Bio-Inspired Smart Systems for IoT Applications

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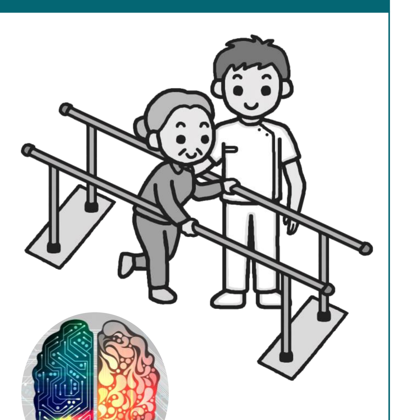
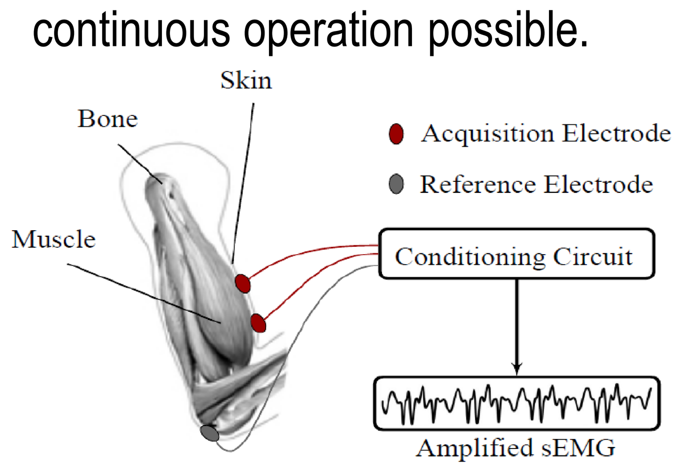
36th Cycle

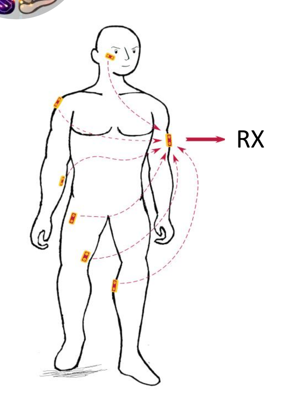
Research context and motivation

- 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.





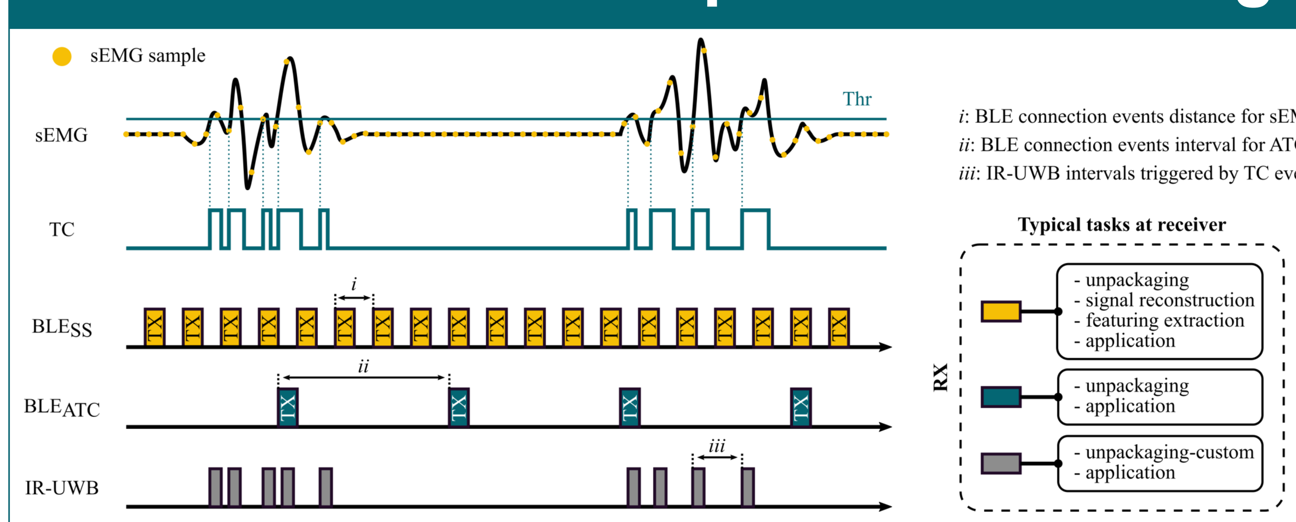
- The surface ElectroMyoGraphic (sEMG) signal is mainly used as a non-invasive sensing of muscular information.
- However, it requires **high computational effort** to extract useful features and the data throughput of a WBAN is very high.

