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 – Second Year

Tutor: Paolo Bifulco

co-Tutor: Mario Cesarelli

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 and co-tutor are respectively Prof. Paolo Bifulco and Prof. Mario Cesarelli.

2. Study and Training activities

Study and training activities are shown below:

a. Modules

- *Data science and optimization* - ad hoc module (1.2 ECTS) – Prof. M.Gaudioso; Prof.ssa L.Palagi; Prof.ssa E.Messina (5-6-7 February 2019);
- *New directions in biomedical engineering research: neuroscience, machine learning and personalized medicine* - ad hoc module (2 ECTS) – Prof. P.Gargiulo; Prof. T. Helgason (16-17 May 2019);
- *True unipolar electrocardiography and application to medicine* – ad hoc module (2.4 ECTS) – Prof. G.D. Gargiulo (2-5 July 2019).
- *Machine learning* – MSc module (5 ECTS) – Prof. C.Sansone (18 November 2019).

b. Seminars

- *Medical thermal therapy and monitoring using microwave inverse scattering* (0.2 ECTS) - Prof. Mahta Moghaddam (2 May 2019);
- *Advanced bioengineering methods, technologies and tools in surgery and therapy* - Annual Ph.D. School of Bioengineering (5 ECTS) - Bressanone (BZ), from 9 to 12 September 2019
  http://www.bioing.it/archiviodati/scuola_bressanone/BRESS19/index.html

	Credits year 2							
		1	2	3	4	5	6	
	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	Summary
Modules	10	1.2	0	2	2.4	0	5	**10.6**
Seminars	5	0	0	0.2	0	5	0	**5.2**
Research	45	8	10	6	8.4	6	5.8	**44.2**
	60	9.2	10	8.2	10.8	11	10.8	**60**

3. Research activity

In this second year of Ph.D., I was mainly involved in researches based on applications of wearable sensors: for patient monitoring (muscle contraction, stethoscope applications, heart mechanical vibrations), prosthetic hand control and human machine interfaces (HMI).

Regarding the measurement of muscle contraction, in a previous study (Esposito et al., 2018), it was presented a simple, non-invasive sensor based on a force-sensitive resistor (FSR). An FSR changes its electrical resistance in the function of the applied force. The FSR active area is suitably mechanically coupled to the muscle through a rigid dome, which enables the measurement of muscle volume changes during contraction (Esposito et al., 2018). It was shown that the FSR-based sensor provides signals quite similar to the EMG linear envelope (EMG-LE) (typically used as a control signal in prosthetics applications and HMI). Moreover, preliminary validation tests on healthy subjects showed the ability of the FSR sensor, used instead of the EMG, to proportionally control the hand prosthesis "Federica" (Esposito et al., 2018; Esposito et al., 2020a), 3D printed and made using low-cost technologies. In particular, the prosthesis is equipped with five fingers and is under-actuated, as a single motor provides for the movement of all the fingers.

Concerning the "Federica" prosthetic hand, I presented two researches at the "Medicon 2019" (XV Mediterranean Conference on Medical and Biological Engineering and Computing) held at Coimbra, Portugal on September 2019. In a first study, entitled *"Experimental study to improve "Federica" prosthetic hand and its control system"* (Esposito et al., 2020a), a new, extremely simple but effective FSR conditioning system, based on current mirror, was presented and tested. In addition, the actual three-dimensional kinematics of a single finger was captured by means of high frame rate cameras and then analyzed. The new sensor conditioning system was characterized: it proved to be as effective as the EMG-LE to proportionally control the hand prosthesis motion, and it allowed an easier connection to common microcontroller boards. Kinematic analysis allowed to accurately reconstruct the actual phalanges motion over time.
A second study, entitled *"Study on the activation speed and the energy consumption of "Federica" prosthetic hand"* (Esposito et al., 2020b), focused on the activation speed and the energy consumption of the "Federica" prosthetic hand. Video acquisitions of complete rotations of the servomotor, when it works freely or fixed to the mechanical components of the prosthesis, were used to compare the different kinematic behaviours of the servomotor. A current sensor was used to measure the absorbed current, i.e. the energy absorption, by the servomotor under different uses of the prosthesis (at rest, grasping objects, raising water bottles, etc.). The comparison between the kinematic behaviours of the servomotor alone or connected to the prosthesis, showed the mechanical efficiency of the prosthesis with very low latencies and small variations in velocity and acceleration profiles. The prosthesis took about half a second from the muscle sensor trigger to the complete closure of the hand, showing a significant speed. Finally, tests on current absorption of the servo-motor in various conditions resembling prosthesis daily usage, revealed the capacity to guarantee an autonomy of at least one day when powered by 7.4 V, 3000 mAh battery pack.

