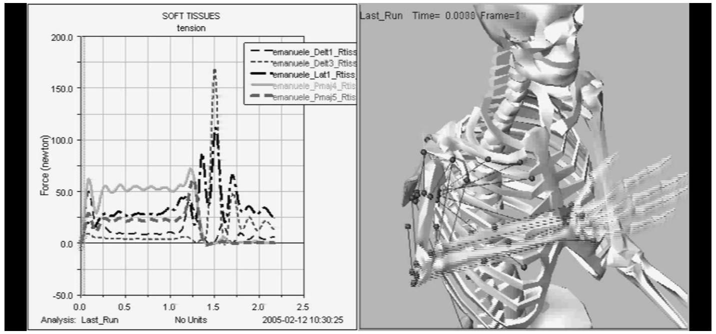


Information Society Technologies

Biomechanical model

Neurobotics

Model of the kinematic and dynamic parameters of the arm joints, links and muscles



Shoulder agonistic/antagonistic muscles activations

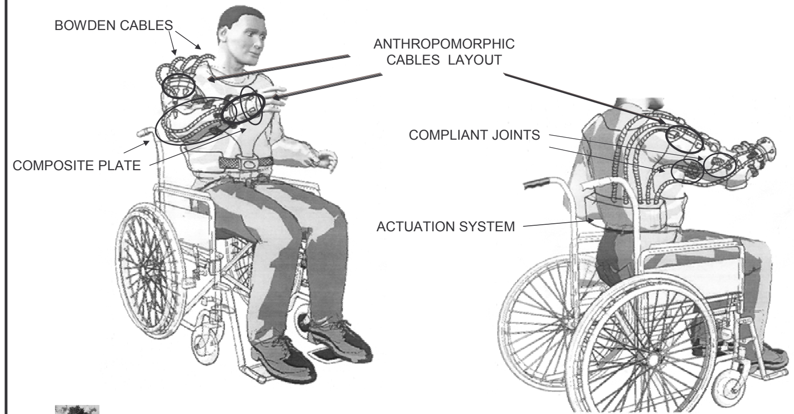
Future and Emerging Technologies

Neurobotics - The fusion of Neuroscience and Robotics, FP6-IST-001917 (www.neurobotics.info). A project funded by the Future and Emerging Technologies arm of the IST programme

Information Society Technologies

"POWERSUITE" CONCEPT

Neurobotics



Future and Emerging Technologies

Neurobotics - The fusion of Neuroscience and Robotics, FP6-IST-001917 (www.neurobotics.info). A project funded by the Future and Emerging Technologies arm of the IST programme

Operational Type Machines

- **The contact between the patient and the machine is only at the end effector, through a purposive mechanical interface (e.g. pedal or handle)**
- **The machine is designed so that the trajectory of its end-effector is equal to that of the natural effector (hand/foot) in the operational space**
- **The patient is expected to exploit her/his own synergies at joint level to follow a trajectory in the operational space**

The MIT-MANUS system (Inmotion Ltd.)

Scuola Superiore Sant'Anna di Studi Universitari e di Perfezionamento

The MIT-MANUS system

- ✓ **A peculiar feature of the MIT-MANUS is its low mechanical impedance (back-driveability) that allows the system to rapidly adapt to the patient's actions**
- ✓ **A second feature is the impedance control, that allows system compliance**

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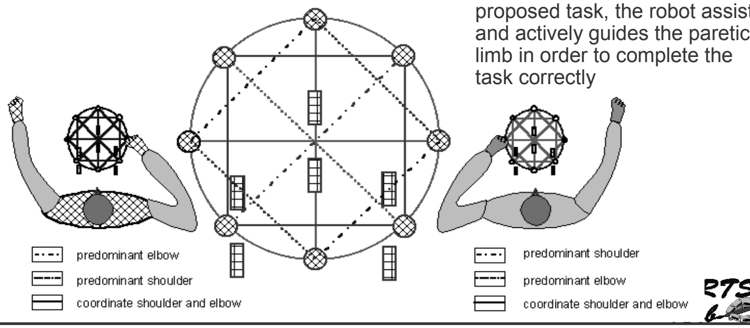
ARTS Lab

MIT-MANUS Therapy

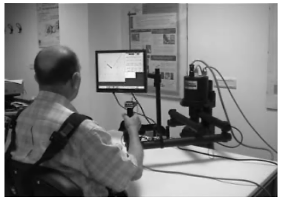
- ✓ **Robotic therapy by means of the MIT-Manus system consits of proposing to the patient a set of complex tasks, like "games", where the robot effector must be moved in orde to draw, for example, geometric shapes like circles and squares**

- In case the patient is not capable of completing the proposed task, the robot assists and actively guides the paretic limb in order to complete the task correctly



