The CYBERHAND Project
IST-2001-35094

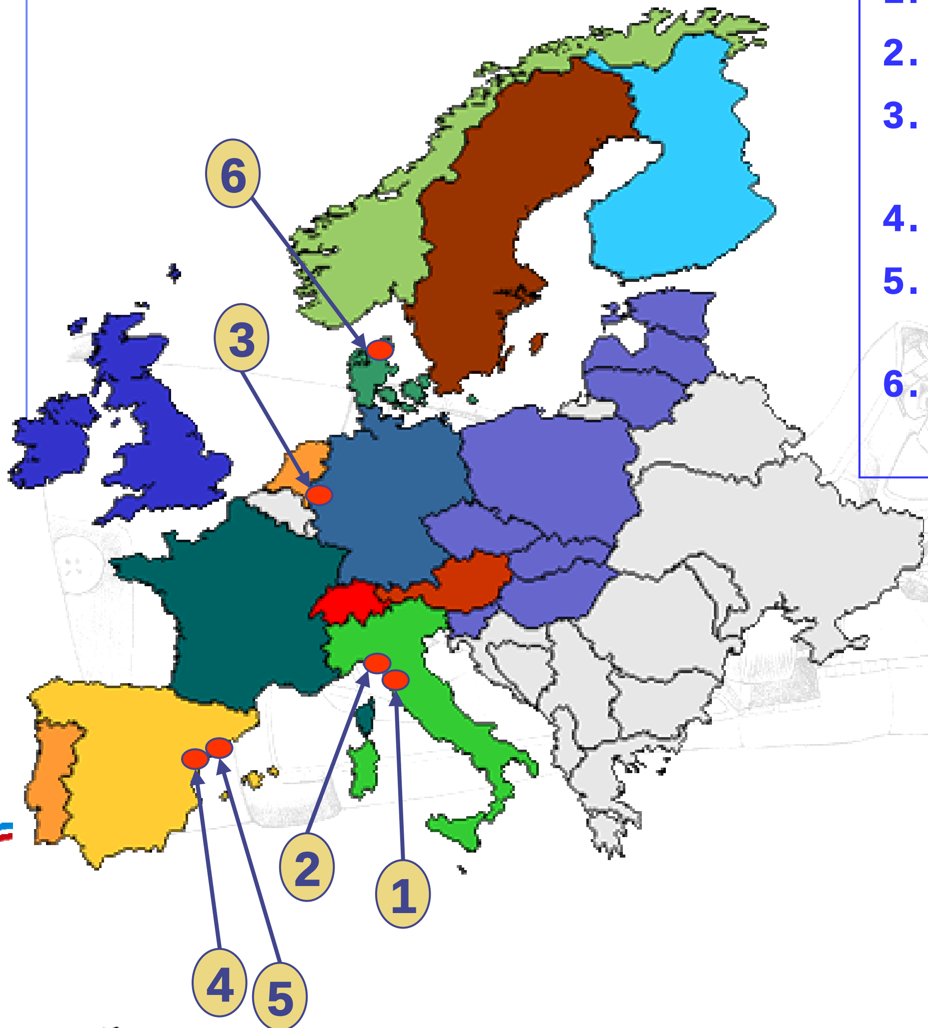
(01/05/2002 – 30/04/2005)

NEURO-IT Workshop

Prof. Paolo Dario
Project Co-ordinator

June 22, 2004 - Bonn, Germany

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**

List of Principal Investigators of CYBERHAND

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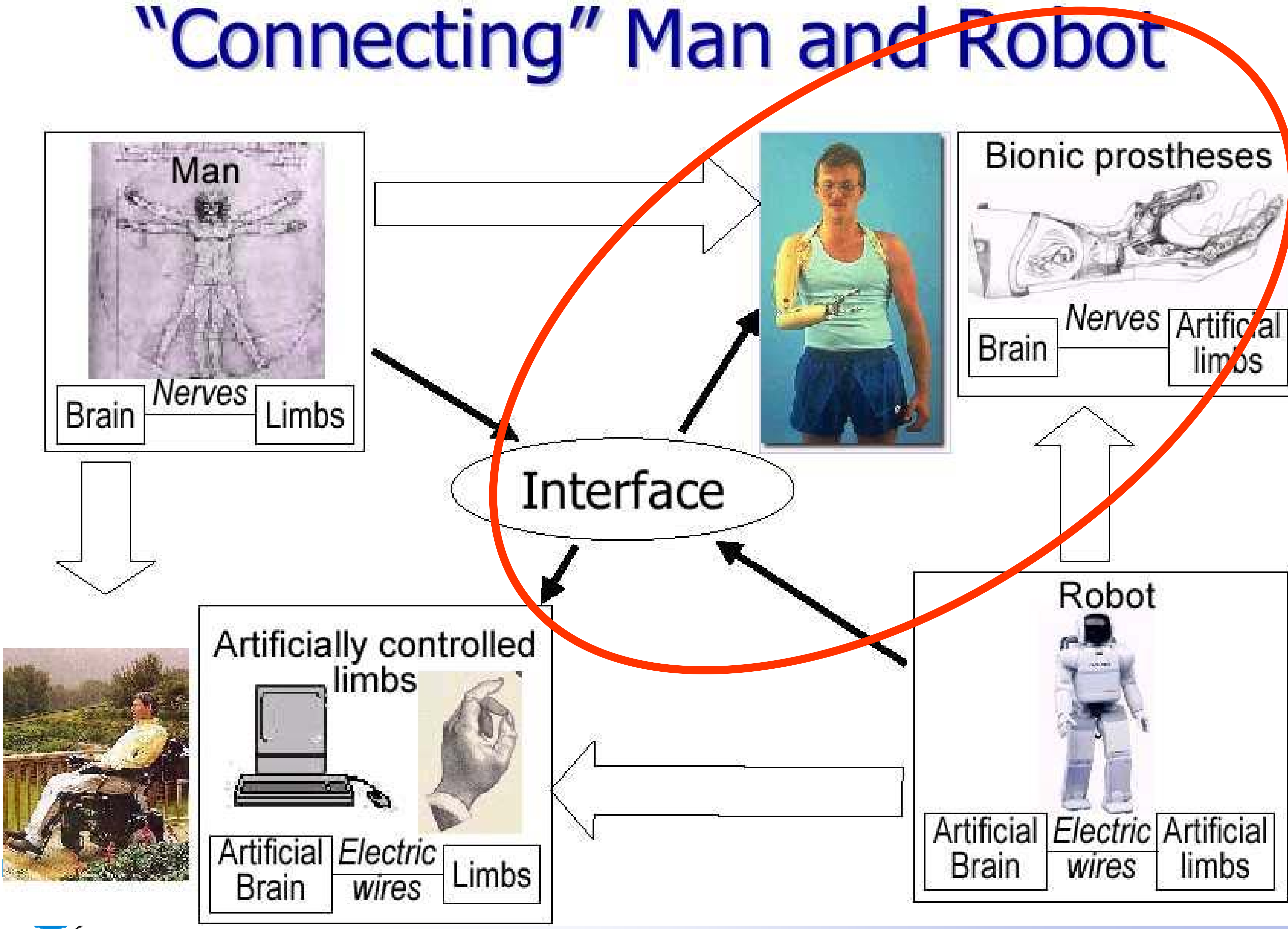
"Connecting" Man and Robot



State of the art of prosthetic hands

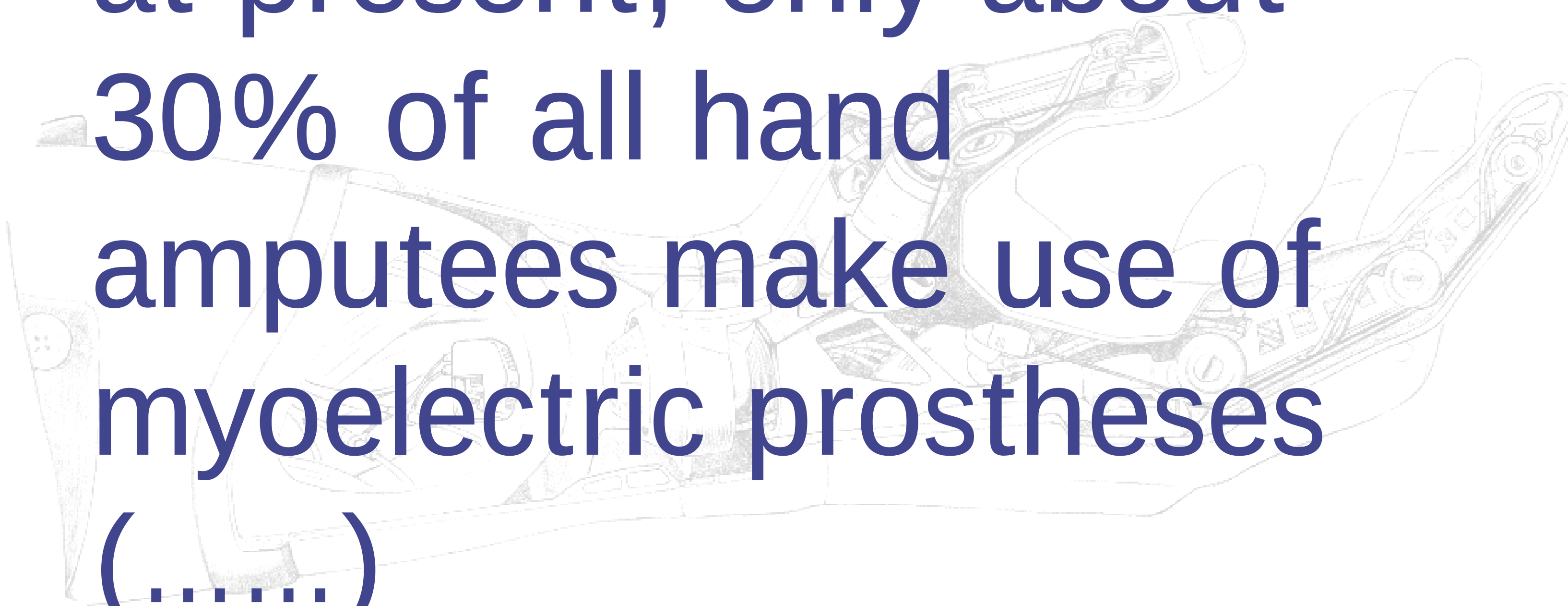
- Passive
  - Cosmetic Prosthetic Hands
- Active
  - Body Powered Prostheses
  - Myoelectric Prostheses
- Hybrid (myoelectric elbow and body-powered hand)
- Task Oriented (designed for specific tasks)

Main advantages and limits of 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)

