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

PhD Student: Giovanni Maria Capuano

Cycle: XXXVIII

Training and Research Activities Report

Year: First

Tutor: prof. Strollo

Co-Tutor: prof. Petra

Date: October 17, 2023

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1. Information:

- ➢ **PhD student: Giovanni Maria Capuano**
- ➢ **DR number: DR996620**
- ➢ **Date of birth: 24/06/1991**
- ➢ **Master Science degree: Electronic Engineering   University: Università degli Studi di Napoli Federico II**
- ➢ **Doctoral Cycle: XXXVIII**
- ➢ **Scholarship type: PNRR – DM 352, Partner company Techno System Developments s.r.l., Pozzuoi (NA)**
- ➢ **Tutor: Professor Antonio G.M. Strollo**
- ➢ **Co-tutor: Professor Nicola Petra**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
Quantum Complexity	Seminar	1	0,2	10/11/22	Scuola Superiore Meridionale	N
Data mining the output of quantum simulators - from critical behavior to algorithmic complexity	Seminar	1	0,2	11/11/23	Università Degli Studi di Napoli Federico II - Department of Physics	N
Anomaly Detection using Image Processing and Deep Learning	Seminar	1	0,2	07/12/23	MathWorks	N
From Cyber Situational Awareness to Adaptive Cyber Defense: Leveling the Cyber Playing Field	Seminar	2	0,4	13/12/23	Prof. Giancarlo Sperlì, DIETI - Unina	Y
Game Theory for Information Engineering	Seminar	3	0,6	13/12/23	Prof. Marcello Caleffi, DIETI - Unina	Y
Malware Analysis	Seminar	2	0,4	15/12/23	Prof. Bonatti, DIETI - Unina	Y
Entangled Relativity	Seminar	1	0,2	15/12/23	Scuola Superiore Meridionale	N

Is control a solved problem for aerial robotics research?	Seminar	1	0,2	12/01/23	Unina - DIETI	**Y**
Industry 4.0 Fundamentals in Bosch Applications	Seminar	10	2	23/01/23 - 26/01/23	Bosch – Centro Studi Component i per Veicoli and the Decision and Control Laboratory of Politecnico di Bari	**Y**
Embracing Data Imperfection Via Domain Enriched Visual Task Learning	Seminar	1	0,2	13/02/23	Prof. Antonio De Maio, DIETI - Unina	**Y**
Algorithm Unrolling: Efficient, Interpretable Deep Learning for Signal and Image Processing	Seminar	1	0,2	14/02/23	Prof. Antonio De Maio, DIETI - Unina	**Y**
Non Distructive Testing in Aeronautics	Seminar	1	0,2	17/02/23	Prof. Carlo Forestiere, Unina	**Y**
AMD Xilinx Versal for Space and its Ecosystem	Seminar	1	0,2	26/01/23	Avnet Silica	**N**
Using Deep Learning Properly	Course	10	4	10/01/23 – 24/01/23	Dr. Andrea Apicella, DIETI - Unina	**Y**
How to boost your PhD	Course	16	4	11/01/23 - 01/03/23	Prof. Antigone Marino (ITEE - ICTH – CQB), Unina	**Y**
Statistical data analysis for science and engineering research	Course	12	4	11/01/23 – 01/03/23	Prof. Roberto Pietrantuon o, DIETI - Unina	**Y**
Enhancing qubit readout with Bayesian Learning	Seminar	1	0,2	05/04/23	Università Degli Studi di Napoli Federico II - DIETI	**Y**

How to Publish Under the CARE-CRUI Open Access Agreement with IEEE	Seminar	1.5	0,3	05/04/23	CARE-CRUI and IEEE	**Y**
Unleashing the Power of LLMs: A Historical Perspective on Generative AI	Seminar	1	0,2	02/03/23	Prof. Carlo Sansone and Dr. Stefano Marrone, DIETI - Unina	**Y**
MLOps: Achieving Operational Velocity with Faster Delivery and Collaboration	Seminar	1	0,2	02/03/23	Prof. Carlo Sansone and Dr. Stefano Marrone, DIETI - Unina	**Y**
Analysis and Control of Functional Brain Networks	Seminar	1	0,2	09/03/23	Università Degli Studi di Napoli Federico II - DIETI	**Y**
Artificial Intelligence for Defence Seabed-to Space Situational Awareness	Seminar	1	0,2	10/03/23	Prof. Antonio De Maio, DIETI - Unina	**Y**
I Pilastri della Trasformazione Digitale	Course	10	3	17/04/23 – 10/05/23	Prof. Nicola Mazzocca – DIETI, Unina	**Y**
Visione Per Sistemi Robotici	Course		9	08/03/23– 09/06/23	Prof. Cozzolino, Unina	**Y**
Symbiotic Control of Wearable Soft Suits for human motion assistance and augmentation	Seminar	2	0,4	26/05/23	Università Degli Studi di Napoli Federico II - DIETI	**Y**
AI, Robots and Society: Challenge and Opportunities for Social Innovation	Seminar	1	0,2	25/05/23	Università Degli Studi di Napoli Federico II - DIETI	**Y**
Cos'è l'Intelligenza Artificial	Seminar	1	0,2	22/06/23	Università Degli Studi di Napoli Federico II – Department of Physics	**N**
Exploring Advanced Aerial Robotics: A journey into cutting-	Seminar	1	0,2	29/06/23	Università Degli Studi di Napoli	**Y**