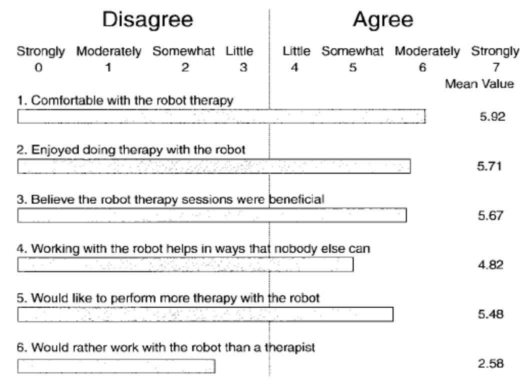
Manipolandum for the analysis of upper limb motor control

- Experiments are being performed in order to understand how the aging process can modify the motor performance and the learning abilities of senior people **especially while dealing with increasing cognitive efforts**



MIT-MANUS system

- ✓ **Substantial acceptability of the machine that is, nevertheless, perceived as not completely subtitutive with respect to the therapist role.**



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MIT-MANUS system: clinical results

- ✓ **96 patients divided in 2 groups: experimental with robot treatment (n=56) and control (n=40), for a total of 3000 hrs of robot assisted neuroreabilitation therapy.**
- ✓ **Hospital ammission within 3 weeks from the first stroke, weakness of an upper limb, capability to follow few simple instructions**
- ✓ **Experimental group: 1 additional hour for week-end of robot therapy**
- ✓ **Control group: 1 hour for week with robot use exclusively for visual feedback**
- ✓ **Average training: 3 ½ weeks**

Comparison by means of clinical values commonly used for a functional assessment

TABLE 51-1. *Results of treating 96 patients with stroke and upper limb paralysis with robot training sensorimotor protocols or control sensory exposure*

Group	FM S/E (max = 42)	MSS S/E (max = 40)	MP (max = 20)
Robot-trained (n = 56)	6.6 ± 1.0	8.6 ± 0.9	4.1 ± 0.4
Control (n = 40)	4.9 ± 0.8	3.4 ± 0.5	2.2 ± 0.3
p Value	NS	<0.001	<0.005

FM S/E, Fugl-Meyer shoulder and elbow measure; max, maximum; MP, motor power; MSS S/E, motor status score shoulder and elbow measure.

The robot-trained group demonstrated significant improvement compared to controls. The impairment measurements depict interval change (mean ± SEM). Timing of stroke to rehabilitation (around 2.5 weeks), duration of rehabilitation experience (around 3.5 weeks), and all admission impairments measures were comparable between groups.

Robot aided sensorimotor training in stroke rehabilitation, Volpe et al,2003

Scuola Superiore Sant'Anna di Studi Universitari e di Perfezionamento

Biomedical Robotics

Robotics for Diagnosis and Surgery
- Micro-robotic systems for minimally-invasive endoscopic diagnosis
- Robotic and mechatronic tools which improve the quality of surgery, in terms of accuracy, reduced invasiveness, predictability of results

Rehabilitation Robotics

Robots and mechatronic tools for clinical therapy in neuro-motor rehabilitation

Assistive Robotics

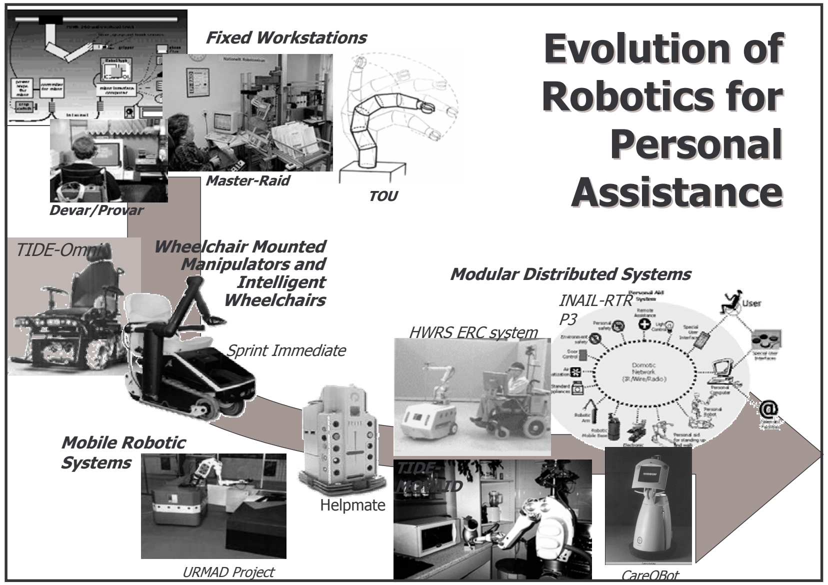
Robots and machines which improve the quality of life of disabled and elderly people, mainly through increased personal independence

Neuro-Robotics

Anthropomorphic robots as tools for neuroscience, for studying the human brain and better understanding human physiology and pathologies

