XXXVII Cycle

Bio-Inspired Wearable Electronics for Rehabilitation

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Research context and motivation

- The clock-based synchronous behavior of today's electronics is one of the main constraints limiting the potential of technology compared to the capabilities of a biological brain. The **information encoding** via neural spikes employed by our nervous system is the key to developing asynchronous bio-inspired approaches to cut down the power consumption of our devices while achieving the desired performance.
- Our research group investigates the use of **event-based** techniques for the realization of low-power devices for biological signal acquisition. In particular, the current application of interest is muscle activity monitoring for rehabilitation purposes.

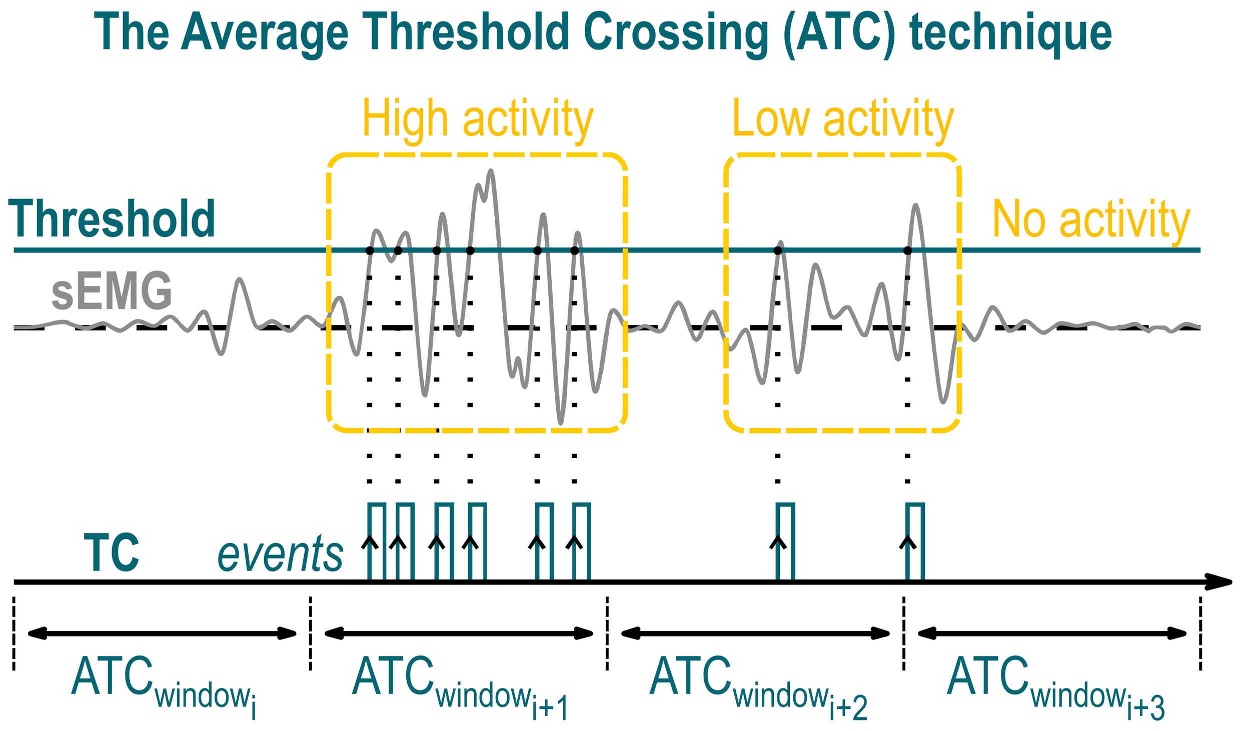
Addressed research questions/problems

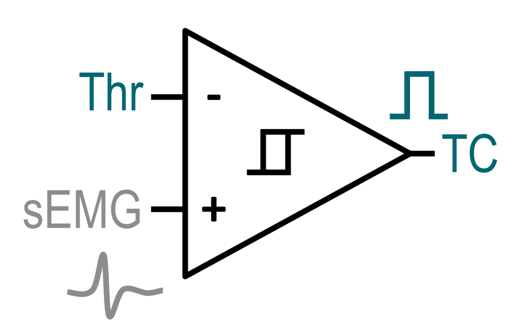
- Need for deployment and validation of a system with event-based modulation for the control of **Functional Electrical Stimulation** (FES).
- Development of a low-power device for **hand gesture recognition** using a minimal feature for the classification, enabling quick and reliable Human-Machine interfaces (HMI).

Adopted methodologies

- The heart of the project are the custom acquisition boards designed by our research group for muscle activity recording. Their peculiarity lies in implementing an event-driven technique named Average Threshold Crossing (ATC), which does not even require sampling the surface ElectroMyoGraphic (sEMG) signal.

