PhD in Information Technology and Electrical Engineering
Università degli Studi di Napoli Federico II

PhD Student: Gerardo Saggese

Cycle: XXXVI

Training and Research Activities Report

Year: First

Tutor: prof. Antonio G.M Strollo

Date: October 21, 2021

1. Information:

- **PhD student: Gerardo Saggese**
- **DR number: 995145**
- **Date of birth: 20/04/1995**
- **Master Science degree: Double Degree in Electronic Engineering and in Electronics and Telecommunications**
- **University: University of Naples Federico II and Technical University of Lodz**
- **Doctoral Cycle: XXXVI**
- **Scholarship type: MIUR-PRIN 2017**
- **Tutor: prof. Antonio G.M Strollo**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
Robot Manipulation and Control	Seminar	2.5	0.5	17/11/2020	Prof. Bruno Siciliano	Y
Digital Project Management: practices, processes, techniques, tools and scientific approach	Seminar	1	0.2	18/11/2020	Prof. Dario Carotenuto	Y
#andràtuttobene: Images, Texts,Emojis and Geodata in a Sentiment Analysis Pipeline	Seminar	1.5	0.3	25/11/2020	Prof. Serena Pelosi	Y
Patent Searching Best Practice with IEEE Xplore	Seminar	1	0.2	27/11/2020	Dr. Eszter Lukacs	Y
At the Nexus of Big data, Machine Intelligence, and Human Cognition	Seminar	1	0.2	2/12/2020	Prof.George S.Djorgovski	Y
How to Get Published with the IEEE	Seminar	1.5	0.3	2/12/2020	Dr. Paul Henriques	Y
Network Systems, Kuramoto Oscillators and Synchronous Power Flows	Seminar	1.5	0.3	3/12/2020	Prof. Francesco Bullo	Y
Exploiting Deep Learning and Probabilistic Modeling for behavior analytics	Seminar	1	0.2	9/12/2020	Prog. Giuseppe Manco	Y
GDPR basics for computer scientists	Seminar	1.5	0.3	10/12/2020	Dr. Rigo Wenning	Y

Measuring the expansion of the universe with Quasars	Seminar	1.5	0.3	10/12/2020	Prof. Guido Risalti	Y
Data Driven Transformation in WINDTRE through Managers voice’	Seminar	2	0.4	16/12/2020	Dr. Marcello Savarese	Y
From Photometric Redshifts Improved Weather Forecast: an interdisciplinary view on machine learning	Seminar	1	0.2	13/1/2021	Prof. Kai Polsterer	Y
Synchronization: A Universal Concept in Nonlinear Sciences	Seminar	1.5	0.3	14/1/2021	Prof. Jurgen Kurths	Y
Cybercrime and e/evidence: the criminal justice response	Seminar	1	0.2	20/1/2021	Dr. Matteo Lucchetti	Y
Proibing gravitational field: a fundamental viewpoint	Seminar	1.5	0.3	21/01/2021	.” Prof. Lorenzo Fatibene	Y
AI LEGAL: Artificial Intelligence for notary’s sector – a case study	Seminar	1	0.2	27/01/2021	Dr. Salvatore Palange	Y
Quantum Simulators	Seminar	1.5	0.3	28/01/2021	Prof. Rosario Fazio	Y
The era of industry 4.0: new frontiers in business model innovation	Seminar	1	0.2	3/02/2021	Dr. Marco Balzano	Y
Engineering the firearm ecosystem: research on media coverage and firearm acquisition in the aftermath of a mass shooting	Seminar	1.5	0.3	4/02/2021	Prof. Maurizio Porfiri	Y
Machine Learning: casuality lost in translation	Seminar	1.5	0.3	10/02/2021	Dr. Edwin A. Valentjin	Y
Measuring the cosmological parameters with SNe/Ia and Gamma/ray Bursts	Seminar	1.5	0.3	11/02/2021	Prof. Massimo della Valle	Y
Approaches to Graph Machine Learning”. Dr. Miroslav Cepe	Seminar	1	0.2	17/02/2021	Dr. Miroslav Cepek	Y
Designing a Socially Assitive Robot for adaptive and personalized assistance to patients with dementia	Seminar	1	0.2	17/02/2021	Dr. Antonio Andriella.	Y
Variation approximations of the Griffith functional	Seminar	1	0.2	18/02/2021	Prof. Francesco Solombrino	Y
The SHIP project at CERN	Seminar	1	0.2	25/02/2021	Prof. Andrey Golutvin	Y

Visual Interaction and Communication in Data Science	Seminar	2	0.4	3/03/2021	Dr. Marco Quartulli	Y
Astroparticle Physics in the era of multi-messenger Astronomy	Seminar	1.5	0.3	04/03/2021	Prof. Gennaro Miele	Y
Big data and Computational Linguistics	Seminar	2	0.4	10/03/2021	Dr. Francesco Cotugno	Y
Hierarchical Seismic Imaging	Seminar	1.5	0.3	11/03/2021	Prof. Jean Virieux	Y
Sensoria Health	Seminar	1	0.2	17/03/2021	Dr. Stefano Rossotti	Y
Additive Manufacturing. A world full of opportunities and challenges	Seminar	1.5	0.3	18/03/2021	Prof. Ferdinando Auricchio	Y
Why do we cooperate? Understanding and Modelling Societies using Reinforcement Learning	Seminar	1.5	0.3	1/04/2021	Prof. Mirco Musolesi	Y
Rheo-Engineeering Microfuids. How to exploit rheological properties of fluids to design microfluidic applications	Seminar	1.5	0.3	08/04/2021	Prof. Luca Maffettone	Y
Classical Cepheids as distance indicatoris from the Milky Way to the hubble constant	Seminar	1	0.3	15/04/2021	Dr. Marcella Marconi	Y
Webinar “IEEE Authorship and Open Access Symposium Best Practices to Get Published to Increse the Exposure and Impact of Your Research	Seminar	1.5	0.3	21/04/2021	Dr. Joseph M. Guerrero, Eszter Lukàcs and Dr. Paul Canning	Y
Microgravity, science and Technology an overview	Seminar	1.5	0.3	23/04/2021	Dr. Fabio Peluso	Y
The coming revolution of Data driven Discovery	Seminar	1.5	0.3	25/03/2021	Prof. Giuseppe Longo	Y
DoveAndiamoDomani - Deep Tech	Seminar	1.5	0.3	28/04/2021	Dr. Francesco Matteucci	Y
Distributional Semantics Methods: How Linguistic features can improve the semantic representation	Seminar	1.5	0.3	28/04/2021	Dr. Alessandro Maisto	Y

Putting More PHYS into PHSA: Advancing Seismic Hazard Analysis with Physics-Based Modelling	Seminar	1.5	0.3	29/04/2021	Prof. Thomas H. Jordan	Y
Modelling the Complexity of Multiagent Activity for Human Al/Interaction using Dynamical Primitives	Seminar	1.5	0.3	06/05/2021	Prof. Micheal Richardson	Y
Dark Energy and Cosmic Acceleration	Seminar	1.5	0.3	13/05/2021	Prof. Jalison Alcaniz	Y
Introduction to FPGAs and the Intel Quartus Prime Software	Workshop	4	0.8	24/05/2021	Dr. Larry Landis	Y
Artificial Intelligence and 5G combined with holographic technology: a new perspective for remote health monitoring	Seminar	2	0.4	26/05/2021	Dr. Pietro Ferraro, Dr. Pasquale Memmolo	Y
Introduction to Simulation and Debug of FPGAs" Intel FPGA Workshop	Workshop	4	0.8	7/06/2021	Dr. Larry Landis	Y
Distributional Semantics Methods: How Linguistic features can improve the semantic representation	Seminar	2	0.4	23/06/2021	Dr. Alessandro Maisto, Prof. Flora Amato	Y
Circuiti per DSP	MSc Course	72	9	18/09/2020 23/12/2020	Prof. Davide De Caro	Y
Scientific Programming and Visualization with Python	Ad hoc course	20	2	8/03/2021 10/03/2021	Prof. Alessio Botta	Y
Statistical data analysis for science and engineering research	Ad hoc course	12	4	17/02/2021 3/04/2021	Prof. Roberto Pietroantuono	Y
Sistemi Elettronici Programmabili	BSc Course	72	9	30/03/2021 7/06/2021	Prof. Ettore Napoli	Y
Cambridge FCE	Course	50	6	3/03/2021 1/06/2021	CLA	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	0	3.2	3.5	0	6.7
Bimonth 2	9	3.6	5	0	17.6
Bimonth 3	6	3	5	0	14
Bimonth 4	15	3.9	4	0	22.9
Bimonth 5	0	0	3	0	3
Bimonth 6	0	0	6	0	6
Total	30	13.7	26.5	0	70.2
Expected	30 - 70	10 -30	80 -140	0 – 4.8	

3. Research activity:

My research interest focuses on brain-machine interfaces (BMIs) with particular attention on the study, analysis and implementation of spike detection algorithms.

Background:

BMIs have become popular in recent years as inexpensive and powerful tools that enables neuroscientists to study the brain over the past few decades. It can be seen as an implantable communication interface that receives and transmits the signal coming from the brain to an outside system or actuators. Nowadays it is possible to integrate thousands of microelectrodes on a single chip of few mm^2 allowing the monitoring of a wide population of neurons. On the other hand, the increase in the channels counts, it has also dramatically broadened the computational throughout required for the elaboration and interpretation of the sampled neural activity amount. This sets a major challenge when it comes to implantable, powered wirelessly or by small batteries, and where the device heating can be seriously destructive for the brain cells. An effective approach is to offload complex operations as spike sorting, clustering, and interpretation of the activity to an external device, where there are not strict constraints, while to apply on-fly a spike detection in order to reduce the transmission bandwidth and to send only the useful information about putative spikes (time stamps and waveforms). Typically, a spike detector consists of two stages: pre-emphasis and threshold crossing. The pre-emphasis step comprises filtering, to remove the lower frequency local field potentials (LFPs); and signal enhancement to improve the Signal-to-Noise Ratio (SNR) by emphasizing the spikes (APs) in preference to noise. Then, the emphasized signal is compared to a threshold value. A spike is detected when the signal crosses this threshold. In addition to the physical constraints of the spike detection, it has also to ensure a good trade-off between real spike and noise being wrongly detected (false positives).
For the sake of clarity, I decided to divide my research activity in two subsections, each with corresponding scientific contributions:

1. **Enhancement algorithms**
2. **Noise estimates**

1. Enhancement algorithms

The simplest spike detection technique is amplitude thresholding, in which a spike is detected when the amplitude of the recorded data crosses a pre-defined voltage threshold. This approach is attractive for real-time implementations because of its computational simplicity but results in low detection performances. Another class of spike detection method uses template matching. These algorithms assume that neural spikes belong to a set of templates, and matched filters are constructed from these templates to emphasize the spikes from the background noise. Unfortunately, these approaches need a long phase of training followed by a constant re-calibration because of the recording environment variability. A more robust group of detection method is based on wavelet transform but they were demonstrated to be computationally prohibitive for a real-time multichannel detector. Other detection methods are the nonlinear energy operator and its variants (TEO, kNEO, SNEO, etc..), that measure the instantaneous energy of the signal. On these latter, I decided to focus my research.

In [**1-j,1-c**] I contributed to carry out a fair comparison among the most popular spike detectors suitable for real-time implementation. It was shown that the energy operators provide the best-trade-off between detection performance and complexity. Specifically, the comparison was performed by using a synthetic dataset generated by a modified version of a toolbox “NEUROCUBE” used to generate extracellular recording with a known ground truth. As matter of fact, by having a noiseless recording it was possible to evaluate and compare the detectors at different SNR levels. This was done by varying the standard deviation of the white noise distribution, linearly added to the synthetic track.

In [**4-j**] I studied a novel energy operator (ASO) which was shown to be simpler than its counterparts, providing a reduction in arithmetic operations and memory requirements without worsening the detection rate. The methodology pursued in this work was lightly different from the previous work since the datasets constitute another challenge when analysing the detectors. One can either use synthetic or real data to evaluate their algorithms. The great advantage with using synthetic data, is that the ground truth is known. The noise level, however, and any drifting/fading of the signal does not behave in a realistic way. Additionally, noise characteristics across different electrodes and instrumentation vary, and within probes or multielectrode arrays across recording channels. It is therefore challenging to utilise established synthetic datasets and to achieve results that are representative of a real recording. Therefore, there can be some inconsistency between the evaluation results and practical performance. On the other hand, real data provides realistic signals, but the ground truth is unknown. To balance the trade-off between these approaches (integrity of a realistic signal vs. integrity in the evaluation), I used both types of datasets. Synthetic data is first used to quantitatively evaluate our proposed algorithm and to make a fair comparison with different algorithms that have been previously published. Experimental recordings (with an annotated ground truth) were then used for demonstrating the practical performance of the proposed algorithm with realistic noise levels and signal quality. With both datasets, the ASO achieved great detection performance, even when it was challenged with different types of noise.

However, setting aside the choice of spike detector and the hardware approach (ASIC, embedded system, etc.), from a hardware implementation point of view, a crucial aspect that pools all the algorithms is the large use of flip-flops required to store and process the data, in particular the enhancement block, that might restrict the increase of the channels to be processed because of the limited resource available. To overcome this limit, I implemented a random-access memory (RAM) based on latch instead of common flip-flops. This was proposed in [**5-j**] together a 1024-channnels spike detector ASO-based implementation. It was shown that its properties were compatible with other spike detectors presented in literature. Overall, the presented spike detector featured high accuracy/sensitivity, small area and low power consumption, demonstrating its feasibility for use in implantable multi-channel neural data acquisition devices.