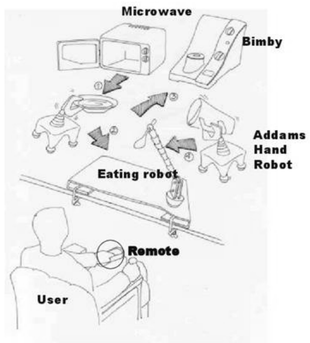
Bionics
- Biomechatronic prostheses
- Bio-mechatronic components for sensory and motor augmentation
- Hybrid bionic systems

Evolution of Robotics for Personal Assistance

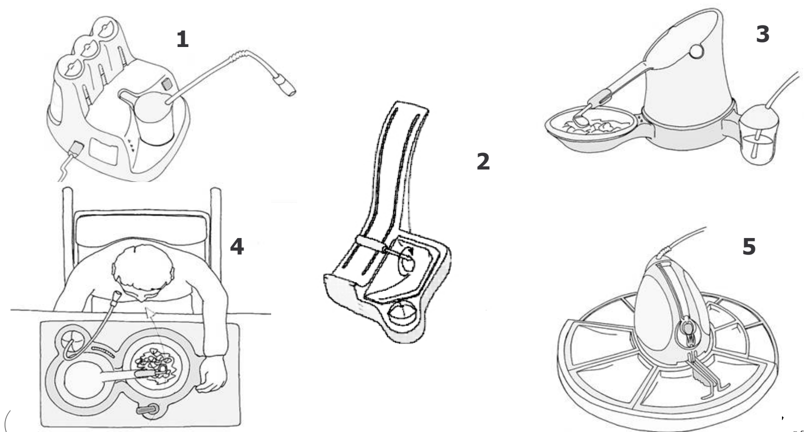


A possible solution: the robot disappears inside new generations of appliances?

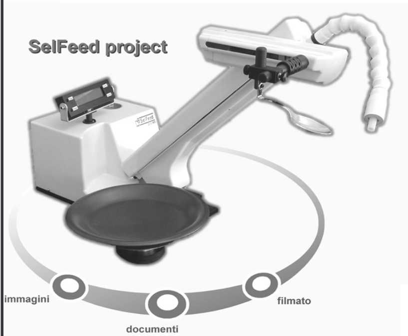
- ✓ **From Standard Appliance:**
  - Task-restricted
  - Portable
  - Affordable
- ✓ **From Information Appliances:**
  - Information sharing
  - Data management
  - Network
- ✓ **From Robotics:**
  - **Complex movement combinations**
  - **Mobility**
  - **Manipulation capabilities**
  - **Vision and intelligent reasoning**
  - **Interaction with other robotic assistants**

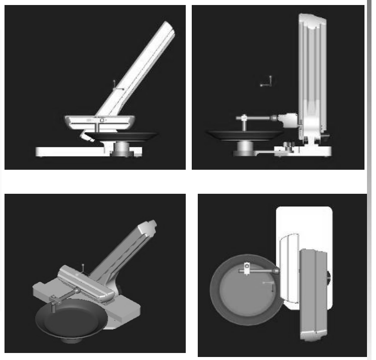


Concepts of robotic appliances as feeding assistive devices



First prototype





Experimentation of the prototypal device

- **Validation of the prototype in comparison to commercial feeding robots**

Handy 1

Neater eater

SelFeed: Usability test

- **For the experiments we developed a specific protocol:**
  - Measurement of objective parameters about the robot's ***usability***;
  - Evalutation of user and his predisposition to technologies and assistive technologies;
  - Evaluation of user/assistive technology interaction;
  - Evaluation the user's ***accepatbility*** of the device;

Biomedical Robotics

Robotics for Diagnosis and Surgery

- Micro-robotic systems for minimally-invasive endoscopic diagnosis
- Robotic and mechatronic tools which improve the quality of surgery, in terms of accuracy, reduced invasiveness, predictability of results

Rehabilitation Robotics

Robots and mechatronic tools for clinical therapy in neuro-motor rehabilitation

Assistive Robotics

Robots and machines which improve the quality of life of disabled and elderly people, mainly through increased personal independence

Neuro-Robotics

Anthropomorphic robots as tools for neuroscience, for studying the human brain and better understanding human physiology and pathologies

Bionics

- Biomechatronic prostheses
- Bio-mechatronic components for sensory and motor augmentation
- Hybrid bionic systems

Frontiers of Neuro-Robotics

- Neuroscience and Robotics are disciplines which evolved separately for years, but now there is a mutual advantage to produce joint efforts
- These efforts can generate break-through advancements in both fields: understanding the human brain, but also developing new paradigms for intelligent machines

