Università degli Studi di Napoli Federico II

PhDprogram in

Information Technology and Electrical Engineering

PhD Student: Jessica Centracchio

Cycle: XXXV

Training and Research Activities Report

Academic Year: 2020-21 -PhD Year:Second

Jessica Centracchio

Tutor: prof. Paolo Bifulco Paolo Bifulco

Date: October 21, 2021

1. Information:

- **PhD student: Jessica Centracchio** **PhD Cycle: XXXV**
- **DR number: 993886**
- **Date of birth: 21 September 1994**
- **Master Science degree: Biomedical Engineering**
- **University: University of Naples "Federico II"**
- **Scholarship type:** ***UNINA***
- **Tutor: Prof. Paolo Bifulco**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
"Professional skills in clinical environment for biomedical engineering"	Ad hoc course	10	2	12.10.2020 – 30.11.2020	Prof. G. D'Addio	Y
"Telemedicina in Italia: i casi di successo"	Seminar	1.5	0.3	17.11.2020	Prof. G. D'Addio	Y
"Robot manipulation and control"	Seminar	2.5	0.5	17.11.2020	Prof. B. Siciliano	Y
"Digital Project Management: prassi, processi, tecniche, strumenti e approccio scientifico"	Seminar	1	0.2	18.11.2020	Prof. G. Longo	Y
"Sistemi per ricostruzione delle immagini TC"	Ad hoc course	6	1.2	24.11.2020	Scuola Medica Ospedaliera della Campania	Y
"L'esperienza del progetto di teleriabilitazione NEUROREAB"	Seminar	1.5	0.3	24.11.2020	Prof. G. D'Addio	Y
"Telemedicina, e-health e «mobile health» si può davvero usare il digitale nel percorso assistenziale"	Seminar	1.5	0.3	26.11.2020	Prof. G. D'Addio	Y
"Patent Searching best practices with IEEE Xplore"	Seminar	1	0.2	27.11.2020	UNINA	Y
"How to Get Published with IEEE"	Seminar	1.5	0.3	02.12.2020	UNINA	Y
"At the Nexus of Big	Seminar	1	0.2	02.12.2020	Prof. G.	Y

Data, Machine Intelligence, and Human Cognition"					Longo	
"CRISPR-cas9 screens and multi-omic data integration for identifying and prioritising anti-cancer therapeutic targets"	Seminar	1	0.2	04.12.2020	Prof. M. Ceccarelli	Y
"Medical Imaging in the Era of Big Data"	Seminar	2	0.4	10.12.2020	Prof. A. Corazza	Y
"GDPR basics for computer scientist"	Seminar	1.5	0.3	10.12.2020	Prof. A. Corazza	Y
"Subclonal reconstruction of tumour architectures by using machine learning and population genetics"	Seminar	1	0.2	11.12.2020	Prof. M. Ceccarelli	Y
"Synthetic MRI: physical principles and applications"	Seminar	1	0.2	16.12.2020	Prof. G. Ruello	Y
"Static magnetic field exposure monitoring of MRI workers: methods and practical implementations"	Seminar	1	0.2	16.12.2020	Prof. G. Ruello	Y
Study on automated ECoG electrodes clustering in CT volumes	Research		2.5	01.11.2020 – 31.12.2020		
Study on Forcecardiography	Research		30	01.11.2020 – 31.10.2021		
"Data Science for Patient Records Analysis"	Ad hoc course	10	2.5	10.02.2021 – 18.03.2021	Prof. M. Cinque	Y
"Statistical Data Analysis for Science and Engineering Research"	Ad hoc course	12	4	17.02.2021 – 04.03.2021	Prof. R. Pietrantuono	Y
"IEEE Autorship and Open Access Symposium: Best Practices to Get Published to Increase the Exposure and the Impact of your Research"	Seminar	2	0.4	21.04.2021	UNINA	Y
"Artificial Intelligence and 5G combined with holographic technology: a new perspective for remote health monitoring"	Seminar	1.5	0.3	27.04.2021	5G Academy	Y
Study on heart-induced	Research		2.5	11.03.2021		