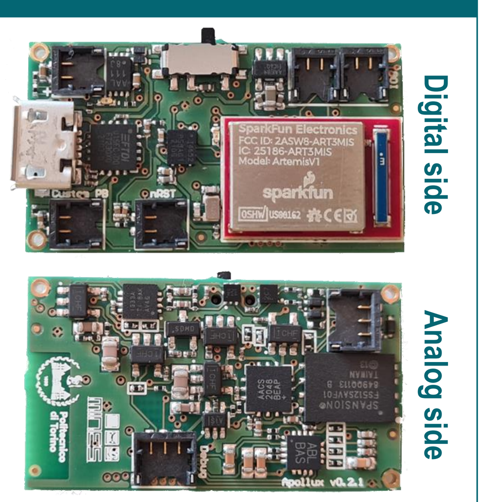


Addressed research questions/problems

- 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.

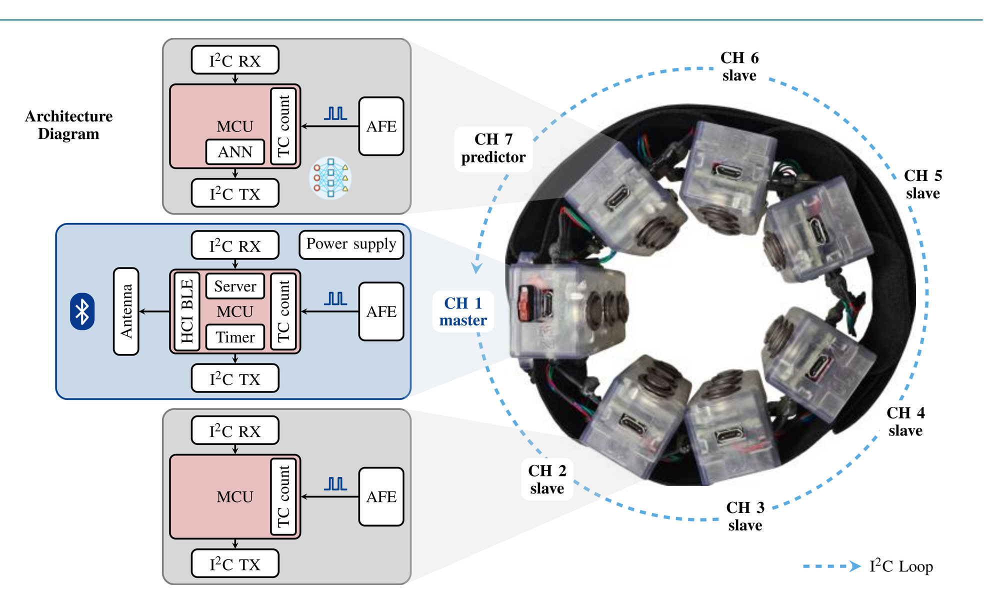
Adopted methodologies





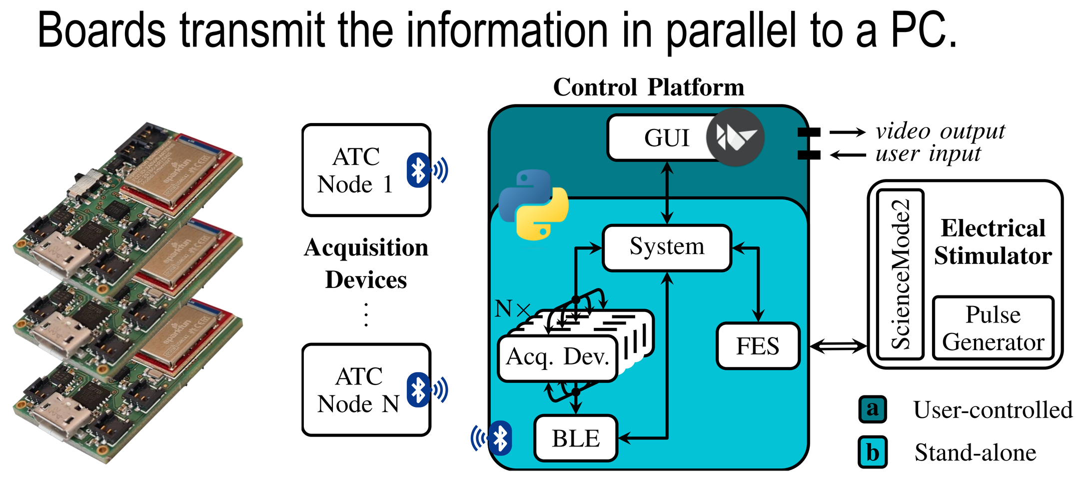
- The developed **custom PCBs** embed both the analog acquisition channel and digital components (the MCU is an Apollo3 Blue), mainly involved in wireless communication.
- sEMG activity is detected by a **threshold comparator** and driven as input to a timer counter, thus obtaining a parameter directly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

- A **wearable armband** has been prototyped leveraging on the efficiency obtained from the developed PCBs, to recognize **hand gestures**.
- Having the same hardware, the boards are programmed separately to define 3 main roles: **master**, **slave** and **predictor**.
- Slave boards 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 manages the slave boards. When requested, it sends predictions or raw data to the user.
- 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**, allowing continuous usage up to **60 h**.

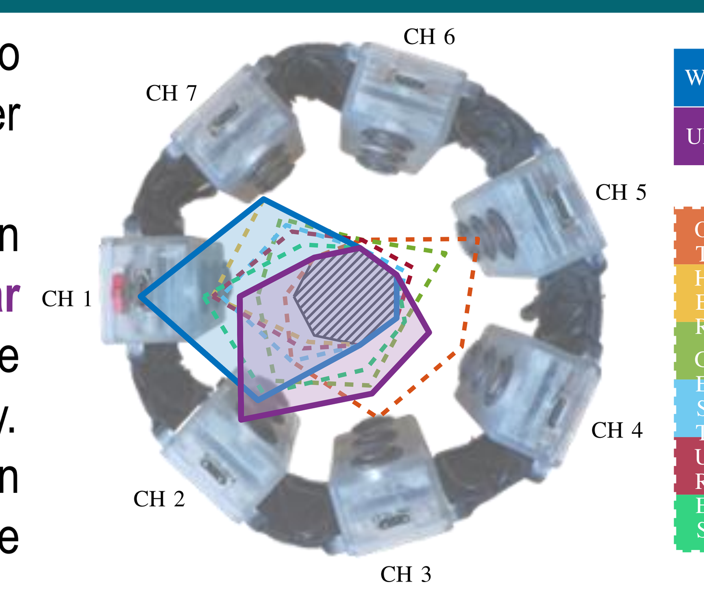
- The same PCB is also involved in FES scenarios, aiming to develop **physiological patterns** to patients in need.
- Boards transmit the information in parallel to a PC.

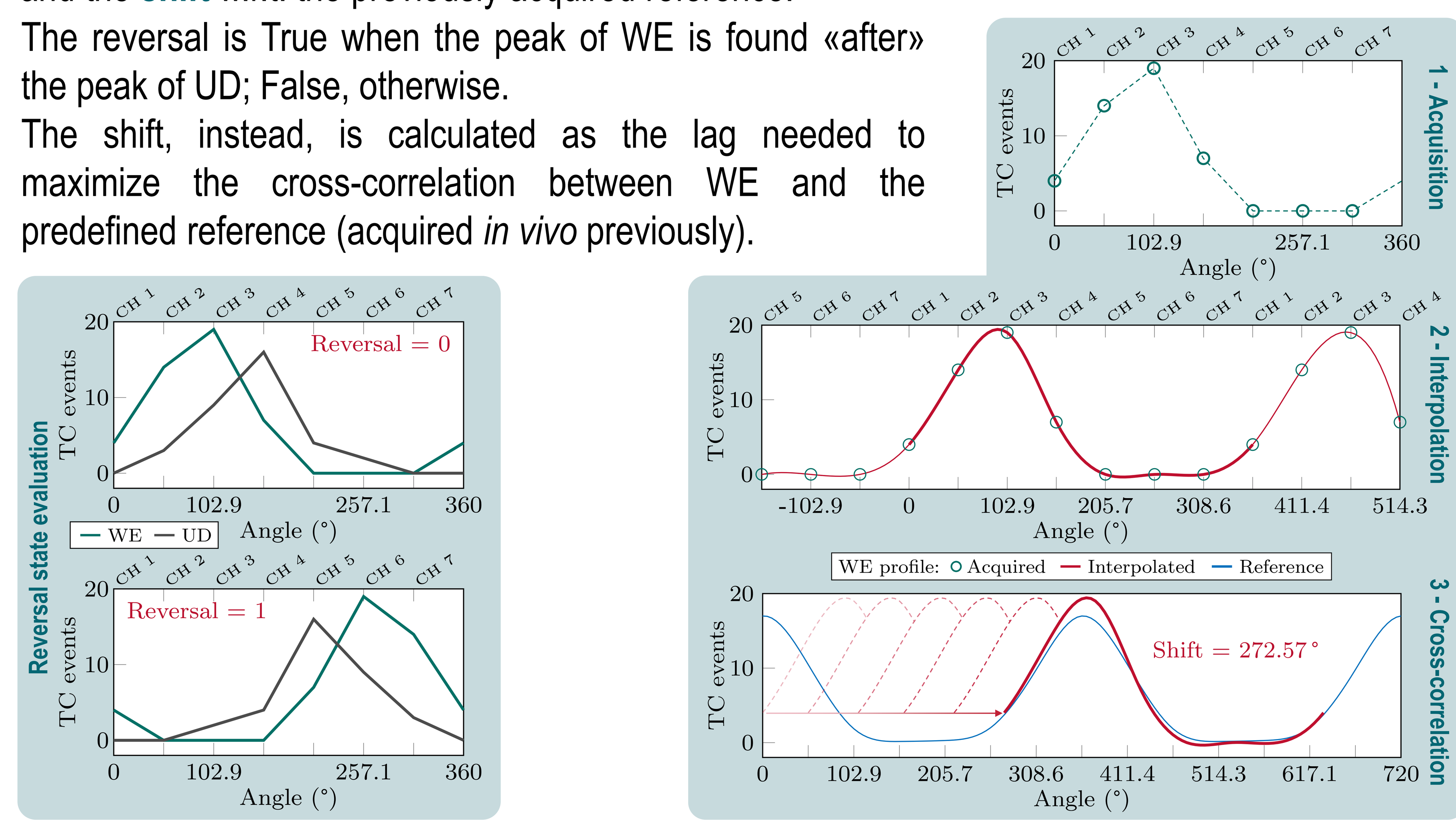


FES therapist-patient scenario

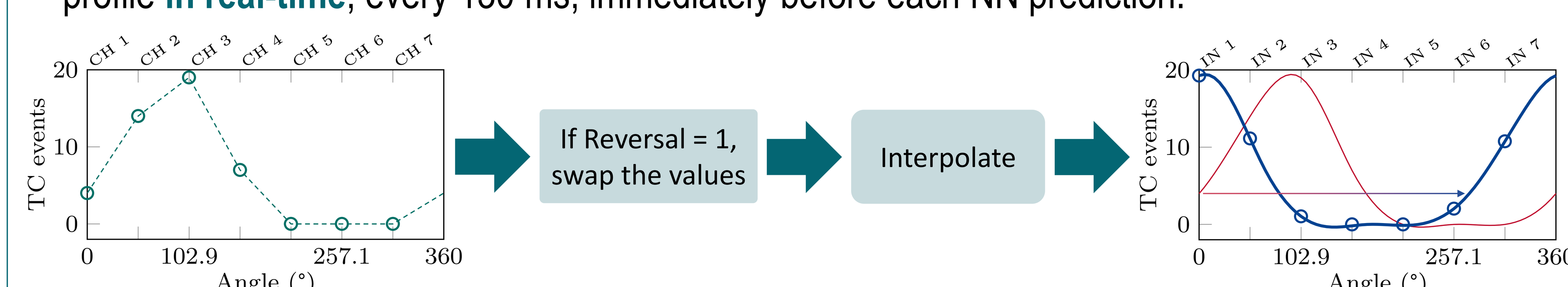
Novel contributions

- The previously prototyped armband was then revised to obtain a **more robust** external structure, thus making it easier for non-technical personnel to use.
- An **automatic orientation calibration algorithm**, based on the recognition of **Wrist Extension (WE)** and **Ulnar Deviation (UD)** gestures, has been developed to enable users to wear the armband without having to align it manually.
- The calibration is executed once the armband has been worn on the forearm and detects two conditions: the **reversal** state and the **shift** w.r.t. the previously acquired reference.
- The reversal is True when the peak of WE is found «after» the peak of UD; False, otherwise.
- The shift, instead, is calculated as the lag needed to maximize the cross-correlation between WE and the predefined reference (acquired *in vivo* previously).





- Once the two conditions have been determined, the armband saves them to **rearrange** the ATC profile **in real-time**, every 130 ms, immediately before each NN prediction.



- On the hardware side, the PCB design has been revised to go **toward a flexible patch**. In particular, some minor components like the I2C connectors and the battery recharger were removed. Those components were selected because they are not essential for long-term acquisition operations, but their removal helped us a lot **reducing the PCB area**.
- Thus, all the components were mounted on the top side of the PCB, allowing for **hard gold electrodes** to be connected on the other side.

Future work

- Design of a complete patch solution for the PCB, including flexible parts where needed.
- Realization of a smaller armband prototype, towards a possible prosthesis integration.
- Investigation of different ML solutions to improve user experience during real-time usage.
- For the rehabilitation topic, a clinical trial on injured subjects, to assess the effectiveness of the system in real life scenarios.

Publications

- Published works: 4 journals, 8 conferences.

Most important publications:

- 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, 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. 16, no. 6, pp. 1348-1365, Dec. 2022.

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