NEUROBOTICS

The fusion of NEUROscience and roBOTICS

Information Society Technologies

Neurobotics

Starting date: 01/01/2004

Duration: 48 months

Funding: 5.640 k€

Roboticists and technologists

1. Scuola Superiore Sant'Anna, Italy (prof. Paolo Dario) – **Project Coordinator**
2. Deutsches Zentrum fur Luft und Raumfahrt, Germany (prof. Gerd Hirzinger)
3. Kungl Tekniska Högskolan, Sweden (prof. Henrik Christensen)
4. National Technical University of Athens, Greece (prof. Kostas Kyriakopoulos)
5. University of Genova, Italy (prof. Giulio Sandini)
6. Fraunhofer Institute for Biomedical Engineering, Germany (prof. Klaus Peter Hoffmann)

Neuroscientists

1. Collège de France, CNRS, France (prof. Alain Berthoz)
2. Karolinska Institutet, Sweden (prof. Sten Grillner)
3. Katholieke Universiteit Leuven, Belgium (prof. Guy Orban)
4. Umea Universitet, Sweden (prof. Roland Johansson)
5. Universitat Autònoma de Barcelona, Spain (prof. Xavier Navarro)
6. University of Parma, Italy (prof. Giacomo Rizzolatti)
7. Université P. et M. Curie / INSERM U483, France (prof. Yves Burnod)
8. Università Campus Biomedico, Italy (prof. Paolo Maria Rossini)
9. Università di Ferrara, Italy (prof. Luciano Fadiga)

Collaboration with non-EU research groups

1. Brown University, USA (prof. John Donoghue)
2. Waseda University, Japan (prof. Atsuo Takanishi)

Management

Pont-Tech, Italy (dr. Fabrizio Vecchi)

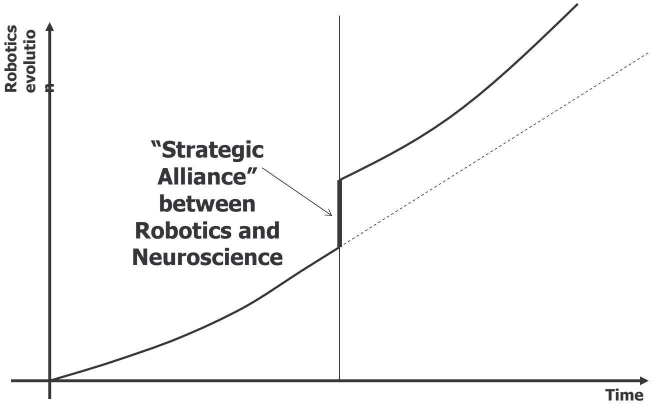
Information Society Technologies

Neurobotics

The objective: introducing a discontinuity in robotics research and paving the way for a new generation of high performance, neuro-inspired, highly acceptable robotics systems

Neurobotics

Break-throughs in robotics research thanks to the “alliance” with Neuroscience

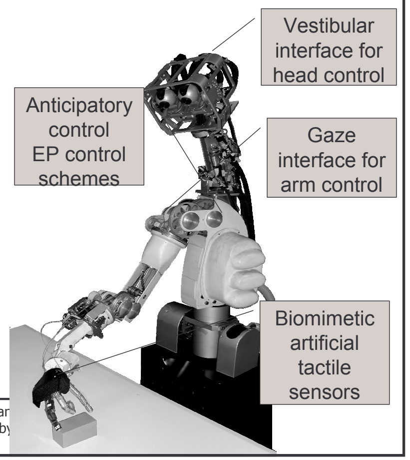


Information Society Technologies

ARTSoid platform

Neurobotics

- Experiments in exoskeleton control by gaze (SSSA, UMEA)
- Experiments in sensory-motor coordination in pick&lift tasks (SSSA, UMEA)
- Experiments in head control by a vestibular interface (CDF, SSSA)
- Experiments in expected perception control schemes (SSSA)
- Learning to reach and grasp objects (UPMC, SSSA)

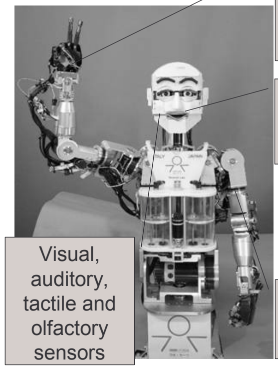


Information Society Technologies

Neurobotics

ROBOCASA platform

- Experiments in humanoid control with remote control interface by human motion or human EMG (WASEDA, SSSA)
- Identification of brain imaging of emotions (UNIPR, CDF, WASEDA, SSSA)



Artificial robotic hand RCH-1

Human-like robotic head

Visual, auditory, tactile and olfactory sensors

9-DOF humanoid arms

Future and Emerging Technologies

Neurobotics - The fusion of Neuroscience and Robotics, FP6-IST-001917 (www.neurobotics.info). A project funded by the Future and Emerging Technologies arm of the IST programme