The Average Threshold Crossing (ATC) technique





- Hardware-based
- Information synthesis
  → Low power
- Loss of sEMG features

List of attended classes

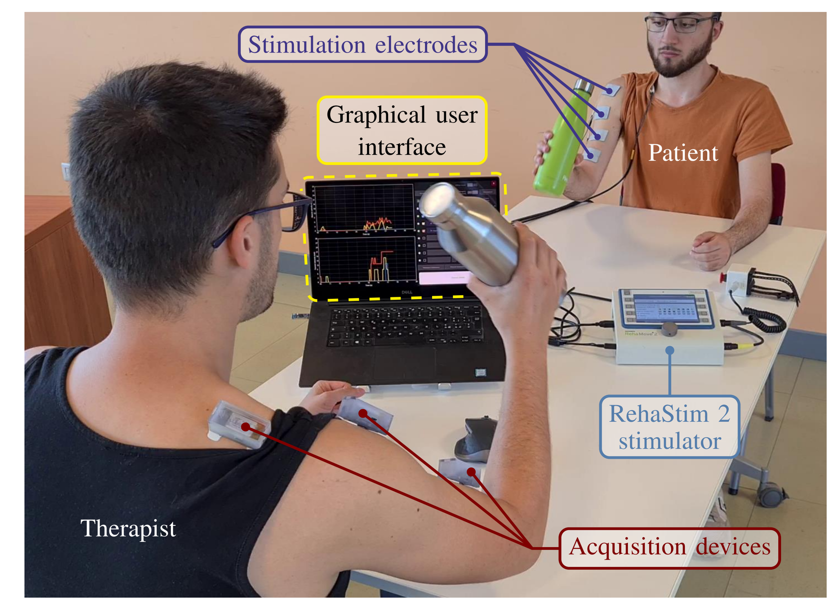
- 01RGGRV – Telemedicine and Distributed Healthcare (22/03/2022, 4 CFU)
- 02SFURV – Programmazione scientifica avanzata in matlab (21/04/2022, 6 CFU)
- 01DNHRV – System level low power techniques for IoT (15/07/2022, 4 CFU)
- 01DUCRV – Principles of digital image processing and technologies (22/07/2022, 5 CFU)
- 01DNMIU – Optimized execution of neural networks at the edge (02/08/2022, 5 CFU)
- 01SWPRV – Time management (05/09/2022, 1 CFU)

Submitted and published works

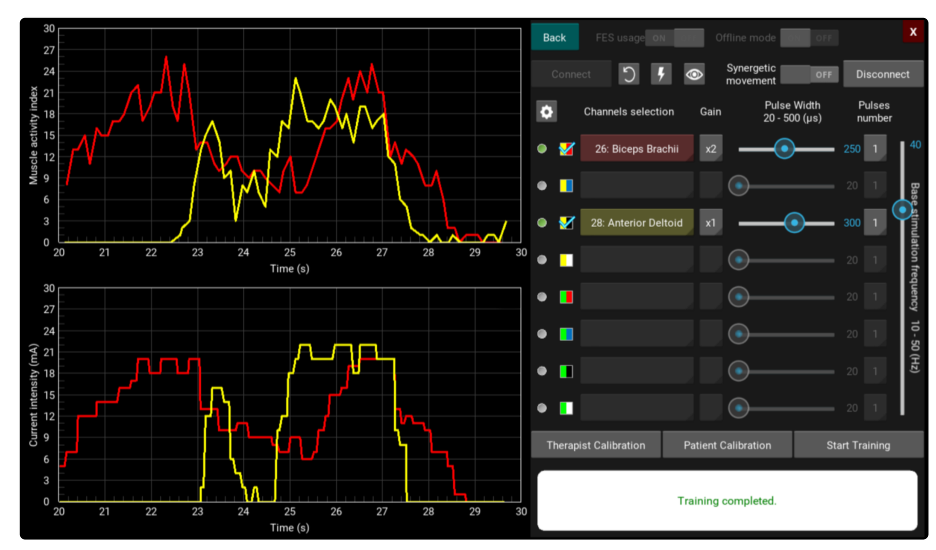
- M. Becchio, N. Voster, A. Prestia, A. Mongardi, F. Rossi, P. Motto Ros, M. Ruo Roch, M. Martina, D. Demarchi, "*Live Demonstration: Event-Driven Hand Gesture Recognition for Wearable Human-Machine Interface*", IEEE Biomedical Circuits and Systems Conference (BioCAS), Berlin, 2021, pp. 1-1, Published
- F. Rossi, F. Savi, A. Prestia, A. Mongardi, D. Demarchi, G. Buccino, "*Combining Action Observation Treatment with a Brain–Computer Interface System: Perspectives on Neurorehabilitation*", MDPI Sensors, vol. 21, no. 24, 2021, pp. 8504-8516, Published
- A. Prestia, F. Rossi, A. Mongardi, P. Motto Ros, M. Ruo Roch, M. Martina, D. Demarchi, "*Motion Analysis for Experimental Evaluation of an Event-Driven FES System*", IEEE Transactions on Biomedical Circuits and Systems, vol. 16, no. 1, 2022, pp. 3-14, Published
- A. Prestia, F. Rossi, A. Mongardi, D. Demarchi, P. Motto Ros, "*Raspberry Pi based Modular System for Multichannel Event-Driven Functional Electrical Stimulation Control*", 44th Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC), Glasgow, 2022, pp. 2592-2597, Published
- N. Landra, A. Prestia, A. Mongardi, F. Rossi, D. Demarchi, P. Motto Ros, "*A Biomimetic Multichannel Synergistic Calibration for Event-Driven Functional Electrical Stimulation*", IEEE Biomedical Circuits and Systems Conference (BioCAS), Taipei, 2022, Accepted
- F. Rossi, A. Prestia, A. Mongardi, N. Landra, P. Motto Ros, D. Demarchi, "*Live Demonstration: A Real-Time Bio-Mimetic System for Multichannel FES Control*", IEEE Biomedical Circuits and Systems Conference (BioCAS), Taipei, 2022, Accepted
- A. Mongardi, F. Rossi, A. Prestia, P. Motto Ros, M. Ruo Roch, M. Martina, D. Demarchi, "*Hand Gestures Recognition for Human-Machine Interfaces: a Low-Power Bio-Inspired Armband*", IEEE Transactions on Biomedical Circuits and Systems, Accepted

