Torque prediction for upper-limb exoskeleton control

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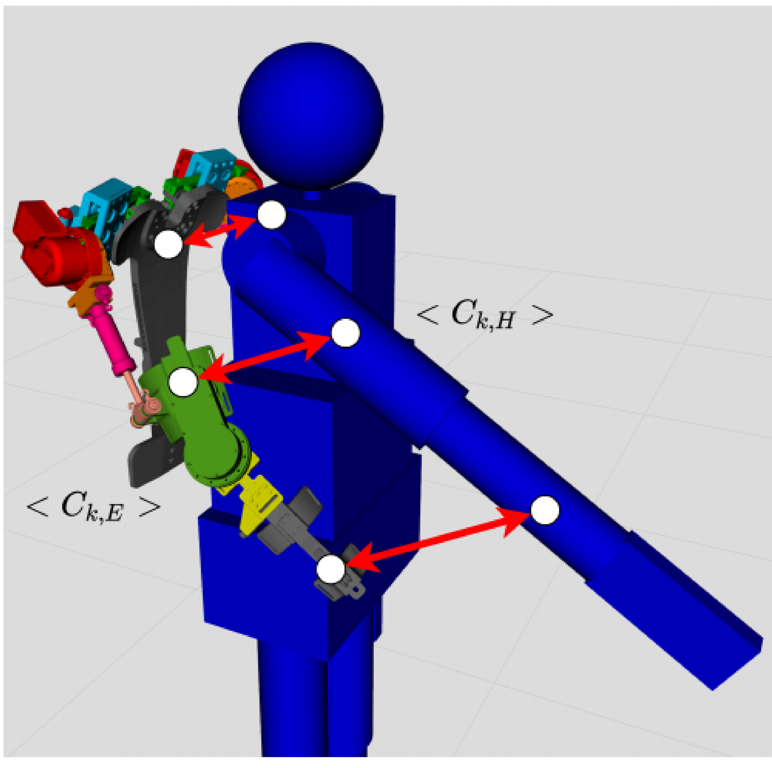
Context: Assistive active upper-limb exoskeletons are a solution to tackle Work-related Musculoskeletal Disorders (WMSDS)

Objective: Need for a prediction method to **assist-as-needed** and a simulator to generate data and test controllers

Contributions: Generating a dataset of simulated exoskeleton sensor data from human Motion Capture (MOCAP) data, and evaluating prediction methods for exoskeleton torque control.