edge projects and neural control					Federico II - DIETI	
Scienza Moderna e Disciplina Giuridica dell'Intelligenza Artificiale	Course	22	6	07/06/23–10/07/23	Prof. Lucio Franzese - DIETI	Y
Ricerca e formazione nella società della transizione digitale	Seminar	-	1	22/09/23	CINI	N
Come Scrivere un Articolo Scientifico?	Seminar	1	0,2	26/09/23	Springer Nature	Y
Come Funzionano le Riviste?	Seminar	1	0,2	27/09/23	Springer Nature	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	2,2	7	0	9,2
Bimonth 2	4	3	7	0	14
Bimonth 3	8	1,3	7	0	16,3
Bimonth 4	12	0,8	4	0	12,8
Bimonth 5	6	0	3	0	9
Bimonth 6	0	1,4	7	0	8,4
Total	30	8,7	35	0	73,7
Expected	30 - 70	10 - 30	80 - 140	0 – 4.8	

3. Research activity:

The research theme regards the "FPGA hardware acceleration for Deep Learning-based image processing on board spacecrafts". During the first year of Ph.D., my research activities focused on the Earth Observation (EO) field and its related applications. Observing the Earth involves utilizing remote sensing technologies to monitor land, seas, and the atmosphere, through sensors, such as passive image sensors, capable of collecting images. The ability to extract information promptly from the acquired data can help in preventing or mitigating risks to the population resulting from events affecting safety. Swift detection of significant events, whether natural or man-made, is crucial for coordinating rapid rescue and protection operations. Given the large volume of acquired data, the limited time window during which the spacecraft is visible to ground stations, and the restricted bandwidth available for downlink communication with them, this research aims to propose solutions for on-board and real-time data processing. The goal is to generate alarm messages (early warning) related to events of interest, without relying on ground stations for data processing, which would inevitably introduce delays. On-board processing would help reduce the data volume to be transmitted

or assess higher-priority information on board, potentially delaying the transfer of less critical data to the ground.

Several early warning applications require the detection, recognition and identification of target of interest on the ground. Object Detection in satellite and remote sensing images can be a very complex task, especially when the objects of interest occupy a small area. Typically, standard detectors tend to yield low accuracy in such scenarios, making the identification and detection of small objects, such as vehicles, particularly challenging, as these objects are often represented by only few pixels.

The spatial resolution, in fact, plays a crucial role in a wide range of EO applications, including environmental monitoring, forecasting, land use analysis and so on. High-Resolution (HR) imagery is characterized by rich semantic contents and spatial details that allows us to extract crucial features and information. However, the spatial resolution may not meet the desired requirement due to the strict mass and volume constrains that characterize satellites, especially small satellite such as CubeSat. These constraints prevent the adoption of large telescopes (with a larger focal length and larger aperture) on board of satellite.

TSD-Space, which is actively engaged in the development of cutting-edge camera solutions for spacecrafts, proposes a piezo-actuated Focal Plane Array (FPA) in order to enhance spatial resolution. This system includes a highly accurate piezoelectric XY Nanopositioner capable of shifting the image sensor, on the focal plane, by half a pixel along both the row and column directions. During satellite pushbroom scanning mode, this image sensor enables the acquisition of two Low-Resolution (LR) images of the same target on the ground, with a known subpixel displacement.

During the first few months of my Ph.D., I studied the state of the art related to image acquisition methodologies for Earth observation and how to design a mission of this kind. My primary task was to assess the operational feasibility of this acquisition method and simulate a potential application scenario based on the knowledge I acquired in the field of Earth Observation during this first year. Simultaneously, I evaluated the critical aspects related to this type of application. Then, I proposed to use AI-based algorithms to fuse the information from these two LR images and reconstruct an HR image with a better qualitative and quantitative quality. For this purpose, I created two different new satellite imagery datasets, starting from freely available satellite image dataset online. The goal was to simulate the image products that would be acquired by the piezo-actuated FPA. Initially, I modified the original architecture of various Convolutional Neural Networks (CNNs), originally designed for the Single Image Super Resolution (SISR) to take two LR images as input. The objective was to demonstrate the superior reconstruction capabilities of our approach respect to the original ones based on the single image. All the models were designed by using Python and the TensorFlow framework and trained by using the GPUs available on *Google Colab* and

Kaggle platforms. Several experimentations were performed, demonstrating the ability of our method to super-resolve images with better quality performance compared to SISR approaches. Our CNN models, combining the information and the features extracted by the two LR shifted images, yield super-resolved images characterized by sharper and higher contrast spatial details, without blurring effects.

Additionally, I am currently developing a new Deep Neural Network for super-resolution, specifically designed for the processing of images acquired through a piezo-actuated FPA. The aim is to create a neural network model with equivalent performance but less computational complexity and a reduced number of neurons. The goal is to utilize this architecture as the backbone of a new neural network designed for object detection, enhancing the detection capabilities. Ultimately, the last phase may involve the hardware acceleration of this detector on FPGA to support early warning applications for critical features.

4. Research products:
- Conference Paper:
  Giovanni Maria Capuano, Antonio G.-M. Strollo, Nicola Petra; *"Super Resolution CNN for a Quincunx Sampling-based Panchromatic Earth Observation Imager for Nanosatellites"*. International Astronautical Congress 2023 (IAC23)
  Status: Published on IAF Digital Library (Not indexed in Scopus)

5. Conferences and seminars attended
- Conference (Paper presentation)
  Name: International Astronautical Congress (IAC)
  Place: Baku, Azerbaijan
  Date: 02/10/23 – 06/10/23

6. Activity abroad:

7. Tutorship: