PDI: Control of a Soft Elbow Orthosis

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Outline

Introduction

What are orthoses?

Active/passive orthoses.

Why are active orthotic devices needed?

- Loss of motor function
- Rehabilitation for neuroplasticity

Objectives

Figure: Ankle-foot passive orthosis

SysML Models

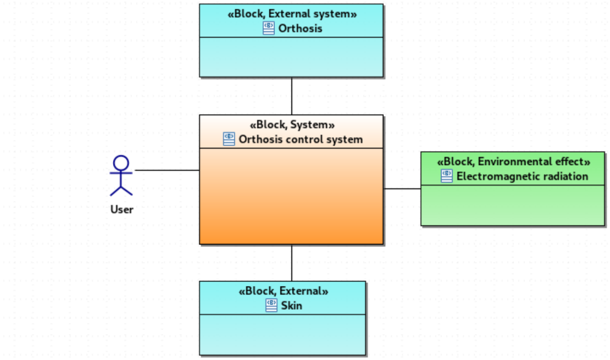


Figure: Context diagram

SysML Models

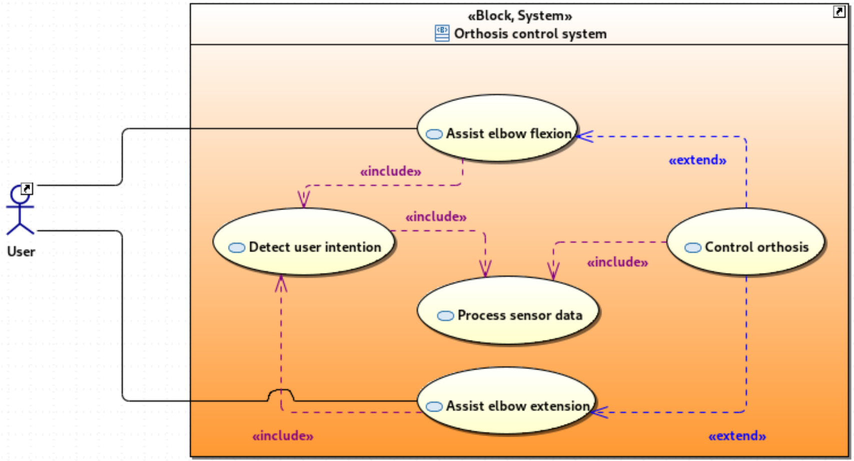


Figure: Use case diagram

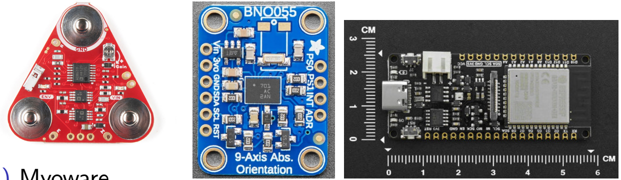
SysML Models

	getAppliedStereotypes()
Allow the control of an elbow orthosis	Requirement, functionalRequirement
Quantify user motion intention	Requirement, functionalRequirement
Receive user sEMG data	Requirement, extendedRequirement
Process user sEMG data	Requirement, extendedRequirement
Control actuators	Requirement, functionalRequirement
Receive system state feedback	Requirement, extendedRequirement
Calculate input from motion intention and system state	Requirement, extendedRequirement
React quickly enough to provide assistance	Requirement, performanceRequirement
Deliver enough force to provide assistance	Requirement, performanceRequirement
Be light enough to be carried daily	Requirement, performanceRequirement

Figure: Requirement table

Hardware

- Sensor system
- Maxon 150W BLDC motor
- Maxon EPOS4 driver
- 64bit Linux PC (Fedora 39)
- 3A - 30V power supply



