The CYBERHAND Project
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NEURO-IT Workshop

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The Consortium

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2. INAIL RTR Center
3. Fraunhofer Institut für Biomedizinische Technik
4. Centro Nacional de Microelectronica
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CYBERHAND Project: Development of a CYBERnetic HAND prosthesis
“Connecting” Man and Robot

Brain → Interface → Nerves

Man

Artificially controlled limbs

Robot

Artificial Brain → Electric wires → Artificial limbs

Bionic prostheses

Brain → Nerves → Artificial limbs
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”

**CYBERHAND** Project: Development of a CYBERnetic HAND prosthesis

- **Neural Connector**
  - 27 channel microelectrode with multiplexer and transcutaneous connector **COMPLETED**
  - Intraneural electrodes **IN PROGRESS**
- **IC for neural recording**
  - ENG signals
- **IC for stimulation and recording** **COMPLETED**
- **Pattern Recognition**
- **Control** (including internal models)
- **Design of the 6-DoFs prosthesis** **COMPLETED**
- **Fabrication** **IN PROGRESS**
- **Artificial Hand**
- **Experiments on sensory feedback in humans** **IN PROGRESS**
- **Artificial Sensory system**
- **Sensory Feedback Module**
- **Perception**
- **Design and development** **COMPLETED**
  - Characterization and hand integration **IN PROGRESS**

**Algorithms for the EMG-control and**
- Algorithms for neural spike sorting **COMPLETED AND TESTED**
- Algorithms for cuff signals processing **COMPLETED AND TESTING**

**Low-level control of the 2-DoFs prosthesis** **COMPLETED**
- Low-level control of the 6-DoFs prosthesis **IN PROGRESS**

**Neural Connector**
- **Neural Coding of the Sensory Information**
- **Motor commands**
- **Ascending sensory information**
- **Patient’s intention**
- **Descending motor commands**
The Final Demonstrator

1. Biomechatronic Hand
   - Different electrodes

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

3. Analysis of the ENG signals recorded

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

5. Stump

6. Receiver
7. Transmitter

CYBERHAND Project: Development of a CYBERnetic HAND prosthesis
The Final Demonstrator

1. Biomechatronic Hand
2. Embedded Biomimetic sensors:
   - within the structure
   - within the glove
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8. Decoding patient’s intentions and Embedded closed-loop control of the artificial hand

Different electrodes
Analysis of the ENG signals recorded
Electrodes for Recording and Stimulation in the PNS

- Sieve Electrode
  - Integrated Electronics for Active Sieve Electrode
  - Sieve Head with Counter Electrodes

- Shaft Electrode
  - Platinum Electrodes on the Shaft

- Tripolar Cuff Electrodes

- LI FE Electrodes

CYBERHAND Project: Development of a CYBERnetic HAND prosthesis
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

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>2 months</th>
<th>6 months</th>
<th>12 months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n)</td>
<td>(10)</td>
<td>(5)</td>
<td>(8)</td>
</tr>
<tr>
<td>Nerve area (mm²)</td>
<td>0.66 ± 0.06</td>
<td>0.29 ± 0.03</td>
<td>0.35 ± 0.05</td>
<td>0.29 ± 0.03</td>
</tr>
<tr>
<td>No. M F</td>
<td>8266 ± 258</td>
<td>4940 ± 1455</td>
<td>8848 ± 1033</td>
<td>4650 ± 838</td>
</tr>
<tr>
<td>Axon diam. (µm)</td>
<td>4.58 ± 0.12</td>
<td>1.86 ± 0.12</td>
<td>2.35 ± 0.17</td>
<td>2.20 ± 0.14</td>
</tr>
<tr>
<td>Myelin thick. (µm)</td>
<td>1.69 ± 0.04</td>
<td>0.64 ± 0.02</td>
<td>0.71 ± 0.03</td>
<td>0.68 ± 0.03</td>
</tr>
</tbody>
</table>

Transverse sections of the regenerated distal nerve, 6 mpo

**CYBERHAND** Project: Development of a **CYBERnetic HAND** prosthesis
Neural recording and stimulation from regenerative-type electrodes

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

External Connector

Microelectrode amplifier

Oscilloscope

Noise eliminator

AD board

Computer

Stimuli
Neural recording from regenerative-type electrodes

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.

Number of detected spikes for the different weeks for the five cases.
The Final Demonstrator

1. Biomechatronic Hand
   - Analysis of the ENG signals recorded
   - Different electrodes
   - Stump

2. Embedded Biomimetic sensors:
   - within the structure
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CYBERHAND Project: Development of a CYBERnetic HAND prosthesis
The Final Demonstrator

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

**EMG-based High-level control**

**Different electrodes**

**Biomechatronic Hand**

**6. Receiver**

**7. Transmitter**

**Embedded Biomimetic sensors:**
- within the structure
- within the glove

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CYBERHAND Project: Development of a CYBERnetic HAND prosthesis
THE I NAI L/ 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 (MINI MOTOR, CH) integrated in the palm

Embedded control system for EMG control

CYBERHAND Project: Development of a CYBERnetic HAND prosthesis
The 1st prototype of the CYBERHAND system: RTR2 I 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 feedback 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).

Prosthetic hand systems controlled by EMG signals: RTR II vs OttoBock hand systems

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

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
Proprioceptive sensory system

5+1 Encoders in the Actuation System

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

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

Three-axial force sensor

Maximum Force (N)
Fx max 4.62
Fy max 5.96
Fz max 4.62

Maximum force magnitude 8.75 N

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

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

Distributed contact sensors

The CYBERHAND Project: Development of a CYBERnetic HAND prosthesis
The human skin...
......and the skin of our next artificial skin

PVDF film strips (incipient slip detection)

Heater and thermal sensors (material recognition from thermal gradient)

3D force sensor (force magnitude and direction)

Accelerometer (event detection)

Ridges and valleys (friction)

Soft materials (compliance)

Foam (cushion and partial isolation from structural vibrations)

CYBERHAND Project: Development of a CYBERnetic HAND prosthesis
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

CYBERHAND Project: Development of a CYBERnetic HAND prosthesis
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., implementing an acute implant of different electrodes in humans for the control of the prostheses).

- Patients, hand surgeons, neurorehabilitators, experts in implanting current hand prostheses and all the other interested actors will be involved in this decision.