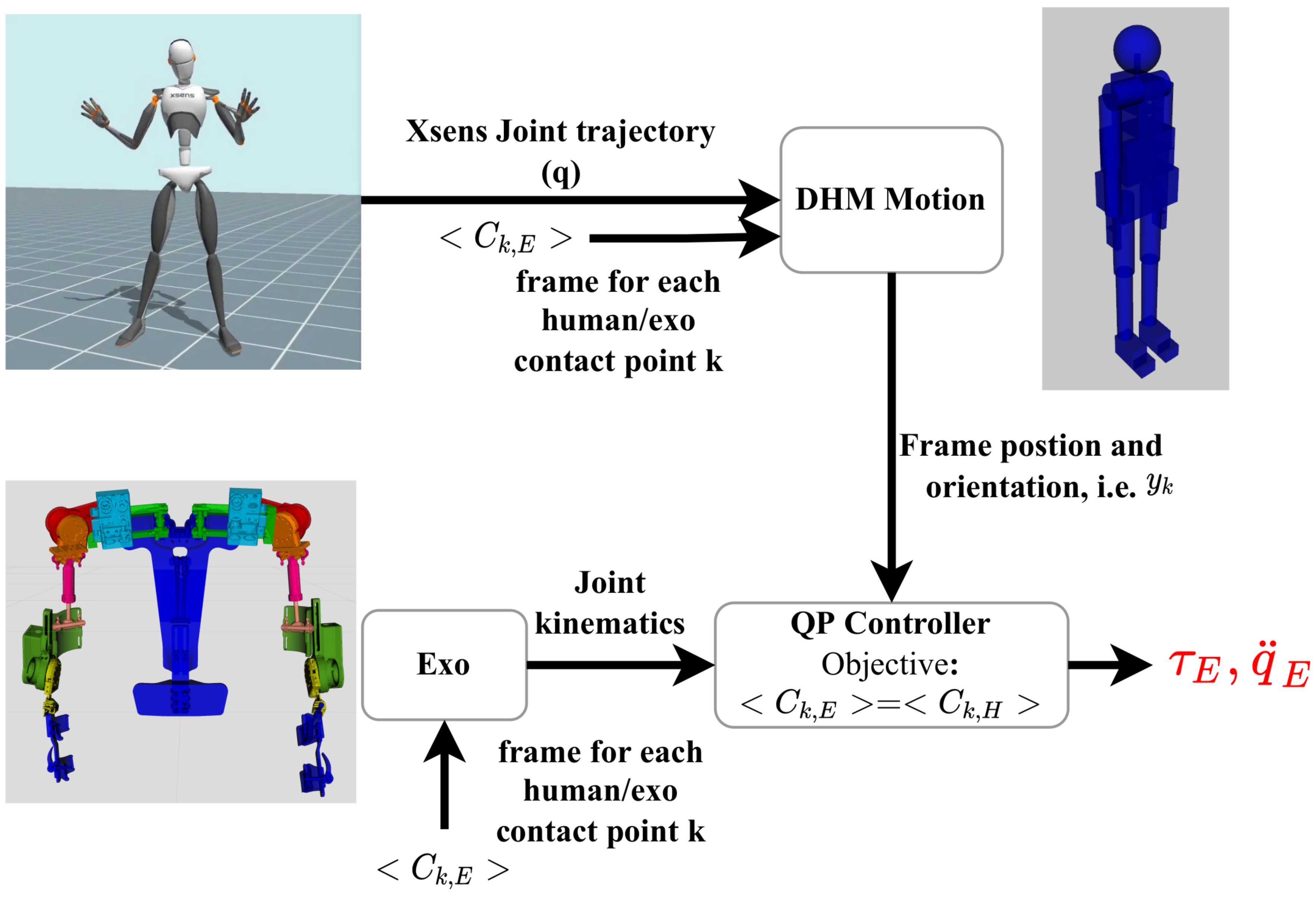
Exoskeleton simulation

- Human frames positions extracted from MOCAP and used as reference for corresponding exoskeleton frames
- Soft contacts between exoskeleton and simulated human are not modeled yet, DHM is only graphics
- Quadratic programming (QP) control solves the multi-task problem



$$\underset{\ddot{q},\tau}{\operatorname{argmin}} \sum_k w_k \|\ddot{y}_k - \ddot{y}_k^d\|^2,$$

s.t. dynamics constraints and joints limits



Torque Prediction

Motor torque τ_M = sum of contributions from exoskeleton and payload:

$$\tau_M(t+1 \rightarrow t+N) = \tau_E(t+1 \rightarrow t+N) + \tau_{load}(t+1 \rightarrow t+N)$$

Comparison of 3 methods to predict τ_M using an LSTM-based neural network:

1. Joint Prediction + Inverse Dynamics:

   Predicted value: $q_E(t+1 \rightarrow t+N) = f(q_E(0 \rightarrow t))$

2. Exoskeleton Torque Prediction + Inverse Dynamics:

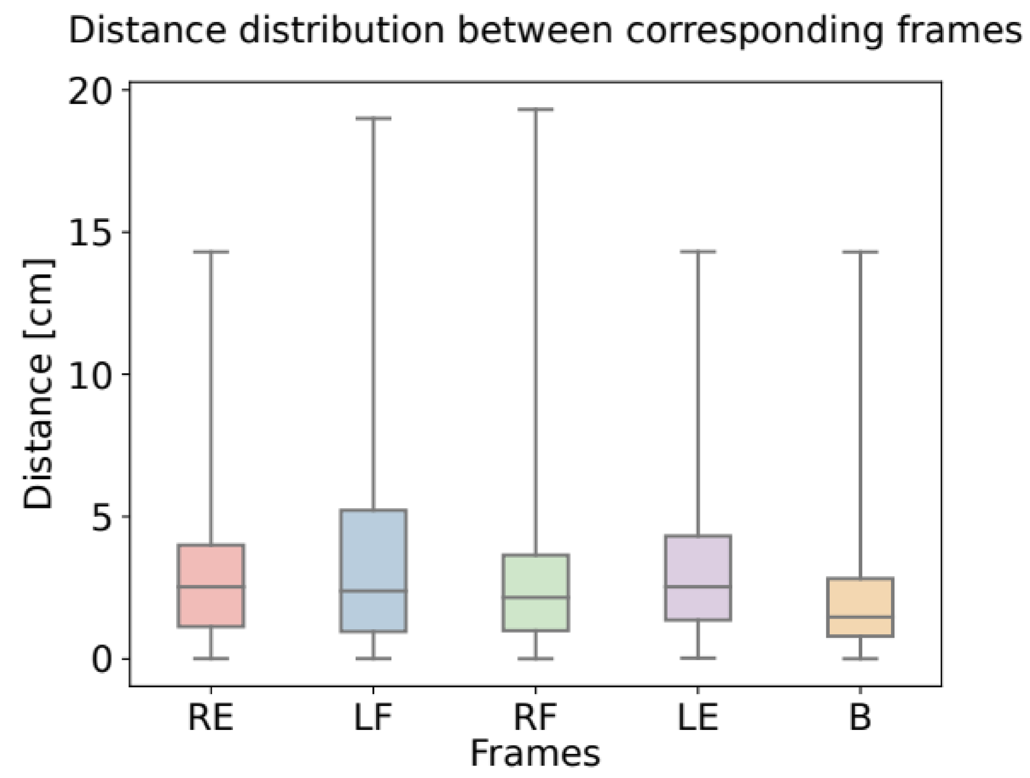
   Predicted value: $\tau_E(t+1 \rightarrow t+N) = f(\tau_E(0 \rightarrow t))$

3. Direct motor torque prediction:

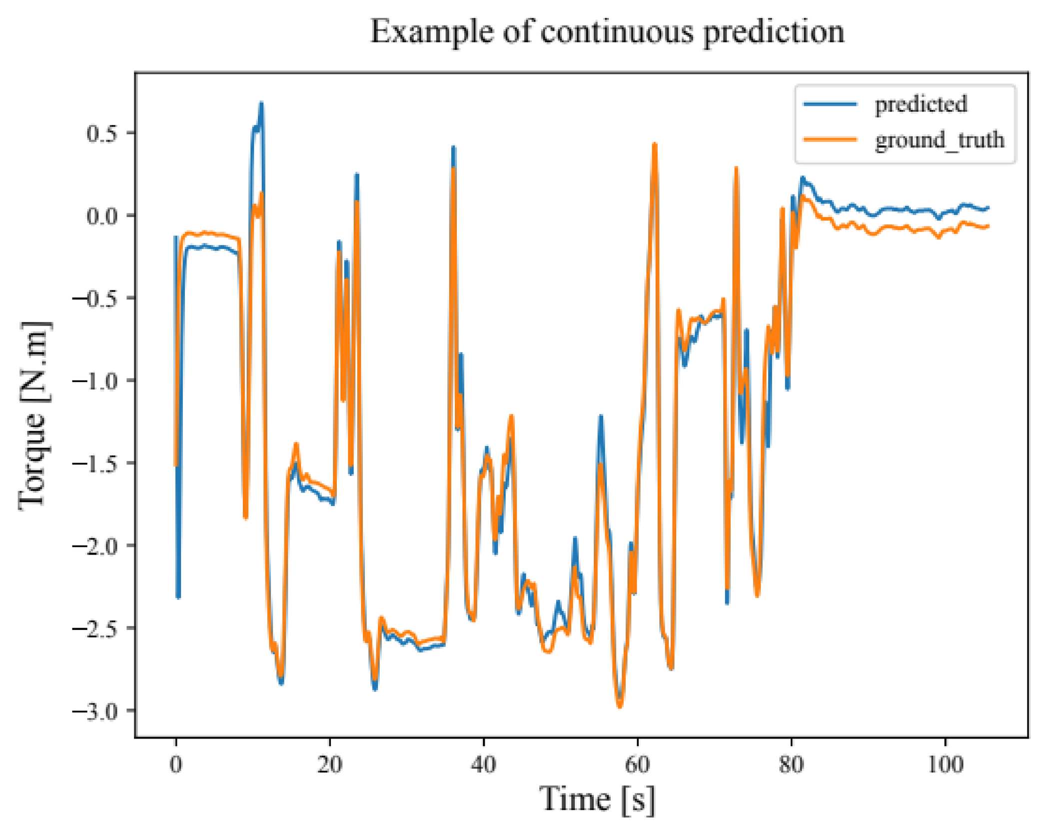
   Predicted value: $\tau_M(t+1 \rightarrow t+N) = f(\tau_E(0 \rightarrow t), w_{load})$

Results

- Quality of the dataset assessed by measuring the tracking performances, ie the distance between corresponding frames at each time step.
- Mean overall distance = 1.55 ± 1.3cm



- Evaluation of the **Mean Absolute Error** (MAE) between the prediction and the ground truth
- Comparison of each motor torque for each proposed method



MAE between the ground truth and the predicted torques from the different methods for 0kg in N.m

	Left Shoulder	Right Shoulder	Left Elbow	Right Elbow
1	0.61 ± 0.88	0.61 ± 0.83	0.012 ± 0.021	0.003 ± 0.005
2	**0.27 ± 0.43**	**0.27 ± 0.51**	**0.003 ± 0.002**	**0.002 ± 0.003**

MAE between the ground truth and the predicted torques from the different methods for 6kg in N.m

	Left Shoulder	Right Shoulder	Left Elbow	Right Elbow
1	0.74 ± 1.64	0.74 ± 1.59	0.15 ± 0.35	0.14 ± 0.35
2	**0.31 ± 0.47**	**0.31 ± 0.54**	**0.02 ± 0.05**	**0.02 ± 0.05**

The second prediction method seems to have better overall results for both 0kg and 6kg, the third method still needs to be evaluated.

Future Work

- Improving the proposed prediction methods
- Testing on physical simulation
- Testing on a real exoskeleton

References

[1] Schneider et al., 2010. European Agency for Safety and Health at Work

[2] Jamsek et al., 2021. IEEE RA-L

[3] Fragkiadaki et al., 2015. IEEE ICCV

[4] Martinez et al., 2017 IEEE CVPR