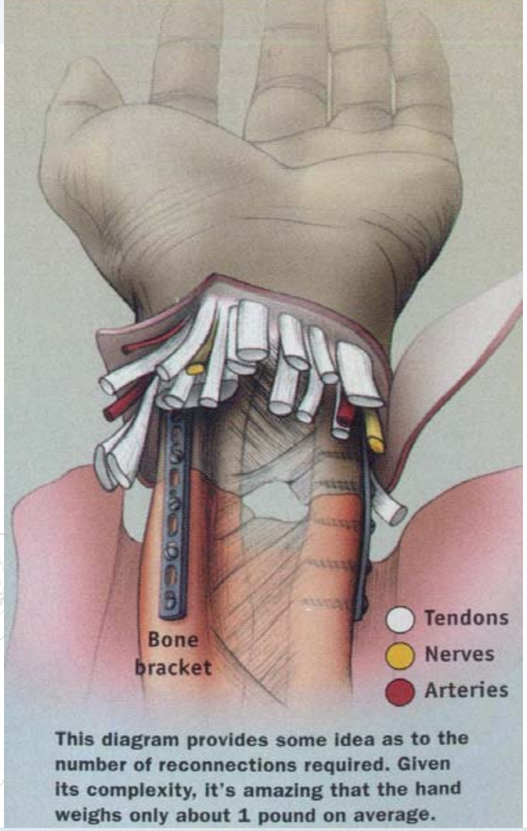
....as a consequence

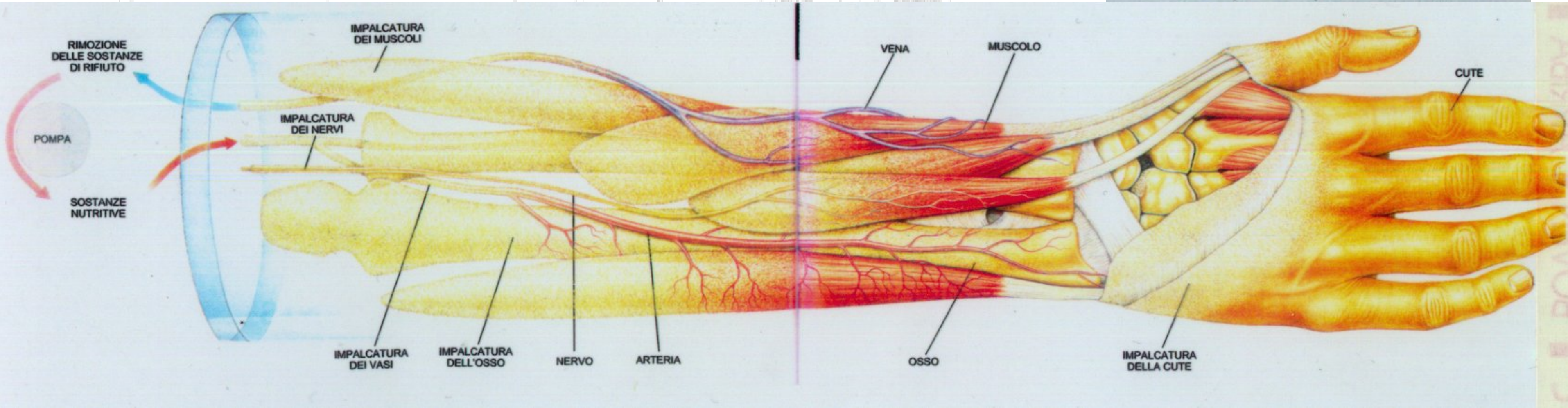


at present, only about 30% of all hand amputees make use of myoelectric prostheses (......)

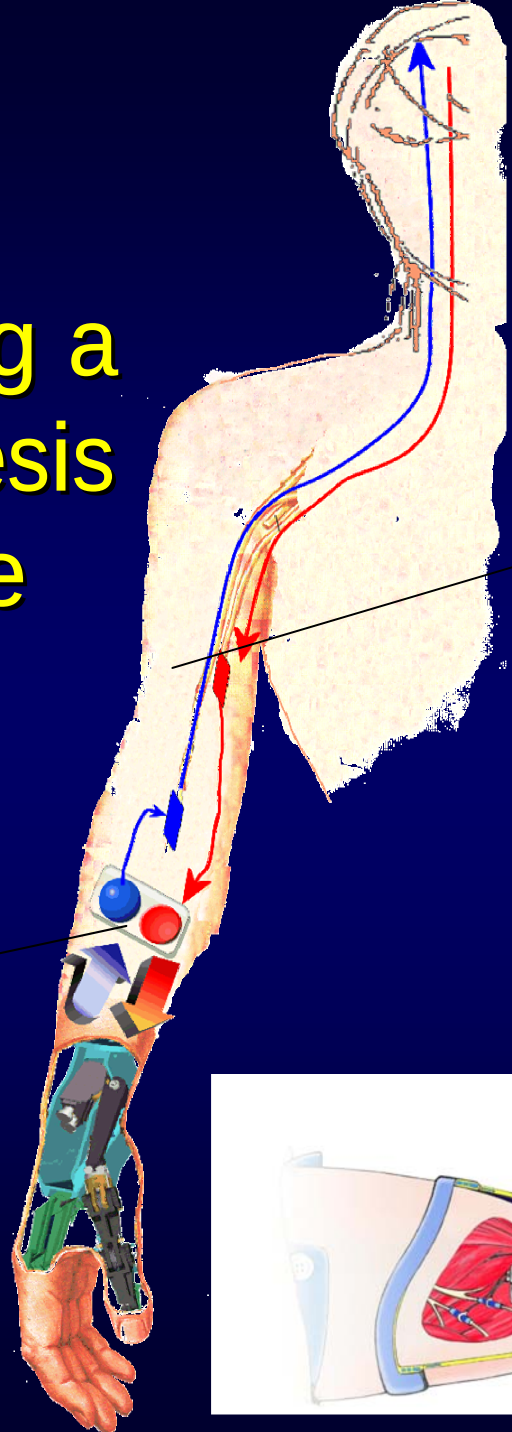
Possible solutions

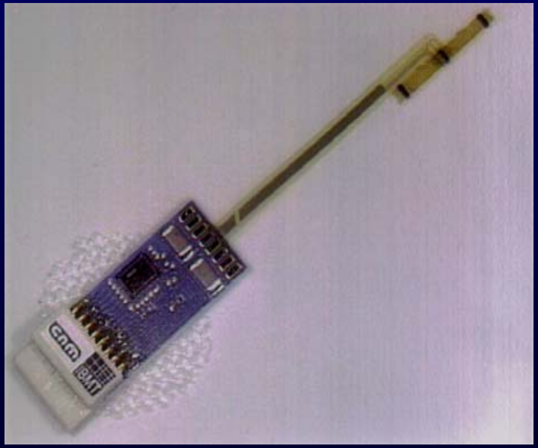
- Hand transplantation
- Hand regeneration
- Cybernetic Hand

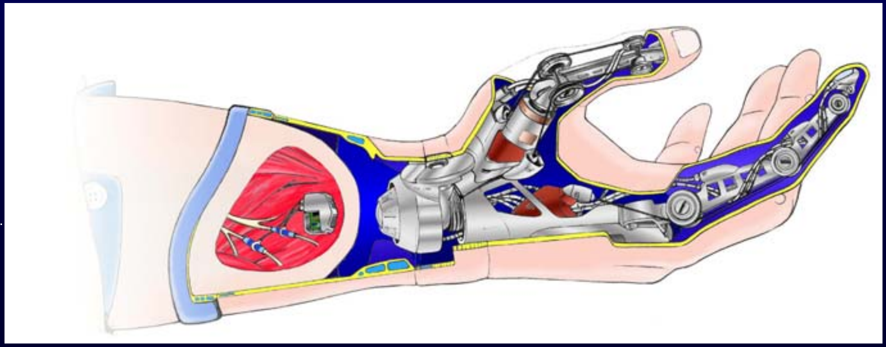




The EU-FET "CYBERHAND" Project: developing a cybernetic prosthesis controlled by the brain







Objectives of the CYBERHAND project

- **Long-Term Objective**:

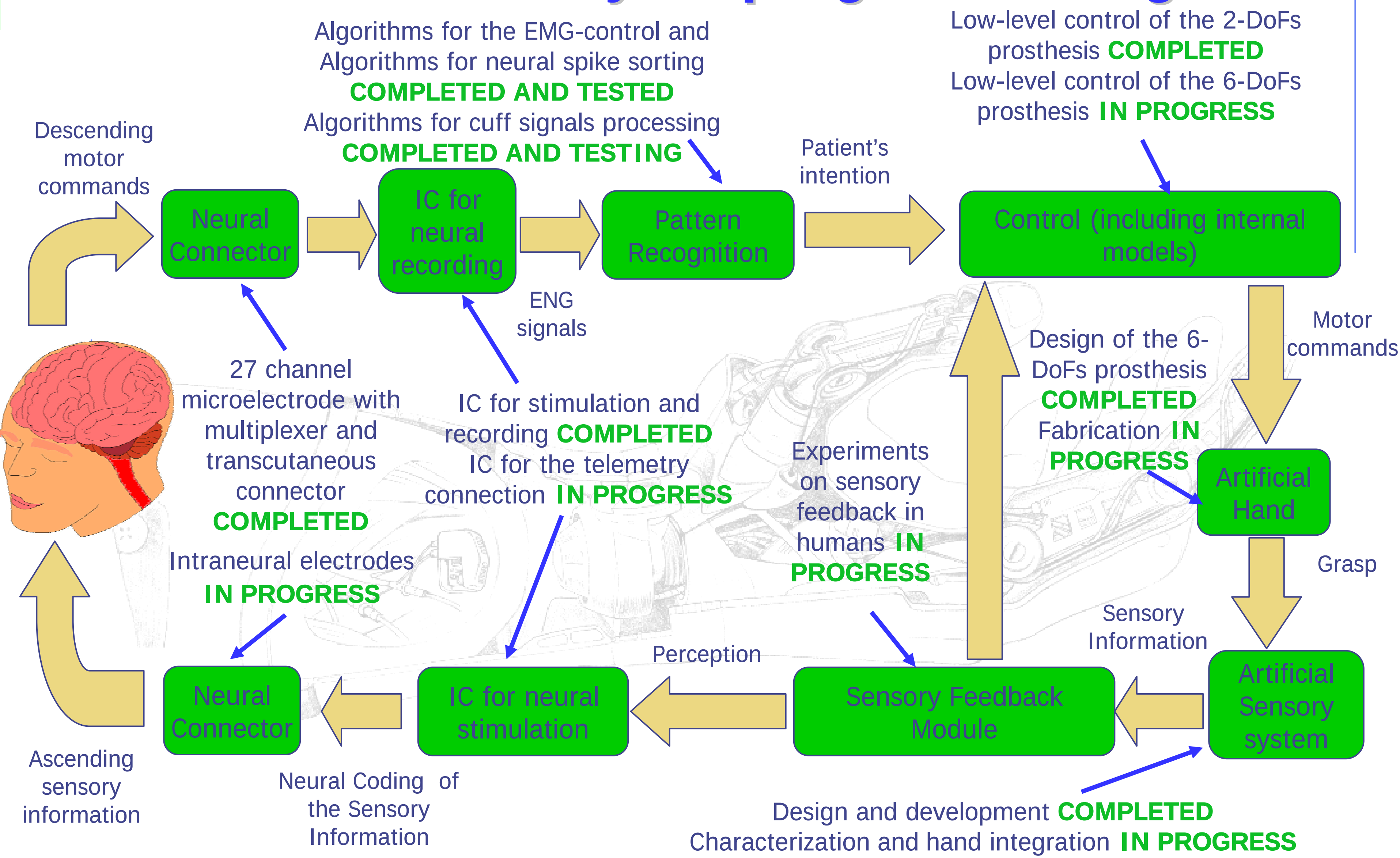
  to increase the basic knowledge of **neural regeneration** and **sensory-motor control** of the hand in humans

- **Middle-Term Objective**:

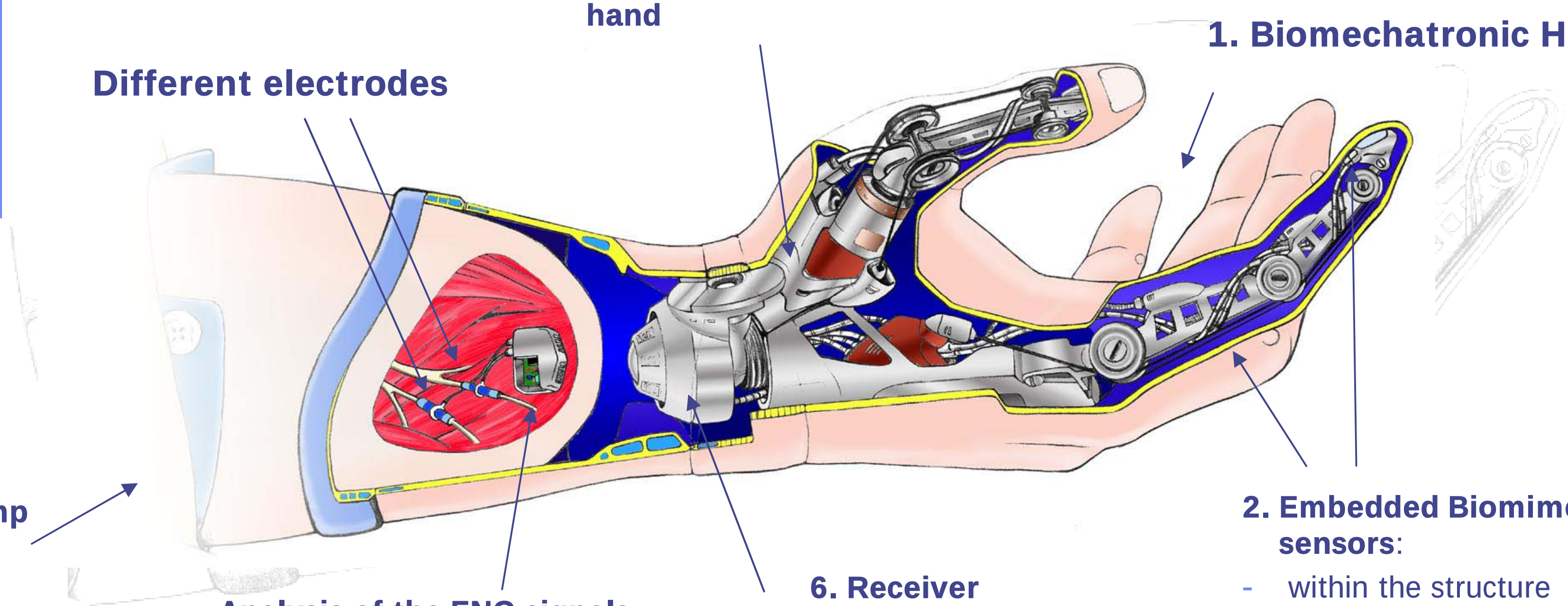
  to exploit this knowledge to develop a **new kind of hand prosthesis** which will overcome some of the drawbacks of current hand prostheses. This new prosthesis will:

  - be felt by an amputee as the lost natural limb delivering her/him a natural sensory feedback by means of the stimulation of some specific afferent nerves;
  - be controlled in a very natural way by processing the efferent neural signals coming from the central nervous system

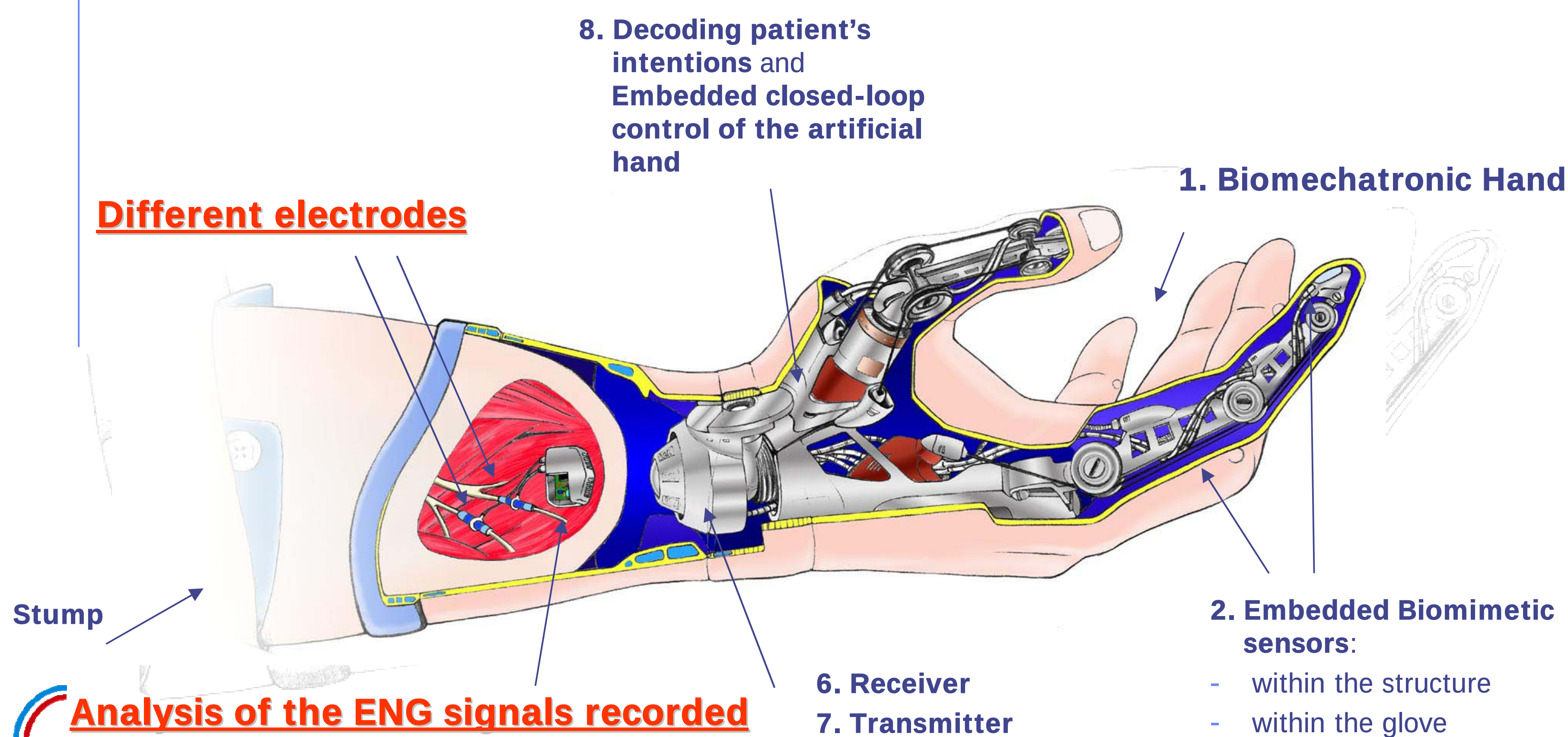
Actual results: 2nd year progress "at a glance"



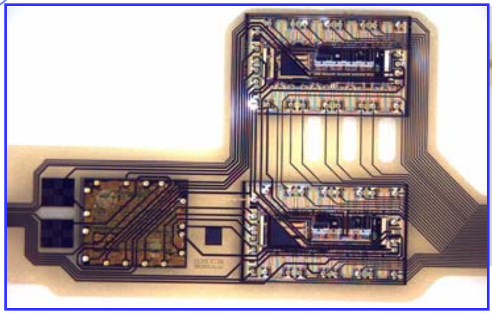
The Final Demonstrator



The Final Demonstrator

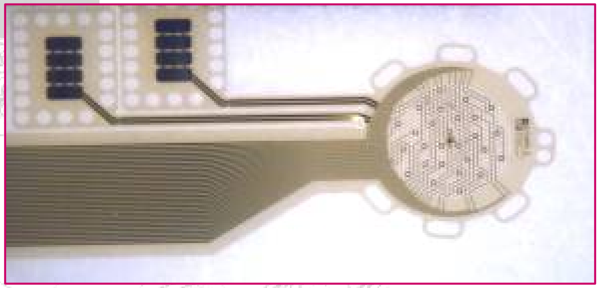


Electrodes for Recording and Stimulation in the PNS



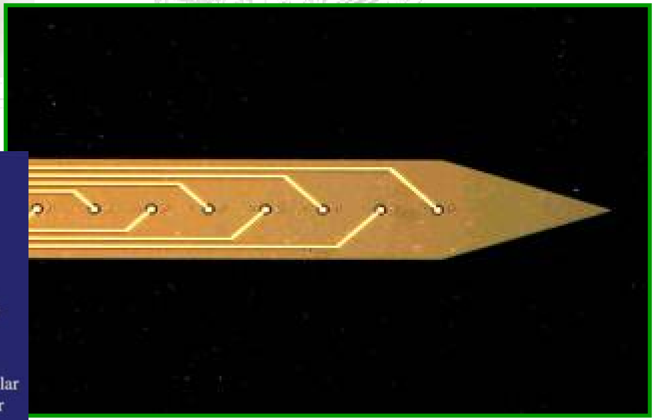
Integrated Electronics for Active Sieve Electrode

Sieve Electrode



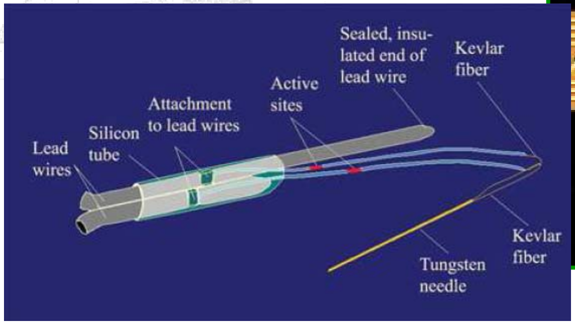
Sieve Head with Counter Electrodes

Shaft Electrode



Platinum Electrodes on the Shaft

Tripolar Cuff Electrodes

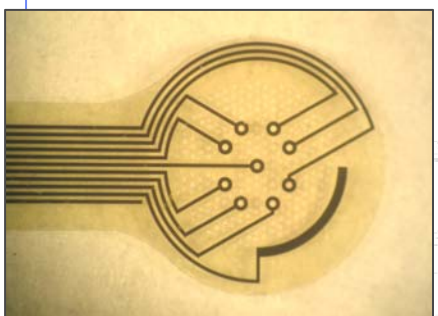


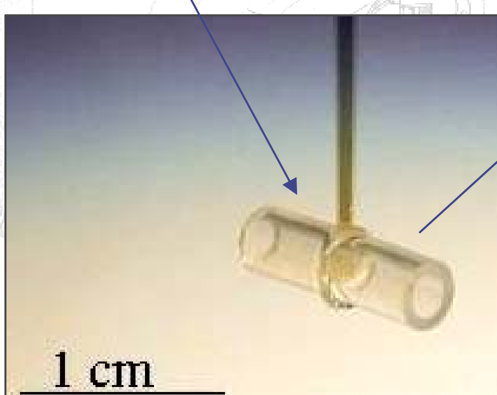
LIFE Electrodes

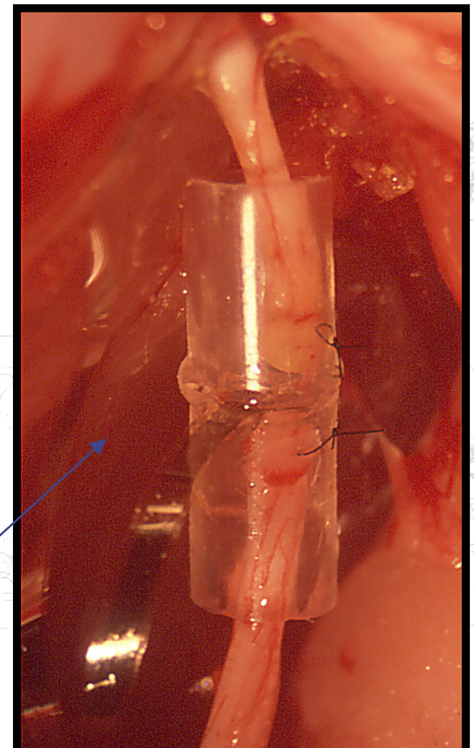
Evaluation of long-term nerve regeneration through regeneration type electrodes

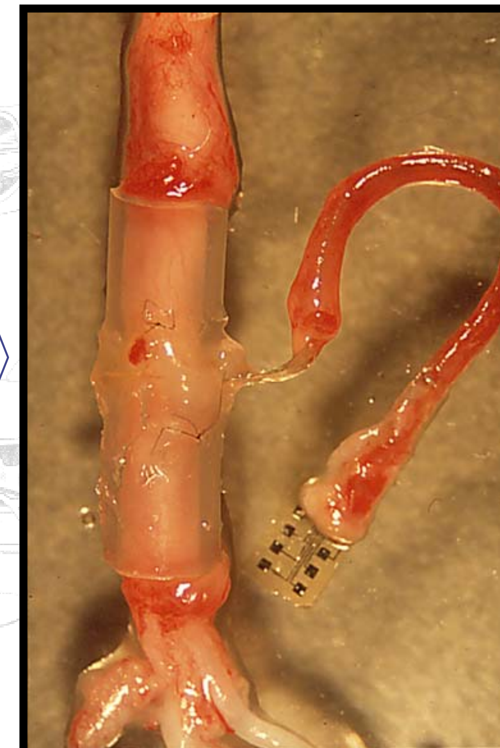
Implantation of regenerative electrodes in the sciatic nerve of rats (n = 30)