2. Noise estimates

Whatever the algorithm used to extract the spikes from the noisy recording, another common problem is the measure of noise level estimation in the raw data. As mentioned above, the putative spike comes from a comparison between the enhanced signal and a threshold value. This should be determined by considering local statistics, providing a measure of the local noise level. There are several challenges in computing this threshold value, particularly for real-time hardware application:

- the inherent need for statistics in computing the threshold places significant memory requirements in a low power/low complexity implementation.
- the fact that each recording electrode observes its own unique SNR means each channel needs to be individually calibrated or trained.
- the signal observed at any given electrode itself changes over time requiring repeated re-calibration.
- developing an iterative function that estimates the noise level without requiring prior history poses its own challenges. For instance, samples that contain spikes or changes of neuron firing rates can contribute to erroneously raising the threshold value.

These challenges motivate the development of an adaptive threshold method that using an algorithmic approach to avoid the need for statistics and to provide blanking to capture a robust noise level.

In [**3-j]** I studied, designed, and compared different noise estimates by considering their complexity and the resources usage. A fair comparison was carried out considering 4 different synthetic datasets obtained by NEUROCUBE, with different neurons firing rates and noise levels. This allowed me to challenge and evaluate the robustness and sensitivity of my proposals. In particularly, the threshold addressed as *winsorization* (WA) was demonstrated to be less sensitive to changes of neurons firing rates. A qualitatively evaluation of resource consumptions highlighted its suitability for applications as BMIs.

Then, I decided to perform a more exhaustive analysis of this threshold technique in [**4-j,5-j**]. Specifically, my proposal was tested under different noise situations: uncorrelated noise, coloured noise and real noise extracted from an extracellular recording. It showed that on average the WA performed better than its golden counterpart, the median absolute deviation

(MAD). To certify its reliability and simplicity, either performance detection on real recording or an ASIC implementation were also provided.

Research products:

Journal contributions:

1.j - M. Tambaro., E.A Vallicelli, **G. Saggese**, A.G.M Strollo, A. Baschirotto, S. Vassanelli "Evaluation of In Vivo Spike Detection Algorithms for Implantable MTA Brain—Silicon Interfaces." in *Journal of Low Power Electronics and Applications*. 2020; 10(3):26.

2.j - G. D. Meo, D. De Caro, **G. Saggese**, E. Napoli, N. Petra and A. G. M. Strollo, "A Novel Module-Sign Low-Power Implementation for the DLMS Adaptive Filter With Low Steady-State Error." in *IEEE Transactions on Circuits and Systems I: Regular Papers*.

3.j - **G. Saggese**, M. Tambaro, E.A Vallicelli, A.G.M Strollo, S. Vassanelli, A. Baschirotto, M.D Matteis," Comparison of Sneo-Based Neural Spike Detection Algorithms for Implantable Multi-Transistor Array Biosensors." in *Electronics* 2021,10(4):410.

4.j - **G. Saggese**, A.G.M Strollo, "Low-Power energy-based spike detector ASIC for implantable multichannel BMI" in Journal of Neuroscience method (**submitted**)

5.j - **G.Saggese**, A.G.M Strollo "A 1024-channels spike detector RAM latch-based for real-time Brain -Silicon Interfaces", in *Electronics* (**in preparation**).

Conference contributions:

1.c - M. Tambaro, E. A Vallicelli, **G. Saggese**, A. La Gala, M. Maschietto, A. G. M Strollo, M. De Matteis, A. Baschirotto, S. Vassanelli "A scalable spike detection method for implantable high-density multielectrode array," *SMACD / PRIME 2021; International Conference on SMACD and 16th Conference on PRIME*, 2021, pp. 1-4.

5. Conferences and seminars attended

- "Introduction to FPGAs and the Intel Quartus Prime Software" Intel FPGA **online**-Workshop 24/5/2021.
- "Introduction to Simulation and Debug of FPGAs" Intel FPGA **online**-Workshop. 7/06/2021

6. Activity abroad:

None

7. Tutorship

Co-supervision of MSc thesis (Orazio Turboli) titled "Architettura hardware per un Sistema di individuazione di impulsi neuronali per un sensore multi transistor da 1024 pixel"

Co-supervision of MSc thesis (Fornaro Claudio) titled "Implementazione a ridotta dissipazione di potenza in tecnologia 28nm di un microsistema impiantabile per l'individuazione di impulsi neuronali.".

Co-supervision of MSc thesis (Nicola Parretta) titled “Realizzazione hardware di un rivelatore di spike multi/canale in tecnologia CMOS 28nm.”.