An Extensible Platform for Measurement and Modification of Muscle Engagement During Upper-Limb Robot-Facilitated Rehabilitation

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Problem

- **Robot-assisted rehabilitation** is a promising tool for upper-limb motor recovery, but its efficacy is limited by **insufficient insight into users' diverse patterns of neuromuscular engagement**.
- Systems are needed that can capture detailed muscle activity in tandem with 6-DoF force and torque exertion, enabling **personalized assessment and improvement of motor strategies** during rehabilitation exercise.

Contributions

- **Development of a novel, extensible, proof-of-concept rehabilitation robot platform** enabling muscle activation measurement (via surface electromyography, or sEMG), during 6-DoF isometric, force- and torque-based trajectory tracking tasks.
- Collection and release of **OpenRobotRehab data set**, including sensing and performance data from 13 healthy and 2 post-stroke participants performing trajectory tracking tasks on this novel platform.
- Preliminary **analyses of force/torque–engagement relationship** and subjective impressions.

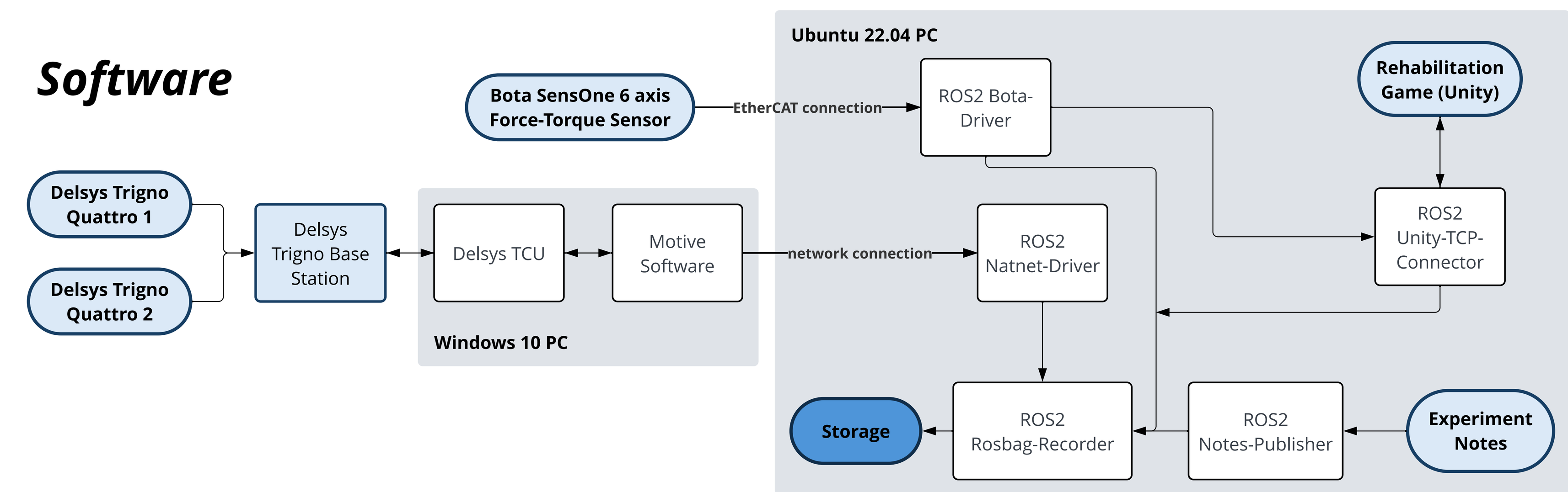
DOWNLOAD

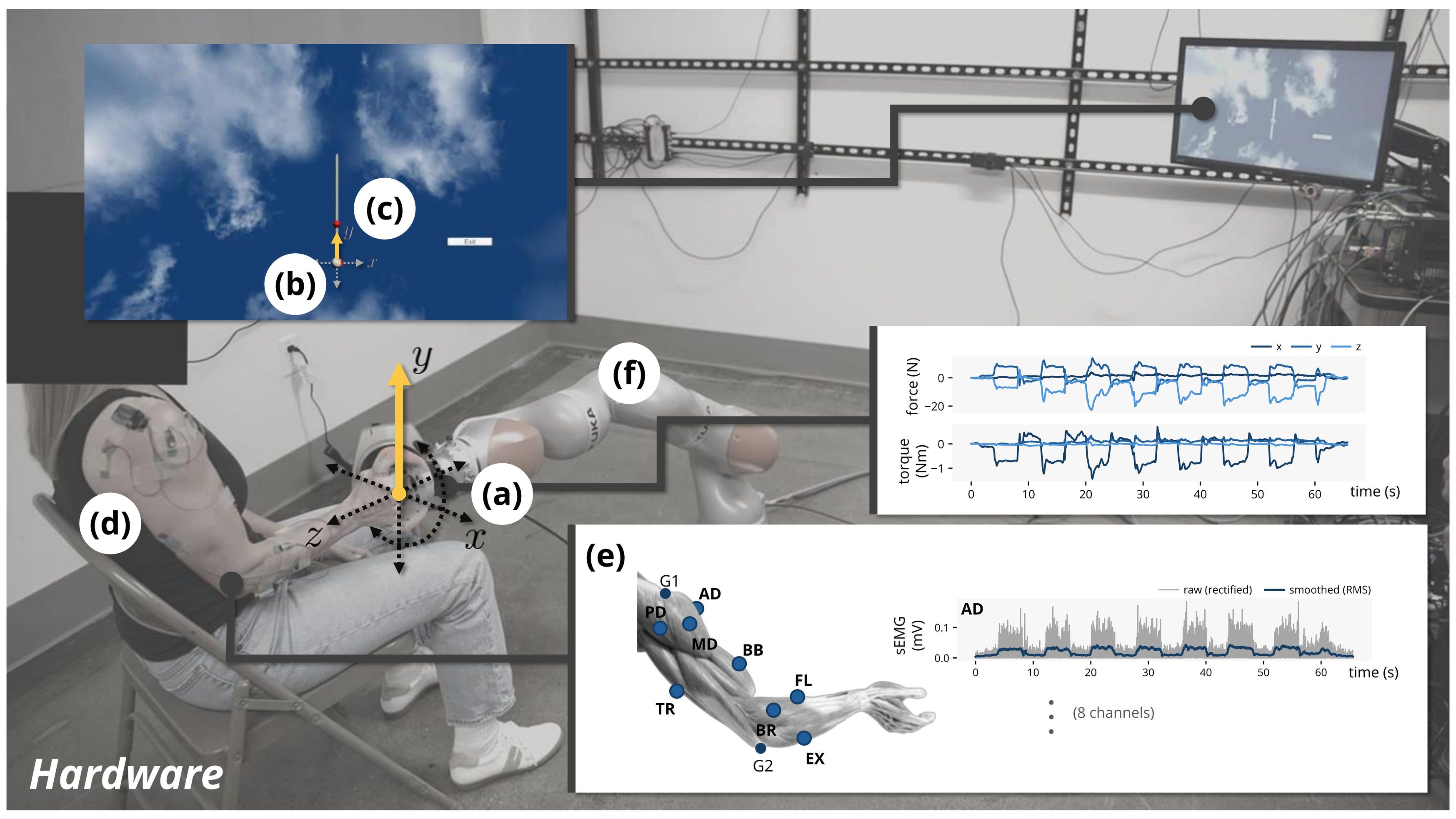
Download all code and data at

`simtk.org/projects/openrobotrehab`

Rehabilitation Platform Design

Motor rehabilitation platform enabling measurement of muscle engagement during trajectory tracking tasks. Users exert forces and torques on load cell (a) through the attached handle, which are then mapped to x–y coordinates of on-screen avatar (b) to allow users to follow red target ball (c) through different trajectories, while surface electromyography (sEMG) electrodes (d) placed on key muscles of the arm (e) record muscle activations. The system currently supports isometric rehabilitation tasks at arbitrary poses — robot (f) remains static — but will be expanded in the future to support a variety of robot controllers.

