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

PhD Student: Maria Gragnaniello

Cycle: XXXIX

Training and Research Activities Report

Academic year: 2023-24 - PhD Year: First

Tutor: prof. Michele Riccio

Date: October 31, 2024

Training and Research Activities Report

PhD in Information Technology and Electrical Engineering

Cycle: XXXIX **Author: Maria Gragnaniello**

1. Information:

- **PhD student: Maria Gragnaniello**
- **PhD Cycle: XXXIX**
- **DR number: DR997196**
- **Date of birth: 20/04/1998**
- **Master Science degree: Biomedical Engineering**
- **University: University of Naples Federico II**
- **Scholarship type: PNRR (DM 118/2023)**
- **Tutor: Prof. Michele Riccio**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
System on Chip	Courses	72	9	20/09-19/12 2023	Prof. N. Petra	Y
IoT Data Analysis	Courses	12	4	08-09-15-16-22-23/02/2024	Prof. R. Della Corte	Y
Using Deep Learning properly.	Courses	12	4	23-25-30/01/2024, 01-06-08/02/2024	Prof. A. Apicella	Y
INTERNATIONAL SUMMER SCHOOL ON WEARABLE SENSORS	Summer School	28	4	10-12/07/ 2024	Prof. C. Massaroni Prof. D. Lo Presti Prof. E. Schena	Y
Ensuring Electronic Reliability Against CERN's Radiation Environment	Seminar	2	0.4	01/12/2023	Dr. S. Danzeca	Y
C - CODE OPTIMIZATION	Seminar	6	1.2	06/03/2024	Ing. G. Di Sirio	Y
Analytic center selection of optimization-based controllers for robot ecology	Seminar	1	0.2	09/05/2024	Prof. G. Notomista	Y
IEEE Authorship and Open Access Symposium	Seminar	1.5	0.3	07/05/2024	IEEE	Y
Data Science Strategies to Analyze the Impact of Transportation and Infrastructure on the Environment	Seminar	1	0.2	09/05/2024	IEEE	Y
Regolazione in tema di Intelligenza artificiale alla luce dell'AI act	Seminar	5	1	16/05/2024	Prof. A.M. Tulino	Y
Intelligenza Artificiale e regole del mercato	Seminar	2	0.4	14/05/2024	Prof. A.M. Tulino	Y
Verso una gestione smart della risorsa idrica con il	Seminar	1	0.2	14/05/2024	Prof. A.M. Tulino	Y

supporto delle digital innovation						
Perché digital in un mondo che sembra gia estensivamente digitale e perche trasformare – TIM	Seminar	4	0.8	10/05/2024	Prof. A.M. Tulino	Y
MEMS AND AI Practical Workshop	Seminar	8	1.6	05/06/2024	STMicroelectronics	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	**9**	**0.4**	**3**	**0**	**12.4**
Bimonth 2	**0**	**0**	**10**	**0**	**10**
Bimonth 3	**4**	**1.4**	**4**	**0**	**9.4**
Bimonth 4	**4**	**4.5**	**2**	**0**	**11**
Bimonth 5	**4**	**0**	**7**	**0**	**11**
Bimonth 6	**0**	**0**	**10**	**0**	**10**
Total	**21**	**6.3**	**36**	**0**	
Expected	**30 - 70**	**10 - 30**	**80 - 140**	**0 – 4.8**	

3. Research activity:

Edge AI is revolutionizing healthcare by enabling artificial intelligence (AI) to operate directly on portable devices like wearables and diagnostic tools, rather than relying on remote servers. This approach offers benefits over traditional cloud computing, such as faster response times, better data privacy, and real-time analysis, essential for timely medical decisions. Unlike cloud systems that require large data transfers to off-site servers, Edge AI processes information locally, reducing latency and data breach risks. However, Edge AI faces challenges due to the limited processing power, memory, and battery life of edge devices, which restricts the complexity of the AI models that can be deployed. To overcome these limitations, AI models are often simplified through techniques like quantization and pruning, though this can impact accuracy and processing speed. Battery efficiency also becomes critical, as continuous AI operation on battery-powered devices like wearables can quickly drain power.

