Journal-First: Koopman-driven Grip Force Prediction Through EMG Sensing

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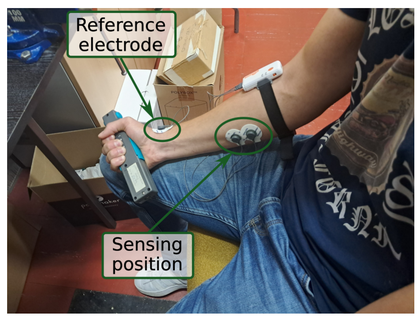
What We Are Doing

Grip-force estimation and 0.5 s-ahead forecasting from a single sEMG pair

What Is EMG?

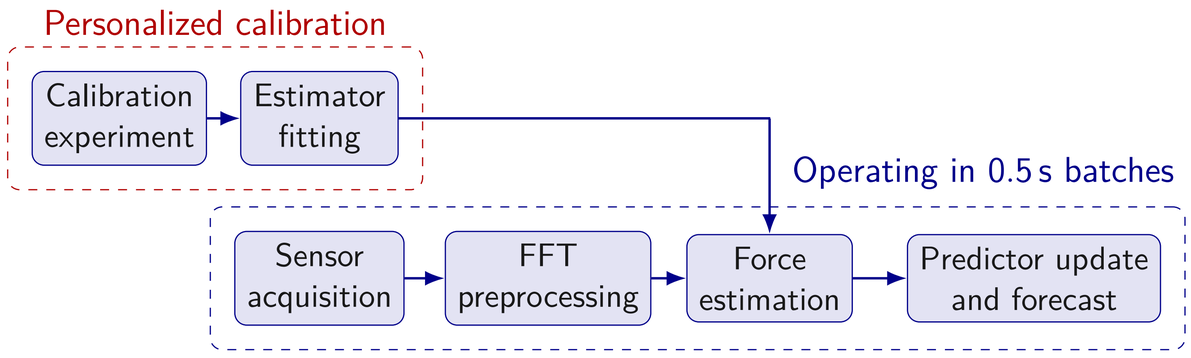
Electromyography (EMG) records myoelectric muscle signals. It answers: *What are the muscles doing?*

- Adaptive robotic assistance requires timely prediction
- One-time personalized calibration before therapy
- Real-time estimation and forecasting in recurring batches

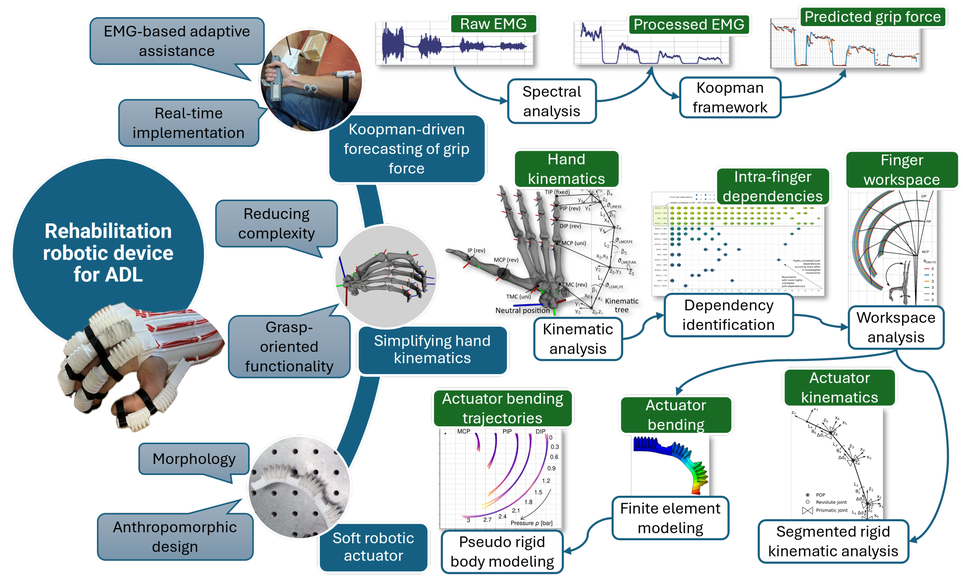


- **Randomized block design**
- Shimmer3 for sEMG
- Vernier Go Direct® hand dynamometer
- 13 subjects, 2 locations, 2 repetitions
- 5 MVC levels; ROS 2/Python acquisition

System Overview



Broader Research Context



Koopman-Based Real-Time Modeling

Estimate current grip force, then forecast the next 0.5 s.

$$\phi(x_{k+1}) = \mathcal{K}\phi(x_k)$$

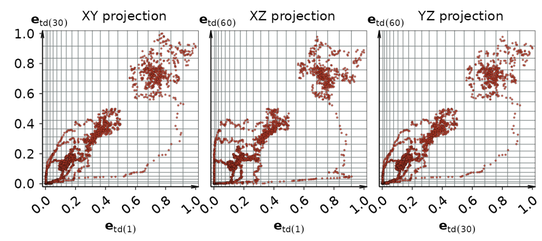
Static Koopman ⇒ Estimation

- Current grip-force estimation from lifted processed EMG

Hankel time-delay embedding

$$E = \begin{bmatrix} \mathbf{e}_0 \\ \mathbf{e}_{\mathrm{td}(1)} \\ \vdots \\ \mathbf{e}_{\mathrm{td}(d-1)} \\ \mathbf{e}_{\mathrm{td}(d)} \end{bmatrix} = \begin{bmatrix} \mathbf{e}_{\mathrm{proc}}[1] & \mathbf{e}_{\mathrm{proc}}[2] & \cdots & \mathbf{e}_{\mathrm{proc}}[N-d] \\ \mathbf{e}_{\mathrm{proc}}[2] & \mathbf{e}_{\mathrm{proc}}[3] & \cdots & \mathbf{e}_{\mathrm{proc}}[N-d+1] \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{e}_{\mathrm{proc}}[d] & \mathbf{e}_{\mathrm{proc}}[d+1] & \cdots & \mathbf{e}_{\mathrm{proc}}[N-1] \\ \mathbf{e}_{\mathrm{proc}}[d+1] & \mathbf{e}_{\mathrm{proc}}[d+2] & \cdots & \mathbf{e}_{\mathrm{proc}}[N] \end{bmatrix}$$

Sparse gridded indicator observables

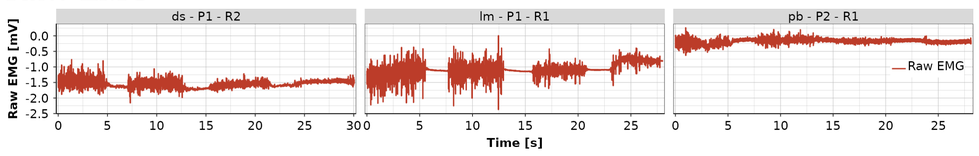


Dynamic Mode Decomposition ⇒ Forecasting

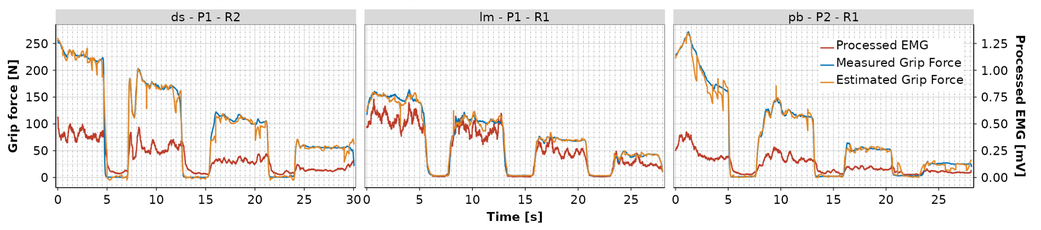
$$\mathcal{K}_{\mathrm{p}} Z = Z\Lambda \Rightarrow Z = (\mathbf{z}_1, \ldots, \mathbf{z}_j, \ldots, \mathbf{z}_r)$$
$$\Lambda = \mathrm{diag}(\lambda_1, \ldots, \lambda_j, \ldots, \lambda_r)$$

