PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Daniele Esposito

XXXIII Cycle

Training and Research Activities Report – First Year

Tutor: Prof. Paolo Bifulco

1. Information

I received the M.Sc. Degree (cum laude) in Biomedical Engineering from the University of Naples 'Federico II' in 7th April 2017, discussing the thesis: "*Design and development of a control system for prosthetic hand*".
I'm attending to the 33th cycle of the Ph.D. in Information Technology and Electrical Engineering.
My fellowship is financed by MIUR (Ministry of Education University and Research).
My tutor is Prof. Paolo Bifulco.

2. Study and Training activities

Study and training activities are shown below:

a. Modules

- *Morphic Sensing* – ad hoc module (2.4 ECTS) – Prof. G.D. Gargiulo – 05/07/18
- *Computer Interface for Biological Systems* – MSc module (6 ECTS) – Prof. P. Bifulco – 18/10/18
- *Author Seminar, how to publish a scientific paper* – ad hoc module (0.4 ECTS) – Aliaksandr Birukou – 26/11/18
- *Meccanica dei Robot* – MSc module (9 ECTS) – Prof. S.Savino – 19/12/18

b. Seminars

- *From medical imaging to surgical planning: new directions for Bone and Muscle Assessment* (0.4 ECTS) – Prof. P. Gargiulo – 29/05/18
- *Using electroencephalography (EEG) to investigate the role of neo-cortical brain in postural control and postural adaptation when exposed to vibratory proprioceptive stimulation* (0.4 ECTS) – Prof. P. Gargiulo – 29/05/18
- *Le verifiche periodiche di sicurezza elettrica ed i controlli funzionali delle apparecchiature elettromedicali* (0.6 ECTS) - Ing. M. Palumbo, Ing. G. Fuschino, Ing. M. Arianna – 31/05/18
- *HTA aziendale come strumento di governance delle tecnologie biomediche: studio di un modello applicativo* (0.4 ECTS) - Ing. A. Lombardi, Ing. M. D'Antò – 05/06/18
- *Acquisizione, collaudo e messa in servizio delle tecnologie biomediche* (0.4 ECTS) - Ing. A. Marra – 05/06/18
- *Le tecnologie biomediche: viaggio nel cosmo gestionale* (0.4 ECTS) - Ing. N. Tufarelli – 06/06/18
- *Analisi e valutazione dei rischi nell'uso di apparecchiature laser medicali* (0.2 ECTS) Ing. A. Perrone – 06/06/18
- *"Immagini biomediche: nuove tendenze in tecnologia, metodi e applicazioni"* - Annual Ph.D. School of Bioengineering, Bressanone (BZ) (5 ECTS); 10-13/09/18. http://www.bioing.it/archiviodati/scuola_bressanone/BRESS18/index.html

	Credits year 1							
	Estimated	1 bimonth	2 Bimonth	3 bimonth	4 bimonth	5 bimonth	6 bimonth	Summary
Modules	**20**	0	0	0	2.4	6	9.4	**17.8**
Seminars	**5**	0	0	2.8	0	5	0	**7.8**
Research	**35**	5	8	9.2	2.6	4	5.6	**34.4**
	60	5	8	12	5	15	15	**60**

3. Research activity

In this first year of Ph.D. I was mainly involved in studying the arguments addressed in my MSc thesis project, that is, measurement of muscle contraction by means of Force Sensitive Resistors (FSRs) sensors, and design of improvements to the prosthetic hand prototype and its control system.
About the measurement of muscle contraction, the related research work was published on the cover of Sensors journal on August 2018 [1], in collaboration with the Industrial Engineering Department of the University of Naples "Federico II" (prof. Sergio Savino, prof. Vincenzo Niola), with the School of Life and Health Sciences of the Aston University - Birmingham, UK (prof. Antonio Fratini) and with the MARCS Institute of the Western Sydney University – Australia (prof. G.D.Gargiulo).
The measurement of muscle contraction is of interest to many medical branches (e.g., neurology, orthopaedics, rehabilitation, sport medicine, etc.). In particular, dynamic measurement of voluntary muscle activity is widely used for active prosthesis control and, more generally, for man-machine interface.
Measurement of muscle contraction is mainly achieved through electromyography (EMG) and is an area of interest for many biomedical applications, including prosthesis control and human machine interface. EMG is based on recording the electric potential connected to muscular fibres depolarization, which is the trigger signal for fibres shortening and muscle contraction. However, EMG has some drawbacks, such as: the need of electrodes, biopotential amplifiers and conductive gel for stabilizing the skin/electrode electrical interface; moreover, raw EMG signal needs to be pre-processed (e.g., rectified and low-pass filtered) to extract its envelope, which is roughly proportional to the muscle contraction level. At last, recordings are very sensitive to external electromagnetic interferences and also to other sources of noise (motion artifacts, crosstalk with other biopotentials).
Taking into account these issues, alternative methods have been evaluated for measuring muscle activity, such as by monitoring the mechanical variations that occur during contraction. In my research study a *Force Sensitive Resistor (FSR)* placed on a patient's skin in correspondence with a muscle belly was used to sense muscle contraction. Generally, FSRs consist of a conductive polymer, which changes its resistance when a force is applied to its surface. However, there should only be concentrated and uniformly distributed force within the FSR active (or sensing) area for reliable use of the FSR. A direct application of the FSR on skin to sense muscle contraction proved to be quite unsatisfactory. The mere sensor, without any mechanical coupler, provided uncertain and unreliable results. A specific mechanical coupler was designed in response to these drawbacks. A rigid spherical cap (made of acrylic resin) facing the patient's skin, provides advantageous force transmission to FSR. The mechanical coupler provides a much more convenient and reliable muscle force transmission to FSR. The increase of muscular transverse section during contraction, as well as the resultant skin stretching, impresses uniform pressure on the FSR active area via the rigid spherical cup.
Although FSR creep causes output drift, it was found that appropriate FSR conditioning, by means of an op-amp trans-impedance amplifier, reduces the drift by fixing the voltage across the FSR and provides voltage output proportional to force.
The frequency response of the FSR sensor was found to be large enough to correctly measure the small mechanical vibrations generated during muscle contraction (i.e., the mechanomyography). Mechanomyography (MMG) can be regarded as the mechanical counterpart of the EMG [2,3], and it can be used as a monitor of muscle stiffness and can be related to muscle force exertion [4]. The amplitude of the MMG signal may be related to the number of active motor units (i.e., motor unit recruitment) [3].

Regarding the prosthetic hand prototype used in the experimentation, it was produced in PLA using a 3D printer, in collaboration with the Industrial Engineering Department of the University of Naples "Federico II", it is under-actuated and powered with a single servomotor [5-7].
The motion of the electrical motor is synergistically distributed to the five fingers by means of inelastic tendons. The prosthetic hand provides a general grasp function, is able to auto-adapt the developed forces, to grasp objects of complex shape and to offer strong grip on them.

The device control system has been completely redesigned in order to embed it into the prosthesis and make the configuration simpler and faster when the prosthesis is worn.
The control signal, that is, the output from the conditioning circuit of the FSR described above, was used to drive the angular position of the servomotor, which by pulling on the inelastic tendons, allows the prosthetic hand to be closed and opened.
Simultaneous recordings of EMG signal and Force signal from flexor carpi ulnaris (muscle on the forearm used to control the prosthesis) showed a high correlation (Pearson's $r > 0.9$) between the FSR output and the EMG linear envelope.
Preliminary validation tests on healthy subjects showed the ability of the FSR sensor, used instead of the EMG, to proportionally control the hand prosthesis, achieving comparable performances.

I also contributed to a research work in a different field that concerned a *"Contactless Sensor for Pacemaker Pulse Detection"* [8], published in Sensors journal on August 2018, for which I was mainly engaged to the interpretation of the experimental data and to write the final review of the manuscript. This study was developed by the need to continuous monitor pacemaker activity. This can be achieved by means of a sensor coil positioned near the patient's thorax, without any need for physical contact, by sensing magnetic field variations due to the current pulse of the pacemaker, in order to provide valuable information to patients. In vitro tests were carried out using real pacemakers immersed in saline solution; experimental data were used to assess the accuracy of the model and to evaluate the sensor performance.