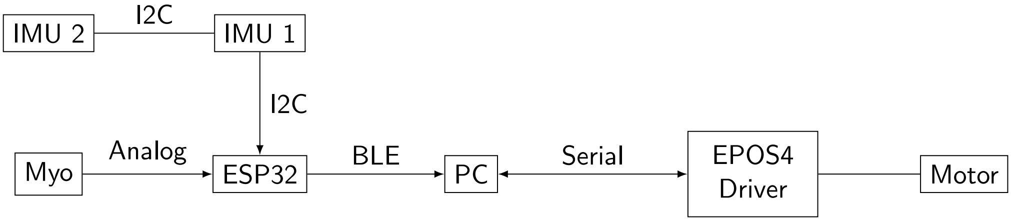
(a) Myoware muscle sensor

(b) BNO055

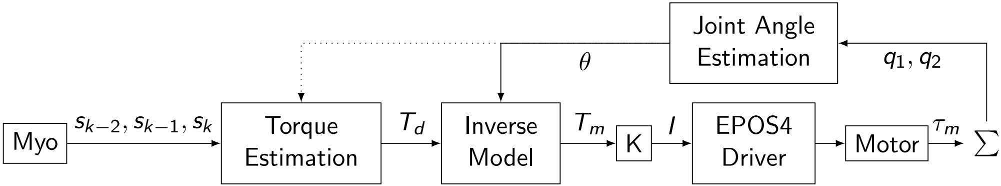
(c) ESP32

Figure: Sensors and microcontroller

Communication Strategy



Control Strategy



Torque estimation

Single-layer sequential neural network.

Single and multi-dataset models were trained.
4 models in total, differing in inputs:

- open: (s_{k-2}, s_{k-1}, s_k)
- closed: $(s_{k-2}, s_{k-1}, s_k, \theta)$

Torque estimation

Training data (sEMG, θ) gathered at INRIA.

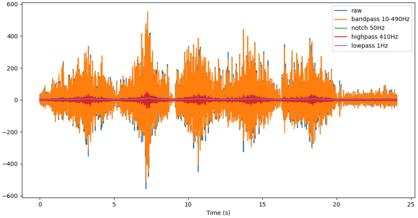


Figure: Signal processing

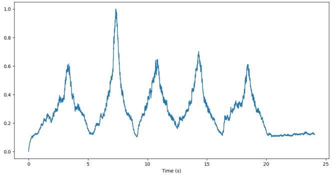


Figure: Processed signal

Torque estimation

Torque calculation from angle measurement:

$$\tau = ((m+\omega)l_{cm}^2 + J)\ddot{\theta} + \beta\dot{\theta} + (ml_{cm} + \omega l)g\sin\theta \qquad (1)$$

- m mass of the subject forearm and arm
- ω mass of the carried load
- l distance from the elbow to the center of the hand
- l_{cm} is the distance from the elbow to the forearm center of mass
- J moment of inertia of the forearm
- g gravitational acceleration
- β joint friction

Torque estimation

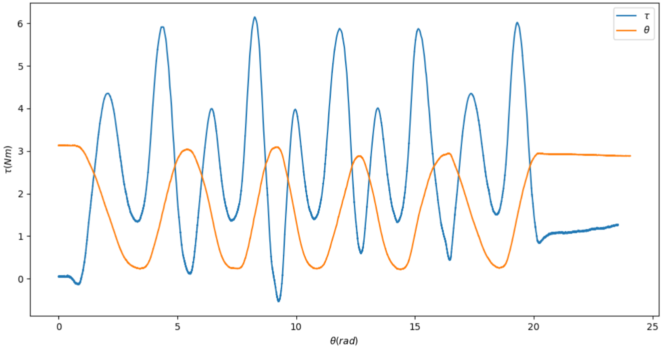
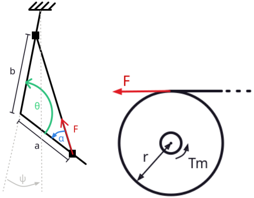


Figure: Torque and angle relationship

Orthosis model



(a) Elbow model (b) Motor front view

Figure: Simplified orthosis model

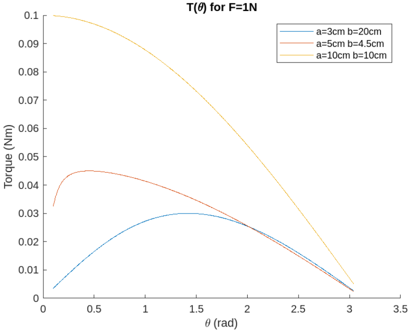


Figure: Torque generated by 1N of force according to cable anchor points

$$||\vec{T}_m|| = \frac{||\vec{b} - \vec{a}|| \cdot r \cdot ||\vec{T}_d||}{||\vec{a} \times (\vec{b} - \vec{a})||} \quad (2)$$

Developed programs

ESP32's embedded code:

- Reads sensor data
- Performs joint angle calculation
- Runs BLE server

PC driver program:

- Sends current, position or velocity commands to the EPOS4 driver
- Runs driver server, listening for connections and commands on port 8080

PC python program:

- Connects to BLE and driver servers
- Implements the control strategy on the received sensor values
- Sends commands to driver server

Torque estimation results

Singe dataset models

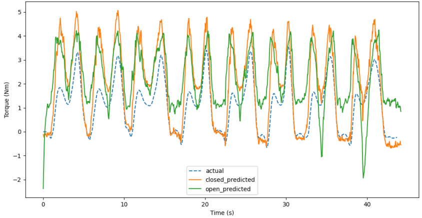


Figure: No load

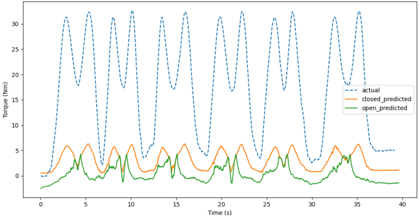


Figure: 10kg load

Torque estimation results

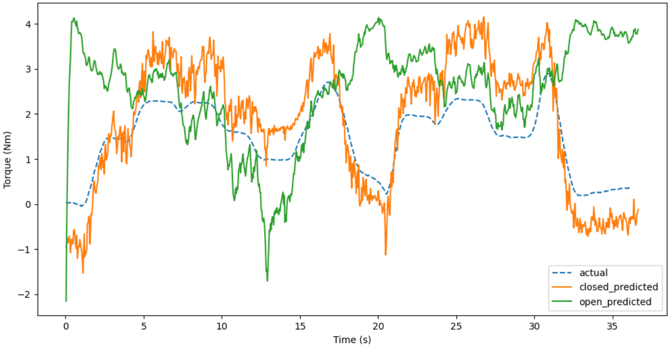


Figure: No load with stops

Torque estimation results

Multi-dataset models

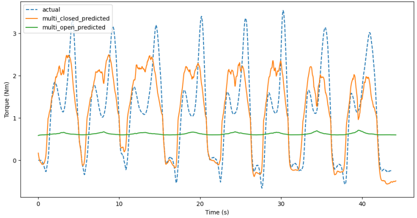


Figure: No load

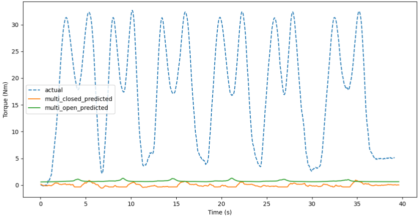


Figure: 10kg load

Torque estimation results

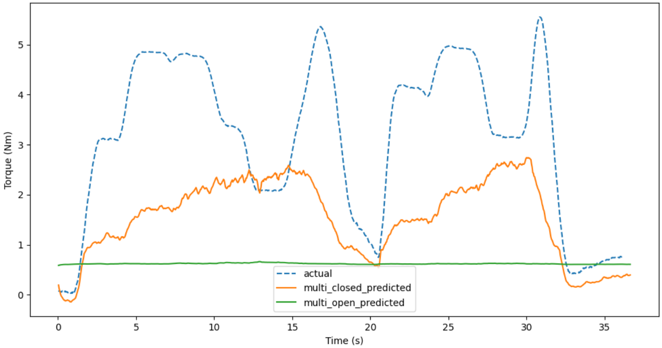


Figure: No load with stops

Experimental results

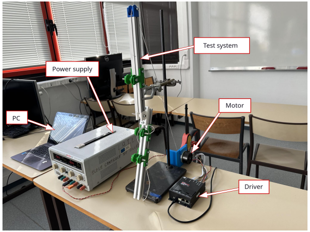
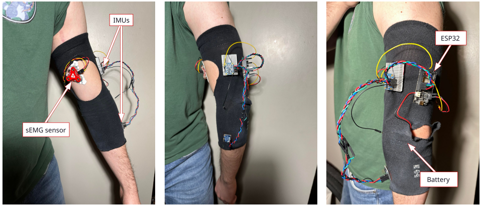


Figure: Experimental setup



(a) Front (b) Side (c) Back

Figure: Control system on a sock

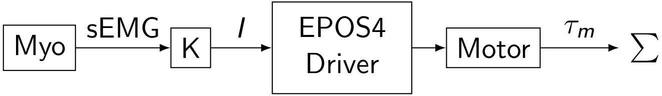


Figure: Simplified Control Diagram - K is an arbitrary gain

Possible Improvements

Torque estimation:

- Using different input parameters for the NN models
- User load estimation (e.g. with an extended state observer)
- Adding a Model Reference Adaptive Controller
- Improving the estimation of the K gain

Control strategy:

- Control position instead of current
- Improving the quality of the training data
- Modifying the NN model architecture
- Smoothing the NN output

Conclusion