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

PhD Student: Salvatore Parlato

Cycle: XXXIX

Training and Research Activities Report

Academic year: 2023-24 - PhD Year: First

Tutor: prof. Paolo Bifulco

Date: October 28, 2024

Training and Research Activities Report

PhD in Information Technology and Electrical Engineering

Cycle: XXXIX **Author: Salvatore Parlato**

1. Information:

- **PhD student: Salvatore Parlato** **PhD Cycle: XXXIX**
- **DR number: DR997185**
- **Date of birth: 25/08/1994**
- **Master Science degree: Biomedical Engineering**
- **University: University of Naples Federico II**
- **Scholarship type: UNINA**
- **Tutor: Prof. Paolo Bifulco**
- **Period abroad:** ***Aston University, Birmingham, UK from October 2, 2024 – November 30, 2024***

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
Basic Labview Programming	Course	20	2	28.11.2023 – 01.12.2023	DIETI	Y
Artificial Intelligence for Ocean Dynamics	Seminar	1	0.2	04.12.2023	Prof. G. Longo	N
Energy-Efficient Data Science	Seminar	1	0.2	13.12.2023	Prof. E. Masciari	Y
Study on measurement techniques to record heartbeat vibrations and sounds.	Research		6	01.11.2023 – 31.12.2023		
AI @ The Deep Edge	Course	27	3	31.01.2024 – 02.02.2024	ST Microelectronics	Y
Study on a novel sensor to record sphygmic waves.	Research		6	01.01.2024 – 29.02.2024		
Statistical data analysis for science and engineering research	Course	12	4	15.02.2024 – 29.02.2024	Prof. Roberto Pietrantuono	Y
Analytic center selection of optimization-based controllers for robot ecology	Seminar	1	0.2	09.04.2024	Prof. Bruno Siciliano	Y
Exploring the Frontiers of Modern Cryptography	Seminar	1.5	0.3	12.04.2024	Prof. Simon Pietro Romano	Y

Machine Learning the Universe with large astronomical surveys	Seminar	1	0.2	18.04.2024	Dr. Francesco Bajardi	Y
Study on blood vessels' vibrations and sounds in patients with arterio-venous fistulas and development of a sensor array for multisite measurement	Research		6	01.03.2024 – 30.04.2024		
Biomedical Imaging	MSc Course	48	6	06.03.2024 – 06.06.2024	Prof. Emilio Andreozzi	Y
An overview of polytopal approximations of partial differential equations	Seminar	1	0.2	02.05.2024	Dr. Francesco Bajardi	Y
IEEE Authorship and Open Access Symposium: Tips and Best Practices to Get Published from IEEE Editors	Seminar	2	0.4	07.05.2024	IEEE	Y
Rewire the brain: the potential of neuroplasticity	Seminar	2	0.4	09.05.2024	Prof. Antonia Tulino	Y
Explaining and controlling turbulent flows through deep learning	Seminar	1	0.2	09.05.2024	Dr. Francesco Bajardi	Y
Symbiotic Control of Wearable Soft Suits for human motion assistance and augmentation	Seminar	2	0.4	10.05.2024	Prof. Fanny Ficuciello	Y
Regolazione in tema di intelligenza artificiale alla luce dell'AI ACT	Seminar	5	1	13.05.2024	Prof. Antonia Tulino	Y
Some aspects of virtual medicine and human space science research	Seminar	1	0.2	16.05.2024	Dr. Francesco Bajardi	Y
Waves where physics meet biology: collective states of motile cilia	Seminar	1	0.2	23.05.2024	Dr. Francesco Bajardi	Y
Machine Deception	Seminar	1	0.2	23.05.2024	Prof. Alessandra Rossi	Y

Sustainable IT: strategies and best practices for a green engineering future	Seminar	5	1	27.05.2024	Prof. Antonia Tulino	Y
Development of a force and acceleration integrated sensor for cardiorespiratory monitoring.	Research		6	01.05.2024 – 30.06.2024		
Computer interface for biological systems	MSc Course	48	6	06.03.2024 – 06.06.2024	Prof. Paolo Bifulco	Y
Development of an automated algorithm for heartbeat localization in cardio-mechanical signals.	Research		5	01.07.2024 – 31.08.2024		
Development of a sensorized garment for cardiorespiratory monitoring.	Research		6	01.09.2024 – 31.10.2024		

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	**2**	**0.4**	**6**	**0**	**8.4**
Bimonth 2	**3**	**0**	**6**	**0**	**9**
Bimonth 3	**4**	**0.7**	**6**	**0**	**10.7**
Bimonth 4	**6**	**4.2**	**6**	**0**	**16.2**
Bimonth 5	**6**	**0**	**5**	**0**	**11**
Bimonth 6	**0**	**0**	**6**	**0**	**6**
Total	**21**	**5.3**	**35**	**0**	**61.3**
Expected	**20 - 40**	**5 - 10**	**10 - 35**	**0 – 1.6**	

3. Research activity:

▪ **Innovative devices and methods for cardio-mechanical monitoring**

During my first year of PhD course, I carried out research activities in the field of "*Innovative devices and methods for cardio-mechanical monitoring*". In this year, my research activity mainly focused on the design, development, and testing of a new wearable wrist sensor for continuous heart rate monitoring. I presented the results of this activity at the 2024 IEEE Sensors Applications Symposium (SAS) in the paper entitled "*A New, Simple Wrist-Mounted PVDF Sensor for Continuous Heart Rate Monitoring*". In particular, I proposed a sensor based on an off-the-shelf polyvinylidene fluoride (PVDF) piezoelectric

transducer inserted into a 3D-printed rubber wristwatch strap that can capture the weak mechanical vibrations generated by the radial artery pulse. The sensor requires much less power consumption and allows continuous and prolonged heart rate monitoring. Sensor output signal and an electrocardiography (ECG) lead were simultaneously acquired from 10 healthy subjects, to assess sensor performance and heart rate accuracy. Sphygmic pulses were automatically identified by a template matching technique, independently of the ECG signal. The template matching approach detected heartbeats with sensitivity and positive predictive value of 98.0 % and 99.0 %, respectively. Inter-beat intervals were then estimated and compared with those obtained from the ECG by means of Passing-Bablok linear regression and Bland-Altman analyses. The results showed high agreement between the two measurements: linear regression coefficient of determination R^2 of 0.994, and Bland-Altman limits of agreement of ± 17.0 ms. These preliminary findings suggest that the proposed sensor can offer continuous and accurate heart rate monitoring. The use of a piezoelectric sensor offers numerous advantages, including the ability to detect small variations in heartbeat and ease of integration into wearable devices. In addition, the 3D-printed TPU backing ensures optimal user comfort during monitoring. In conclusion, the proposed system is characterized by very low power consumption compared to modern photoplethysmography sensors and the ability to generate a relatively wide sphygmic signal. The high sensitivity of the transducer potentially allows small changes in the sphygmic wave to be faithfully reproduced. This means that changes in shape due to respiration, changes in blood pressure, and other factors could be detected and used for broader monitoring of cardiovascular well-being. The combination of a wide signal and low power consumption makes the proposed system particularly suitable for battery-powered wearable applications, ensuring a long battery life without compromising the quality of the acquired data. In addition, the use of the template matching technique allows very accurate heart rate monitoring and, presumably, accurate estimation of arrythmias (e.g. atrial fibrillation, ectopic ventricular beats, etc.) or heart rate variability indices. This further enriches the potential diagnostic capabilities of the proposed system and expands its potential use in clinical application and remote monitoring contexts.

- **Development of innovative devices to record the mechanical vibrations and sounds generated by blood flow in patients with arterio-venous fistulas**

During the first year of my PhD, I also developed a 4-force sensor acquisition system to record the vibrations and sounds induced by blood flow in patients with arteriovenous fistulas. The arteriovenous fistula (AVF) generates easy vascular access for hemodialysis in end-stage kidney disease patients. AVF management is essential for a successful dialysis treatment and can influence long-term patient survival. Physical examination is the first step to diagnose and treat a malfunctioning AVF and includes palpation of AVF pulse and thrill, and auscultation of bruit sounds. Guidelines recommend frequent visits during AVF maturation and throughout the dialysis period, with large deployment of financial and human resources. A tele-monitoring system can enable more frequent monitoring and earlier recognition of stenoses.

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

Cardio-mechanical monitoring can be performed by means of accelerometers and gyroscopes attached to subjects' chests, which produce Seismocardiography (SCG) and Gyrocardiography (GCG) signals.

Detection of heartbeats in SCG and/or GCG signals is commonly carried out by taking advantage of a simultaneous electrocardiogram (ECG). SCG/GCG-based long-term monitoring would certainly be less obtrusive and easier to implement without a concurrent ECG. For this reason, I focused my research activity on the development of ECG-free method for heartbeats detection in cardio-mechanical signals. This method is based on template matching technique. Normalized cross-correlation (NCC) function is used a similarity measure and can localize individual heartbeats. The template matching approach was tested on a large cohort of healthy and pathological subjects.
Results obtained on healthy subjects were presented at the e-Health and Bioengineering (EHB) 2023 in the paper entitled "*Accurate ECG-Free Heartbeats Localization in Long-Lasting SCG Recordings*". The proposed method accurately identified 65963 heartbeats out of a total of 67671 in the SCG signals, scoring a sensitivity of 97.5% and a PPV of 95.4%. Furthermore, the statistical analyses reported a coefficient of determination R^2 greater than 0.999, and Bland-Altman limits of agreement of ±4.7 ms.

Another paper, entitled "*A Novel Approach to Recognize Valvular Heart Diseases Based on Morphological Similarity of Heartbeats in Seismocardiography Signals*" and presented at the same conference, dealt with the comparison of SCG signals from healthy and pathological subjects affected by valvular heart diseases (VHDs). Morphological variation in SCG signals from VHDs patients was detected with respect to healthy subjects. Gaussian SVM and LDA machine learning classifiers were able to discriminate between healthy and VHD patients, scoring an overall accuracy of 94.2%, with a high sensitivity and PPV in excess of 96%.

In the second part of the year, 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. I published a journal paper entitled "*Accurate Localization of First and Second Heart Sounds via Template Matching in Forcecardiography Signals*". This study focused on separately recognizing S1 and S2 heart sounds in FCG signals via template matching technique. The results of this study are exceptionally encouraging. In fact, the proposed approach proved capable of separately classifying S1 and S2 sounds in more than 96% of all heartbeats. Linear regression, correlation, and Bland–Altman analyses showed that the template matching method allowed the estimation of inter-beat intervals with high accuracy. Indeed, 95% of the estimation errors were confined within 10 ms, which corresponds to relative errors lower than 2% by considering heart rates between 50 and 120 bpm. Further statistical analyses showed that HRV indices were estimated with reasonable accuracy, by achieving mean absolute percentage errors within 8% for all time-domain and non-linear indices, apart from NN50 (the number of pairs of successive NN intervals that differ by more than 50 milliseconds) and pNN50 (the percentage of successive NN intervals that differ by more than 50 milliseconds).

- **Innovative devices for atrial fibrillation early detection**

In the last part of the year, I collaborated with other colleagues on a project to design and test a narrowband personal IoT sensor for long-term heart rate monitoring and atrial fibrillation (AF) detection, mainly dealing with the software part. This study proposes an Internet of Things (IoT) sensor that can provide a very long period of continuous monitoring. The sensor consists of an ECG-integrated Analog Front End, a microcontroller, and an IoT narrowband module. The instantaneous heart rate is extracted from the ECG recording in real time. Software implementing the Lorentz algorithm, one of the best detectors of atrial

fibrillation, was implemented on the cloud platform. Across all patients, the proposed method achieved an accuracy of 0.88, a sensitivity 0.71, and a specificity 0.99.

- **Other research activities**

I contributed to a study that aimed to evaluate the performance of Forcemyography (FMG) compared to surface Electromyography (EMG) in estimating instantaneous muscle force during isometric contractions. This study involved simultaneously recording FMG, EMG, and torque signals during gradual and rapid isometric biceps brachii contractions in ten healthy subjects. Sigmoidal regression models were used to estimate the actual developed force recorded at the wrist using a load cell.

4. Research products:

a. scientific papers:

Title: Accurate Localization of First and Second Heart Sounds via Template Matching in Forcecardiography Signals
Authors: Centracchio, J.; Parlato, S.; Esposito, D.; Andreozzi, E.
Journal: Sensors – indexed in Scopus and ISI Web of Science
Year: 2024
Current status: Published (https://doi.org/10.3390/s24051525)

Title: A Narrowband IoT Personal Sensor for Long-Term Heart Rate Monitoring and Atrial Fibrillation Detection
Authors: Cinotti, E.; Centracchio, J.; Parlato, S.; Andreozzi, E.; Esposito, D.; Muto, V.; Bifulco, P.; Riccio, M.
Journal: Sensors – indexed in Scopus and ISI Web of Science
Year: 2024
Current status: Published (https://doi.org/10.3390/s24144432)

b. conference papers:

Title: Accurate ECG-Free Heartbeats Localization in Long-Lasting SCG Recordings
Authors: Parlato, S.; Muto, V., Bifulco, P.
Conference: Conference on e-Health and Bioengineering (EHB) 2023 11th Edition - indexed in Scopus and ISI Web of Science
Year: 2024
Current status: Published (https://doi.org/10.1007/978-3-031-62520-6_23)

Title: A Novel Approach to Recognize Valvular Heart Diseases Based on Morphological Similarity of Heartbeats in Seismocardiography Signals
Authors: Parlato, S.; Muto, V., Bifulco, P.

Conference: Conference on e-Health and Bioengineering (EHB) 2023 11th Edition - indexed in Scopus and ISI Web of Science
Year: 2024
Current status: Published (https://doi.org/10.1007/978-3-031-62520-6_22)

Title: A New, Simple Wrist-Mounted PVDF Sensor for Continuous Heart Rate Monitoring
Authors: Parlato, S.; Esposito, D.; Centracchio, J.; Andreozzi, E.; Gragnaniello M.; Riccio, M.; Bifulco, P.
Conference: 2024 IEEE Sensors Applications Symposium (SAS) - indexed in Scopus and ISI Web of Science
Year: 2024
Current status: Published (https://doi.org/10.1109/SAS60918.2024.10636484)

5. Conferences and seminars attended

During my first year of PhD activities, I attended the 2024 IEEE Sensors Applications Symposium (SAS) presenting the paper "*A New, Simple Wrist-Mounted PVDF Sensor for Continuous Heart Rate Monitoring*".

6. Periods abroad and/or in international research institutions

During my first year of PhD, I carried out study and research activities abroad, from 2nd October 2024 to 31st October 2024, at Department of Mechanical, Biomedical and Design Engineering, Aston University, Birmingham B47 7ET, UK, under the supervision of Prof. Antonio Fratini. During this period, I focused on the study of heart activity monitoring sensors for wearable devices. In particular, I analyzed accelerometer and gyroscope data recorded via a smartphone in order to estimate instantaneous heart and breathing rates. I also helped in the development of a sensorized garment for cardio-respiratory monitoring using pressure sensors. Details are outlined below:

Expected period abroad: October 2, 2024 - November 30, 2024
City: Birmingham B47 7ET, UK
Host University: Aston University
Supervisor: Prof. Antonio Fratini
Activities carried out abroad: Development of wearable devices based on pressure sensors for monitoring vital signs.
Months spent abroad in the current year: 1 (30 days).

7. Tutorship