mechanical vibrations				– 21.03.2021		
Study on biosignal-based Human-Machine Interfaces	Research		10	15.04.2021 – 31.08.2021		
"Matrix Analysis for Signal Processing with Matlab Examples"	Ad hoc course	8	2	20.04.2021 – 07.05.2021	Prof. A. De Maio, A. Aubry, V. Carotenuto	Y
Assistant for the BSc course "Elaborazione dei Segnali e dei Dati Biomedici"	Tutorship	20	0.8	08.03.2021 – 11.06.2021	Prof. F. Amato	
Assistant for the MSc course "Strumentazione e Ingegneria Clinica"	Tutorship	10	0.4	08.03.2021 – 11.06.2021	Prof. P. Bifulco	
Assistant for the MSc course "Computer Interface for Biological Systems"	Tutorship	10	0.4	08.03.2021 – 11.06.2021	Prof. P. Bifulco	
"Short and ultrashort, high voltage electric pulses for biological and medical applications"	Seminar	1.5	0.3	13.05.2021	Prof. G. Ruello	Y
"L'avvincente storia degli acceleratori"	Seminar	1.5	0.3	14.05.2021	Prof. G. Ruello	Y
"The new paradigms of soft tissues assessment: medical imaging, machine learning and 3D printing"	Seminar	1.5	0.3	20.05.2021	Prof. M. Cesarelli	Y
"Introduzione alle applicazioni della RM in medicina"	Seminar	1.5	0.3	04.06.2021	Prof. G. Ruello	Y

1) Courses, Seminar, Doctoral School, Research, Tutorship
2) Choose: Y or N

2.1. Study and training activities - credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	**3.2**	**3.8**	**7.5**	**0**	**14.5**
Bimonth 2	**0**	**0**	**7.5**	**0**	**7.5**
Bimonth 3	**6.5**	**0.7**	**7.5**	**1**	**15.7**
Bimonth 4	**2**	**1.2**	**7.5**	**0.6**	**11.3**
Bimonth 5	**0**	**0**	**7.5**	**0**	**7.5**
Bimonth 6	**0**	**0**	**7.5**	**0**	**7.5**
Total	**11.7**	**5.7**	**45**	**1.6**	**64**
Expected	**30 - 70**	**10 - 30**	**80 - 140**	**0 – 4.8**	

3. Research activity:

Innovative bioengineering methods for diagnosis and monitoring

During my second year of PhD course, I carried out two research activities within my research field, namely "ECoG electrodes recognition in CT images" and "Analysis and monitoring of cardiovascular and pulmonary mechanical activity via force sensors".

- **ECoG electrodes recognition in CT images**

In the first part of the year, I improved the automated method for ECoG electrodes recognition in CT images. In particular, a simplified workflow of the method, with increased performances, was presented. The proposed method takes the head CT volumes as input and provides the 3D coordinates of recognized electrodes as output. The method consists of three main steps: 1) re-sampling; 2) thresholding; 3) shape analysis. In detail, the CT volumes are first re-sampled via a cubic interpolation, to obtain a cubic voxel of 0.5 mm side. Then, a thresholding on radiodensity values (Hounsfield Units, HU) is performed to detect the metal objects within the CT volume. All metal objects with high attenuation coefficients are identified by using an HU threshold of 2500. This operation is not able to selectively identify the electrodes, but also wires, stitches, connectors, metal dental fillings, etc. The binary volumes obtained after the thresholding are processed to identify clusters of six-connected voxels. Then, a shape analysis of these binary clusters is carried out to separate the electrodes from the other metal objects. The shape analysis is divided in two steps, namely geometric features extraction and classification. In particular, six geometric features are extracted for each cluster of voxels: 1) Volume; 2) Primary axis length; 3) Secondary axis length; 4) Tertiary axis length; 5) Circularity and 6) Cylinder similarity. The 3D coordinates of centroids belonging to each cluster of voxels are also provided. The considered geometric features for each of the metal objects within the CT volume, as well as their centroids, are organized in a proper dataset. Then, a Gaussian Support Vector Machine (G-SVM) classifier takes such dataset as input and provides the predicted class for all considered objects as output. Two classes are considered, namely "ECoG" and "Non-electrode".
Moreover, a training phase is usually required for a classifier to achieve good performances and demands the a priori knowledge of the true class for each object. To this aim, a distinct dataset was built for each patient considered, with rows corresponding to all metal objects within the CT volume, and columns to the six geometric features and a manually assigned class. In detail, the presented method was retrospectively tested on two different patient cohorts with drug-refractory focal epilepsy. 24 head CT volumes provided by "IRCCS Neuromed" (Pozzilli, Italy) and 7 head CT volumes made available by Mayo Clinic on IEEG public repository were included in this study. The classification performances were assessed by applying the 10-fold cross-validation on each single-patient dataset and combined dataset. Further analyses were carried out by using completely distinct datasets for classifier training and testing. Therefore, the feasibility of recognizing ECoG electrodes in CT volumes of a medical center by using a classifier trained on data acquired from another center was investigated.
The G-SVM average classification accuracies across all patients were 99.74% and 98.27% for the Neuromed and Mayo databases, respectively. The G-SVM achieved comparable performances also on the combined datasets, by scoring classification accuracies of 99.74% and 99.68%, respectively. In addition, the G-SVM classifier trained on the Neuromed database and tested on the Mayo database scored a mean classification accuracy of 98.94%.

