**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 – Third Year**

**Tutor: prof. Paolo Bifulco**

**co – Tutor: prof. Mario Cesarelli**

**co – Tutor: prof. Vincenzo Niola**

**abroad tutor: prof. Gaetano Gargiulo**

## 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 and my co-tutors are Prof. Mario Cesarelli and Prof. Vincenzo Niola.
My abroad supervisor at the at the "School of Computing, Engineering and Mathematics" of the Western Sydney University, Australia, was the prof. Gaetano Gargiulo.

## 2. Study and Training activities

Study and training activities are shown below:

### a. Modules

- *Complementi di meccanica* – MSc module (9 ECTS) – Prof. V.Niola e Prof. S.Savino (26 November 2020).

### b. Seminars

- *IEEE Seminar – How to get published with IEEE* (0.4 ECTS) – Eszter Lukacs – 20/04/2020;
- *Spring School – BCI and Neurotechnology* (5 ECTS) – GTec Medical Engineering (https://www.gtec.at) - from April 20 through 24, 2020;
- *Sistemi per ricostruzioni immagini TC* (1 ECTS) – Scuola Medica Ospedaliera della Campania (SMOC) - 24/11/2020.

| | Credits year 3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | |
| | **Estimated** | bimonth | bimonth | bimonth | bimonth | bimonth | bimonth | **Summary** |
| **Modules** | **0** | 0 | 0 | 0 | 0 | 0 | 9 | **9** |
| **Seminars** | **0** | 0 | 5.4 | 0 | 0 | 0 | 1 | **6.4** |
| **Research** | **60** | 8 | 6.6 | 8 | 7 | 8 | 7 | **44.6** |
| | **60** | 8 | 12 | 8 | 7 | 8 | 7 | **60** |

## 3. Research activity

In this third year of Ph.D., I was mainly involved in the following research activities:

- hardware/software improvements and performances analyses of a 3D-printed, low-cost, underactuated prosthetic hand, named "Federica";
- hardware/software improvements and testing of a Human-Machine-Interface (HMI) based on a piezoresistive array armband for gesture recognition and prosthetic control purposes;
- a comparison study between electromyography (EMG) and force-myography (FMG) for muscle contraction timing in prosthesis control applications.

My main focus was a study presenting the state-of-the-art of the "Federica" prosthetic hand [1], that was submitted to "Research in Biomedical Engineering" Springer Journal (currently under revision).
Generally, hand prostheses are intended to restore both the appearance and some functionalities of the hand, for people with amputations or congenital malformations. Commercial hand prostheses are usually not affordable by people living in poor and developing countries. It is therefore very useful to make available low-cost devices, taking into account the simplicity of realization, as well as the robustness and durability. The "Federica" prosthetic hand became an open-source project to go forward these demands, providing the readers of the study with all the knowledge required for the device reproduction. "Federica" is 3D printed, low-cost, and equipped with an efficient mechanical system, which by means of a single actuator allows to perform a grasp function, auto-adapting the developed forces around objects of any shape. The innovative control system based on a force sensor (FMG signal), as alternative to the electromyography (EMG) for monitoring the muscle contraction of the residual limb, makes the training phase much simpler and faster; further advantages are to avoid all EMG-related issues (high sensitivity to motion artifacts and electromagnetic interferences, physiological cross talk with near muscles, complex signal processing for computing a suitable signal for prosthetic control, etc.). Moreover, the activation speed of less than half a second, from the muscle sensor trigger until to the complete hand closure, together with the grip sensory feedback provided by a vibration motor, could make the prosthesis perception more physiological. The software was developed to run on an Arduino open-source platform, facilitating future code improvements and sharing. Ultimately, considering that the "Federica" prosthetic hand was made available as an open-source project, other research groups are given the opportunity to test the device in its current state and be able to actually make customizations and improvements.

In a further study, I focused on the evaluation of the grip force and the energy efficiency of the "Federica" hand [2], that was published in "Machines MDPI" journal.
The grip force is often considered an important parameter in evaluating the performances of prosthetic hands. Indeed, it is a kinematic measure of the energy efficiency of the prosthetic mechanical system, which transfers the energy from the actuators to the grasped objects. The study presents a grip force measure system, consisting of a 3D printed split cylindrical handlebar embedding a single axis load cell, with the aim to test the grip performances of the "Federica" hand. Eight different angular positions of the artifact with a 45-degree step were tested and the average of the L2 norms (according to NIST guidelines [3]) between each different pair of orthogonal directions were computed. In addition, force sensors were applied on selected phalanxes of the prosthesis, in order to map the distribution of the grasping force between them. The current absorption of the single servomotor that actuates all the five fingers of the prothesis, was monitored for estimating the mechanical torque generated by the servomotor, as well as the force exerted on the main actuator tendon of the prosthesis, while the tendon displacement was evaluated by a rotary potentiometer fixed to the servomotor shaft. The energy efficiency of the whole system was about 12.85 %, and the mean dissipated energy for a complete cycle of closing-opening was 106.80 Nmm, resulting lower than that of many commercial prostheses. The mean grip force of the "Federica" hand was 8.80 N, that is enough to support the user in many actions of daily life, also considering the adaptive wrapping capability of the prosthesis. On average, the middle phalanges exerted the greatest grip force (2.65 N) on the handlebar, while the distal phalanges a force of 1.66 N.

Concerning the HMI research topic, I attended the IEEE EHB 2020 web conference (International Conference on e-Health and Bioengineering, 8th edition) held in Iasi, Romania, presenting the paper [4] entitled: *"Improvements of a simple piezoresistive array armband for gesture recognition".*
The study follows a previous paper [5] published in *"Frontiers in Neurorobotics"* journal, which presented a simple Human Machine Interface (HMI) for gesture recognition purpose, based on a piezoresistive armband. The armband embeds three sensors, based on Force Sensitive Resistors (FSRs) applied on specific forearm muscles, which provide signals comparable to the electromyography linear envelope [6]. The system aims to recognize in real-time some hand gestures, opportunely processing the force signals. The HMI control system is based on Arduino platform and implements a Linear Discriminant Analysis (LDA) classifier to perform real-time gesture recognition. This conference paper presented some innovations and improvements made to the aforementioned gesture recognition system [5]. Inspired by other well-assessed EMG gesture recognition devices, like the Myo Armband, five hand gesture classes were considered (rest, wrist flexion, wrist extension, fist, spreading fingers). A new double-threshold segmentation technique was applied to the FSR raw signals, in order to detect the entire gesture evolution from the rest condition, in particular, to recognize explicitly the transition phases (the short periods before and after the completely performed gesture). This allowed to introduce a new gesture class named "transition". The device was miniaturized, and a wireless Bluetooth connectivity replaced the USB wired PC connection, easing usability. LDA classification performances were assessed by applying the 10-fold cross validation technique. The mean accuracy across all participants resulted 93.48%. The results suggest that the HMI device allows easy user's interaction with a computer in real-time. In prospective, this device could find practical applications in neuromotor rehabilitation (e.g. exergaming), and in controlling prosthetic hands.

Moreover, I also focused my research activity on the comparison between EMG and FMG for prosthetic control applications. At the IEEE MeMeA 2020 web conference (International Symposium on Medical Measurements and Applications, 15th edition) held in Bari, Italy, I presented a study [7] on the measurement of muscle contraction timing, obtainable with EMG and FMG respectively.
Active hand prostheses are usually controlled by EMG signals acquired from few muscles available in the residual limb. In general, it is necessary to estimate the envelope of the EMG in real-time to implement the control of the prosthesis. Recently, sensors based on Force Sensitive Resistor (FSR) proved to be a valid alternative to monitor muscle contraction, providing the FMG signal [6]. However, FSR-based sensors measure the mechanical phenomena related to muscle contraction rather than those electrical. The aim of this study was to test the difference between the EMG and FMG in controlling a prosthetic hand. Particular emphasis has been placed on verify the prosthesis activation speed and their application to fast grabbing hand prosthesis as the "Federica" hand. Indeed, there is an intrinsic electro-mechanical delay during muscle contraction, since the electrical activation of muscle fibres always precedes their mechanical contraction. However, the EMG signal needs to be processed to control prosthesis and such filtering unavoidably causes a delay. On the contrary the force signal doesn't need any processing. Both EMG and FMG signals were simultaneously recorded from the flexor carpi ulnaris muscle, while subject performed wrist flexions. The raw EMG signals were rectified and low-pass filtered to extract their envelopes. Different widespread operators were used: Moving Average, Root Mean Square, Butterworth low-pass; the cut-off frequency was set to 5 Hz. Afterward, a classic double threshold method was used to compute the muscle contraction onsets (i.e. the signal should exceed a threshold level for a certain time period [7]). Results showed that the lag introduced by the low-pass filtering of the rectified EMG, generates delays greater than those associated with the force sensor. This analysis confirms the possibility of using force sensors as a convenient alternative to EMG signals in the control of prostheses.

Furthermore, I also contributed to a study that was published in "Sensors MDPI" journal [8], presenting the force-cardiography (FCG) technique, with the aim to measure local, cardiac-induced vibrations onto the chest wall, by means of the FSR-based sensor [6]. The proposed FCG provides signals with a richer informational content as compared to the seismocardiography (SCG), the gold standard method that is performed by placing accelerometers onto the subject's chest.

A further study, in collaboration with the mechanical engineering research group of the Department of Industrial Engineering of the University "Federico II", focused on the computer vision for control, by using RGB-Depth camera, with the purpose to measure the displacement of mechanical systems in contactless mode. The study was published in "Machines MDPI" Journal [9].

Finally, in the field of image processing, I was involved in different research activities. A study was carried out in collaboration with the IRCCS Neuromed (Pozzilli, Italy) and the National Institute for Nuclear Physics (INFN - Naples, Italy), regarding the ElectroCorticoGraphy (ECoG) technique, used as invasive investigation in patients with drug-resistant epilepsy. The study was submitted to the *"International Journal of Computer Assisted Radiology and Surgery"* (Springer Nature Journal) and is under revision [10]. I was also involved in a study concerning the topic of real-time denoising in fluoroscopic devices, that was submitted to "*BioMedical Engineering OnLine"* journal [11] and is in press.

During this year, thanks to the various research activities, 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 Department of Neurorehabilitation, IRCCS Istituti Clinici Scientifici Maugeri, Pavia, Italy.
- IRCCS Neuromed, Pozzilli, Italy
- National Institute for Nuclear Physics (INFN), Naples, Italy.

### References

1. Esposito, D.; Savino, S.; Andreozzi, E.; Cosenza, C.; Niola, V.; Bifulco, P. The "Federica" Hand, submitted to "Research in Biomedical Engineering" Springer Journal – under revision

2. Esposito, D.; Savino, S.; Cosenza, C.; Andreozzi, E.; Gargiulo, G.D.; Polley, C.; Cesarelli, G.; D'Addio, G.; Bifulco, P. Evaluation of Grip Force and Energy Efficiency of the "Federica" Hand. Machines 2021, 9, 25, doi:10.3390/machines9020025.

3. Falco, J.; Wyk, K.V.; Messina, E. Performance Metrics and Test Methods for Robotic Hands (Draft).; 2018.

4. Esposito, D.; Gargiulo, G.D.; Polley, C.; D'Addio, G.; Bifulco, P. Improvements of a Simple Piezoresistive Array Armband for Gesture Recognition. In Proceedings of the 2020 International Conference on e-Health and Bioengineering (EHB); October 2020; pp. 1–5.

5. Esposito D, Andreozzi E, Gargiulo GD, Fratini A, D'Addio G, Naik GR and Bifulco P (2020) A Piezoresistive Array Armband With Reduced Number of Sensors for Hand Gesture Recognition. Front. Neurorobot. 13:114. doi: 10.3389/fnbot.2019.00114

6. 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.

7. Esposito, D.; Gargiulo, G.D.; Parajuli, N.; Cesarelli, G.; Andreozzi, E.; Bifulco, P. Measurement of muscle contraction timing for prosthesis control: a comparison between electromyography and force-myography. In Proceedings of the 2020 IEEE International Symposium on Medical Measurements and Applications (MeMeA); 2020; pp. 1–6.

8. Andreozzi, E.; Fratini, A.; Esposito, D.; Naik, G.; Polley, C.; Gargiulo, G.D.; Bifulco, P. Forcecardiography: A Novel Technique to Measure Heart Mechanical Vibrations onto the Chest Wall. Sensors 2020, 20, 3885, doi:10.3390/s20143885.

9. Cosenza, C.; Nicolella, A.; Esposito, D.; Niola, V.; Savino, S. Mechanical System Control by RGB-D Device. Machines 2021, 9, 3, doi:10.3390/machines9010003.

10. Centracchio J., Sarno A., Esposito D., Andreozzi E., Pavone L., Di Gennaro G., Bartolo M., Esposito V., Morace R., Casciato S., Bifulco P. Efficient Automated Localization of ECoG Electrodes in CT Images Via Shape Analysis. Submitted to the International Journal of Computer Assisted Radiology and Surgery (Springer Nature) – in press.