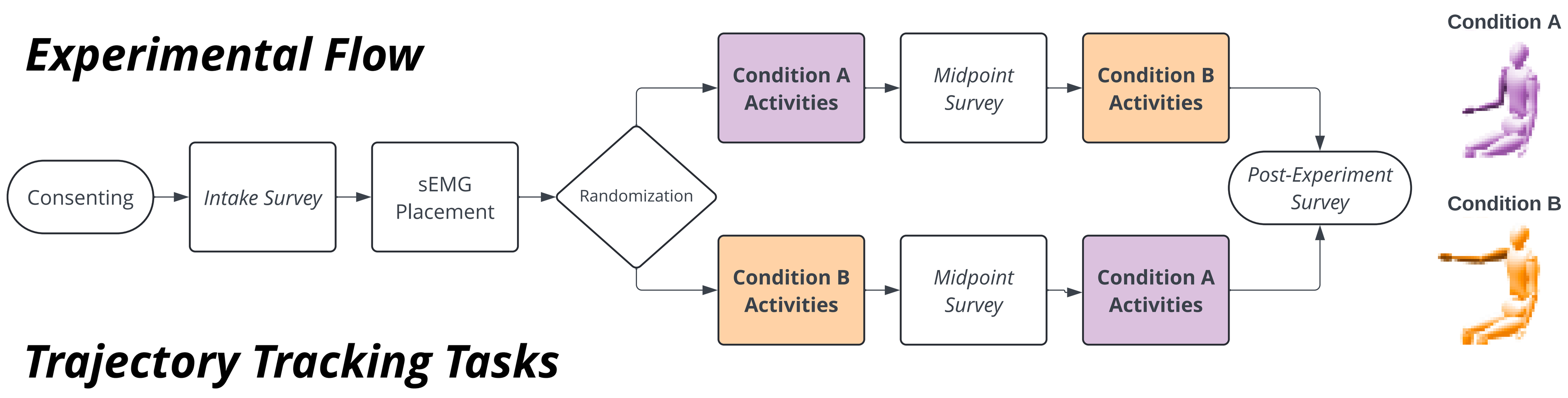


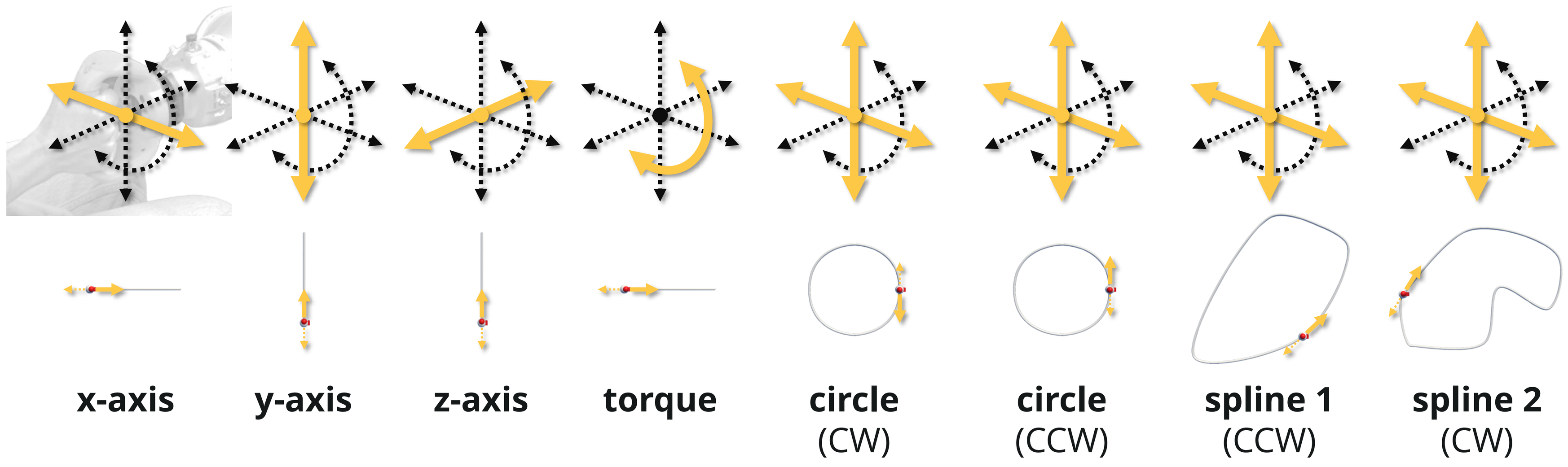


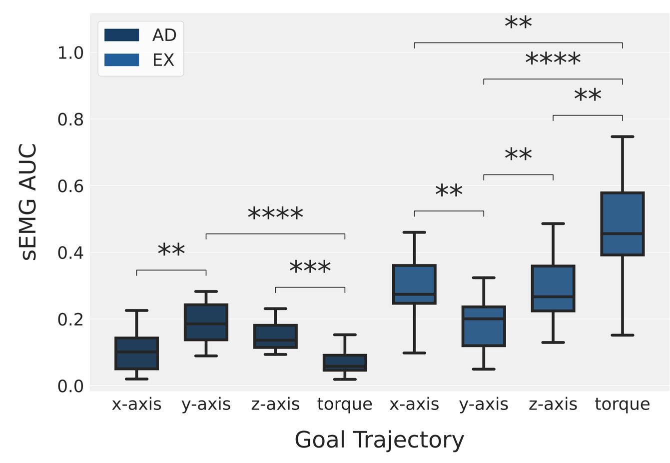
Surface EMG electrode placements: anterior deltoid (AD), middle deltoid (MD), posterior deltoid (PD), and biceps brachii (BB), grounded at the acromion (G1); triceps brachii (long head, TR), brachioradialis (BR), wrist flexors (FL), and wrist extensors (EX), grounded at the olecranon (G2).