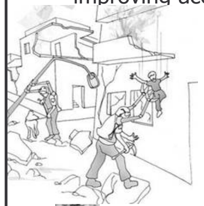
Information Society Technologies

Neurobotics

NEUROBOTICS "Beyond Robotics" platforms

"Beyond Tele-operation": robotic aliases for explorations in remote and/or difficult to access environments

"Beyond Ortheses": a smart exoskeleton for improving accuracy, endurance and strength of human arm and hand movements



"Beyond Prostheses": a novel highly anthropomorphic arm/hand system, for limb substitution or for adoption of additional limbs

Future and Emerging Technologies

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- Hybrid bionic systems

Current prosthetic hands

✓ **PROS**
- Robust and reliable
- Simple to control
- Lightweight (especially passive prostheses)
- Noiseless
- Acceptable cosmetics (with gloves)

✓ **CONS**
- **Low dexterity (only 1 active degree of freedom)**
- **Little or no sensorisation**
- **The prosthesis is perceived as a foreign body**
- Quite expensive (myoelectric prostheses)

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…as a consequence…

- ✓**At present, only about 30% of all hand amputees make use of myoelectric prostheses (……)**
- ✓**For this reason several research groups are trying to overcome the major limits of the current devices:**
  - Reduced dexterity
  - Complex EMG-based control strategies
  - Absence of sensory feedback

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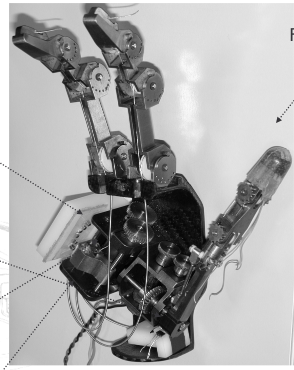
Short-term solution#1: increased dexterity using underactuated prostheses



Exteroceptive: "Tactile"

FSR pressure sensor embedded in a silicone cap at thumb tip

Proprioceptive: Position

Hall Effect sensor for linear slide positioning

Proprioceptive: Joint Angle

Angular Hall Effect sensor for thumb adduction/abduction

Proprioceptive: Force

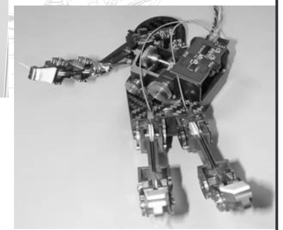
Tension cable/tendon sensor

2 DC actuators (MINIMOTOR, CH) integrated in the palm

Embedded control system for EMG control

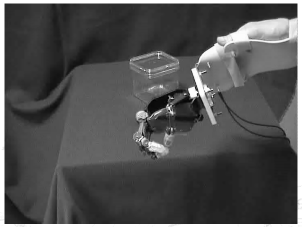
The hand weight is ~320 grams.

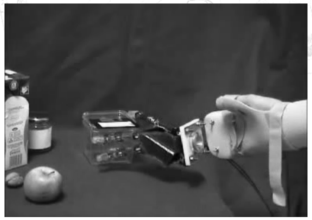
RTR2 hand is underactuate and it has 8 degrees of freedom and 2 actuators