11. Andreozzi, E.; Fratini, A.; Esposito, D.; Cesarelli, M.; Bifulco, P. Toward A Priori Noise Characterization for Real-Time Edge-Aware Denoising in Fluoroscopic Devices. Submitted to "BioMedical Engineering OnLine" – under revision

## 4. Publications

I. **Esposito, D.;** Gargiulo, G.D.; Parajuli, N.; Cesarelli, G.; Andreozzi, E.; Bifulco, P. Measurement of muscle contraction timing for prosthesis control: a comparison between electromyography and force-myography. In Proceedings of the 2020 IEEE International Symposium on Medical Measurements and Applications (MeMeA); 2020; pp. 1–6.

II. Andreozzi, E.; Fratini, A.; **Esposito, D.;** Naik, G.; Polley, C.; Gargiulo, G.D.; Bifulco, P. Forcecardiography: A Novel Technique to Measure Heart Mechanical Vibrations onto the Chest Wall. Sensors 2020, 20, 3885, doi:10.3390/s20143885.

III. **Esposito, D.;** Gargiulo, G.D.; Polley, C.; D'Addio, G.; Bifulco, P. Improvements of a Simple Piezoresistive Array Armband for Gesture Recognition. In Proceedings of the 2020 International Conference on e-Health and Bioengineering (EHB); October 2020; pp. 1–5.

IV. Centracchio J., Sarno A., **Esposito D.,** Andreozzi E., Pavone L., Di Gennaro G., Bartolo M., Esposito V., Morace R., Casciato S., Bifulco P. Efficient Automated Localization of ECoG Electrodes in CT Images Via Shape Analysis. Submitted to the International Journal of Computer Assisted Radiology and Surgery (Springer Nature) – in press.

V. Cosenza, C.; Nicolella, A.; **Esposito**, D.; Niola, V.; Savino, S. Mechanical System Control by RGB-D Device. Machines 2021, 9, 3, doi:10.3390/machines9010003.

VI. **Esposito, D.;** Savino, S.; Cosenza, C.; Andreozzi, E.; Gargiulo, G.D.; Polley, C.; Cesarelli, G.; D'Addio, G.; Bifulco, P. Evaluation of Grip Force and Energy Efficiency of the "Federica" Hand. Machines 2021, 9, 25, doi:10.3390/machines9020025.

VII. **Esposito, D.;** Savino, S.; Andreozzi, E.; Cosenza, C.; Niola, V.; Bifulco, P. The "Federica" Hand, submitted to "Research in Biomedical Engineering" (Springer Journal) – under revision

VIII. Andreozzi, E.; Fratini, A.; **Esposito, D.;** Cesarelli, M.; Bifulco, P. Toward A Priori Noise Characterization for Real-Time Edge-Aware Denoising in Fluoroscopic Devices. Submitted to "BioMedical Engineering OnLine" (BMC journal) – under revision

## 5. Conferences and Seminars

I attended:

- the IEEE MEMEA 2020 (International Symposium on Medical Measurements and Applications, 15th edition) – Web conference – 1st to 3rd June 2020, Bari, Italy, presenting the paper entitled: "*Measurement of muscle contraction timing for prosthesis control: a comparison between electromyography and force-myography*", in the regular session of *"Biosignal processing".*

- the IEEE EHB 2020 (International Conference on e-Health and Bioengineering, 8th edition) – Web Conference - 29th to 30th October 2020, Iasi, Romania, presenting the paper entitled: *"Improvements of a simple piezoresistive array armband for gesture recognition",* in the regular session of *"Medical devices, Instrumentation, Modelling/Simulation, Robotics".*

## 6. Activity abroad

I carried out (in smart working modality) from 25th May 2020 to 31st August 2020, research activities about biomedical instrumentation, at the “School of Computing, Engineering and Mathematics” of the Western Sydney University, Australia, under the supervision of the prof. Gaetano D. Gargiulo. In particular, the research was focused on the Research, development and experimentation of wearable sensors for detecting physiological parameters.

## 7. Tutorship

- Assistant for the MSc courses of “*Strumentazione Biomedica*” (10 hours), “*Fondamenti di Ingegneria Clinica*” (5 hours), “*Computer Interface for Biological Systems*” (5 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 “Lorenzo Crispino”, supervisor prof. P. Bifulco. Thesis title: *“Progetto e realizzazione di un sensore di raggi UV per verifiche funzionali di apparecchiature di fototerapia”.*

- Assistant thesis supervisor for the MSc student in Biomedical Engineering “Francesca Renza”, supervisor prof. P. Bifulco. Thesis title: *“Progettazione e sviluppo di un sistema di feedback sensoriale della forza di presa per protesi di mano”.*