- up to 2 mo (n = 12)
- up to 6 mo (n = 8)
- up to 12 mo (n = 10)



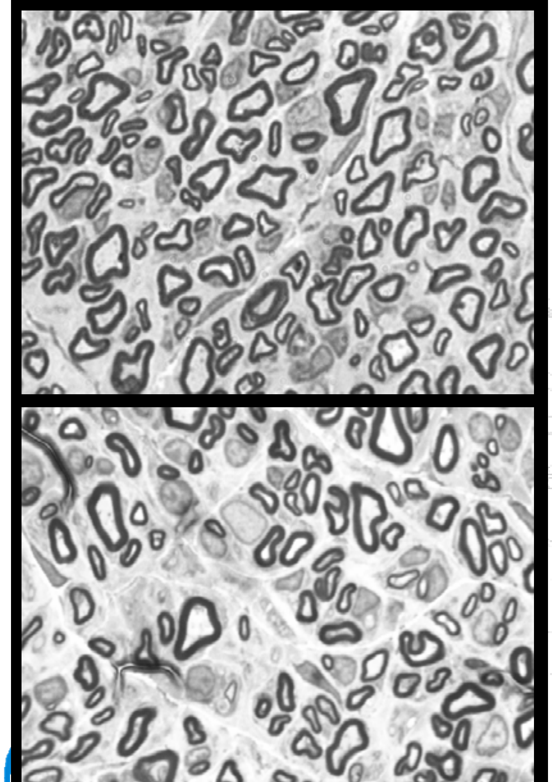






Evaluation of long-term nerve regeneration through regeneration type electrodes

Morphological evaluation of regeneration (distal nerve) at 2, 6 and 12 months

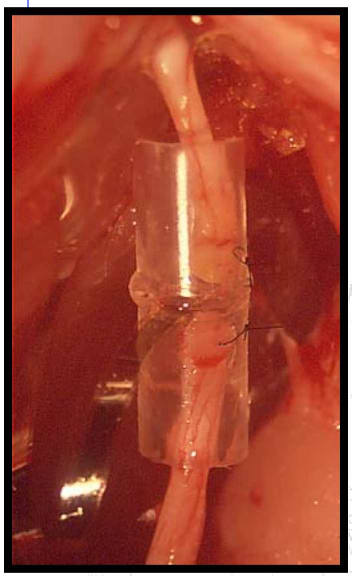


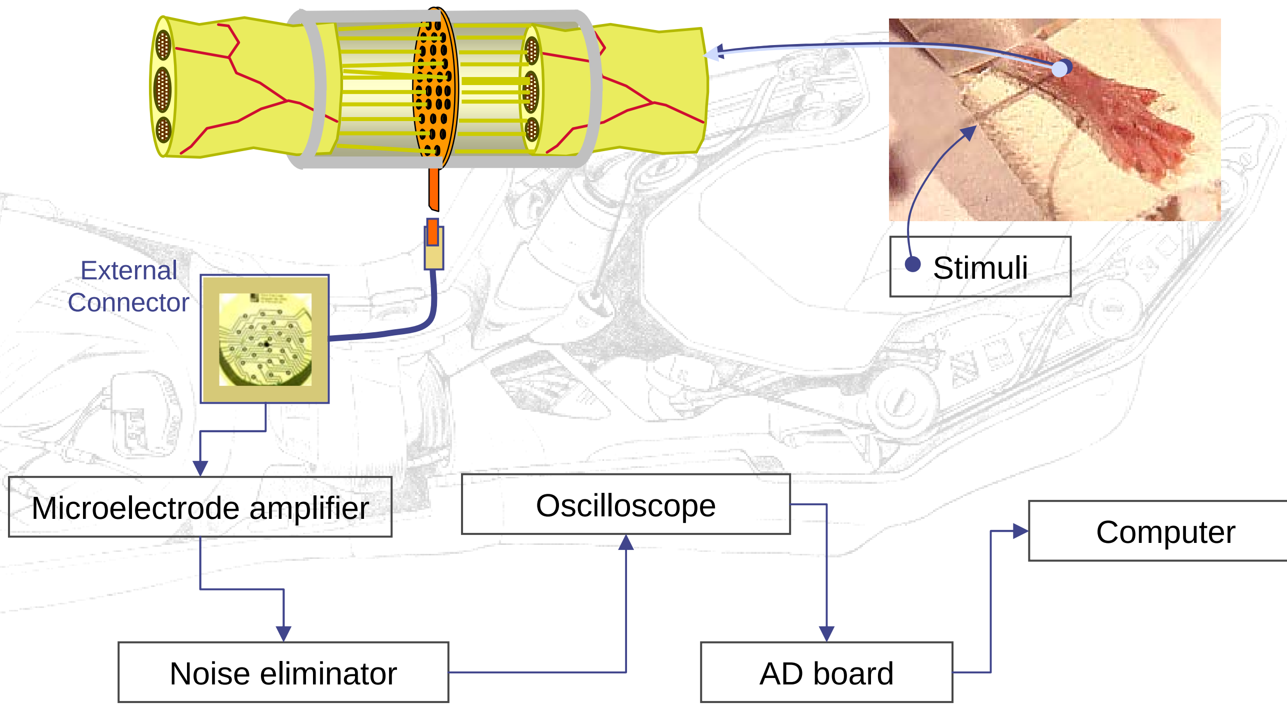
Transverse sections of the regenerated distal nerve, 6 mpo

	Control	2 months	6 months	12 months
(n)	(10)	(5)	(8)	(10)
Nerve area (mm^2)	0.66 ± 0.06	0.29 ± 0.03	0.35 ± 0.05	0.29 ± 0.03
No. M F	8266 ± 258	4940 ± 1455	8848 ± 1033	4650 ± 838
Axon diam. (µm)	4.58 ± 0.12	1.86 ± 0.12	2.35 ± 0.17	2.20 ± 0.14
Myelin thick. (µm)	1.69 ± 0.04	0.64 ± 0.02	0.71 ± 0.03	0.68 ± 0.03

Neural recording and stimulation from regenerative-type electrodes

Set-up of equipment and protocol for neural recording and stimulation

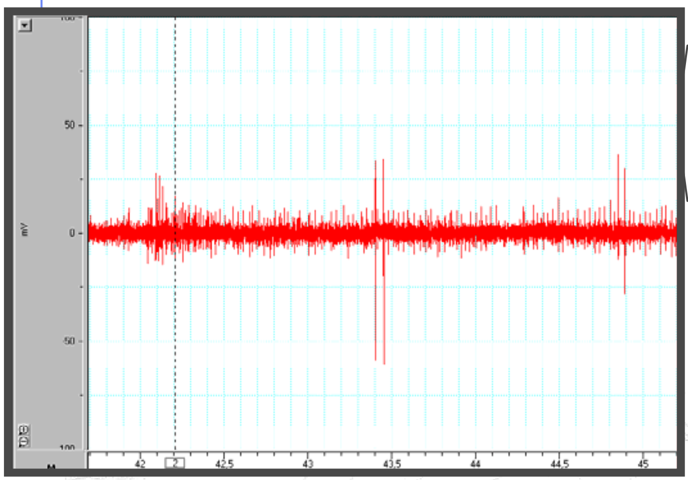




Neural recording from regenerative-type electrodes

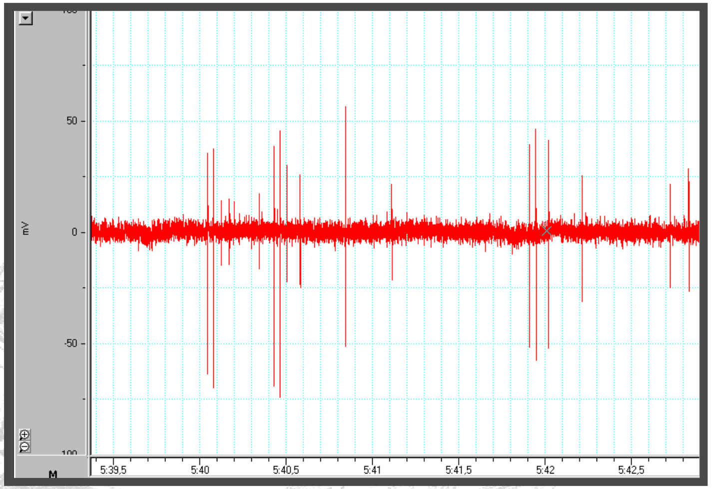
Sieve electrode recording. Rat sciatic nerve (ep4) 4mpo

Baseline activity + response to mechanical stimuli



light touch on plantar skin

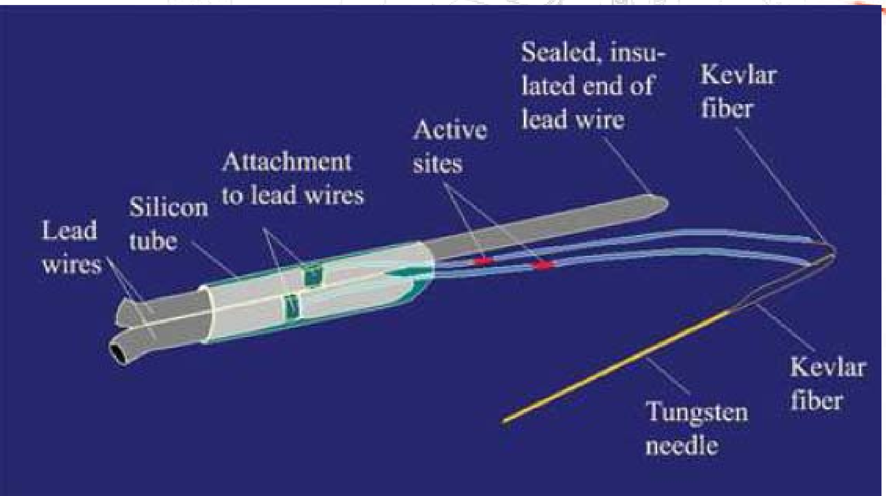
repeated touch on plantar skin

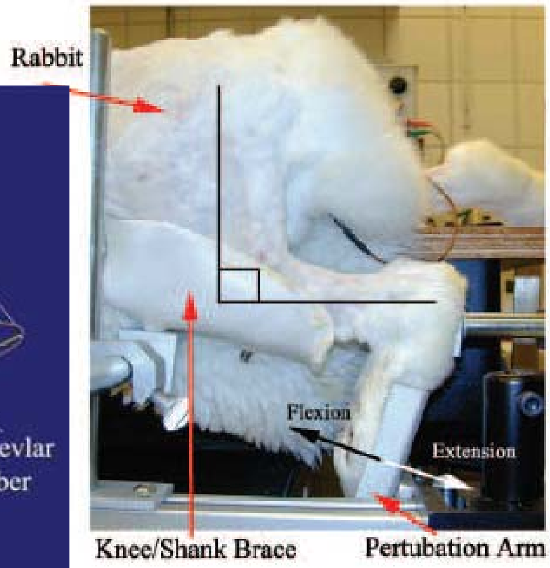


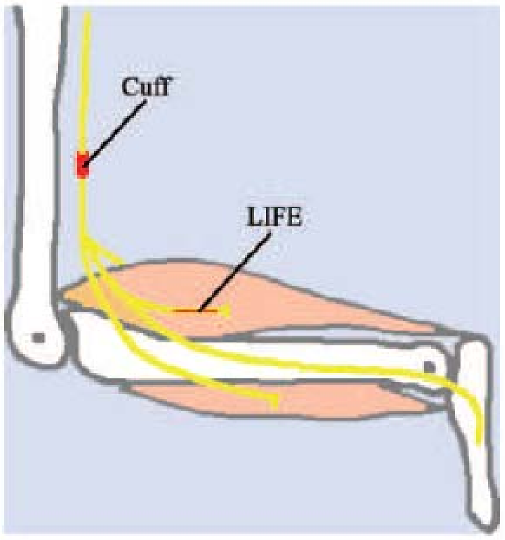
- **Polyimide sieve electrodes allow regeneration of axons through the via holes in all animals implanted**
- **Motor fibers regenerate with more delay and difficulties across the sieve perforations.**
- **To overcome these limitations, further neurobiological studies need to be performed to:**
  - **Enhance axonal regeneration after nerve section**
  - **Promote selective regeneration of motor axons**

