Mastinu, E., Ortiz-Catalan, R., and Håkansson, B., **Digital Controller for Artificial Limbs fed by Implanted Neuromuscular Interfaces via Osseointegration**, in Proceedings of the 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society. Orlando, Aug 16-20, 2016.

Digital Controller for Artificial Limbs fed by Implanted Neuromuscular Interfaces via Osseointegration

Enzo Mastinu, *Student Member, IEEE,* Max Ortiz-Catalan, *Member, IEEE,* and Bo Håkansson

***Abstract*— Despite the technological progress in robotics, mechatronic limbs still lack functionality, reliability and comfort. This work builds upon osseointegration and implanted neuromuscular interfaces for the realization of an embedded system for artificial upper limb control. The controller allows for bioelectric signals acquisition, processing, decoding and prosthetic control. It includes a neurostimulator to provide direct neural feedback aimed for restoration of tactile sensations. It was designed to be reliably used in activities of daily living, as well as a research platform to monitor prosthesis usage and training, machine learning based control techniques and neural stimulation paradigms. The system has passed bench tests and its functionality was proven in a first pilot patient.**

I. INTRODUCTION

Although the development of myoelectrically controlled upper limb prosthesis started in the 1970's, the majority of amputees do not use this technology today due to its poor functionality, reliability and comfort [1]. New advanced wearable solutions are recently introduced to the market [2], and more commonly in research laboratories [3], aim to close the gap between the robotics potential and control possibilities.

This work aims to exploit the advantages of a recently developed bidirectional interface into the human body that provides permanent access to implanted neuromuscular electrodes, namely the Osseointegrated Human-Machine Gateway (OHMG) [4]. We have developed an Artificial Limb Controller (ALC) for the decoding of motor volition and provide direct neural sensory feedback (Fig. 1).

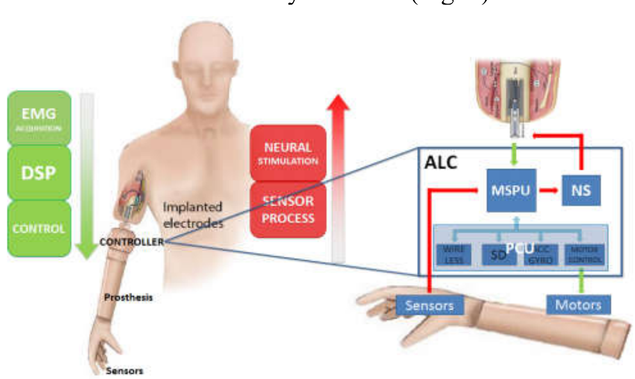

Figure 1. Overall view of ALC and OHMG [4] systems.

E. Mastinu and B. Håkansson are with the Dept. of Signals and System, Chalmers University of Technology (CTH), Gothenburg, Sweden (e-mail: enzo@chalmers.se, boh@chalmers.se).

M. Ortiz-Catalan is with the CTH, the Centre for Advance Reconstruction of Extremities (C.A.R.E.), Sahlgrenska University Hospital (SUH), and Integrum AB (e-mail: maxo@chalmers.se).

II. SYSTEM'S ARCHITECTURE & DESIGN

The ALC system is composed by 3 modules:

- Neurostimulator (NS)
- Mixed signals processing unit (MSPU)
- Prosthetic control unit (PCU)

The MSPU is responsible for managing all the modules, bioelectric and artificial signal processing, communication and motor volition decoding. In the MSPU bioelectric signals are digitalized at 24 bits with a variable sampling rate [5]. Band-pass and power line notch filters are implemented via firmware. Pattern recognition and direct control algorithms are implemented and evaluated in real-time. The data from the force sensors in the artificial limb is then used to mediate the stimulation pulses that are generated by the NS to elicit the perception of touch. In its simplest stimulation mode, amplitude and pulse-width are constant while the frequency varies proportionally with the grasping force.

A communication dongle can be plugged into the system providing wireless communication with a PC for fitting, monitoring, and data management. The system includes a SD card to continuously keep track of all relevant processes in order to better understand prosthetic use and the potential sources of errors. Inertial sensors are also included in the system to complement information on prosthetic use, and to potentially improve the controllability of the system by incorporating such information into the motor volition decoding. This system has passed bench tests and its functionality was proven in a first pilot patient.

ACKNOWLEDGMENT

The authors thank the Swedish Research Council (Vetenskapsrådet), VINNOVA, Integrum AB and Chalmers University of Technology.

REFERENCES

[1] D. Farina, N. Jiang, H. Rehbaum, A. Holobar, B. Graimann, H. Dietl, and O. C. Aszmann, "The extraction of neural information from the surface EMG for the control of upper-limb prostheses: Emerging avenues and challenges," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 22, no. 4, pp. 797–809, 2014.

[2] COAPT, "Complete Control." [Online]. Available: https://www.coaptengineering.com/.

[3] S. Benatti, F. Casamassima, B. Milosevic, E. Farella, P. Schonle, S. Fateh, T. Burger, Q. Huang, and L. Benini, "A Versatile Embedded Platform for EMG Acquisition and Gesture Recognition.," *IEEE Trans. Biomed. Circuits Syst.*, vol. PP, no. 99, p. 1, 2015.

[4] M. Ortiz-Catalan, B. Hakansson, and R. Branemark, "An osseointegrated human-machine gateway for long-term sensory feedback and motor control of artificial limbs," *Sci. Transl. Med.*, vol. 6, no. 257, pp. 257re6–257re6, Oct. 2014.

[5] E. Mastinu, M. Ortiz-catalan, and B. Håkansson, "Analog Front-Ends comparison in the way of a portable , low-power and low-cost EMG controller based on Pattern Recognition," *EMBC 2015*, pp. 2111–2114, 2015.