In the initial phase, my research focused on an in-depth analysis of the state of the art to establish a foundation for subsequent development of hardware and firmware. For the electronic component, I examined embedded systems, such as microcontrollers, that facilitate the acquisition and processing of biosignals for monitoring vital parameters. This analysis included analog and digital front-end circuits, essential for optimizing signal acquisition and minimizing power consumption. On the firmware side, my research targeted real-time analysis techniques through Artificial Intelligence algorithms, following the Edge AI paradigm. I assessed how these techniques impact hardware in terms of memory and power requirements, analyzing the performance of various microcontroller architectures in terms of processing speed, power consumption, and memory footprint. AI techniques included Machine Learning, Deep Learning, and Transfer Learning models, with a particular focus on fully connected networks, as well as 1D and 2D CNNs, to evaluate their impact on resource-constrained devices.

Building on these studies, I developed two prototypes designed for specific cases to validate the potential of Edge AI in biomedical applications.

1. Multi-Signal PPG and Sensor System: This system collects data from PPG sensors (at different wavelengths) along with signals from piezoelectric sensors, force-sensing resistors, and accelerometers. The initial objective is to analyze and differentiate pulse wave patterns across these signal types, followed by training a model mainly on PPG data using well-documented datasets. The model will then be tested on piezoelectric and force-sensing resistor signals to assess its ability to generalize across signals with similar morphology. This approach will reduce the final system's energy consumption, as it eliminates the need to power LEDs continuously. Preliminary tests on a small dataset showed promising results, and the next step involves training with larger datasets to expand its applicability in wearable devices, a notable challenge in the medical field.

2. ECG-Based Health Monitoring System: This portable, chest-mounted ECG monitor is built with a 32-bit microcontroller that collects and processes ECG signals. It can send early detection alerts via Bluetooth Low Energy (BLE), making it suitable for real-time health monitoring. The device is designed for two primary applications:

- **Myocardial Infarction (MI) Detection:** A 1D Convolutional Neural Network (1D-CNN) was developed to detect myocardial infarction (MI) using ECG signals, achieving an accuracy of 95.94% after transforming the signals into spectrograms. In addition to the deep learning approach (DL), a machine learning (ML) method was also explored. This involved segmenting ECG data into 2-second frames with 0.5-second overlap, then decomposing each frame into frequency bands using the Fourier Decomposition Method. Key features such as energy, kurtosis, skewness, variance, and entropy were extracted from each band and used as inputs for a traditional ML classifier. The DL model ultimately showed the highest accuracy, and memory optimization techniques, such as quantization, significantly reduced the model's memory usage without sacrificing performance.

- **Diabetes Detection**: This study investigated non-invasive diabetes detection using ECG signals processed by a 1D-CNN. Model quantization was applied, achieving an accuracy of 89.52% with efficient memory usage, which proved effective across various ARM-based microcontrollers. Benchmarking was conducted on several 32-bit ARM architectures, including the M4, M7, M33, F7, H7, H5, U5, G4, and F4 series, using the ST Edge AI Developer Cloud tool. Among these, the F4 series emerged as the optimal choice due to its low inference time and reduced power consumption.

3. Explorations in Early Detection of Diabetes and **Skin Lesion Classification** were also conducted. For diabetes, a thermal imaging system was developed to detect early signs of diabetic foot ulcers, comparing machine learning techniques like decision trees and transfer learning with MobileNet v2. For skin lesion classification, a prototype was designed to categorize lesions using transfer learning on pre-trained models. While preliminary results are promising, further optimization of preprocessing and transfer learning techniques is needed to balance resource limitations and performance. Future efforts will focus on enhancing energy efficiency and preprocessing methods to improve Edge AI capabilities in healthcare diagnostics.

4. Research products:

- **Gragnaniello**, M.; Borghese, A.; Marrazzo, V.R.; Breglio, G.; Irace, A.; Riccio, M., 'A Microcontroller-Based System for Human-Emotion Recognition with Edge-AI and Infrared

Thermography', Lecture Notes in Electrical Engineering, vol. 1110 LNEE, pp. 327–332, 2024, doi: 10.1007/978-3-031-48121-5_46.

- **Gragnaniello**, M.; Balbi, F.; Martellotta, G.; Borghese, A.; Marrazzo, V.R.; Maresca, L.; Breglio, G.; Irace, A.; Riccio, M., 'Edge-AI on Wearable Devices: Myocardial Infarction Detection with Spectrogram and 1D-CNN', presented at the 2024 IEEE 22nd Mediterranean Electrotechnical Conference, MELECON 2024, 2024, pp. 485–490. doi: 10.1109/MELECON56669.2024.10608624.
- Parlato, S., Esposito, E., Centracchio, J., Andreozzi, E., **Gragnaniello**, M., Riccio, M., Bifulco P., 'A New, Simple Wrist-Mounted PVDF Sensor for Continuous Heart Rate Monitoring', in 2024 IEEE Sensors Applications Symposium (SAS), Jul. 2024, pp. 1–6. doi: 10.1109/SAS60918.2024.10636484.
- **Gragnaniello**, M.; Borghese, A.; Marrazzo, V.R.; Maresca, L.; Breglio, G.; Irace, A.; Riccio, M.,'Real-Time Myocardial Infarction Detection Approaches with a Microcontroller-Based Edge-AI Device', Sensors 2024, 24, 828. https://doi.org/10.3390/s24030828

5. Conferences and seminars attended

- 22nd IEEE Mediterranean Electrotechnical Conference (IEEE MELECON 2024) – Porto, Portugal / June 25-27, 2024. Oral Presentation.
- 2024 IEEE Sensors Applications Symposium (IEEE SAS) – Naples, Italy / July 23-25,2024. Oral Presentation.
- International Summer School on Wearable Sensors Summer, Campus Biomedico Roma, July 10-12, 2024.

6. Periods abroad and/or in international research institutions

A six-month period abroad scheduled from January 9, 2026, to July 9, 2026, at the College of Engineering and Physical Sciences, Aston University, Birmingham, UK, under the supervision of Professor Antonio Fratini.

7. Tutorship

- Co-supervision of MSc student (Gabriella Martellotta) thesis on "Design and Development of a Wearable Device for Myocardial Infarction Diagnosis Using Edge-AI Techniques: Comparison between Machine Learning and Deep Learning".
- Co-supervision of MSc student (Noemi Iorio) thesis on "Development, Firmware Implementation, and Characterization of a Multi-LED Photoplethysmographic Sensor: Comparative Analysis with a Piezoelectric Sensor".
- Co-supervision of MSc student (Francesca Di Sauro) thesis on "Development of a Multi-LED Circuit Prototype for Photoplethysmographic Signal Detection and Comparison with an Accelerometric Sensor".
- Co-supervision of MSc student (Elisabetta Errico) thesis on "Design of a Wearable Device Prototype for Diabetes Mellitus Detection Using Edge-AI Techniques".
- Co-supervision of MSc student (Emanuele Di Somma) thesis on "Design of a Device for Early Diagnosis of Diabetes Mellitus Using IR Thermography and Edge-AI Techniques".
- Co-supervision of MSc student (Anna Marino) thesis on "Design and Development of a System for Skin Lesion Detection and Classification Using Edge-AI Techniques".

- Co-supervision of MSc student (S. Ten. Aurora Giannone) thesis on “Development and Implementation of a System for Predictive Maintenance in Aircraft Using Edge-AI Techniques”.