

## Peripheral Nerve WIFI Interfaces and Electrodes for Mechatronic Prosthetic Hand

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**Abstract.** In this paper a unified approach of a nerve direct coupled electronic controller for hand prostheses is presented. The study starts with the forearm and hand dynamics analysis in order to achieve a neural interface connecting the peripheral median nerve from the patient's amputee arm with a prosthetic hand. After identifying the median and the ulnar nerves, the nerve direct coupling system is presented and the command electrodes experimental implantation in the operating amputee arm was performed. The proposed experimental system for the biopotentials generated by a motor nerve fiber using electrodes positioned on the nerve to control a hand prosthesis is shown. The peripheral interface is connected to a prosthetic hand with independent fingers in order to test the possibility of a nervous direct control for fingers motion.

**Key-words:** hand dynamics, median nerve, peripheral nerve interface, multielectrodes.

### 1. Introduction – Analyzing Hand Motion

The motion of each toe from the upper limbs is transmitted through a nerve fiber from the median nerve (fingers 1, 2 and 3) and the ulnar nerve (fingers 4 and 5). Both the median nerve and the ulnar nerve are composed of many nerve fibers. Starting from the radial and peroneal nerve fascicular anatomy the following analyses was performed in order to identify the specific nerve fibers through which the upper limb fingers are commanded inside the median nerve. In the nerve, the motor and sensory components are separated into discrete fascicles [1]. Awake stimulation was used to separate the motor and sensory components of these nerves, while anatomic

dissection was performed to identify them distally. The motor side of the nerve fascicle is useful in this work, while the other part can be used as a source of donor graft material. In the next phase of the study, a patient with amputated hand was tested to check the position of the nerve fibers that transmit the fingers motion.

## 1.1. Forearm and Hand dynamics

The fingers dynamics are given by the movements of the hand tendons on the skeleton, tendons that represent prolongations of the forearm muscles. The forearm has flexor muscles in the forearms and the extensor muscles in the dorsal face.

The hand muscles are divided into the muscles of the tough region (the police abductor, the short flexor shelf, the police adductor, the police opposed), the muscles of the hypotensive region (short palmar, small tooth abductor, short thumb flexor, small toe) and muscles of the mediaeval region (lumbar, interpersonal volars and dorsal interos). The innervation is provided by the median nerve and the ulnar nerve.

Upper limb innervation is provided by branches from the brachial plexus as shown in Figure 1. The brachial plexus consists of the anterior roots C5-C8 and T1. By joining the C5-C7 roots. the upper trunk is formed and by joining the C8-T1 roots the lower trunk is formed; both trunks bordered with the underlying artery up to the level of the axle where the axillary artery is surrounded by the extension ram, the inner ram and the back ram.

From the external branch, the external portion of the second thoracic nerve is formed, the musculocutaneous nerve and the median nerve (external head). The inner incision forms the internal portion of the second anterior thoracic nerve, the Wrisberg nerve, the ulnar nerve and the median nerve (internal head). The musculocutaneous nerve and the circumflex nerve form from the back.

## 1.2. Hand Volar Side

### A. Superficial plan

The pronator's round muscle determines by its contraction the forearm flexion on the arm (humeral head) and the pronation of the forearm and hand; its innervation is provided by branches in the median nerve.

The radial carp flexor, by its contraction, determines mainly flexing the hand on the forearm; its intake is provided by a ram in the median nerve.

The long palmar - tensor of the palmar aponeurosis, has the innervation provided by a ram in the median nerve.

The ulnar of the carp by its contraction is the forearm, the flexion of the hand, and the inner- vation is provided by a ram in the ulnar nerve.

Superficial flexor of the fingers – determines the flexion from the proximal interphalangeal joint (AIFP), flexion of the fingers II-V on the hand and flexion in the radiocarpal joint; the innervation is provided by branches in the median nerve.

## **B. Deep plan**

Flexor Fingers - Determines the flexion of AIFD by flicking the distal phalanges of the fingers II-V and the additions of fingers and hands. It is torn by the anterior intestinal anterior nerve formed by the median and ulnar nerve dynamics.