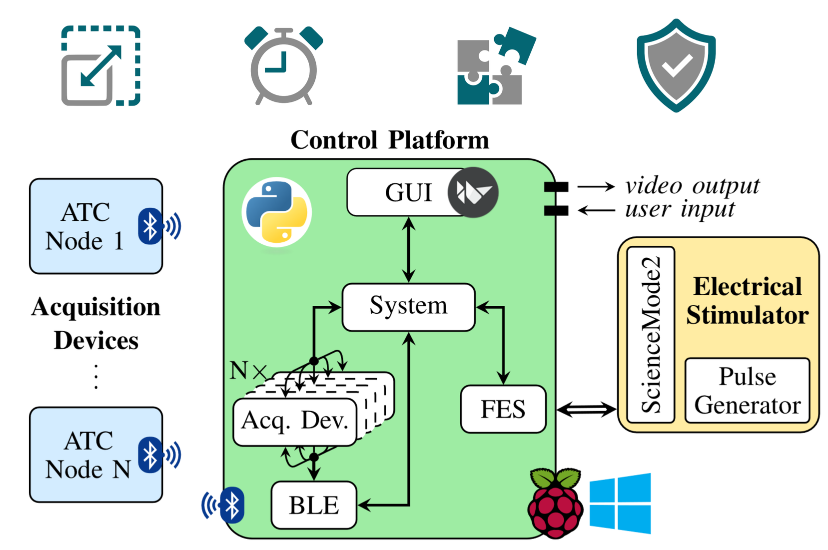
Novel contributions

- The development of event-driven systems with low computational cost is enabled by using the ATC feature as the control input.
- Applications of interest include the control of FES. Our approach consists of **movement mirroring**, i.e., rehabilitating a muscle by applying stimulation patterns modulated by the activity recorded on a healthy side. This results in two possible rehabilitation scenarios: a self - modulated control, in which a hemiplegic subject can control her/his pathological side by moving the healthy side; and a therapist - patient control, in which a pathological subject, supported by FES, replicates the movement performed by her/his physical therapist. In both cases, the combination of FES with **action observation** (AO), whereby motor cortical regions are activated, has beneficial effects as promoters of neuroplasticity.