Prosthetic hand systems controlled by EMG signals: RTRII vs OttoBock hands

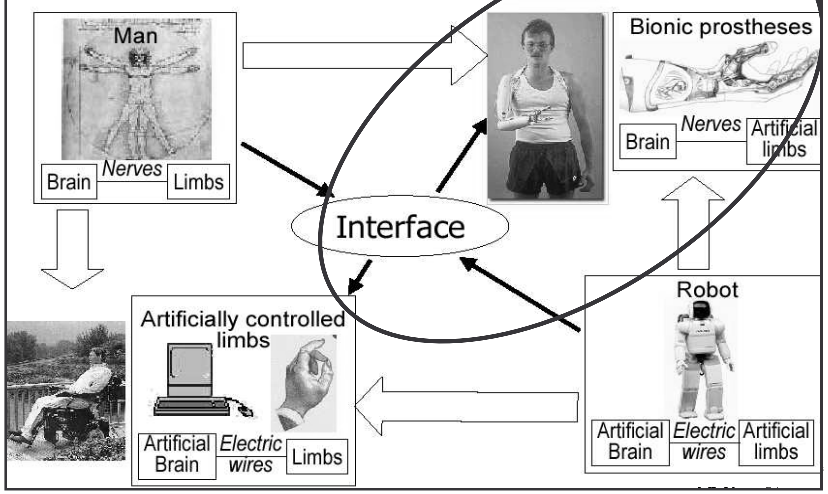
RTR 2 Hand system



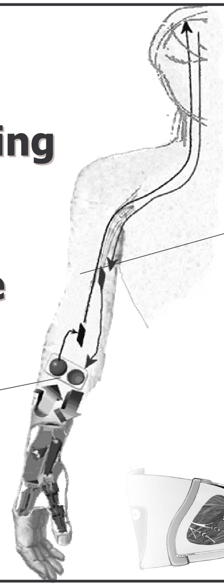


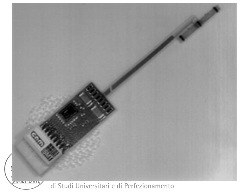
OTTO BOCK Hand system

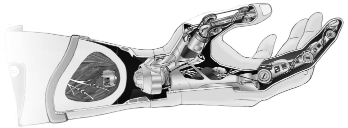
"Connecting" Man and Robot



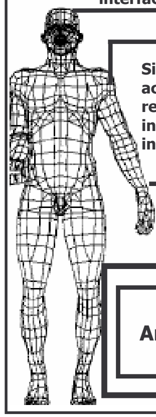
The EU-FET "CYBERHAND" Project: developing a cybernetic prosthesis controlled by the brain







Conceptual scheme of a Hybrid Bionic System



Cortical signals recorded using invasive and non-invasive interfaces

Acquisition and Pre-processing

Extraction of patient's intention

Signals related to the activity of the PNS recorded using invasive and non-invasive interfaces

Signals related to the indirect interfaces

Control of the robotic artefact

Artificial feedback and learning

Sensory Feedback (Natural Learning)

Artificial sensors

Artificial musculo-skeletal system (mechanisms)

Artificial muscles (actuators)

CYBERHAND Project: the final demonstrator

Project Co-ordinator
Prof. Paolo Dario

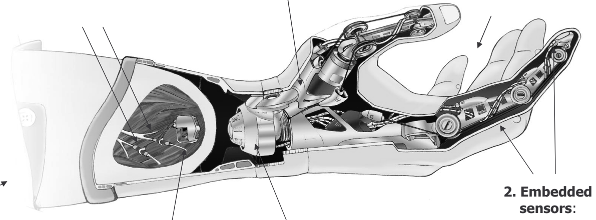
The Consortium

1. Scuola Superiore Sant'Anna
2. INAIL RTR Center
3. Fraunhofer Institut für Biomedizinische Technik
4. Centro Nacional de Microelectronica
5. Universidad Autonoma de Barcelona
6. Center for Sensory-Motor Interaction

Neural interfaces:
3. Efferent nerves
4. Afferent nerves

8. Decoding patient's intentions and **Embedded closed-loop control of the artificial hand**

1. Biomechatronic Hand



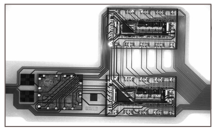
Stump

5. Implanted neural interface:
- ENG efferent signals recording (patient's intention detection)
- Afferent nerves stimulation (to provide sensory feedback to the patient)

6. Receiver
7. Transmitter

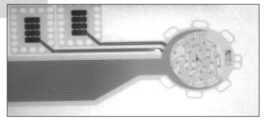
2. Embedded Biomimetic sensors:
- within the structure
- within the glove

Electrodes for Recording and Stimulation in the PNS

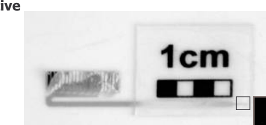


Integrated Electronics for Active Sieve Electrode

Sieve Electrode

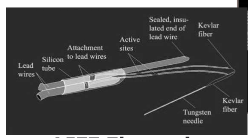


Sieve Head with Counter Electrodes

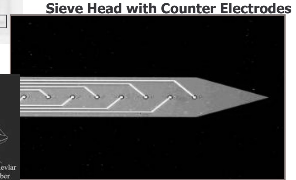


Shaft Electrode

Tripolar Cuff Electrodes

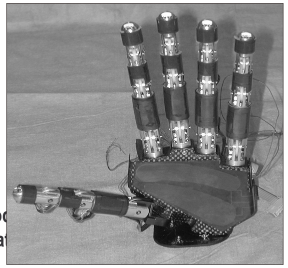


LIFE Electrodes



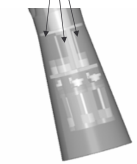
Platinum Electrodes on the Shaft

Proprioceptive sensory system



15 Embedded Joint Angle Sensors (Hall effect)
(Operational range: 0 – 90 degrees, Resolution: ~0.1 degrees).

5+1 Enco... the Actua... System



5 cable/tendon tension sensors
(Operational range: 0 – 35 N, output characteristic: linear, resolution: ~20 mN)

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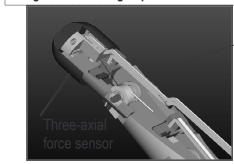
Exteroceptive sensory system

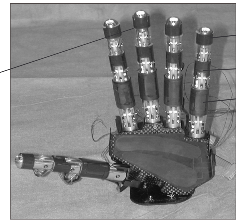
Three-axial strain gauge force sensors integrated in the fingertips



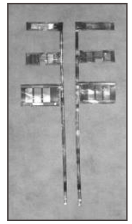
Maximum Force (N)

Fx max	4.62
Fy max	5.96
Fz max	4.62

Maximum force magnitude 8,75 N

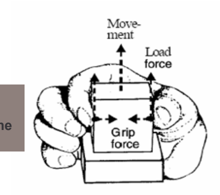


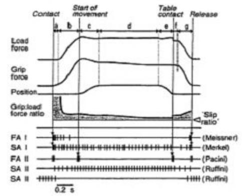
Distributed contact sensors



Contact sensors at fingertips and palm (threshold ~60 -100 mN)

The basic human grasping and manipulation tasks involve lifting an object and placing it back in the environment





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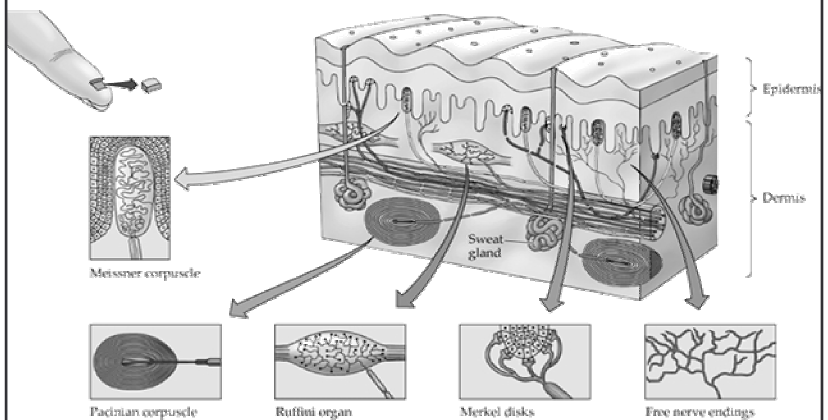
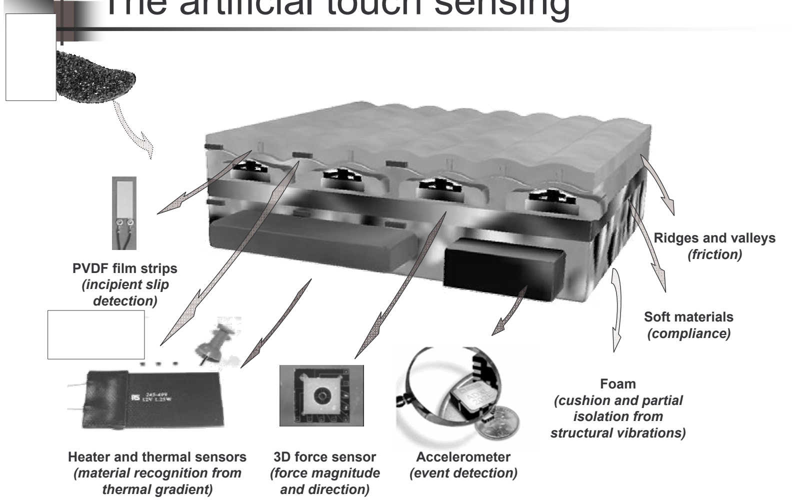
The human touch sensing

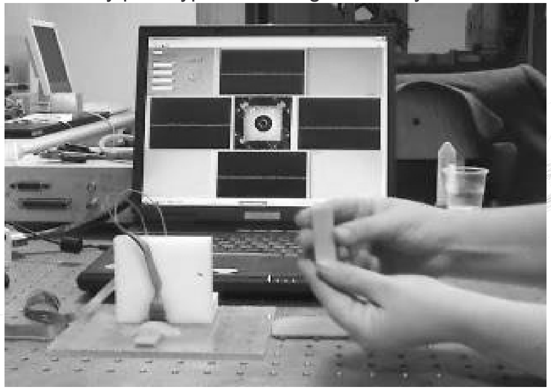


The artificial touch sensing



Smart skin development

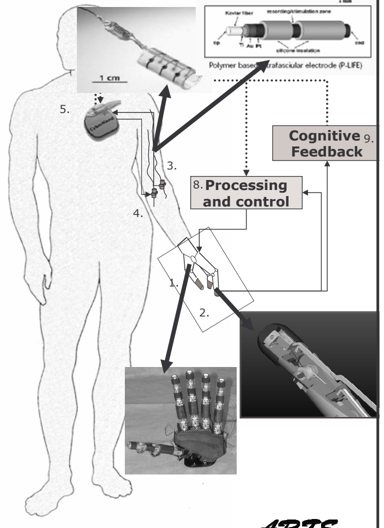
- Preliminary prototypes show high flexibility



CYBERHAND Project: Development of a CYBERnetic HAND prosthesis

Status

- ✓ The final goal of the project (e.g., implementing an acute implant of different electrodes in humans for the control of the prosthesis) is within reach
- ✓ Human implant may be performed within a few months, at a clinical institution, in Italy.



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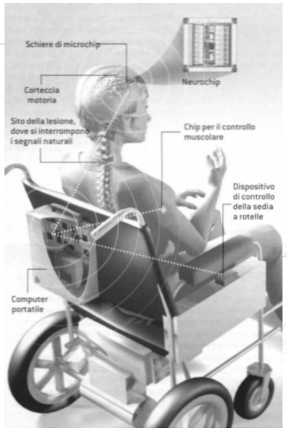
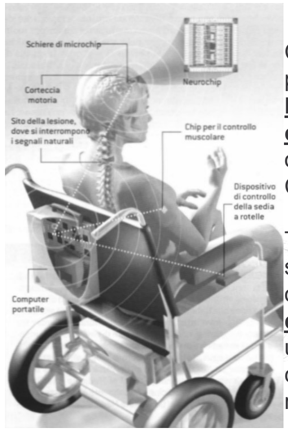


Brain to Computer Interface is one of the 10 Emerging Technologies that will change the world

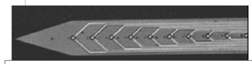
Technology Review, January/February, 2001, pp 97-113



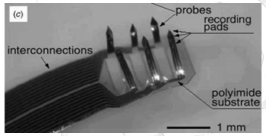
Cyberkinetics Neurotechnology Systems, Inc. presented some preliminary findings of **the BrainGate(TM) Neural Interface System pilot clinical study in humans** at the annual meeting of the Society for Neuroscience in San Diego, California.

The presentation included a discussion of the scientific, mathematical and practical observations that lead to **the first demonstration of a person with quadriplegia** using thoughts and the BrainGate System to control a computer, environmental controls and a robotic limb.

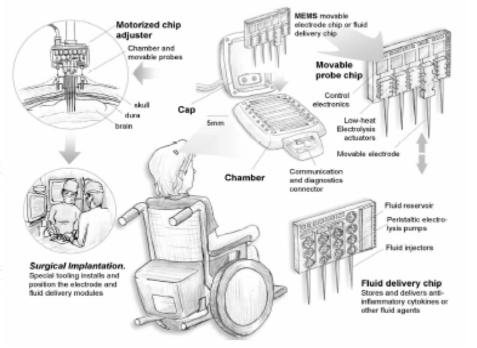
Invasive interfaces with the CNS



IBMT, Germany, Sensors and Actuators, 2002b



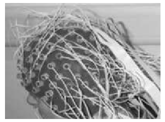
University of Tokyo, 2004



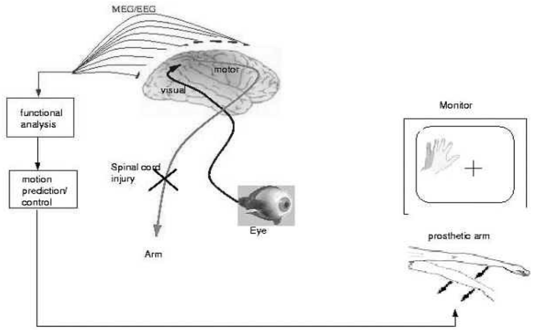
California Institute of Technology, 2004

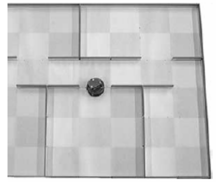
Several strategies can be used to implement a BCI

Control of robotic devices using non invasive neural signals (EEG)



- 2-DoFs robotic devices can be controlled through the processing of EEG signals
- It is very difficult to increase the performance of the control (i.e., more DoFs or better accuracy)





Control of a mobile robot using EEG
Millan et al., 2004

ARTS Lab

DARPA BAA05-26 REVOLUTIONIZING PROSTHETICS

✓ **VISION**

- Produce a fully neural integrated upper extremity prosthetic with appropriate documentation for clinical trials, FDA approvals, and manufacturing transition

✓ **MISSION**

- Apply an understanding of the underlying function and control of the human arm and hand when performing the basic functions of reaching, pointing grasping, and coordinated finger movements to the design of this prosthetic
- Understand and address the amputees' needs to promote and enhance quality of life issues

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Who will design the new Biomedical Robots?

- A paradigm change in the design of robots
- The challenge: educating new robotics engineers (competent, creative, multi and interdisciplinary)

Conclusions

- Biomedical Robotics is an exciting new frontier for advanced research in robotics and in biomedical engineering
- Biomedical Robotics is also a very attractive area for educating and training competent and creative students and researchers, as well as for clinical application and industrial exploitation
- Research on Biomedical Robotics requires deeply inter-disciplinary and even trans-disciplinary skills
- The “alliance” of robotics with biomedical engineering, life sciences and even humanities is a strategic research opportunity

Acknowledgements to: