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XXXVI Cycle

Bio-Inspired Smart Systems for IoT Applications

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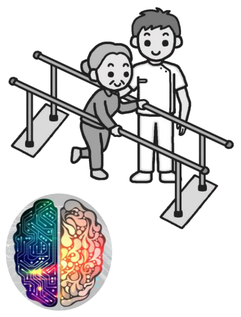
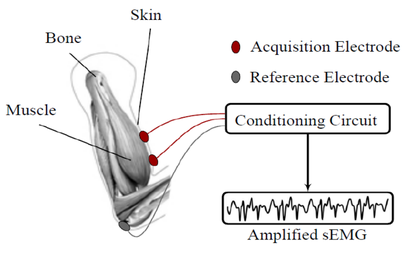
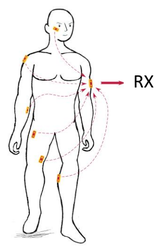
Research context and motivation

- The rehabilitation field requires automatic procedures to handle patients faster and more efficiently.
- Automatic rehabilitation processes requires lot of computational effort to adapt to people physiology.
- Devices have to be powerful enough to handle machine learning computations, but they also need to have a **low power consumption**, in order to make continuous operation possible.





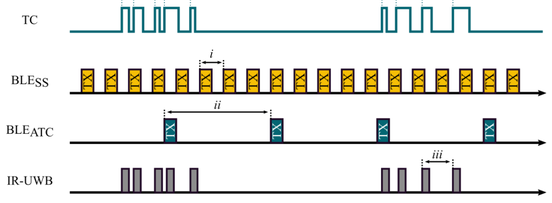
- The surface ElectroMyoGraphic (sEMG) signal is mainly used as a non-invasive sensing of muscular information.
- However, it requires **high computational effort** to extract useful features and the data throughput of a WBAN is very high.



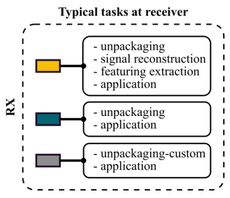
Addressed research questions/problems

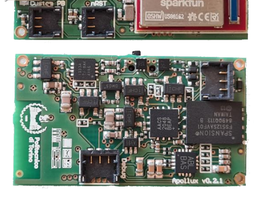
- The proposed acquisition device is designed towards minimal area and power consumption, to ease **wearability** and allow **longer rehabilitation routines**.
- The **information synthesis** performed at the edge is crucial for wireless data transmission.
- **Bio-mimetic patterns** for Functional Electrical Stimulation (FES) make the exercises more comfortable and effective.

Adopted methodologies



i: BLE connection events distance for sEMG sampling
ii: BLE connection events interval for ATC
iii: IR-UWB intervals triggered by TC events





- The developed **custom PCBs** embed both the analog acquisition channel and digital components (the MCU is an Apollo3 Blue), mainly involved in wireless communication.
- sEMG activity is detected by a **threshold comparator** and driven as input to a timer counter, thus obtaining a parameter directly correlated with the **exerted force**.

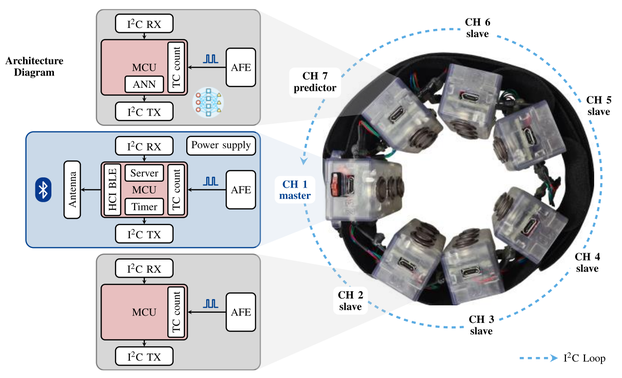
Submitted and published works

- A. Mongardi, P. Motto Ros, F. Rossi, M. Ruo Roch, M. Martina and D. Demarchi, *"A Low-Power Embedded System for Real-Time sEMG based Event-Driven Gesture Recognition,"* 2019 26th IEEE International Conference on Electronics, Circuits and Systems (ICECS), 2019, pp. 65-68.
- A. Mongardi, F. Rossi, P. Motto Ros, A. Sanginario, M. Ruo Roch, M. Martina and D. Demarchi, *"Live Demonstration: Low Power Embedded System for Event-Driven Hand Gesture Recognition,"* 2019 IEEE Biomedical Circuits and Systems Conference (BioCAS), 2019, pp. 1-1.
- F. Rossi, A. Mongardi, P. Motto Ros, M. Ruo Roch, M. Martina and D. Demarchi, *"Tutorial: A Versatile Bio-Inspired System for Processing and Transmission of Muscular Information,"* in IEEE Sensors Journal, vol. 21, no. 20, pp. 22285-22303, 2021.
- A. Mongardi, F. Rossi, E. Pellegrino, P. Motto Ros, M. Ruo Roch and M. Martina, "Low Latency Protocols Investigation for Event-Driven Wireless Body Area Networks," 2021 IEEE Biomedical Circuits and Systems Conference (BioCAS), 2021, pp. 01-06.
- M. Becchio, N. Voster, A. Prestia, A. Mongardi, F. Rossi, P. Motto Ros, M. Ruo Roch, M. Martina and D. Demarchi, *"Live Demonstration: Event-Driven Hand Gesture Recognition for Wearable Human-Machine Interface,"* 2021 IEEE Biomedical Circuits and Systems Conference (BioCAS), 2021, pp. 1-1.
- A. Prestia, F. Rossi, A. Mongardi, P. Motto Ros, M. Ruo Roch, M. Martina and D. Demarchi, *"Motion Analysis for Experimental Evaluation of an Event-Driven FES System,"* in IEEE Transactions on Biomedical Circuits and Systems, vol. 16, no. 1, pp. 3-14, Feb. 2022.
- F. Rossi, F. Savi, A. Prestia, A. Mongardi, D. Demarchi and G. Buccino, *"Combining Action Observation Treatment with a Brain–Computer Interface System: Perspectives on Neurorehabilitation,"* in Sensors, vol. 21, no. 24: 8504.
- A. Prestia, F. Rossi, A. Mongardi, D. Demarchi and P. Motto Ros, *"Raspberry Pi based Modular System for Multichannel Event-Driven Functional Electrical Stimulation Control,"* 2022 44th Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC), 2022, pp. 2592-2597.

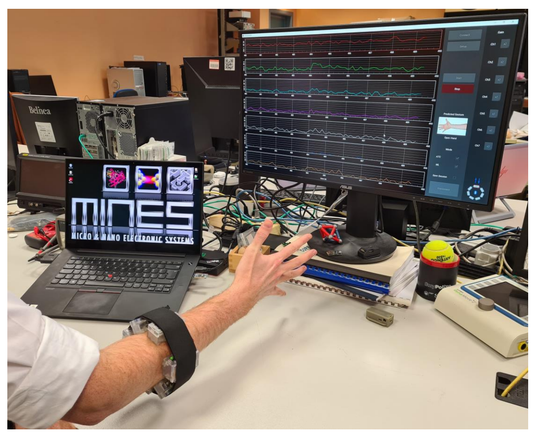
- N. Landra, A. Prestia, A. Mongardi, F. Rossi, D. Demarchi and P. Motto Ros, *"A Biomimetic Multichannel Synergistic Calibration for Event-Driven Functional Electrical Stimulation,"* 2022 IEEE Biomedical Circuits and Systems Conference (BioCAS), 2022, pp. 1-5. (ACCEPTED)
- F. Rossi, A. Prestia, A. Mongardi, N. Landra, P. Motto Ros and D. Demarchi, *"Live Demonstration: A Real-Time Bio-Mimetic System for Multichannel FES Control,"* 2022 IEEE Biomedical Circuits and Systems Conference (BioCAS), 2022, pp. 1-1. (ACCEPTED)
- A. Mongardi, F. Rossi, A. Prestia, P. Motto Ros, M. Ruo Roch, M. Martina and D. Demarchi, *"Hand Gestures Recognition for Human-Machine Interfaces: a Low-Power Bio-Inspired Armband,"* in IEEE Transactions on Biomedical Circuits and Systems, vol. xx, no. x, pp. 1-18. (ACCEPTED)

Novel contributions

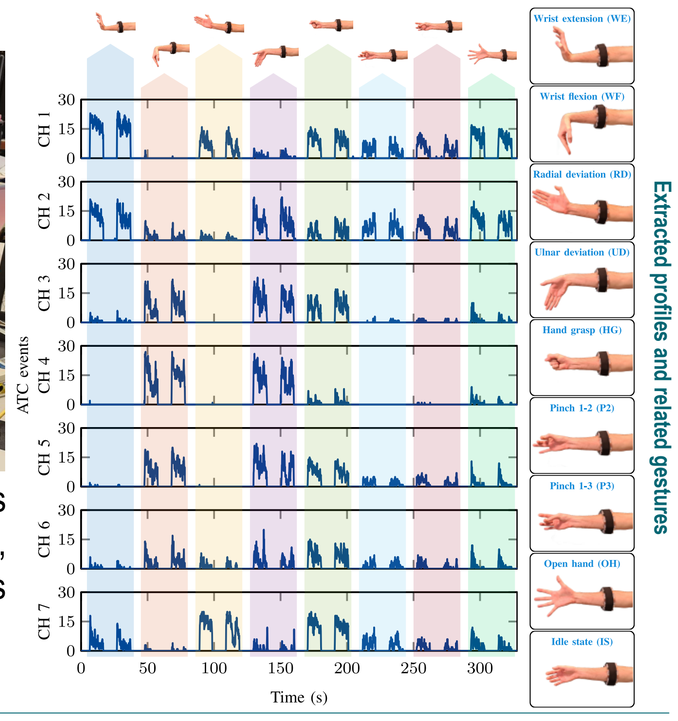
- A **wearable armband** has been prototyped leveraging on the efficiency obtained from the developed PCBs, to recognize **hand gestures**.
- Having the same hardware, the board are programmed separately to define 3 main roles: **master**, **slave** and **predictor**.
- Slaves board only count events and transmit them to the master.



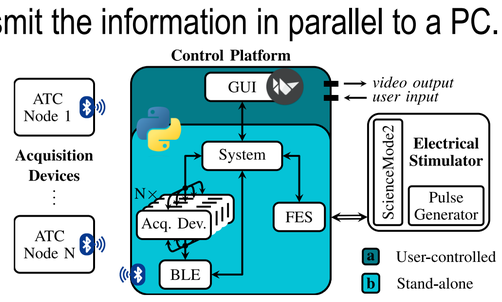
- The predictor is in charge of gestures recognition, with a dedicated Neural Network (NN).
- The master board handles user commands received via BLE communication and manage slaves functioning and information. It sends predictions or raw data to the user if requested.



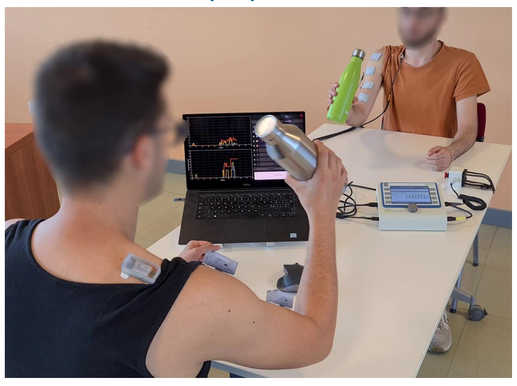
- A NN with 2 hidden layer and 50 nodes each was embedded in the MCU, recognizing **8** different **gestures** plus the idle state with a **91.3%** accuracy.
- The prototype absorbs only **2.92 mA**.



- The same PCB is also involved in FES scenarios, aiming to develop **physiological patterns** to patients in need.
- Boards transmit the information in parallel to a PC.



FES therapist-patient scenario



Future work

- Implementation of a calibration routine for the armband to be positioned with less effort.
- Investigation of different ML solutions to improve user experience during real-time usage.
- Realization of a smaller armband prototype, towards a possible prosthesis integration.
- For the rehabilitation topic, improvement of the already developed GUI, to ease its usage by clinicians and physiotherapists, without constant need of technical intervention.

List of attended classes

- 02SFURV – Programmazione scientifica avanzata in Matlab (25/05/2021, 6 CFU)
- 01DUCRV – Principles of digital image processing and technologies (didattica di eccellenza) (22/07/2022, 5 CFU)
- 01QEZRV – Sviluppo e gestione di sistemi di acquisizione dati (13/12/2021, 5 CFU)
- 01DNHRV – System level low power techniques for IoT (15/07/2022, 4 CFU)
- 01RGGRV – Telemedicine and Distributed Healthcare (22/03/2022, 4 CFU)
- 02QZURR – Pianificazione, gestione e analisi di ricerca clinica e di laboratorio (12/02/2021, 3 CFU)
- 02RHORV – The new Internet Society: entering the black-box of digital innovations (08/11/2020, 1 CFU)
- 01RISRV – Public speaking (12/11/2020, 1 CFU)
- 01SWQRV – Responsible research and innovation, the impact on social challenges (08/11/2020, 1 CFU)
- 01UNTRV – Managing conflict: negotiation and communication (12/03/2021, 1 CFU)
- 08IXTRV – Project management (09/11/2020, 1 CFU)
- 01SHMRV – Entrepreneurial Finance (13/11/2020, 1 CFU)
- 02LWHRV – Communication (09/11/2020, 1 CFU)
- 01SYBRV – Research integrity (08/11/2020, 1 CFU)
- 01SWPRV – Time management (06/11/2020, 1 CFU)
- 01UNVRV – Navigating the hiring process: CV, tests, interview (28/01/2022, 1 CFU)
- 01DMJRV – Design Thinking, Processes and Methods (04/05/2022, 1 CFU)
- 01UNXRV – Thinking out of the box (06/11/2020, 1 CFU)
- 01UNYRV – Personal branding (10/11/2020, 1 CFU)

Politecnico di Torino

PhD program in
Electrical, Electronics and Communications Engineering