CYBERHAND - A CONSORTIUM PROJECT FOR ENHANCED CONTROL OF POWERED ARTIFICIAL HANDS BASED ON DIRECT NEURAL INTERFACES

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ABSTRACT

The goal of the CyberHand project is to develop an advanced powered prosthetic hand for upper extremity amputees. The project is a collaborative effort by several research groups and is funded by the European Commission program. The project encompasses several areas:

Mechanical Design -A three fingered anthropomorphic powered hand is being developed by the researchers at SSSA. The hand will incorporate tactile and joint angle sensors. Two motors are employed, one to operate the thumb and the other for the index and middle fingers. Emphasis is on developing a device that is light weight, reliable, cosmetic, energy efficient and highly functional and that will ultimately be commercially viable.

Neural Interface - Neural interfaces based on a 'sieve' structure fabricated from metalized polyamide are being developed at IBMT for bi-directional communication with the residual limb nerves of the amputee. The implantable interface includes integral multiplexing circuitry. These devices are being in-vivo tested at UAB for their ability to record and to stimulate regenerated nerve fibers in chronic preparations.

Implantable Telemetric Stimulate/Record Electronics - A implantable system is being developed at CNM which can drive multiple nerve stimulation sites (to provide cognitive feedback) as well as simultaneously record efferent neural activity (to obtain voluntary user commands). The capabilities of the planned system include 8 independent channels of stimulation and 4 channels of simultaneous recording. The implanted portion of the system will be RF powered.

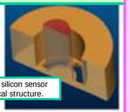
Control Strategies - Control algorithms that utilize fuzzy logic and artificial neural networks are being developed by personnel at SSSA to translate the recorded neural efferent activity that the prosthesis user generates into reliable and intuitive commands for operating the powered hand.

Cognitive Feedback - Strategies are being developed at SMI that will allow the prosthesis user to receive cognitive feedback about tactile events during grasping and object manipulation. This feedback is planned to include user awareness of finger position as well. The approach is to use the neural interface to apply electrical stimulation to the afferent nerves in the amputee's limb. This will make use of the topographical mapping that exists between the peripheral nerve fascicles and the prosthesis users referred 'phantom' sensations as much as possible.

ARTIFICIAL SENSORY SYSTEM

The artificial sensory system is the core of the hand control system. It will provide input signals for the low-level control loop of the grasping phase, and it will generate sensory signals to be transmitted to the user through the neural interface.

The sensory system will comprise three different kind of sensors: position sensors, which will detect the position of the joints; a matrix of contact sensors, distributed on the volar part of the hand, will enable the control system to understand where the contact is; and several 3D force sensors, distributed in 5 different zones (each fingertip, the palm, and the side of the index finger) will provide information about slippage and shear.



Section of silicon sensor mechanical structure.

Matrix of contact sensors on a flexible circuit

PROSTHETIC HAND

A three fingered anthropomorphic hand is being developed. This hand will be composed of an actuator system embedded in an mechanical structure (artificial muscoskeletal system), a proprioceptive (position sensors) and exteroceptive sensory system (tactile and force sensors), an embedded control unit (low level control loop to control the incipient slippage and the grasping), and a human/machine interface (an ENG control unit)). The design goal of the mechanical structure is to enable a stable grasp with objects of different size, texture and shape, without augmenting the mechanical and the control complexity. The design approach of the CYBERHAND prosthesis will exploit underactuated mechanisms, which allow to obtain self-adaptive grasping capabilities, thanks to a large number of degrees of freedom (DoFs) controlled with a limited number of actuators and differential mechanisms.

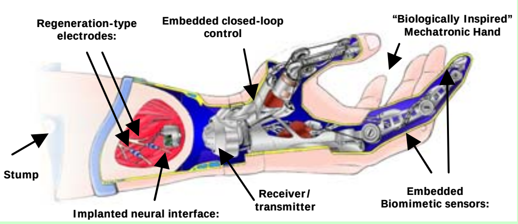
RTR II Prosthetic hand

This hand will have four motors (one for the adduction/abduction of the thumb, and one for each finger for opening and closing) which will move 9 DoFs in total. Emphasis is on developing a device that will be light weight, reliable, cosmetic, energy efficient, highly functional and that will ultimately be commercially viable.

CONTROL STRATEGIES

Control algorithms that utilize fuzzy logic and artificial neural networks will translate the recorded neural efferent activity into reliable and intuitive commands for operating the powered hand, by processing the natural efferent neural signals (High Level Pattern Recognition Module (HLPRM)),and the sensory information obtained from the biomimetic sensors embedded in the prosthesis (Low Level Controller).

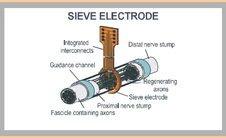
The Final Demonstrator



SENSORY FEEDBACK

Ideally, a sensory feedback system should induce tactile sensations in a prosthesis user by driving discreet, identified tactile afferents using proper biological codes. However, because single fiber connectivity hasn't yet been achieved using sieve interfaces, we are anticipating that initial feedback systems will activate small groups of afferent fibers (which hopefully, may share common or adjacent skin loci). To prepare for this eventuality we are studying the capacity of normal individuals to attend to multiple cutaneous sites that are activated simultaneously. For example, we wish to know to what extent it will be beneficial to provide tactile feedback from both the thumb and the index finger simultaneously. This can be studied in normal subjects using ring electrodes to stimulate the digital nerves. Another area of investigation is to determine to what extent activation of muscle afferents by mechanical vibration of the muscles in a below-elbow amputee's residual limb, can induce consistent kinesthetic and proprioceptive illusions. This phenomenon has been previously demonstrated for normal individuals *[Goodwin et al. 1972 Brain 95:336-29; Roll and Gilhodes, Can. J. Physiol. Pharm. 1995:295-304].*

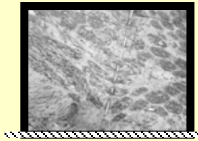
NEURAL INTERFACE

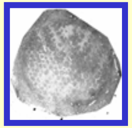


IN -VIVO EVALUATION

Longitudinal semithin section showing nerve bundles traversing sieve via holes

Cross section of regenerated sciatic n. at exit of sieve device after 60 days





IMPLANTED SYSTEM FOR STIMULATION & RECORDING

Recording - system allows 4 channels of neural signals to be recorded continuously at 40 kHz per channel, 8 bit resolution.

Amplifiers - amplitude 4 uV-400uV pp; Gain 100 dB; CMRR - 90dB; Band-width 500 - 5 kHz

Stimulation - stimulator will control 8 channels independently

Amplitude - two ranges: 2-127uA resolution 2uA and 20-1270uA resolution 20uA

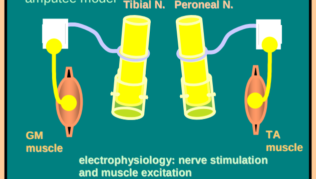
Duration & Interphase delay- 4 to 255us resolution 1us

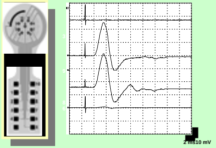
Frequency - 7-300 Hz (1 Hz res at low freq; 3 Hz res at high freq. The freq can be different for each channel.

Impedance measurement - The resistive component of the electrode Z will be provided for electrode verification.

Connectivity - multiplexed to all electrodes to allow connection to any of 64 sites to record or stimulate.

Waveform - bi-phasic charge balanced; with and w/o pre-pulse option.





Recording of CMAPs from the Ant. Tib. m evoked by electrical stimulation through different via-hole electrodes

Navarro X, Calvet S, Rodríguez FJ, Stieglitz T, Blau C, Butí M, Valderrama E, Meyer JU. *Stimulation and recording from regenerated peripheral nerves through polyimide sieve electrodes*. J Periph Nerv System 1998, 3:91-101.

Ceballos D, Valero-Cabré A, Valderrama E, Schüttler M, Stieglitz T, Navarro X. *Morphological and functional evaluation of peripheral nerve fibers regenerated through polyimide sieve electrodes over long term implantation*. J Biomed Mat Res 2002, 60:517-528.

ACKNOWLEDGMENTS

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