Experiments with “LIFE” (Longitudinal Intra-Fascicular Electrodes): protocol

- The hind limb was supported by a custom made cast and the foot was placed on a pedal attached to a servo controlled motor to standardize the perturbations delivered to the ankle
- A series of ramp-and-hold angular displacements were applied. Electrodes were implanted in the sciatic nerve
- Recordings were made for several weeks (up to 32) at the Aalborg University

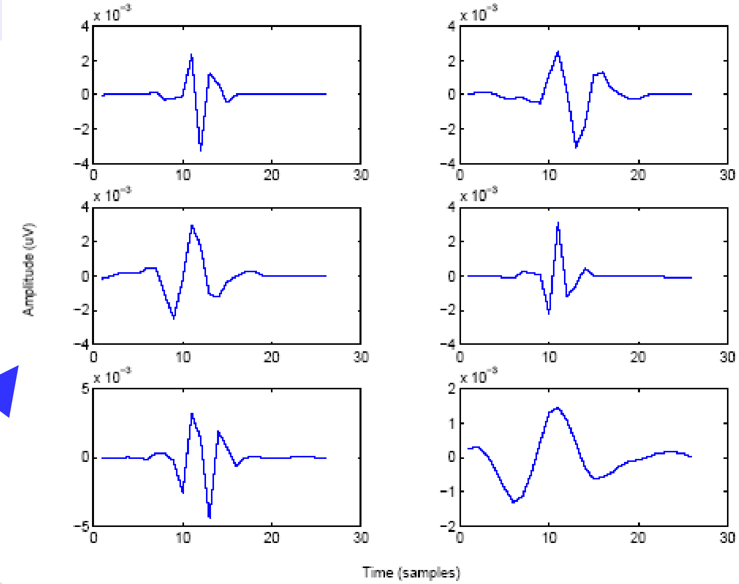




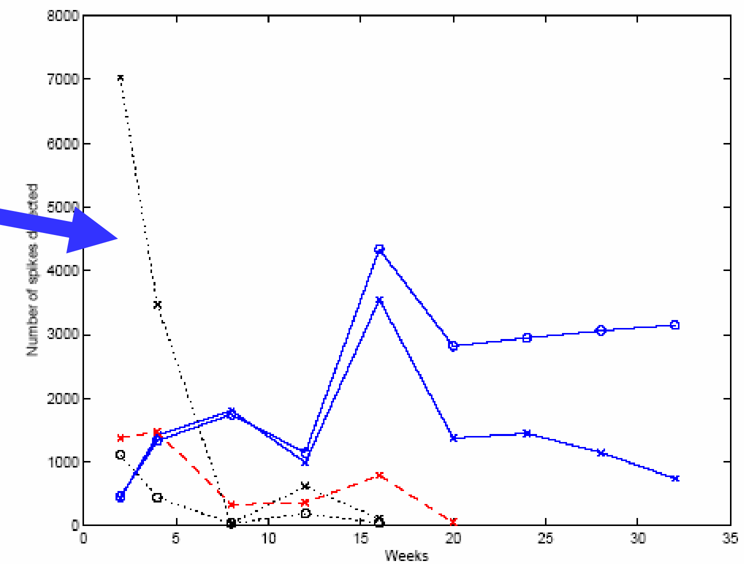


Experiments with LIFE electrodes: discussion

- The results show that the LIFE electrodes are very promising as neural interfaces for the bi-directional control of cybernetic prostheses
- In fact, it was possible to extract and identify different “spike classes” in a quite stable view
- In some cases the drift of the electrodes provoked the reduction of the information available. The problem of placement and stabilization must be addressed
- **They seem very interesting also for delivering sensory feedback by stimulating afferent nerves**

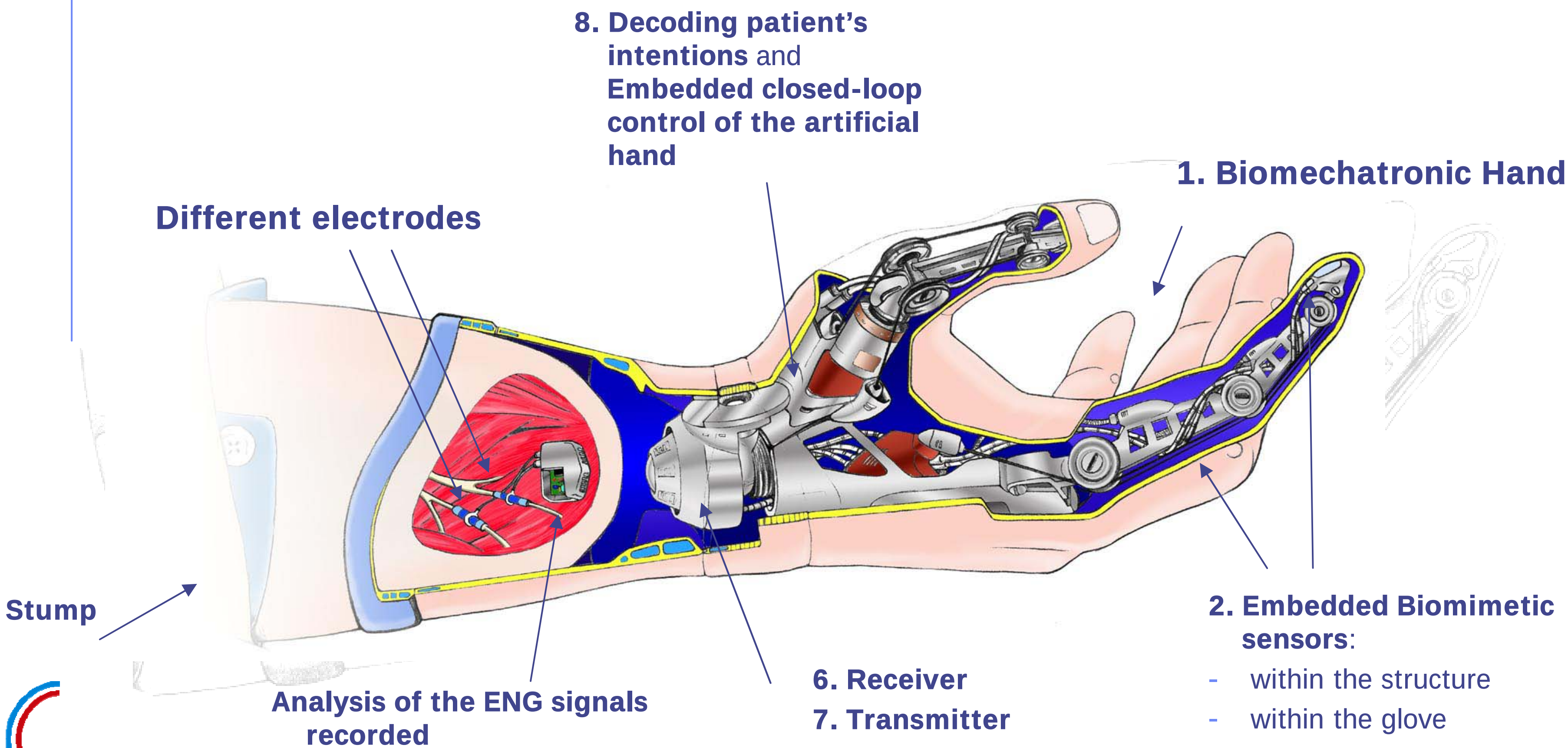


SPIKES DETECTED THROUGH LIFEs



Number of detected spikes for the different weeks for the five cases

The Final Demonstrator

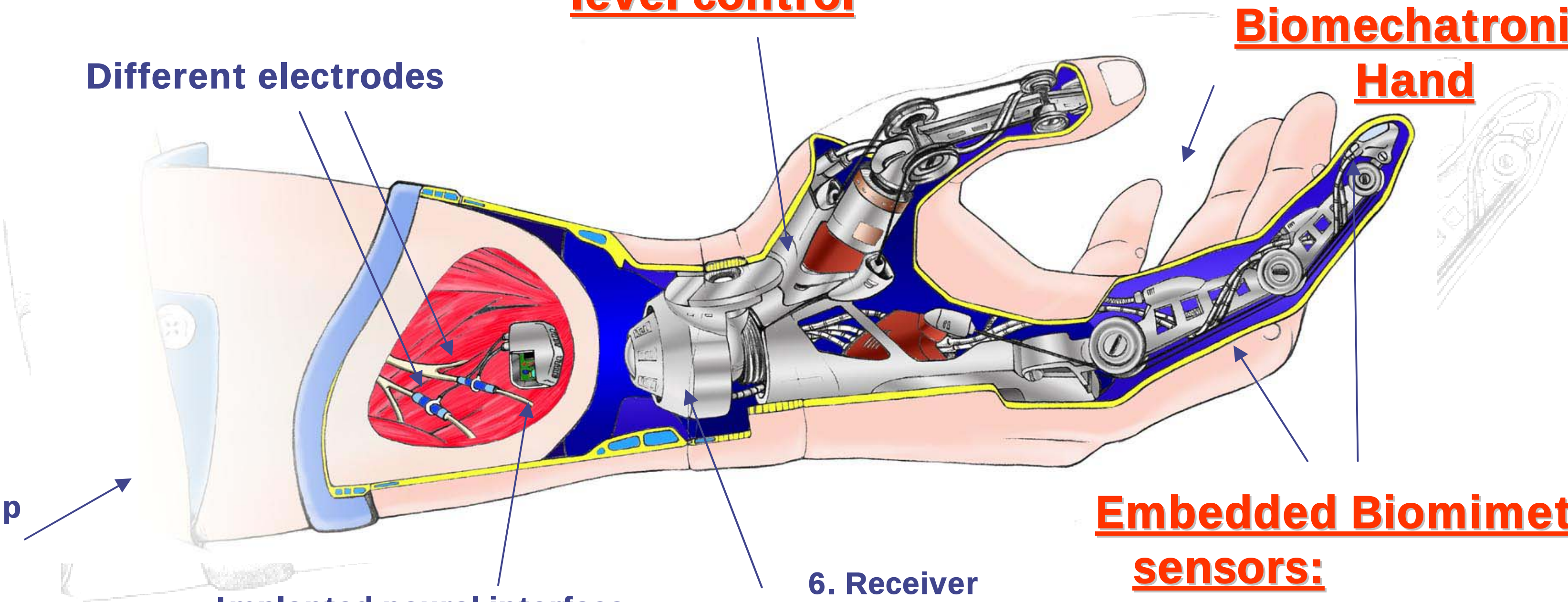


The Final Demonstrator

EMG-based High-level control

Biomechatronic Hand

Different electrodes



Stump

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

Embedded Biomimetic sensors:

- within the structure
- within the glove

THE INAIL/SSSA RTRII Prosthetic HAND

Proprioceptive: Position

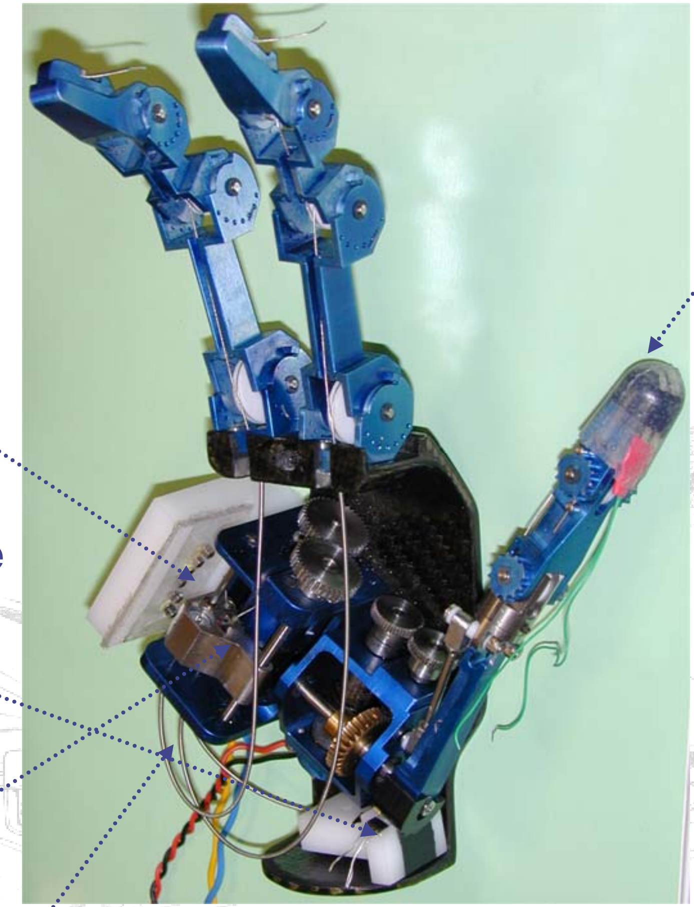
Hall Effect sensor for linear slide positioning

Proprioceptive: Joint Angle

Angular Hall Effect sensor for thumb adduction/abduction

Proprioceptive: Force

Tension cable/tendon sensor



Exteroceptive: "Tactile"

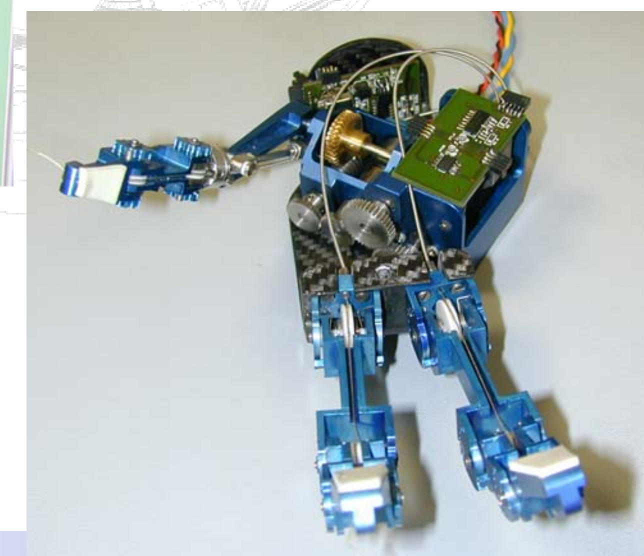
FSR pressure sensor embedded in a silicone cap at thumb tip

The hand weight is ~320 grams.

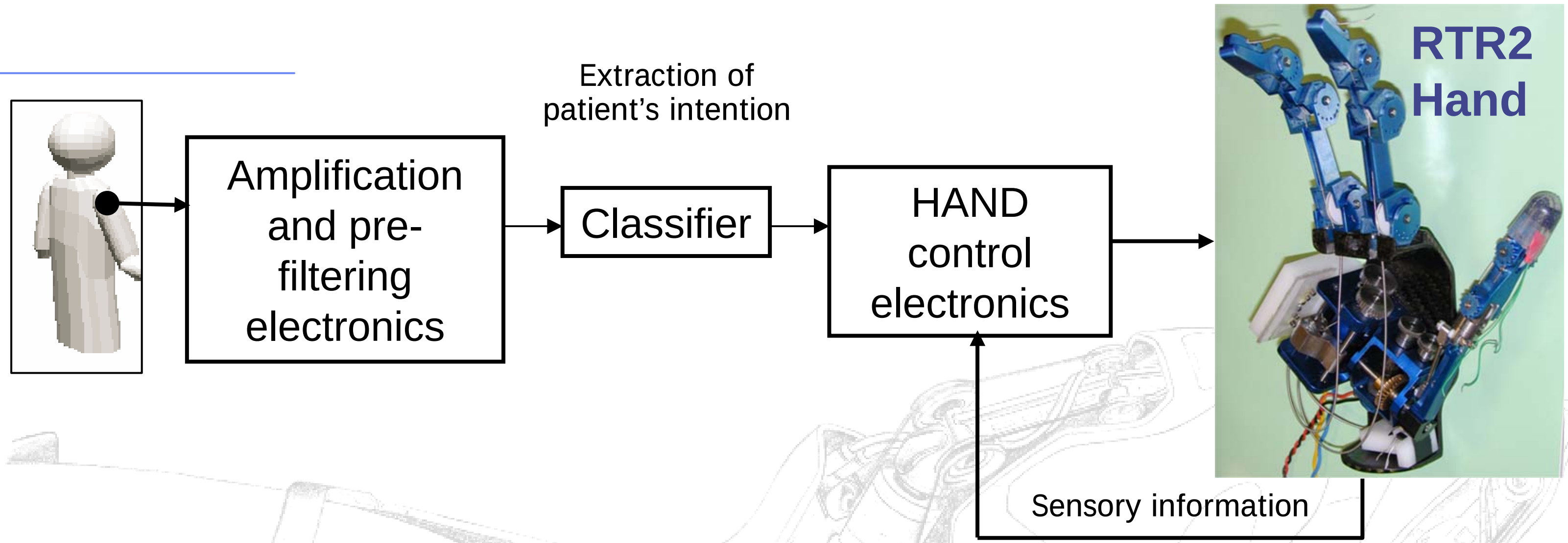
RTR2 hand is underactuated and it has 8 degrees of freedom and 2 actuators

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

Embedded control system for EMG control



The 1st prototype of the CYBERHAND system: RTRII prosthetic hand controlled by EMG signals

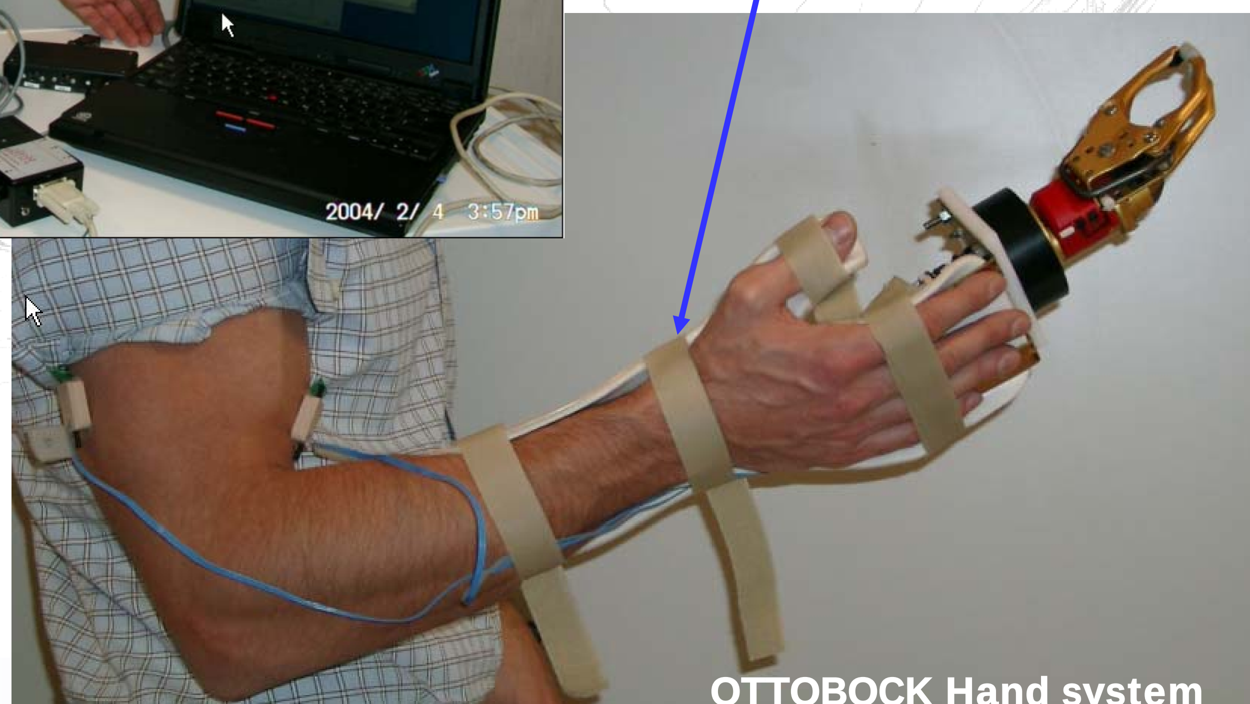


- The main aim is to analyse the performance of the multi DoF hand during complex manipulation tasks exploiting the potentialities of the RTR2-SSSA hand. In particular, this activity will allow to understand the limits of the EMG signals as an effective source of voluntary information in this specific case.
- The artificial hand has integrated sensors whose output signals will be used both for the sensor-based control of the hand and for providing feed-back to the patient through non invasive means
- **The design and implementation of the control of the system is being carried out with the scientific objective of demonstrating that the EMG control of a prosthesis is efficient, and acceptable by the patient, for a 'smart' prosthesis (i.e. including sensors and advanced controls).**

M.C. Carrozza, G. Cappiello, E. Cavallaro, S. Micera, F. Vecchi, P. Dario, "Design and control of an underactuated cybernetic artificial hand", ***Proc. of ISORA*****, 2004**

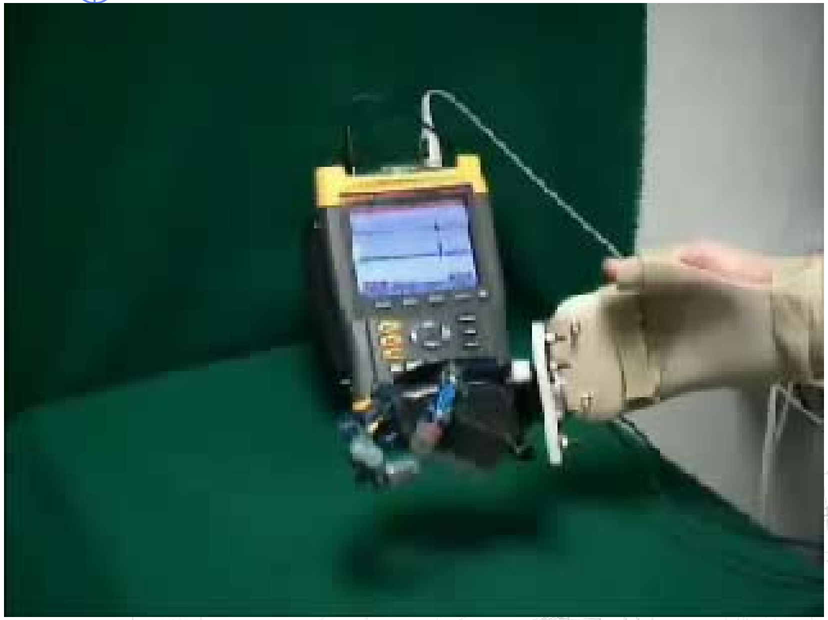
Prosthetic hand systems controlled by EMG signals: RTRII vs OttoBock hand systems

The prosthetic device can be assessed by normal subjects wearing the prosthetic system with a splint



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

RTR 2 Hand system

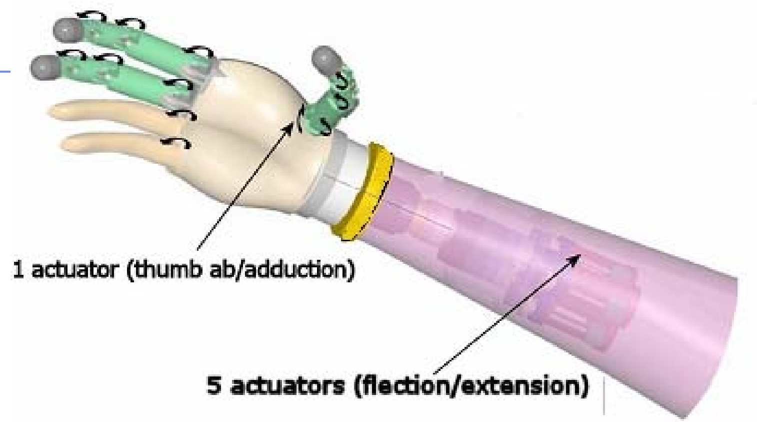


Six able-bodied subjects have been enrolled in the experiments. The rate of successful classification was around 85% with the simple NN algorithm and around 95% with the neuro-fuzzy classifier.

OTTO BOCK Hand system

This latter performance are quite similar to the state of the art in this field (see for example Englehart et al., 2001 and Englehart and Hudgins, 2003) **even if in our case fewer electrodes have been used.**

Work in progress towards the CYBERHAND prosthesis: 2nd prototype

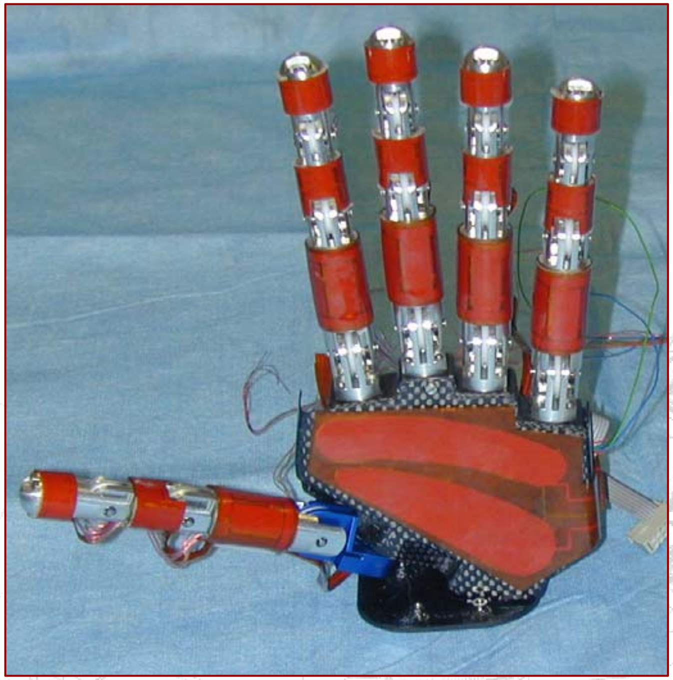


Mechanical specifications:

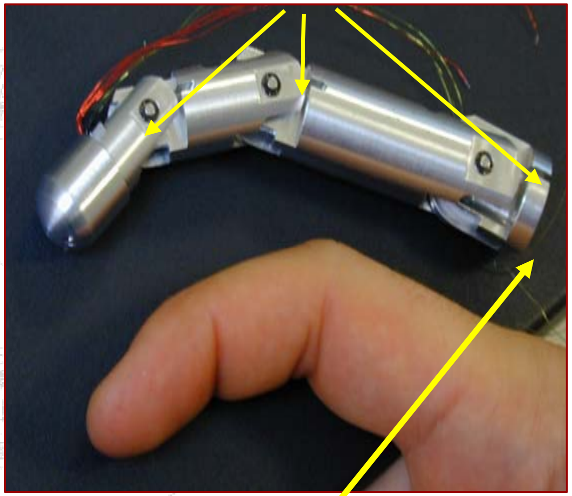
- 5 fingers
- 16 DoF
- 6 DoM (1 motor integrated into the palm for thumb positioning (adduction/abduction), 5 motors integrated in the forearm for each finger (flexion/extension)
- Underactuated fingers, each driven by a single cable actuated by a motor.
- 6 DC 6V motors
- Weight: Palm+fingers about 320 gr.,
  Socket interface (actuation and transmission system) about 700 gr.
- Maximum grasping force 45 N (expected)
- Anthropomorphic size, and kinematics

The ROBOCASA Hand

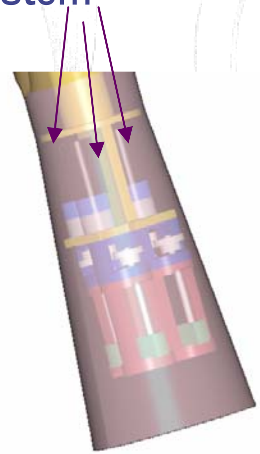
Proprioceptive sensory system



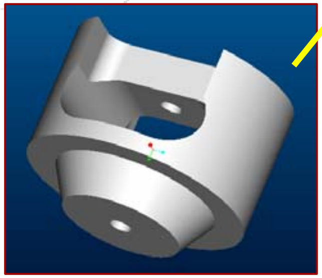
15 Embedded Joint Angle Sensors (Hall effect)
(Operational range: 0 – 90 degrees, Resolution: ~0.1 degrees).



5+1 Encoders in the Actuation System

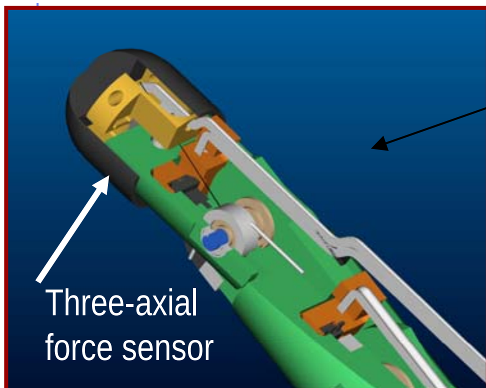


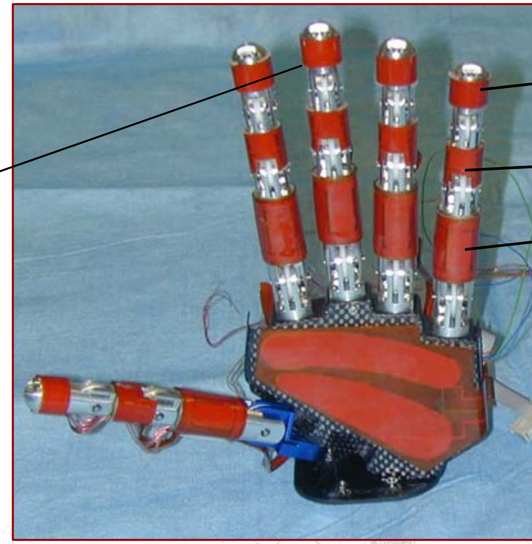
5 cable/tendon tension sensors
(Operational range: 0 – 35 N, output characteristic: linear, resolution: ~20 mN)



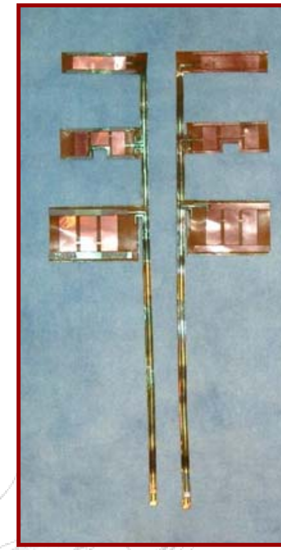
Exteroceptive sensory system so far…

Three-axial strain gauge force sensors integrated in the fingertips





Distributed contact sensors



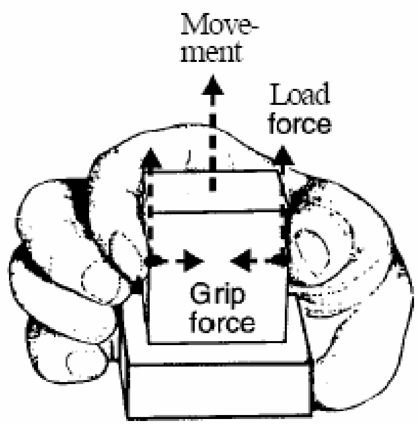
Maximum Force (N)

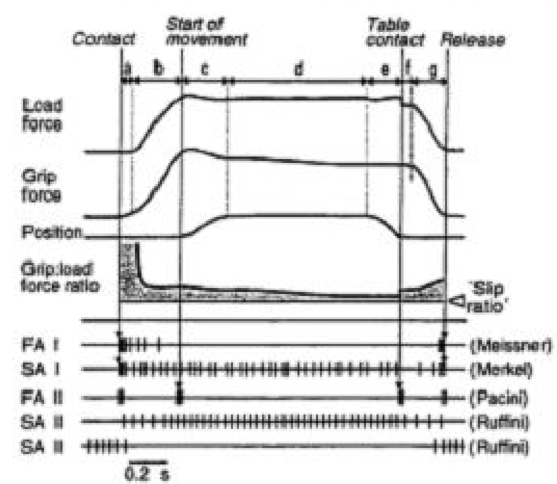
Fx max	4.62
Fy max	5.96
Fz max	4.62

Maximum force magnitude 8,75 N

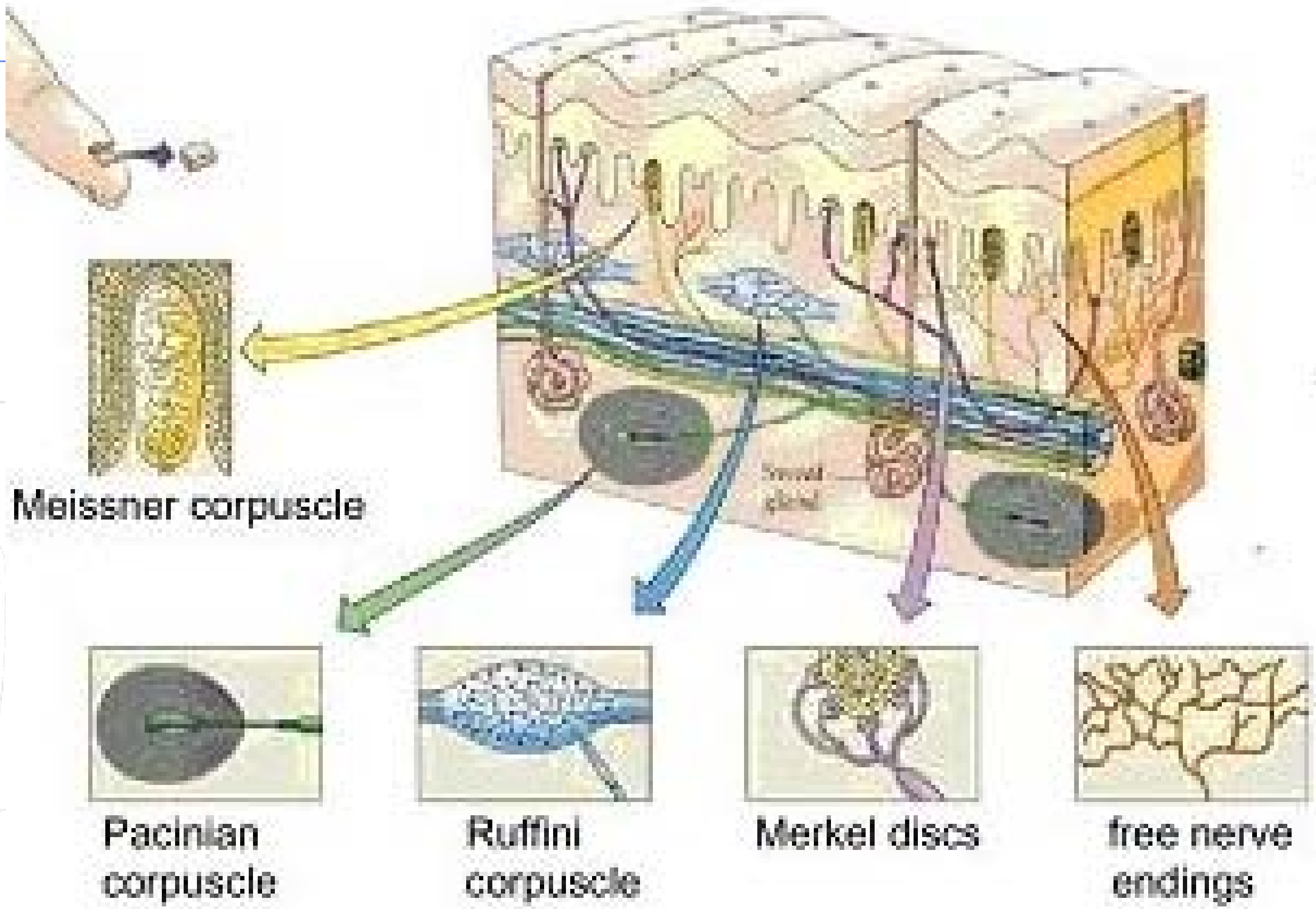
Contact sensors at fingertips and palm (threshold ~60 -100 mN)