Long shelf flexor - determines flexural AIF mainly and participates in flexion of AMF I and ARC flexion along with other flexor muscles. The innervation is provided by the anterior anterior antebrahial nerve.

The pronator square muscle - the pronation of the hand and the forearm, and the innervation is provided by the anterior intestinal nerve - we are from the median nerve.

## **1.3. Forearm Dorsal Face**

### **A. Superficial plan**

Common finger extensor muscles - determine the AIFD extension of fingers II-V (mainly), AIFP fingers II-V, AMF II-V (together with interacted muscles), ARC; determine the adduction of the hand and the abduction of the fingers. The innervation is ensured by the intestinal antebrahial nerve posterior to the radial nerve.

The Finger Extension Muscle V - determines the extension of AIFD V, AIFP V, AMF V, and provides the innervation through the intestinal anterior antebrahial nerve, the ram of the radial nerve.

The ulcer carp extension muscle - determines the strong ARC extension and hand adduction and has innervation provided by the anterior intestinal antebrahial nerve, ram in the radial nerve.

Anconeus - determines the strong elbow extension and abdominal abduction when the carp is prone; has the innervation provided by the radial nerve.

### **B. Deep plan**

The short supine-supportive muscle of the hand and forearm is annoyed by the intestinal anterolateral posterior nerve - the radial nerve.

The short extensor muscles of the police - determine the extension of the AMF I and is torn by the interos posterior nerve in the radial nerve.

The long police abductor muscles - the abduction of the policeman, receives the innervation from the intestinal anterior antebrahial nerve, the ram from the radial nerve.

The long extensor muscle - determine the extension of AIF I and AMF I and is torn by the anterior intestinal antebrahial nerve, the ram of the radial nerve.

Extension muscle II - determines the index extension (especially with the common finger extensor) and the hand (along with the other extensions tendons). The innervation comes from the anterior intestinal antebrahial nerve, the ram from the radial vein.

Radial face: Long supine muscles - determines supination of the forearm and hand and is innervated by the anterior intestinal antebrahial nerve, ram from the radial nerve.

The long radial extension of the carp - determines the extension and abduction of the hand on the forearm and is innervated by the radial nerve.

The short radial extension of the carp - determines the extension and the delivery of the hand on the forearm and is torn by the intestinal anterior antebraial nerve, the ram in the radial nerve.

