PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Emilio Andreozzi

XXXIII Cycle

Training and Research Activities Report – Second Year

Tutor: Prof. Mario Cesarelli – co-Tutor: Prof. Paolo Bifulco

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

1. Information

I received a M. Sc. Degree, cum laude, in Electronic Engineering from University of Naples Federico II in July 12th 2017 with the thesis "Design and implementation of a device for contactless monitoring of pacemaker activity". I belong to the XXXIII PhD cycle in Information Technology and Electrical Engineering (ITEE), and my fellowship is financed by European PON project funds. My tutors are Prof. Mario Cesarelli and Prof. Paolo Bifulco.

2. Study and Training activities

During my second year of PhD I followed courses to enrich my knowledge particularly in the field of medical and biological applications of Information Technologies. I also attended a PhD school organized by the Italian National Group of Bioengineering.

a. Modules
- Data Science and Optimization – Dr. Claudio Sterle [1.2 ECTS]
- New directions in biomedical engineering research: neuroscience, machine learning and personalised medicine – Prof. Paolo Gargiulo, Prof. Thordur Helgason [2 ECTS]
- True Unipolar Electrocardiography and Application to Medicine – Prof. Gaetano Gargiulo [2.4 ECTS]

b. Seminars
- PhD School "XXXVIII School of the National Group of Bioengineering: Advanced bioengineering methods, technologies and tools in surgery and therapy" – Gruppo Nazionale di Bioingegneria [5 ECTS]
- Medical Thermal Therapy and Monitoring Using Microwave Inverse Scattering – Prof. Mahta Moghaddam [0.2 ECTS]

c. External courses (modules)
- High Resolution Electronic Measurements in Nano-Bio Science – Prof. Marco Sampietro, Prof. Giorgio Ferrari [5 ECTS]

	Credits year 2							
	Estimated	bimonth 1	bimonth 2	bimonth 3	bimonth 4	bimonth 5	bimonth 6	Summary
Modules	10	1.2	5	2	2.4	0	0	**11**
Seminars	5	0	0	0.2	0	5	0	**5.2**
Research	43	8.8	5	7.8	7.6	5	10	**44**
	58	10	10	10	10	10	10	**60**

3. Research activity

- Main research topic:

<u>*Improvements of noise suppression for low-dose X-ray imaging*</u> – In my second year of PhD course, I exploited the results of literature analysis and preliminary experimentation carried out in the first year, to analyse and improve the performances of the Noise Variance Conditioned Average (NVCA) algorithm [1,2,3,4].

My research activity on this topic mainly focused on:

1. In-depth analysis of NVCA performances and comparison with state-of-the-art algorithms;
2. Improvement of the trade-off between noise reduction and edge preservation for the NVCA algorithm.

A performance comparison between NVCA and V-BM4D (the state-of-the-art for gaussian denoising of video sequences) was carried out both on synthetic and real fluoroscopic sequences, to assess the denoising and edge preservation capabilities of the two algorithms. As V-BM4D is specifically tailored for additive white gaussian noise, while low-dose x-ray images are affected by a Poisson-distributed noise, fluoroscopic data where pre-processed with the Anscombe transform to stabilize the noise variance before the application of V-BM4D.

This activity led to the publication of the journal paper "*Sarno, A.; Andreozzi, E.; De Caro, D.; Di Meo, G.; Strollo, A.G.M.; Cesarelli, M.; Bifulco, P. Real-time algorithm for Poissonian noise reduction in low-dose fluoroscopy: performance evaluation. (2019). BioMed Eng OnLine; 18, 94 doi:10.1186/s12938-019-0713-7",* where NVCA and V-BM4D performances where compared in terms of computational complexity and in terms of image quality, by means of different Image Quality Assessment (IQA) metrics, namely Contrast-to-Noise Ratio (CNR), Full-Width at Half-Maximum (FWHM) of the line spread function and Feature Similarity Index (FSIM). The study reported that the whole V-BM4D processing has a computational complexity of several orders higher than NVCA's one: indeed, for an image of NxN pixels, the sole block matching phase of V-BM4D has a complexity of $O(N^4K^2)$, with K being the mask size, while the whole NVCA processing has a complexity of $O(N^2)$. Referring to image quality, it was found that V-BM4D performed slightly better than NVCA on static sequences both in terms of noise and edge preservation, but did not achieve good results on moving scenes, with performances worsening with increasing objects speed (FWHM doubled when doubling speed). NVCA, instead, provided better edge preservation regardless of objects speed.