Moreover, I participated to a "Research Projects of Relevant National Interest competition announcement (PRIN 2017)" with the following project: "*Multiscale multidisciplinary biomechanical approach for low back pain classification"* coordinated by the professor Cristoforini Luca of the University of Bologna.

I am currently engaged in a study regarding the use of an *"array of FSR sensors"* mounted on the forearm, in order to monitor the simultaneous activation of multiple muscles related to different gestures of the hand. The aim of the study is to demonstrate that this device is able to perform gesture recognition, with possible applications both in the human-interface machine and in prosthetic control. Finally, I'm evaluating different applications of the FSR sensor for patient monitoring.

1. D. Esposito, E. Andreozzi, A. Fratini, G.D. Gargiulo, S. Savino, V. Niola, P. Bifulco; A Piezoresistive Sensor to Measure Muscle Contraction and Mechanomyography. Sensors 2018, 18(8), 2553, https://doi.org/10.3390/s18082553.

2. Ibitoye, M.O.; Hamzaid, N.A.; Zuniga, J.M.; Abdul Wahab, A.K. Mechanomyography and muscle function assessment: A review of current state and prospects. Clin. Biomech. 2014, 29, 691–704.

3. Beck, T.W.; Housh, T.J.; Cramer, J.T.; Weir, J.P.; Johnson, G.O.; Coburn, J.W.; Malek, M.H.; Mielke, M. Mechanomyographic amplitude and frequency responses during dynamic muscle actions: A comprehensive review. Biomed. Eng. Online 2005, 4, 67.

4. Deffieux, T.; Gennisson, J.L.; Tanter, M.; Fink, M. Ultrafast imaging of in vivo muscle contraction using ultrasound. Appl. Phys. Lett. 2006, 89, 184107.

5. F. Penta, C. Rossi, S. Savino. "An underactuated finger for a robotic hand". International Journal of Mechanics and Control, ISSN: 1590- 8844, Vol. 15,No. 02, pp. 63-68, 2014.

6. C. Rossi, S.Savino. "An underactuated multi-finger grasping device" International Journal of Advanced Robotic Systems, 17 February 2014, Volume 11, Issue 1, Article number 20, doi: 10.5772/57419.

7. C. Rossi, S. Savino, V. Niola, S. Troncone. "A study of a robotic hand with tendon driven fingers". Robotica, ISSN: 02635747, 13 June 2015, Volume 33, Issue 5, pp 1034-1048, 2015. doi: 10.1017/S0263574714001179.

8. E. Andreozzi, G.D. Gargiulo, A. Fratini, D. Esposito, P. Bifulco; A Contactless Sensor for Pacemaker Pulse Detection: Design Hints and Performance Assessment. Sensors 2018, 18(8), 2715, https://doi.org/10.3390/s18082715.

4. Products

Publications as Journal papers

i. D. Esposito, E. Andreozzi, A. Fratini, G.D. Gargiulo, S. Savino, V. Niola, P. Bifulco; *A Piezoresistive Sensor to Measure Muscle Contraction and Mechanomyography.* Sensors 2018, 18(8), 2553, https://doi.org/10.3390/s18082553.

ii. E. Andreozzi, G.D. Gargiulo, A. Fratini, D. Esposito, P. Bifulco; *A Contactless Sensor for Pacemaker Pulse Detection: Design Hints and Performance Assessment.* Sensors 2018, 18(8), 2715, https://doi.org/10.3390/s18082715.

5. Conferences and Seminars

During my first year of Ph.D., I did not experience as a speaker in conferences or seminars.

6. Activity abroad

During my first year of Ph.D., I didn't spend time aboard.

7. Tutorship

- Assistant for the MSc courses of "*Strumentazione Biomedica*" (10 hours), "*Computer interface for biological systems*" (10 hours), held by prof. Paolo Bifulco.
- Assistant for the BSc course of "*Elaborazione dei segnali e dei dati biomedici*" (20 hours), held by prof. Mario Cesarelli.
- Assistant thesis supervisor for the student Davide Vitiello, who graduated in Biomedical Engineering (MSc) on 4th April 2018, discussing the thesis: *"Study of a new muscle contraction sensor for the control of prosthetic hand"*; supervisor prof. P. Bifulco.