1. Time-delay embedding
2. ln-transformed interaction matrix
3. Dynamic mode decomposition
4. Koopman amplitudes
5. Threshold predictions
6. Hyperparameter tuning

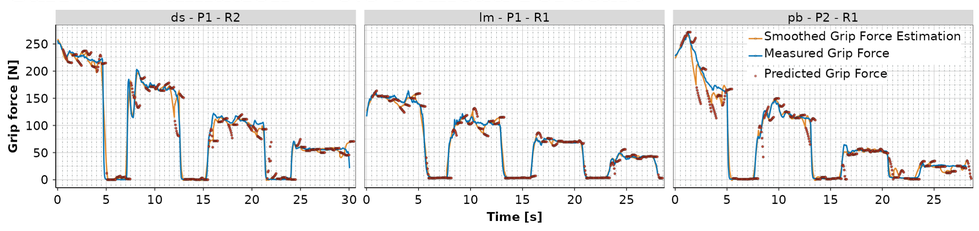
Raw EMG



Processed EMG + Estimation

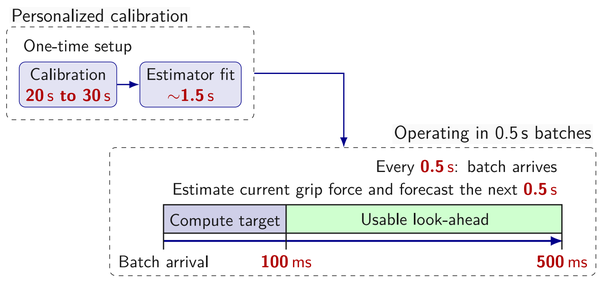


Current Estimation + 0.5 s-Ahead Forecast

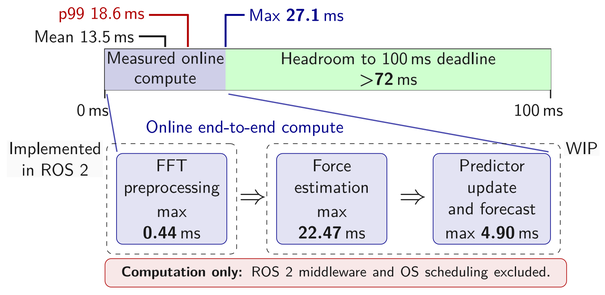


Timing Constraints and Measured Compute

100 ms compute target

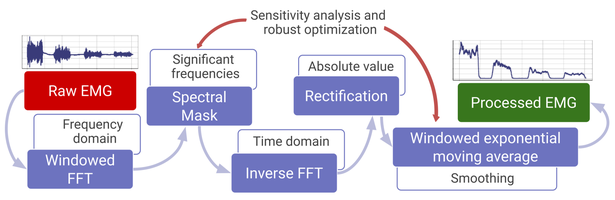


27.1 ms measured max compute

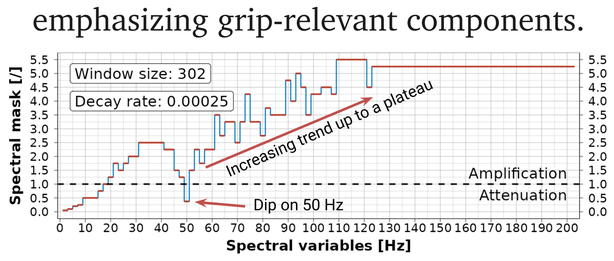


Batch Signal Processing

FFT masking, rectification, and smoothing optimized for peak EMG–force cross-correlation.



Spectral mask: attenuates low-frequency artifacts and 50 Hz interference while emphasizing grip-relevant components.



ROS 2 Implementation

- Acquisition, calibration, and signal processing already run in ROS 2.
- Estimation and prediction nodes are in progress.

`shimmer_ros2`
`godirect_ros2`
`emg_grip_interfaces`

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Scan for full paper

Main Results

27.1 ms max compute; >72 ms headroom to 100 ms.

Peak Correlations
∼ 0.96

Estimation wMAPE
5.48%

Forecast wMAPE
17.92%

Position Effect
non-significant