Pilot Data Set Collection & Analysis

To **illustrate platform efficacy in activating varied motor behaviors** and inform future system development, sEMG, force torque, and game performance data were collected from **13 healthy** and **2 post-stroke participants** as they performed various isometric trajectory tracking tasks in multiple poses.

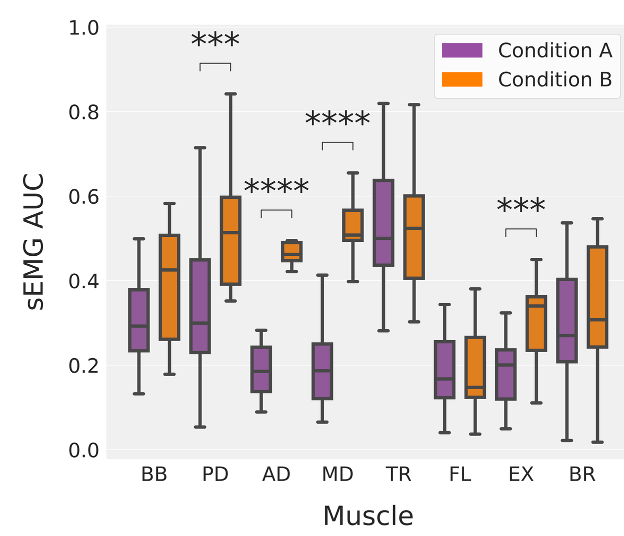


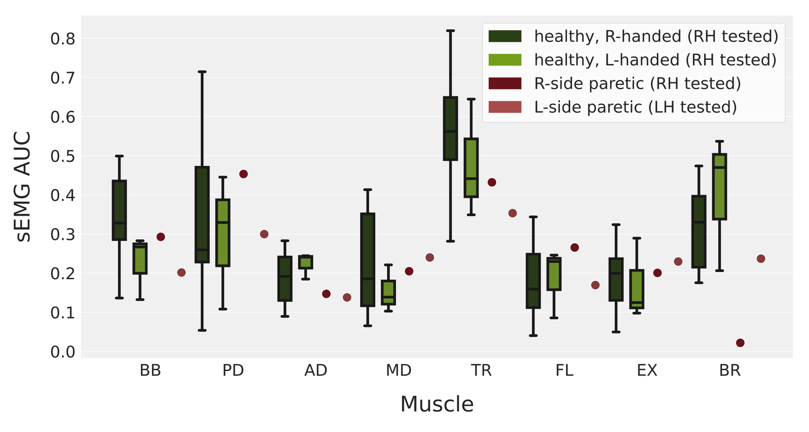




Muscle activation analysis across trajectories revealed that **different prescribed motions reliably induced distinct muscle activation patterns**. *(Plot: Pose condition A, across all participants)*

Muscle activation analysis across poses showed that in Condition B (shoulder raised), shoulder muscle engagement (PD, AD, MD) was consistently higher, suggesting that **pose can be used to selectively modulate muscle activations for rehabilitative purposes**. *(Plot: y-axis task, across all participants)*





All values reported as aggregate area under the curve (AUC) of processed sEMG signal.

Both healthy and mildly impaired post-stroke participants successfully completed all tasks, with AUC-based metrics showing **similar overall motor strategies**. Qualitative observations revealed compensatory movement (torso rotation, shoulder lifting, etc.) in post-stroke participants, highlighting subtle deficits not captured by sEMG alone. These findings emphasize the **need for richer sensing modalities to fully characterize motor strategies** and support more individualized therapy. *(Plot: Pose condition A, y-axis task)*

Conclusions

- Our novel rehabilitation platform successfully measures muscle engagement and 6-DoF force/torque exertion during upper-limb tasks, enabling **new, detailed quantification of motor behavior in end-effector-robot-mediated rehabilitation**.
- Preliminary results demonstrate that **both user pose and task design significantly influence muscle activation**, underscoring the importance of engagement-aware, multidimensional systems for personalized therapy and paving the way for more adaptive and effective rehabilitation approaches.

Current Extensions

- To enable dynamic motions, we are developing **transparent and gravity-compensated impedance controllers** with **hybrid control strategies** and motion planning algorithms to **optimize robot dexterity** for individual users.
- To better interpret and modify motor engagement and impairment, we are developing human–robot neuromechanical models using **muscle synergy analysis** and **biomechanical simulation frameworks**.

Acknowledgments / Sponsors

*These authors contributed equally to this work.

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