I contributed to a more general study on hand prostheses control, entitled *"Real-Time EMG Based Pattern Recognition Control for Hand Prostheses: A Review on Existing Methods, Challenges and Future Implementation"* (Parajuli et al., 2019). This review paper examines the suitability of upper limb prosthesis inventions in the healthcare sector from their technical control perspective. More focus is given to the review of real-world applications and the use of pattern recognition control on amputees. First, the general structure of the pattern recognition schemes for myo-controlled prosthetic systems is reviewed and then their real-time use on the amputee upper limbs is discussed. Finally, the paper presents the existing challenges and future research recommendations.

I also participated to two research works presented at the "ICEERP 2019" (International Conference on Electrical Engineering Research and Practice, held in Sydney, Australia, on 24-28 November,

2019), concerning further experimental applications of the FSR-based sensors. A first study, entitled *"Electrodeless FSR linear envelope signal for muscle contraction measurement"* (Parajuli et al., 2020) focused on the validation experiments aimed at finding the best FSR position(s) to replace a single EMG lead. FSR-based sensors were directly applied over the EMG electrodes, by means of custom 3D printed cases. Simultaneously recordings of EMG and FSR signals, showed a high correlation between FSR output and EMG-LE.
A second study, entitled *"Low Cost Analogue Front End for Electronic Stethoscopes Application with Silicone Enclosure"* (Polley et al., 2020), presented a piezoelectric sensor cast in a two different domed silicone enclosure to protect the unit and provide better acoustical transmittance of the sounds generated from the human body. The results collected form the carotid artery, showed that both systole and diastole sounds can be detected in good quality and then processed to increase bodily sounds volume and enable the use of this device in stethoscope applications.

In the biomedical image processing field, I contributed to the research work: *"A Comparison of Denoising Algorithms for Effective Edge Detection in X-Ray Fluoroscopy"* (Andreozzi et al., 2020), presented at the "Medicon 2019". This study presents a comparison of two denoising algorithms to evaluate their performance in edge-detection for real fluoroscopic sequences. VBM4D is one of best video-processing method for Additive White Gaussian Noise (AWGN), while Noise Variance Conditioned Average (NVCA) is a recent, real-time, algorithm specifically tailored for fluoroscopy. The results show that both approaches provide effective identification of object contours (i.e. vertebral bodies). Despite of its simplicity the NVCA algorithm shows better performances than VBM4D on delineation of boundaries of examined spine fluoroscopic scenes. Furthermore, the NVCA algorithm can be realized in hardware and can offer real-time fluoroscopic processing.

Anyway, my main focus of the year, was the realization and experimentation of a Human Machine Interface (HMI) for gesture recognition purpose. The HMI is based on three piezoresistive Force Sensitive Resistors (Interlink FSR 402) mounted on an inextensible armband by means of 3D printed rigid supports. The support was designed with a housing site for the FSR-based sensor, and an opening to allow sensor sliding along the band and precise positioning on a target muscle. The armband can be wrapped around user's forearm and fastened with a Velcro strip in order to measure muscle contractions and recognize some hand gestures. Indeed, each gesture generates a characteristic force distribution on the sensors, and this allows discriminating the intentional movements. The armband was tested on 10 volunteers, who performed eight hand gestures: rest; wrist flexion; wrist extension; wrist adduction; wrist abduction; wrist rotation (supination); finger abduction; clenched fist. The hand gestures were classified by means of different machine learning algorithms and classification performances were assessed applying the 10-fold cross-validation. A Linear Support Vector Machine classifier provided 96% mean accuracy across all participants and was implemented on an Arduino platform, allowing successful control for videogames in real-time. The related research paper, entitled *"A piezoresistive array armband with reduced number of sensors for hand gesture recognition",* was accepted by "Frontiers in Neurorobotics" journal on December 2019 (Esposito et al., in press).

Closely linked to this research work, a project entitled "*Personalized Smart Sensors for Exergaming in Neuromotory Rehabilitation"* was activated (in March 2019) at the Care and Research Institute: "IRCCS Istituti Clinici Scientifici Maugeri", Italy. The proposed HMI can be applied in "exergaming" applications: graphical interfaces can provide patients with real-time feedback on the quality of the performed gestures, inducing self-corrections of their movements. Moreover, the possibility to monitor the contractions of specific muscles would provide additional clinical information about patients' progress. Thus, the exergaming could be used in clinical practice to make neuromotor rehabilitation processes more stimulating and enjoyable.
Another project entitled "*Clinical trials of "Federica" prosthetic hand*" was activated (in March 2019) in the aforementioned research and care institute. The aim of the project is the clinical trial of the innovative "Federica" hand prosthesis, that with the only grip function could allow the amputee

patients to perform a wide range of actions of daily interest such as: grasping rigid and / or deformable objects, drinking from a glass, assisting the actions performed with the other hand, etc. The innovative control system, based on the detection of the residual mechanical muscle activation by means of the bespoke FSR-based sensors (Esposito et al., 2020a), provides versatility and robustness to the control, and allows to significantly minimize hand prosthesis training. The high speed of closing and opening of the prosthetic hand (Esposito et al., 2020b), makes the use of the prosthesis more natural, also allowing to perform gestures that require particular promptness (such as grasping objects on the fly). The speed of the prosthesis is related both to the mechanical efficiency and to the simplicity and effectiveness of the control system. At present, a patient with trans-carpal amputation is performing the first tests (at the “IRCCS Istituti Clinici Scientifici Maugeri” of Bari) with the "Federica" hand prosthesis. It is expected that more patients will benefit from the light, fast and extremely simple to use, "Federica" prosthetic hand.

Regarding the monitoring of the heart mechanical vibrations, I am contributing to a study about a novel technique to measure local cardiac-induced vibrations of the chest wall, by means of the bespoke FSR-based sensors and accelerometers.

Finally, I am currently engaged in more extended studies on the “Federica” prosthetic hand. In a study I am comparing the activation times of the prosthetic device, when controlled by EMG signal or via the FSR-based sensor. The electromechanical delay (EMD) (Canavagh et al., 1979) between the electrical muscle activation signal (EMG) and the mechanical muscle contraction, detected by means of the FSR sensor, is well known. On the other hand, to obtain an effective EMG control signal, a processing on the signal is necessary (i.e. rectification and low-pass filtering to compute the EMG-LE), while the FSR output signal, although delayed in respect of the EMG, is both very similar to the EMG-LE and ready to use.
In another study, by means of load cells suitably coupled to the palm of the prosthetic hand, I am performing measurements of the gripping force generated in various conditions of use of the prosthesis. The gripping force estimation, together with the measurement of the current absorbed by the servomotor, will allow the realize a sensory feedback system for the prosthesis. This system has the purpose of giving the user a sensory capacity that could allow him to regulate the exerted gripping force.

During this year, thanks to the various research works, I had the opportunity to collaborate with researchers from:

- The Department of Industrial Engineering, University of Naples “Federico II”, Italy;
- The Department of Chemical, Materials and Production Engineering University of Naples “Federico II”, Italy;
- The School of Life and Health Sciences of the Aston University - Birmingham, UK;
- The School of Computing, Engineering and Mathematics, Western Sydney University;
- The MARCS Institute of the Western Sydney University – Australia;
- The School of Engineering Macquarie University NSW, Australia;
- The Department of Neurorehabilitation, IRCCS Istituti Clinici Scientifici Maugeri, Pavia, Italy.

References

Cavanagh P.R., Komi P.V. (1979). Electromechanical delay in human skeletal muscle under concentric and eccentric contractions. Europ. J. Appl. Physiol. 42, 159–163. doi:10.1007/BF00431022

Esposito D., Andreozzi E., Fratini A., Gargiulo G., Savino S., Niola V., and Bifulco P. (2018). A piezoresistive sensor to measure muscle contraction and mechanomyography. Sensors (Basel) 18:2553. doi: 10.3390/s18082553.

4. Publications

I. Esposito D., Andreozzi E., Gargiulo GD, Fratini A., D'Addio G., Naik GR and Bifulco P. (in press) A Piezoresistive Array Armband With Reduced Number of Sensors for Hand Gesture Recognition. Front. Neurorobot. 13:114. doi: 10.3389/fnbot.2019.00114.

II. Esposito, D., Cosenza, C., Gargiulo, G. D., Andreozzi, E., Niola, V., Fratini, A., et al. (2020a). Experimental study to improve "Federica" prosthetic hand and its control system, in Proceedings of the 15th Mediterranean Conference on Medical and Biological Engineering and Computing, eds J. Henriques, P. de Carvalho, and N. Neves, (Coimbra: Springer International Publishing), 586–593. doi: 10.1007/978- 3- 030- 31635- 8_70

III. Esposito, D., Savino, S., Cosenza, C., Gargiulo, G. D., Fratini, A., Cesarelli, G., et al. (2020b). Study on the activation speed and the energy consumption of "Federica" prosthetic hand, in Proceedings of the XV Mediterranean Conference on Medical and Biological Engineering and Computing – MEDICON 2019, Vol. 76, eds J. Henriques, N. Neves, and P. de Carvalho, (Cham: Springer International Publishing), 594–603. doi: 10.1007/978- 3- 030- 31635- 8_71.

IV. Andreozzi E., Pirozzi M.A., Sarno A., Esposito D., Cesarelli M., Bifulco P. (2020) A Comparison of Denoising Algorithms for Effective Edge Detection in X-Ray Fluoroscopy. In: Henriques J., Neves N., de Carvalho P. (eds) XV Mediterranean Conference on Medical and Biological Engineering and Computing – MEDICON 2019. MEDICON 2019. IFMBE Proceedings, vol 76. Springer, Cham.

V. Parajuli, N.; Sreenivasan, N.; Bifulco, P.; Cesarelli, M.; Savino, S.; Niola, V.; Esposito, D.; Hamilton, T.J.; Naik, G.R.; Gunawardana, U.; Gargiulo, G.D. (2019). Real-Time EMG Based Pattern Recognition Control for Hand Prostheses: A Review on Existing Methods, Challenges and Future Implementation. Sensors 2019, 19, 4596. doi: 10.3390/s19204596.

VI. Parajuli N., Ulloa F., Sreenivasan N., Naik GR, Bifulco P., Esposito D., Savino S., Cesarelli M., Hamilton T., Gunawardana U. and Gargiulo G.D. Electrodeless FSR linear envelope signal for muscle contraction measurement. International Conference on Electrical Engineering Research and Practice, Sydney, Australia, 24-28 November, 2019. Proceedings of the conference submitted to IEEE on 10/12/2019.

VII. Polley C., Andreozzi E., Bifulco P., Esposito D., Naik GR, Gunawardana U. and Gargiulo GD. Low Cost Analogue Front End for Electronic Stethoscopes Application with Silicone Enclosure. International Conference on Electrical Engineering Research and Practice, Sydney, Australia, 24-28 November, 2019. Proceedings of the conference submitted to IEEE on 10/12/2019.

5. Conferences and Seminars

I attended the MEDICON 2019 (XV Mediterranean Conference on Medical and Biological Engineering and Computing held at Coimbra, Portugal, on September 26th - 28th 2019), being the chair and oral presenting two papers (*Esposito et al., 2020a, Esposito et al., 2020b*) in the regular session of "Biomechanics, robotics and rehabilitation".

6. Activity abroad

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

7. Tutorship

- Assistant for the MSc courses of "*Strumentazione Biomedica*" (10 hours), "*Fondamenti di Ingegneria Clinica*" (10 hours), held by prof. P. Bifulco.

- Assistant for the BSc course of "*Elaborazione dei segnali e dei dati biomedici*" (20 hours), held by prof. F. Amato.

- Assistant thesis supervisor for the MSc student in Biomedical Engineering Ilaria Luongo, supervisor prof. P. Bifulco.

- Assistant thesis supervisor for the MSc student in Mechanical Engineering Alessia Liccardo, supervisor prof. S. Savino.