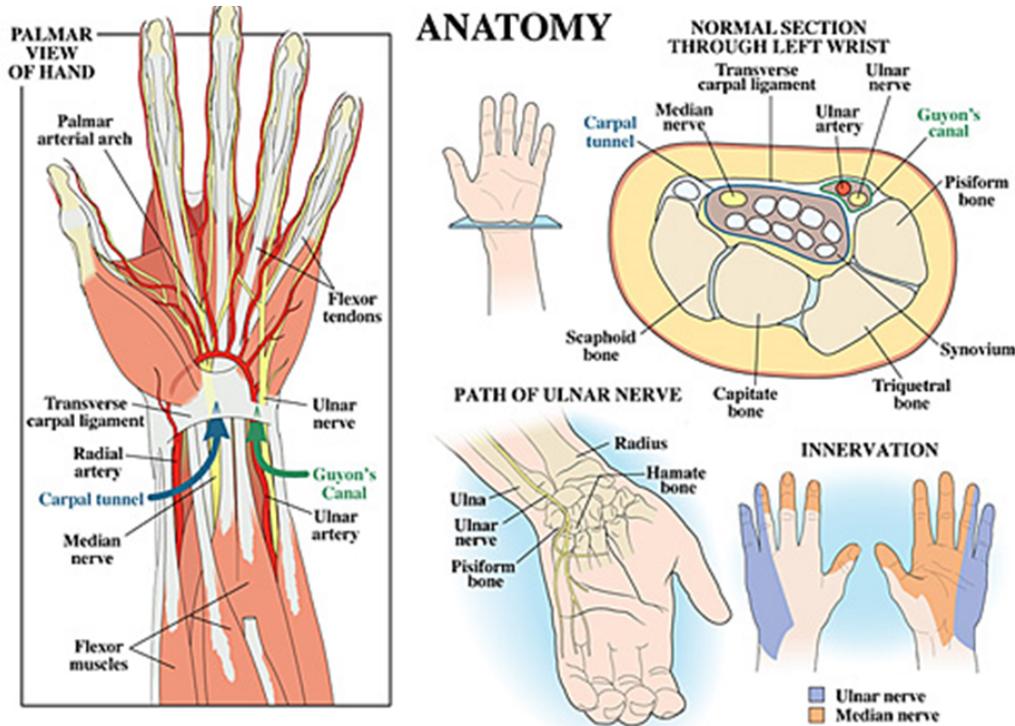


Fig. 1. The wrist innervation (from Handsport surgery Institute [2]) (color online).

## 2. Neural interface connecting the peripheral median nerve from the patient's amputee arm with a prosthetic hand

More than thirty muscles, intrinsic (located in the hand) or extrinsic (located in the forearm) are involved in fingers movements [3]. Fingers fine movements are controlled by intrinsic muscles innervated by terminal branches of median and ulnar nerves [3].

The control of the prosthesis can be effectively realized by muscular or neural commands. Muscular commands can be acquired in invasive or non-invasive ways using epymisial or superficial electrodes. Myoelectric prostheses are commercially available. Although they provide a practical and reliable control, it is quite unnatural and requires a great mental effort[3].

More recent studies use neural commands, acquiring a neural signal that requires the use of an invasive technique to implant neural interfaces around (cuff electrodes) or inside the nerve (intra-neural electrodes) [3].

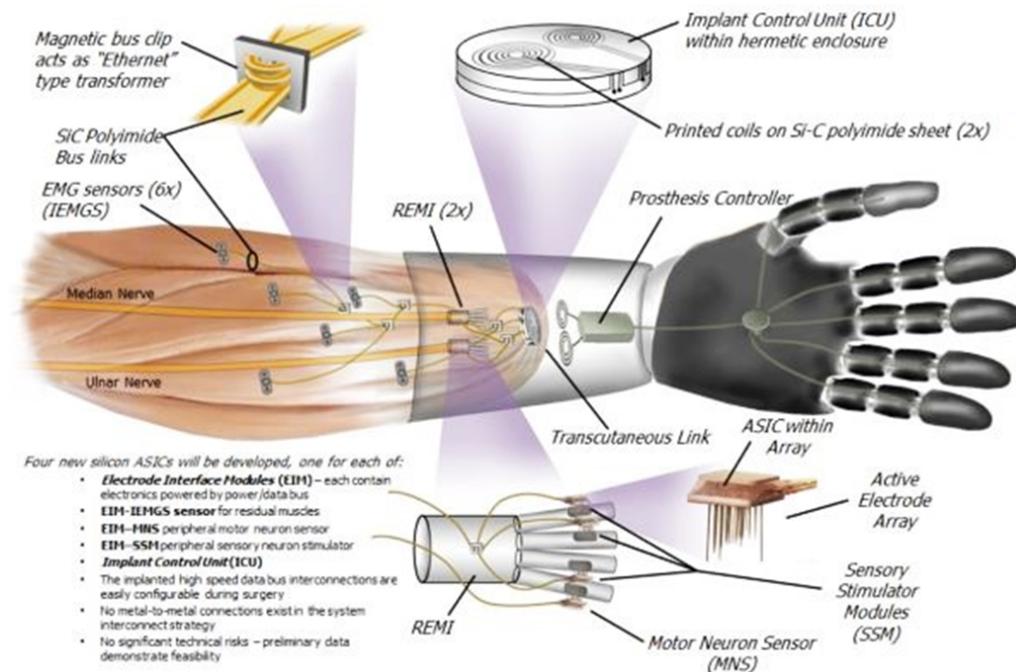
The hand control improvement using implanted EMG sensors and the feasibility of eliciting tactile sensations in chronic implants was demonstrated in [4].

The neural electrodes implement a more natural control, allowing the nerve direct usage for both execution of motor command and the sensory feedback[3] with the price of a more invasive

solution.

For connecting a prosthesis with independent fingers to the patient's amputee arm trunk, several interfaces were designed all over the world, depending on the chosen acquisition and stimulation electrodes.

In the figure below a functional diagram of a neuroprosthetic system made by specialists at Pitt's Innovation Institute and Philadelphia, Pa.'S University City Science Center is presented [4].

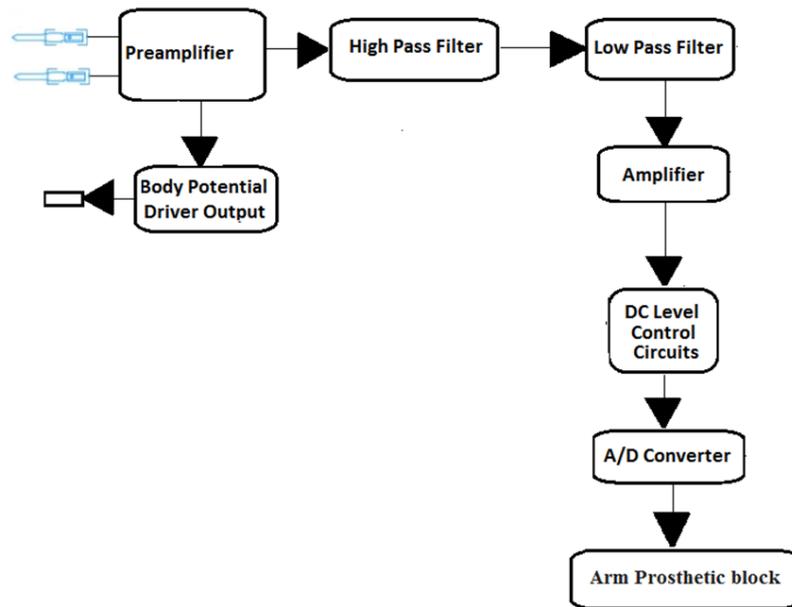


**Fig. 2.** The block diagram of a neuroprostheses designed by Pitt's Innovation Institute and Philadelphia, Pa.'s University City Science Center [5] (color online).

### 3. Neural interface Block diagram

The proposed experimental system for taking biopotentials generated by a motor nerve fiber using electrodes (Microelectrode Neurography Needle 30080 [6]) positioned on the nerve to control a hand prosthesis is shown in Figure 3.

The preamplifier is a biopotential amplifier, a symmetrical differential amplifier for instrumentation. It takes up the electrical potentials generated by the motor nerve by means of two spiral electrodes or a cuff positioned around the motor nerve. The measuring mass electrode is an active one having a larger surface and which is in the body or in the liquid medium in which the nerve is in a position furthest away from the warm electrodes. Body Potential Driver Output provides the mass meter electrode control to ensure that the common mode potential (the continuous component and the noise signal induced by interference with the supply network's electromagnetic field) are diminished by a few orders of magnitude.