In conclusion, the proposed automated method achieves unprecedented recognition accuracy and could provide a substantial reduction in the effort and time consumption required for manual operation. Moreover, it can be easily implemented into existing software for preoperative analysis process.
Furthermore, I carried out research activity about the topic of automated ECoG electrodes clustering in CT volumes.

- **Analysis and monitoring of cardiovascular and pulmonary mechanical activity via force sensors**

During my second year of PhD course, I focused on the study of Forcecardiography (FCG). FCG is a novel, non-invasive technique, previously presented by the research group I joined, to monitor cardiovascular and pulmonary mechanical activity via force sensors. Indeed, when placed onto the chest wall, they can measure the local mechanical vibrations induced by the beating heart and by the expansions and consequent releases of the ribcage during the breathing acts.
FCG provides signals with a richer informational content as compared to Seismocardiography (SCG), which is currently the most widespread technique to measure cardiac-induced mechanical vibrations and is usually based on MEMS accelerometers. In addition, FCG signal shows a low-frequency component, not visible in SCG, that seems to be related to the filling and emptying of the heart. Furthermore, in the raw FCG signal, the typical FCG components related to the cardiac activity appear as superimposed to a much larger and slower component, which is related to the respiration.
Therefore, FCG can provide detailed information on relevant clinical parameters, such as heart rate, respiratory rate, thus standing as a promising wearable technique for continuous, long-term monitoring of cardio-respiratory function.
My research activity aims to investigate FCG signal in order to mark fiducial points related to physiological events, thus capturing as many relevant clinical parameters as possible, such as heart rate, respiratory rate, cardiac valves opening and closing intervals, stroke volume variations.
By considering its recent introduction, accuracy analyses were carried out to assess the performances of the proposed technique. To this end, experimental tests were performed on 7 healthy volunteers at the Biomedical Instrumentation Laboratory under different acquisition modalities. The subjects were comfortably seated on a chair and the FCG sensor (i.e. a FSR sensor with a rigid dome on its active area) was attached to their chest. FCG was compared to reference methods. In detail, regarding cardiac activity, FCG, SCG and ECG signals were acquired simultaneously on the subjects while holding their breath. Low-frequency (LF) and high-frequency (HF) components of FCG and SCG signals were extracted. R-peaks were located on ECG signals in order to compute the inter-beat intervals. Regarding respiratory activity, simultaneous recordings were obtained from a FCG sensor, an ECG monitor and an Electroresistive band (ERB) both during normal breathing and forced inhalation and exhalation phases. ECG-derived respiration (EDR) signals were then obtained from ECG and the respiratory component of FCG (R-FCG) was extracted via low-pass filtering. R-FCG and EDR were compared with respect to ERB, which was assumed as the benchmark. The positive peaks related to the inspiratory acts were located on the signals in order to compute the inter-breath intervals. Afterwards, correlation and Bland-Altman analyses were carried out on the inter-beat and inter-breath intervals measurements.
The HF-FCG and HF-SCG turned out to be highly comparable (Pearson's correlation coefficient > 0.95) although lagged. The lag was estimated in about tens of milliseconds. Results also confirmed that both LF-FCG and HF-FCG are highly correlated with heart contractions. The correlation analyses reported a slope of 1.004 and intercept of −0.004 for both LF-FCG and HF-FCG, with R^2 values of 0.984 for the

former and 0.995 for the latter. The Bland–Altman analyses reported a null bias for both LF-FCG and HF-FCG, with limits of agreement of 23.5 ms and 13.0 ms, respectively. Moreover, statistical analyses of R-FCG, EDR and ERB signals showed that FCG sensors ensure a more sensitive and precise detection of respiratory acts than EDR. R-FCG and ERB measures exhibited slope and intercept of 0.99 and 0.026, respectively, with an R^2 value of 0.98, while slope and intercept for EDR and ERB measures were 0.98 and 0.11, respectively, with a substantially lower R^2 value of 0.88. In addition, both methods exhibited a null bias with respect to the ERB; however, the limits of agreement were more than doubled in the EDR with respect to the FCG (about ±1.5 s compared to ±0.61 s), which demonstrated superior accuracy.

- **Other research activities**

In my second year of PhD course, together with my research group, I also reviewed the scientific literature of the last two decades about the topic of biosignal-based Human-Machine Interfaces (HMIs) for assistance and rehabilitation. To the best of our knowledge, a broad overview of the current research trends on assistive and rehabilitation HMIs was missing. Indeed, literature reviews in these fields were limited to particular applications or focused on specific biosignals. Therefore, a survey was presented to outline state of the art and identify emerging technologies and potential future research trends.
PubMed and other databases were surveyed by using specific keywords. The found studies were further screened in three levels (title, abstract, full-text), and eventually 144 journal papers and 37 conference papers were included. Four macrocategories were considered to classify the different biosignals used for HMI control: biopotential, muscle mechanical motion, body motion, and their combinations (hybrid systems). The HMIs were also classified according to their target application by considering six categories: prosthetic control, robotic control, virtual reality control, gesture recognition, communication, and smart environment control.
An ever-growing number of publications has been observed over the last years. About 67% of the studies pertain to the assistive field, while 20% relate to rehabilitation and 13% to assistance and rehabilitation. A moderate increase can be observed in studies focusing on robotic control, prosthetic control, and gesture recognition in the last decade. In contrast, studies on the other targets experienced only a small increase. Biopotentials are no longer the leading control signals, and the use of muscle mechanical motion signals has experienced a considerable rise, especially in prosthetic control. Hybrid technologies are promising, as they could lead to higher performances. However, they also increase HMIs' complexity, so their usefulness should be carefully evaluated for the specific application.
The future will probably be characterized by the development of interactive/intelligent systems that allow any person, even someone affected by severe motor disabilities, to provide commands to a wide range of machines. Shared control, predictable machine learning techniques, closed-loop control based on sensory feedback, and human-oriented design requirements will be the critical challenges for future research. In addition, the HMIs design, especially in the field of assistive technologies, would probably be directed towards the development of "universal interfaces", capable of recognizing and executing any user command (e.g., home automation devices, smart wheelchairs, personal communicators, etc.) in order to let these systems to be easily used by all kinds of users, regardless of age, languages, and degree of disability.

4. Research products

a. scientific papers:

Title: Efficient automated localization of ECoG electrodes in CT images via shape analysis
Authors: Centracchio, J.; Sarno, A.; Esposito, D.; Andreozzi, E.; Pavone, L.; Di Gennaro, G.; Bartolo, M.; Esposito, V.; Morace, R.; Casciato, S.; Bifulco, P.
Journal: International Journal of Computer Assisted Radiology and Surgery (Int J CARS) – indexed in Scopus
Year: 2021
Current status: Published (https://doi.org/10.1007/s11548-021-02325-0)

Title: Respiration Monitoring via Forcecardiography Sensors
Authors: Andreozzi, E.; Centracchio, J.; Punzo, V.; Polley, C.; Gargiulo, G.D.; Bifulco, P.
Journal: Sensors – indexed in Scopus and ISI Web of Science
Year: 2021
Current status: Published (https://doi.org/10.3390/s21123996)

Title: Biosignal-based Human-Machine Interfaces for Assistance and Rehabilitation: A Survey
Authors: Esposito, D.; Centracchio, J.; Andreozzi, E.; Gargiulo, G.D.; Naik, G.R.; Bifulco, P.
Journal: Sensors – indexed in Scopus and ISI Web of Science
Year: 2021
Current status: Published (https://doi.org/10.3390/s21206863)

Title: Small silicone encased piezoelectric sensor for wearable Bluetooth triage healthcare monitoring
Authors: Polley, C.; Jayarathna, T.; Gunawardana, U.; Naik, G.R.; Hamilton, T.; Andreozzi, E.; Bifulco, P.; Esposito, D.; Centracchio, J.; Gargiulo, G.D.
Journal: Sensors – indexed in Scopus and ISI Web of Science
Year: 2021
Current status: Submitted

5. Conferences and seminars attended

During my second year of PhD, I did not attend conferences or seminars.

6. Periods abroad and/or in international research institutions

During my second year of PhD, I carried out study and research activity abroad, from 1st June 2021 to 31st August 2021, at School of Computing, Design and Built Environment, Western Sydney University, Penrith 2747, Australia, under the supervision of Prof. Gaetano D. Gargiulo (g.gargiulo@westernsydney.edu.au). Because of COVID-19 pandemic's restrictions, being forbidden to go to the country, I accomplished this activity remotely. During this period, I focused on the study of heart activity monitoring sensors.

I spent 3 months abroad (smart work modality).

7. Tutorship

Assistant for the BSc course of "Elaborazione dei Segnali e dei Dati Biomedici" (20 hours), held by Prof. Francesco Amato; assistant for the MSc course of "Strumentazione e Ingegneria Clinica" (10 hours), held by Prof. Paolo Bifulco; assistant for the MSc course of "Computer Interface for Biological Systems" (10 hours), held by Prof. Paolo Bifulco.

8. Plan for year three

Next year, I will mainly focus on Forcecardiography (FCG), which will be the topic of my PhD thesis. Indeed, the main future goals are a more accurate study on the physiological origin of FCG signals and a deeper investigation on relevant clinical information that can be extracted from them. To this aim, a larger subjects cohort, possibly also suffering from cardiovascular or respiratory diseases, will be considered. Furthermore, FCG will be compared with Echocardiography, in order to further explore its effectiveness as a promising wearable technique for continuous, long-term monitoring of cardio-respiratory function.

At the moment, I have no research periods abroad planned.