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

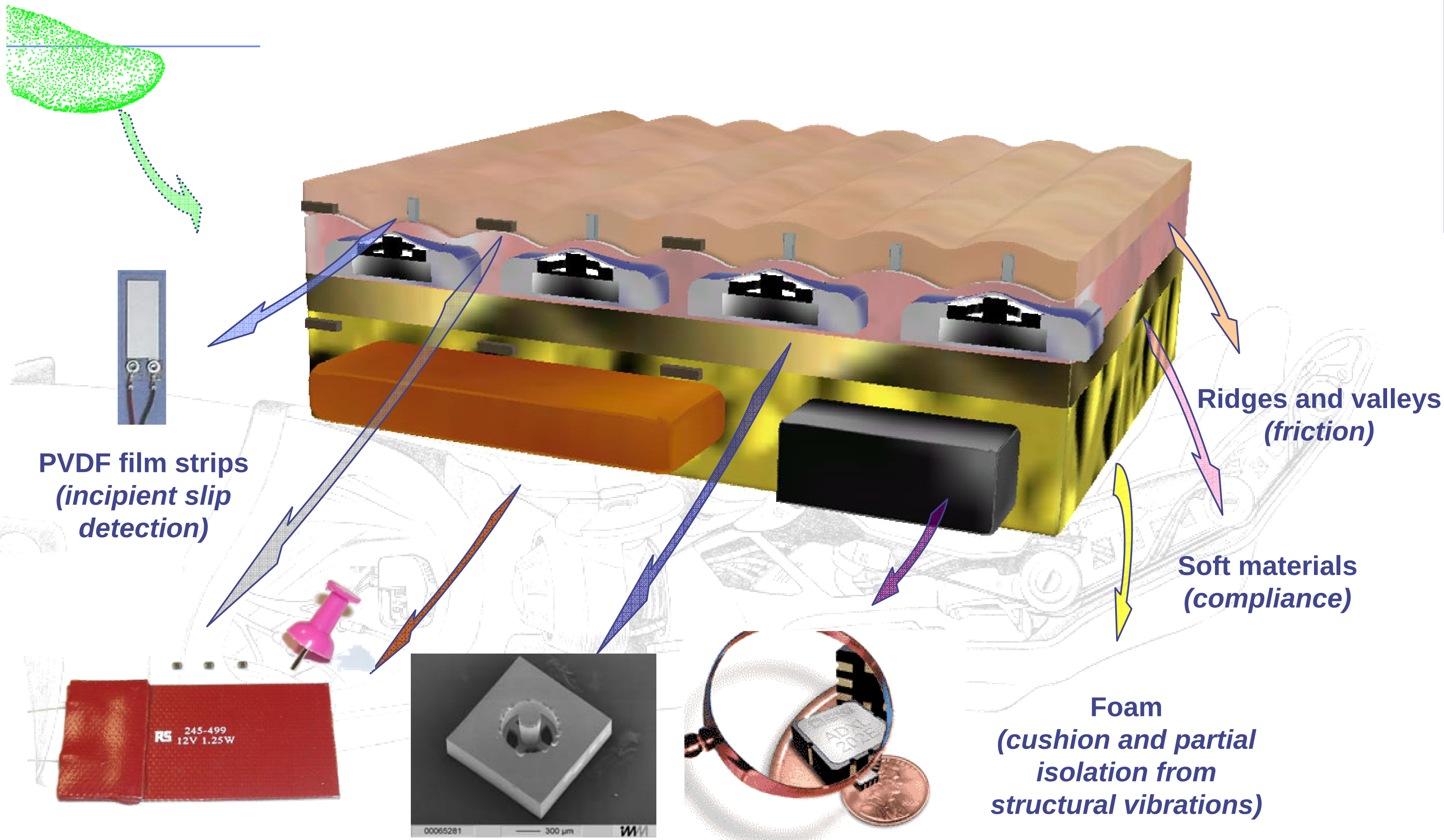




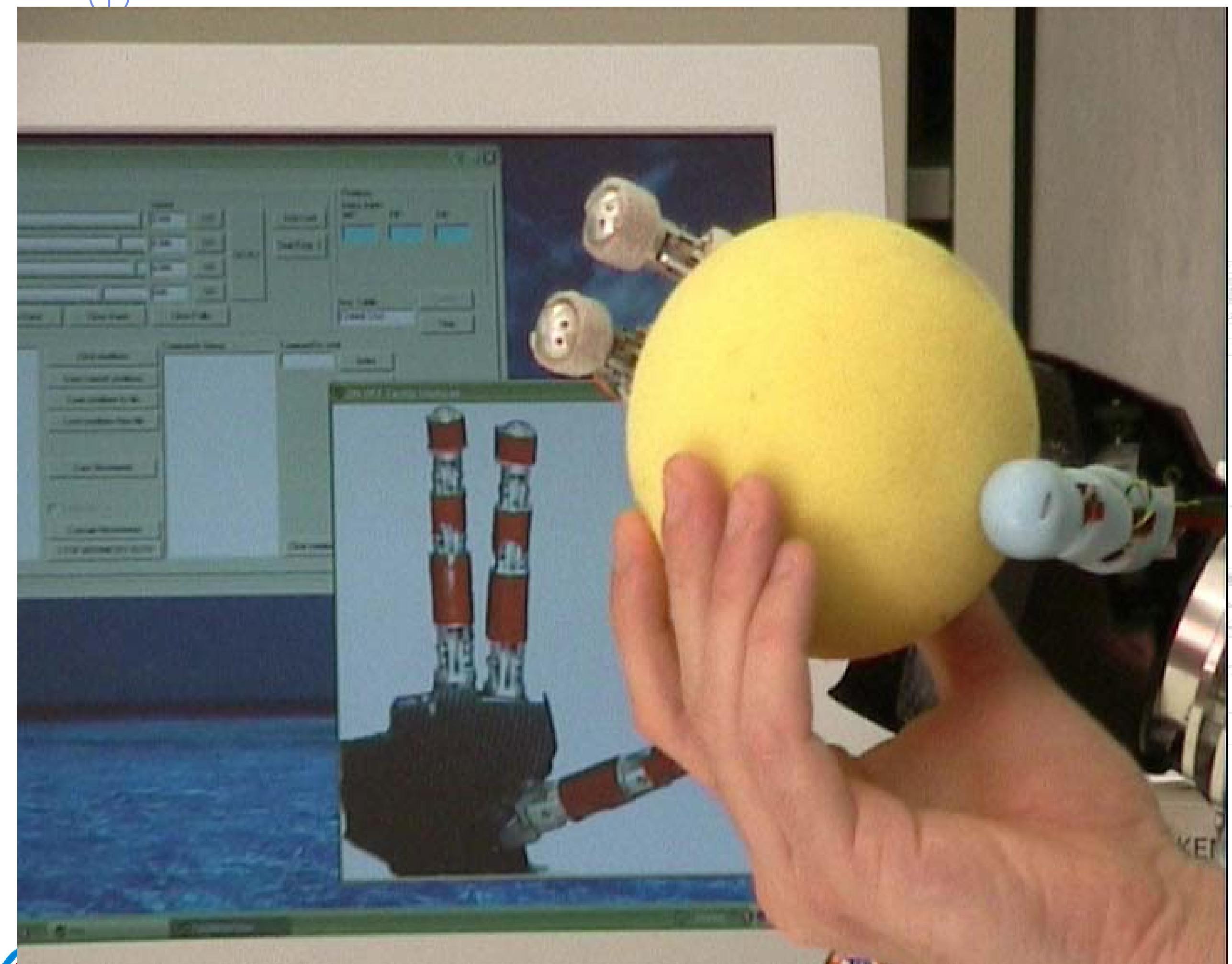
The human skin.....



……and the skin of our next artificial skin



Contact sensors operating during manipulation



Wide open/Full close in 6 sec

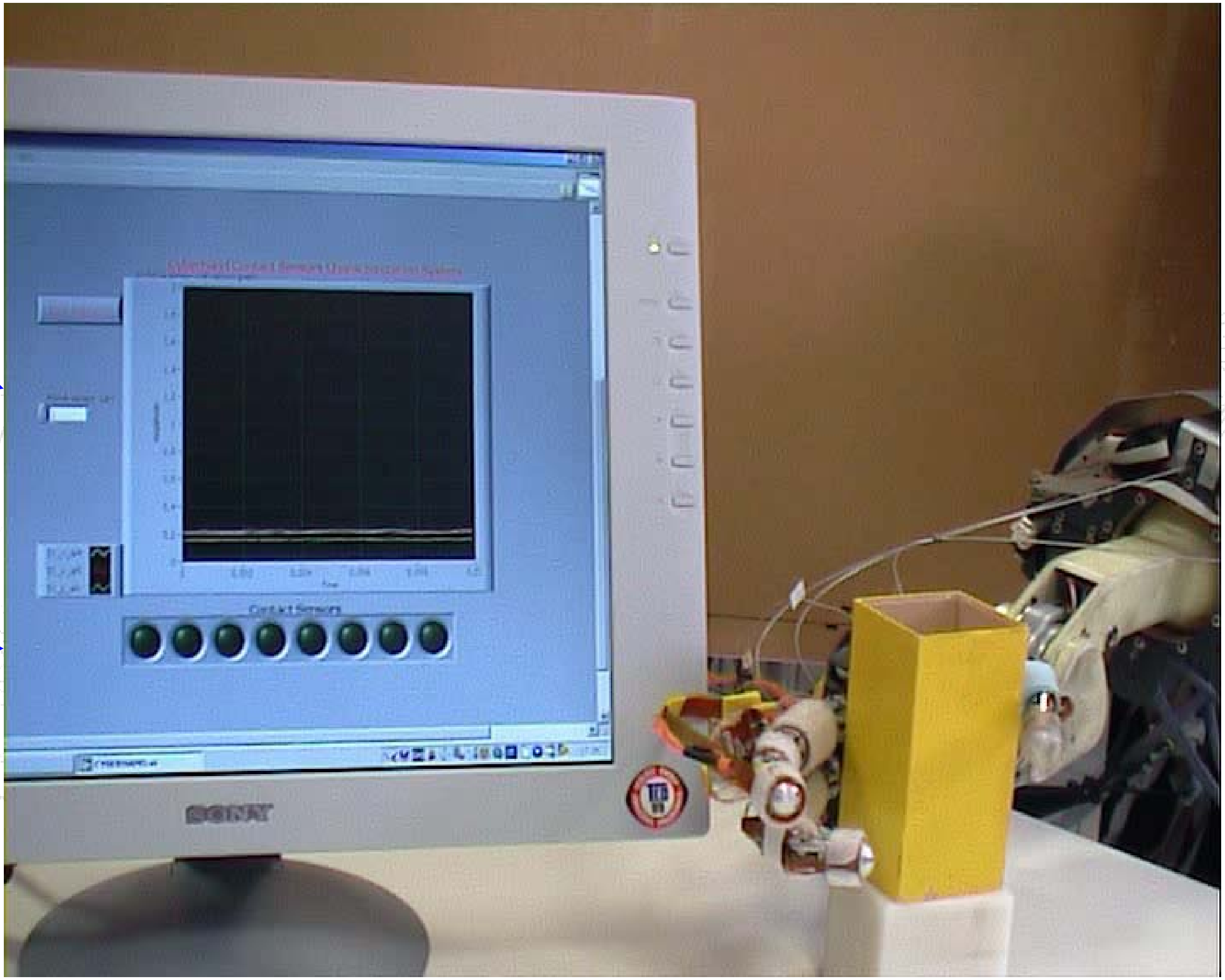
(90° for each finger)

Force exerted on a Ø60 cylinder: 10 N for each finger

Contact and fingertip force sensors operating during pick and lift task

Three axial force sensor signals

Contact sensors signals



Activities planned during the 3rd Year

- Particular efforts will be carried out in order to verify whether it is possible to achieve the final goal of the project (e.g., <u>implementing an acute implant of different electrodes in humans for the control of the prostheses</u>)
- Patients, hand surgeons, neurorehabilitators, experts in implanting current hand prostheses and all the other interested actors will be involved in this decision