**Fig. 3.** Block diagram of the implanted electrode.

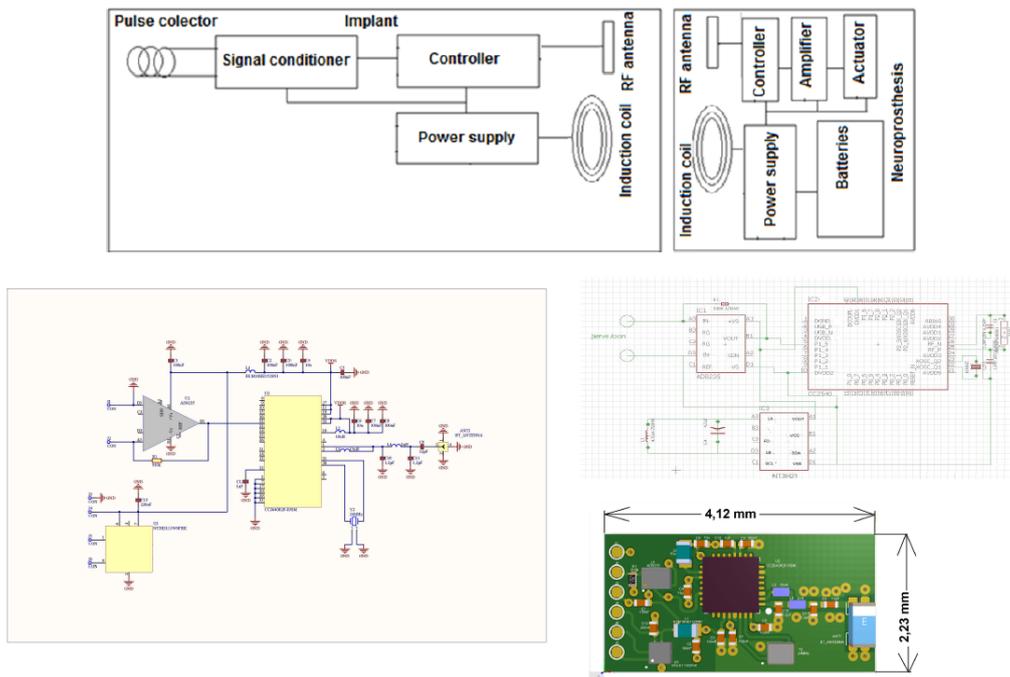
The signal is passed through a band pass filter consisting of two successive filters, the High Pass Filter and the Low Pass Filter, which limits the band of the measured signal to the relevant one and eliminates the possibility of the alias due to the Nyquist failure of the signal sampling.

The bipolar signal is then amplified using the Amplifier block and converted to positive values by half the supply voltage of the A/D Converter block that sampling and quantization the pickup signal. The digital signal thus obtained after the conversion is transmitted for processing and control of the Arm Prosthetic block.

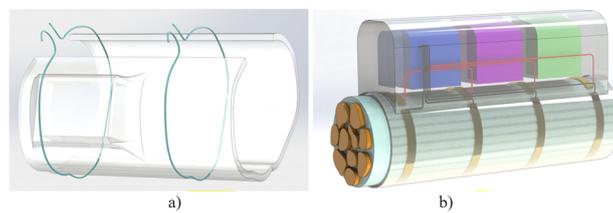
#### 4. WIFI Neural interface, electrodes and collar for neurosignals acquisition

The WIFI neural interface include: microcontroller - CC2640R2F (a wireless microcontroller (MCU) targeting Bluetooth<sup>®</sup> 4.2 and Bluetooth 5 low energy applications), ceramic antenna (WLA.01 2.4GHz Loop antenna), signal conditioning (AD 8235), and power supply with induction coil. The diagram block, electric circuit and PCB implementation of the WIFI neural interface is presented in figure 4.

The fabrication of the interfaces was made in a compact form with a total area of  $(2 \times 2,5 \times 5 \text{ mm}^3)$  so they can be implanted into the patient's stump. The electronic components of the neural interface were encapsulated in a structure fabricated with biocompatible materials. The neural interface can be anchored to the median nerve using a grip sleeve fabricated with biocompatible materials (fig 5a). In figure 5 is present the collar design for neural interface encapsulation (a) and the neural interface mounting on the Flexor Digitorum Superficialis branch in order to command the finger III movement (b).



**Fig. 4.** Block diagram of the WIFI neural interface (color online).



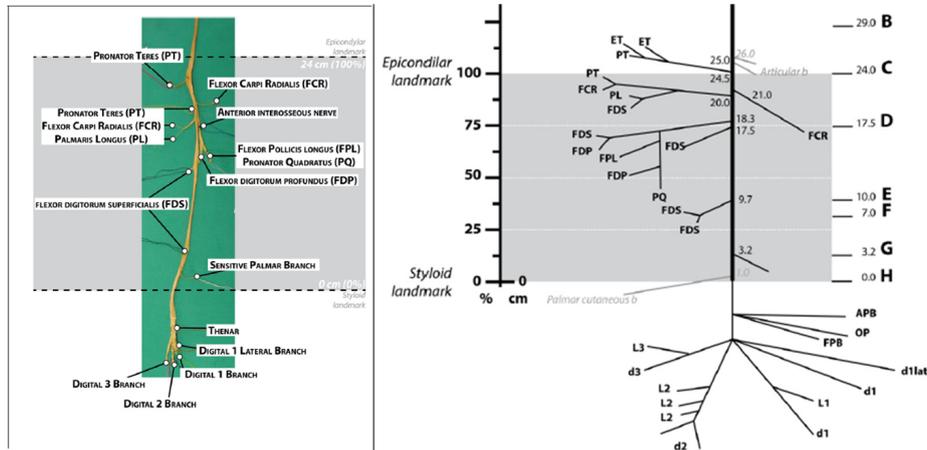
**Fig. 5.** a) The collar design for neural interface encapsulation; b) The mount of the neural interface on Flexor Digitorum Superficialis branch (from the median nerve) (color online).

In figure 6 are presented the neural interface and the collar.



**Fig. 6.** a) Neural interface before encapsulation; b) Collar for neural interface encapsulation (color online).

From the topography of the median nerve (fig. 7) it results that for prosthesis fingers III movement signals from the FDP branch of the median nerve and the FDS (Flexor Digitorum Superficialis) Digital3 branch of the median nerve should be extracted.



**Fig. 7.** a) Fascicular Topography of the Human Median Nerve for Neuroprosthetic Surgery [7] b) Distribution of the muscles branches of the median nerve at the forearm. The letter A–H on the right side indicates the level at which the respective slice from Figure was obtained. Location of the fascicles innervating the main muscles of the forearm at different levels [7] (color online).

## 5. Control Electrodes Experimental Implantation in the operating amputee arm

This study was conducted in accordance with the Helsinki Declaration of 1975 at the Bucharest University Hospital. The Ethics Commission of the Bucharest University Hospital approved the working protocol for the implantation of two electrodes in the patient's amputee arm. A single incision with a length of several mm was made. During surgery, it has been found that the motor nerve fibers of the median nerve were healthy.

The patient was given antibiotic treatment before and after surgery and the organism reaction was positive. Two weeks later the implants were removed by surgery with general anesthesia. The patient had no pain after the operation and the termination of the medication. The patient had no fever and no signs of local infection were identified. The operation did not cause complications or side effects.

## 6. Neuroprosthetic experimental command of the amputee upper limb

Sampled potentials from peripheral nerve stumps with intrafascicular electrodes were studied in [7]. They offered residual motor transmission and demonstrated the feasibility of nerve signal-controlled artificial limbs. The long-term amputee can generate motor neuron activity related to

phantom limb movement [8]. Microelectrode Neurography Needles implanted in amputees were able to control the flexion-extension of a robotic finger. The patient performed two-day exercises to control a neuroprosthetic motor. The exercises involved simultaneous motor neural commands for both hands (amputated hand and healthy hand) to move simultaneous the middle finger from the healthy hand and from the prosthesis. The structure of the exercises has been taken from other training programmes made by other people with amputations that have been reported in other scientific articles [9, 10]. In some articles, amputees perform a special training connected to virtual environments to gain the confidence they need to manage a prosthesis [11, 12].



**Fig. 8.** Third finger command using the median nerve signals (color online).

## 7. Conclusion

Neuroengineering provides new methods of the mechanical or mechatronic prosthetic devices control using bidirectional interfaces connected with neural signals.

Invasive methods can place electrodes directly in the amputee upper limb, connecting the peripheral nerves.

This paper offers a study on implanted microelectrode neurographic needles inside the median nerve from a patient amputee trunk that can acquire electric signals. The acquired signals must have a high rate over the noise caused by bones or tissue and must be amplified in order to command a mechanical prosthetic device. The achieved signal from the median nerve can command the first three fingers using a special designed interface.

Experimental phase risks and ethical problems, cognitive and emotional loads, were scientifically surmounted in this study.

A complex team must be involved in developing a neuro-commanded prosthetic hand: the surgeons that develop the electrode implantation procedure, the patient that has to train to control the movement of the prosthesis, the engineers that adjust the interface between the neural signals and the prosthetic hand control system.

The whole prosthetic system limitations should embed control algorithms able to manage more sensory information and improve hand control in the real environment.

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