The denoising and edge preservation capabilities of NVCA and V-BM4D were also tested for effective edge detection on a real fluoroscopic scene of the lumbar spine. The results of this activity were presented in the conference paper: "*Andreozzi, E.; Pirozzi, M.A.; Sarno, A.; Esposito, D.; Cesarelli, M.; Bifulco, P. (2020) A Comparison of Denoising Algorithms for Effective Edge Detection in X-Ray Fluoroscopy. In: Henriques J., Neves N., de Carvalho P. (eds) XV Mediterranean Conference on Medical and Biological Engineering and Computing – MEDICON 2019. MEDICON 2019. IFMBE Proceedings, vol 76. Springer, Cham. doi: 10.1007/978-3-030-31635-8_49*". In this study, edges were extracted from sequences filtered with NVCA and V-BM4D (combined with Anscombe transform) and compared in terms of noise reduction and edge blurring. NVCA provided better edge preservation and denoising with respect to V-BM4D, which produced substantial edge blurring.

An improved version of the NVCA algorithm was designed via separation of temporal and spatial filtering operations. Indeed, the successive samples of a pixel are uncorrelated as the lag time of the X-ray detectors is much shorter than the time interval between two frames: thus, in quasi-static scenes, temporal NVCA filtering is more effective and less prone to inferential error than spatial NVCA filtering. Therefore, temporal NVCA filtering is first applied to reduce the noise, then a spatial NVCA filtering operation with an adaptive threshold is performed. Considering that the temporal filtering reduces the noise variance by a factor that depends on the number of pixels included in the time averaging operation, the threshold coefficient of the spatial NVCA filter is reduced accordingly for each pixel to be filtered, allowing to better preserve low-contrast edges.

This activity led to the publication of the paper: "*Castellano, G.; De Caro, D.; Esposito, D.; Bifulco, P.; Napoli, E.; Petra, N.; Andreozzi, E.; Cesarelli, M., Strollo, A.G.M. An FPGA-Oriented Algorithm for Real-Time Filtering of Poisson Noise in Video Streams, with Application to X-Ray Fluoroscopy. Circuits Syst Signal Process. (2019). 38: 3269. doi:10.1007/s00034-018-01020-x*", where the improved NVCA algorithm was tested and compared to state-of-the-art algorithms on both static and moving sequences corrupted by simulated Poisson noise, and its hardware implementation on the smallest Xilinx StratixIV FPGA was presented. The proposed algorithm outperformed all the considered state-of-the-art algorithms (BM3Dc, V-BM3D, NLM, STGSM among others) and its hardware implementation performed a real-time processing of a 1024x1024 resolution video stream at 49 fps (well above the maximum 30 fps frame rate adopted by fluoroscopes), by using only 22% of FPGA logic resources.

Finally, I started an experimental activity for the analysis of the performances of NVCA algorithm via different Image Quality Assessment (IQA) metrics. To this aim, I created different synthetic fluoroscopic sequences to quantify the effect objects' dimensions, shape and speed, and of CNR, on optimal NVCA parameters which provide the best trade-off between noise reduction and edge preservation for moving objects.

- Other research topics:

  Force-Seismocardiography – Seismocardiography (SCG) is a non-invasive measurement technique which allows the detection of local cardiac-induced vibrations of the chest wall, usually by means of accelerometers [5,6,7]. SCG offers the possibility to investigate and monitor the mechanical behaviour of the heart and, therefore, it can provide additional information to the electrocardiography (ECG) [6]. According to the literature, many events, such as cardiac valves opening and closure, isovolumic contraction, cardiac filling and blood injection well relate to peaks and valleys of the SCG signals [7,8]. Hence, it is possible to estimate time intervals and velocities of physiological relevance, which give important insights into the mechanics of the beating heart (such as left ventricular ejection time, rapid diastolic filling time, isovolumic contraction and relaxation times [9,10], left ventricular lateral wall and septal wall contraction peak velocities, trans-aortic and trans-pulmonary peak flows [11]).

  In my second year of PhD course, I started a research activity to investigate the suitability of Force Sensitive Resistors (FSR) to monitor the heart-induced vibrations of the chest wall. Indeed, the flat amplitude response of the FSR in the 0-1 kHz frequency band and the ability to record the small vibrations occurring during muscle contractions (i.e. the Mechanomyogram, MMG), assessed during the research activity carried out in my first year of PhD and presented in [12], suggested the possibility to record the mechanical vibrations of other body parts, particularly those induced on the chest wall by the cardiac activity. To this aim, I designed and realized an analog front-end for FSR-based sensor conditioning and I acquired multiple synchronized measurements of FSR-based sensor output, SCG and ECG (which provided a time reference for the characteristic events of the cardiac cycle). The FSR-based sensor proved capable of recording the heart-induced vibrations of the chest wall and supported the development of a novel technique, which was named force-Seismocardiography (fSCG).

  This activity led to the preparation and submission of the paper: "*Force-Seismocardiography: A Novel Technique to Measure Heart Mechanical Vibrations onto the Chest Wall*" to the MDPI journal Sensors. In this study, the novel force-Seismocardiography technique, which employs FSR-based sensors, was presented and compared against the well-established accelerometric SCG. To this aim, simultaneous measurements of fSCG and SCG were acquired from an FSR-based sensor and an accelerometer, placed onto the xiphoid process with a belt and fixed on a small rigid board in order to make them integral. The fSCG and SCG signals resulted very similar ($r > 0.95$) but delayed of about tens of milliseconds, as it would be expected since they measure, respectively, force and acceleration, whose relationship is complex and depends on the local mechanical impedance. fSCG provides new information on local forces exerted on the chest wall by the beating heart, which have not been measured by any other sensor proposed in literature. The availability of e-textile force sensors, which could be embedded in various garments, could support a continuous, pervasive monitoring of the mechanical behaviour of patients' hearts.

The possibility to widen the range of detectable biomechanical signals by coupling the FSR-based sensor with a piezoelectric sensor has been considered. Preliminary tests were carried out to realize a simple and cheap analogue front-end for a small ceramic piezo. The results of this activity were presented in the paper: "*Polley, C.; Andreozzi, E.; Bifulco, P.; Esposito, D.; Naik, G.R.; Gunawardana, U.; Gargiulo, G.D. Low Cost Analogue Front End for Electronic Stethoscopes Application with Silicone Enclosure. International Conference on Electrical Engineering Research and Practice, Sydney, Australia, 24-28 November, 2019. Proceedings of the conference submitted to IEEE on 10/12/2019*" at the *International Conference on Electrical Engineering Research and Practice (*Sydney, Australia, 24-28 November, 2019).

Piezoresistive sensor for muscle contraction – In my second year of PhD I joined a research activity which exploited the results obtained in the first year on the characterization and use of FSR-based sensors for muscle contraction monitoring [12]. The main focus of such activity was the development and test of a novel piezoresistive array armband for real-time gesture recognition. In particular, the armband was realized with only three FSR-based sensors, to be positioned onto specific forearm muscles involved in the execution of different gestures. The gesture recognition was carried out by means of several supervised classification approaches and their performances were compared in terms of accuracy and computational burden. Support Vector Machine (SVM) and Linear Discriminant Analysis (LDA) classifiers were selected for real-time classification of performed gestures. The final gesture recognition system was composed of a piezoresistive array armband to be worn by the subject, a personal computer used to train the classifier and to transfer its parameters to an Arduino board, which was dedicated to the acquisition and the real-time classification of FSR-based sensors signals, to perform the gesture recognition.

This activity led to the publication of the paper: "*Esposito, D.; Andreozzi, E.; Gargiulo, G.D.; Fratini, A.; D'Addio, G.; Naik, G.R. A piezoresistive array armband with reduced number of sensors for hand gesture recognition. (2020). Front. Neurorobot. doi:10.3389/fnbot.2019.00114 (Article in press).* ", where the performances of the array armband were tested on 10 subjects, who performed several repetitions of 8 different gestures. The gesture recognition system achieved a mean classification accuracy of 96% and was used to build some video games, where the recognized gestures were used in place of joystick's control signals.

Realistic Neuronal Modelling and Simulation – In my second year of PhD course, my research activity on this topic focused on a side by side performance comparison between the Hodgkin & Huxley model and the Balbi Markov-type kinetic model in the reproduction of the electrophysiological properties of the ion channel Nav1.5. This activity led to the publication of the paper: "*Andreozzi, E.; Carannante, I.; D'Addio, G.; Cesarelli, M.; Balbi, P. Phenomenological models of NaV1.5. A side by side, procedural, hands-on comparison between Hodgkin-Huxley and kinetic formalisms. (2019). Sci Rep; 9, 17493 doi:10.1038/s41598-019-53662-9.*", which showed where and how the higher flexibility of the kinetic models (i.e. the higher number of free parameters) provided superior performances in the simulation of channel's response to several voltage-clamp protocols with respect to the HH model. Moreover, the study highlighted that the computational burden of a 5-states Markov-type kinetic model, which was thought to be much higher than HH's one, is actually about 5% higher, and can be reasonably considered comparable.

References:

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3. Cerciello, T.; Bifulco, P.; Cesarelli, M.; Fratini A. A comparison of denoising methods for X-ray fluoroscopic images. Biomed Signal Process Control. 2012, 7:550−559.
4. Genovese, M.; Bifulco, P.; De Caro, D.; Napoli, E.; Petra, N.; Romano, M.; Cesarelli, M.; Strollo AGM. Hardware implementation of a spatio-temporal average filter for real-time denoising of fluoroscopic images. J VLSI. 2015, 49:114−124.
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12. Esposito, D.; Andreozzi, E.; Fratini, A.; Gargiulo, G.D.; Savino, S.; Niola, V.; Bifulco, P. A Piezoresistive Sensor to Measure Muscle Contraction and Mechanomyography. (2018). Sensors; 18, 2553.

- Collaborations:
  - Western Sydney University, Prof. Gaetano Gargiulo
  - Aston University, Dr. Antonio Fratini
  - Istituti Clinici Scientifici Maugeri, Dott. Pietro Balbi
  - Reykjavik University, Prof. Paolo Gargiulo
  - IMT Atlantique, Dr. Francesco Ferranti

4. Products

a. Journal papers:

- *Castellano, G.; De Caro, D.; Esposito, D.; Bifulco, P.; Napoli, E.; Petra, N.; Andreozzi, E.; Cesarelli, M., Strollo, A.G.M. An FPGA-Oriented Algorithm for Real-Time Filtering of Poisson Noise in Video Streams, with Application to X-Ray Fluoroscopy. Circuits Syst Signal Process. (2019). 38: 3269. doi:10.1007/s00034-018-01020-x.*
- *Sarno, A.; Andreozzi, E.; De Caro, D.; Di Meo, G.; Strollo, A.G.M.; Cesarelli, M.; Bifulco, P. Real-time algorithm for Poissonian noise reduction in low-dose*

fluoroscopy: performance evaluation. (2019). BioMed Eng OnLine; 18, 94 doi:10.1186/s12938-019-0713-7.

- *Andreozzi, E.; Carannante, I.; D'Addio, G.; Cesarelli, M.; Balbi, P. Phenomenological models of NaV1.5. A side by side, procedural, hands-on comparison between Hodgkin-Huxley and kinetic formalisms. (2019). Sci Rep; 9, 17493 doi:10.1038/s41598-019-53662-9.*
- *Iuppariello, L.; D'Addio, G.; Lanzillo, B.; Balbi, P.; Andreozzi, E.; Improta, G.; Faiella, G.; Cesarelli, M. A novel approach to estimate the upper limb reaching movement in three-dimensional space. Informatics in Medicine Unlocked, 2019, 15, 100155. doi:10.1016/j.imu.2019.01.005*
- *Esposito, D.; Andreozzi, E.; Gargiulo, G.D.; Fratini, A.; D'Addio, G.; Naik, G.R. A piezoresistive array armband with reduced number of sensors for hand gesture recognition. (2020). Front. Neurorobot. doi:10.3389/fnbot.2019.00114* ***(Article in press)****.*
- *Andreozzi, E.; Fratini, A.; Esposito, D.; Naik, G.; Gargiulo, G.D.; Bifulco, P. Force-Seismocardiography: A Novel Technique to Measure Heart Mechanical Vibrations onto the Chest Wall. (****Submitted to Sensors MDPI****)*

b. *Conference papers*

- *Andreozzi, E.; Pirozzi, M.A.; Sarno, A.; Esposito, D.; Cesarelli, M.; Bifulco, P. (2020) A Comparison of Denoising Algorithms for Effective Edge Detection in X-Ray Fluoroscopy. In: Henriques J., Neves N., de Carvalho P. (eds) XV Mediterranean Conference on Medical and Biological Engineering and Computing – MEDICON 2019. MEDICON 2019. IFMBE Proceedings, vol 76. Springer, Cham. doi: 10.1007/978-3-030-31635-8_49.*
- *Pirozzi, M.A.; Andreozzi, E.; Magliulo, M.; Gargiulo, P.; Cesarelli, M.; Alfano, B. (2020) Automated Design of Efficient Supports in FDM 3D Printing of Anatomical Phantoms. In: Henriques J., Neves N., de Carvalho P. (eds) XV Mediterranean Conference on Medical and Biological Engineering and Computing – MEDICON 2019. MEDICON 2019. IFMBE Proceedings, vol 76. Springer, Cham. doi: 10.1007/978-3-030-31635-8_35.*
- *Esposito, D.; Cosenza, C.; Gargiulo, G.D.; Andreozzi, E.; Niola, V.; Fratini, A.; D'Addio, G.; Bifulco, P. (2020) Experimental Study to Improve "Federica" Prosthetic Hand and Its Control System. In: Henriques J., Neves N., de Carvalho P. (eds) XV Mediterranean Conference on Medical and Biological Engineering and Computing – MEDICON 2019. MEDICON 2019. IFMBE Proceedings, vol 76. Springer, Cham. doi: 10.1007/978-3-030-31635-8_70.*
- *Polley, C.; Andreozzi, E.; Bifulco, P.; Esposito, D.; Naik, G.R.; Gunawardana, U.; Gargiulo, G.D. Low Cost Analogue Front End for Electronic Stethoscopes Application with Silicone Enclosure. International Conference on Electrical Engineering Research and Practice, Sydney, Australia, 24-28 November, 2019. Proceedings of the conference submitted to IEEE on 10/12/2019.*

5. Conferences and Seminars

a. Participation to the XV Mediterranean Conference on Medical and Biological Engineering and Computing, MEDICON 2019 (Coimbra; Portugal; 26-28 September 2019), contributing with 3 papers.
b. Presentation of the paper "*Andreozzi, E.; Pirozzi, M.A.; Sarno, A.; Esposito, D.; Cesarelli, M.; Bifulco, P. (2020) A Comparison of Denoising Algorithms for Effective Edge Detection in X-*

Ray Fluoroscopy. In: Henriques J., Neves N., de Carvalho P. (eds) XV Mediterranean Conference on Medical and Biological Engineering and Computing – MEDICON 2019. MEDICON 2019. IFMBE Proceedings, vol 76. Springer, Cham. doi: 10.1007/978-3-030-31635-8_49", at the poster session of MEDICON 2019.

6. Activity abroad

No activity abroad.

7. Tutorship

a. Assistant for:

- B.Sc. course "Elaborazione di Segnali e Dati Biomedici" held by Prof. Francesco Amato (**20 hours**);
- M.Sc. course "Computer Interfaces for Biological Systems", held by Prof. Paolo Bifulco (**4 hours**);
- M.Sc. course "Strumentazione Biomedica", held by Prof. Paolo Bifulco (**10 hours**);
- M.Sc. course "Fondamenti di Ingegneria Clinica", held by Prof. Paolo Bifulco (**10 hours**).

b. Bachelor of Science co-supervisor:

- I assisted Ludovica Scorzelli (supervisor Prof. Mario Cesarelli) during the research activities for her Bachelor Thesis in Biomedical Engineering entitled: "*Modelli neuronali biologicamente accurati: Nuove direzioni nella caratterizzazione e modellazione matematica dei canali ionici voltaggio-dipendenti*";
- I assisted Giuseppe Salvatore (supervisor Prof. Mario Cesarelli) during the research activities for his Bachelor Thesis in Biomedical Engineering entitled: "*Analisi quantitativa delle performance dell'algoritmo NVCA per il denoising di sequenze fluoroscopiche*";
- I assisted Erica Di Palma (supervisor Prof. Mario Cesarelli) during the research activities for her Bachelor Thesis in Biomedical Engineering entitled: "*Realizzazione e test di un algoritmo di denoising per sequenze fluoroscopiche*";
- I assisted Antonella De Martino (supervisor Prof. Mario Cesarelli) during the research activities for her Bachelor Thesis in Biomedical Engineering entitled: "*Analisi comparativa di indici di qualità delle immagini mediche per la rilevazione di distorsioni sui bordi*".

c. Master of Science co-supervisor:

- I assisted Nicola De Prisco (supervisor Prof. Paolo Bifulco), during the research activities for his Master Thesis in Biomedical Engineering entitled: "U*n metodo innovativo per il monitoraggio del ritmo cardiaco e respiratorio basato su un sensore di forza*";
- I assisted Saverio Cecere (supervisor Prof. Paolo Bifulco), for his Master Thesis in Biomedical Engineering entitled: "*Misure biomediche con sensori di forza: applicazioni in sismocardiografia*".