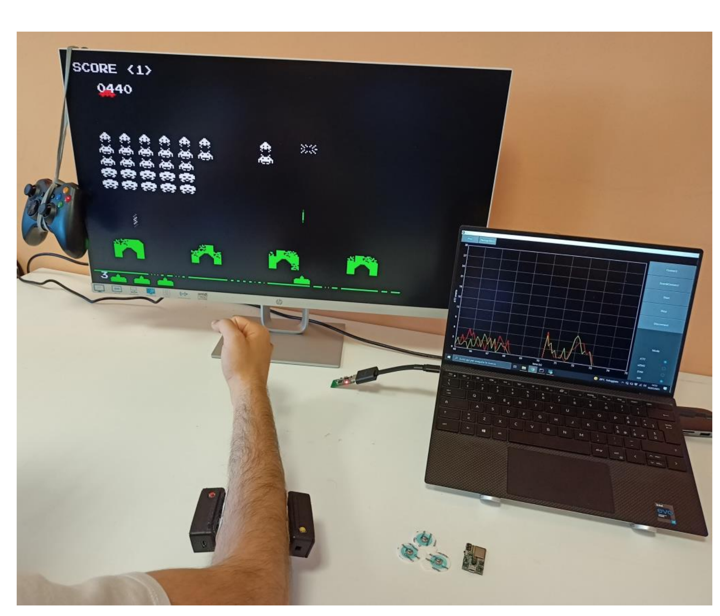


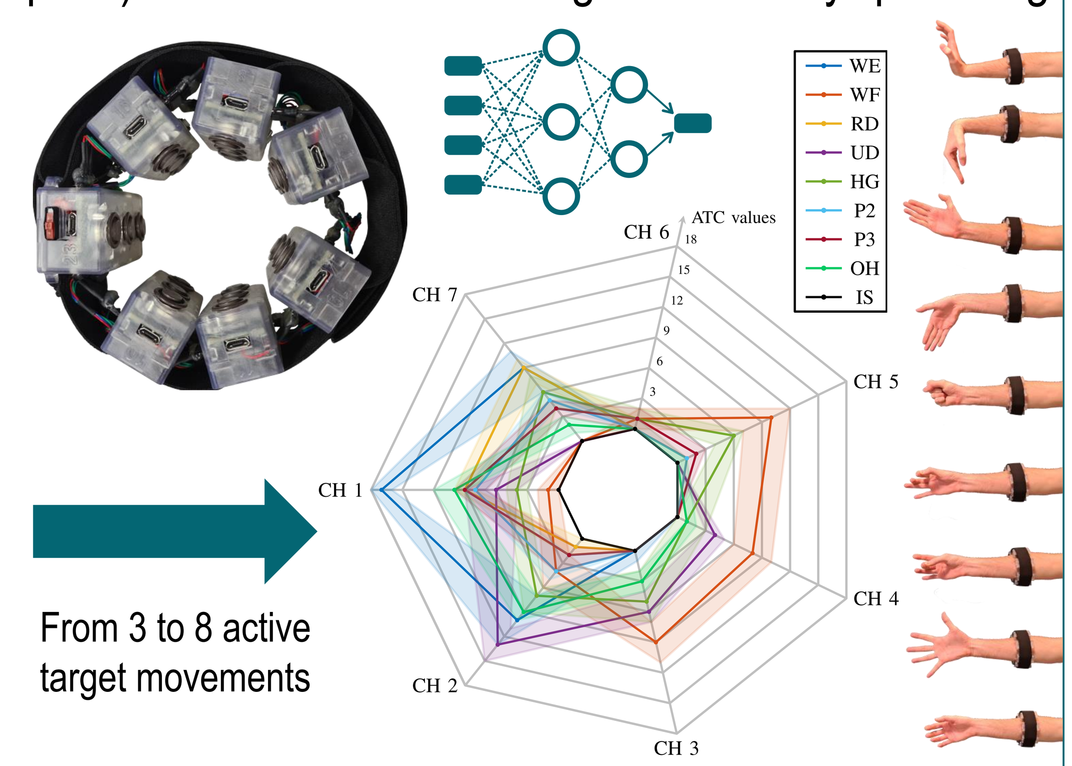
- Moving toward using our system outside our laboratory for real-case rehabilitation sessions, a **cross-platform control software** has been developed aiming for a versatile graphical user interface and focusing on scalability, real-time operation, modularity, and reliability.





- Obtained **results** up to now show a median value of the cross-correlation coefficient equal to **0.910** between the body trajectories of the controller side and the controlled one, while the median value of the replication delay is **800 ms**. On the other hand, the median value of the computational time taken by the software to process ATC data and communicate with the electrical stimulator while the GUI is running, when all the 8 available channels are used in parallel, is **7 ms** if a Raspberry Pi 4B is employed as control platform.
- The second main ATC-based application of interest is hand gestures recognition for HMI. Its rehabilitative utility lies in the possibility to integrate interactive tasks into a patient's rehabilitation session. In this context, the use of **serious games** (i.e., videogames where entertainment is not the main purpose) stimulate the training session by providing feedbacks to the patient's activities.





- By combining our acquisition boards, we designed an armband consisting of 7 channels and able to distinguish among 8 gestures, plus an idle state, with an accuracy of **91.9%**. Using ATC as the only feature for classification allowed us to achieve a total current absorption of **2.92 mA**, with latency due to prediction of only **1.34 ms**.

Future work

- ATC-FES system software finalization for rehabilitation use / clinical trials
- Fully embedded version of the ATC-FES system
- IoT implementation of the ATC-FES system for telerehabilitation
- Fatigue monitoring solution on stimulated muscles without EMG
- WBAN for motion analysis
- Automatic orientation of the armband channels w.r.t. the neural network inputs

Politecnico di Torino

PhD program in
Electrical, Electronics and Communications Engineering