Continuous 2-DoF SMG Control via Optical Flow Feature Grouping and Principal Component Analysis

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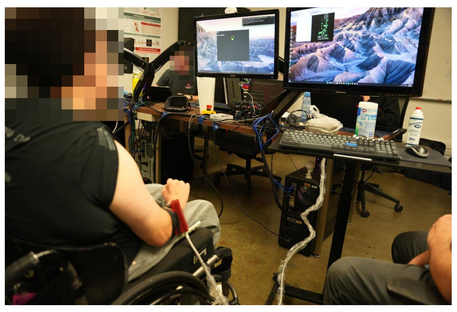
We developed three new methods of extracting **two continuous sonomyographic (SMG) control signals from a single B-mode ultrasound probe** placed anywhere on the body, toward control of high-degree-of-freedom (DoF) assistive devices by users with tetraplegia.

Motivation

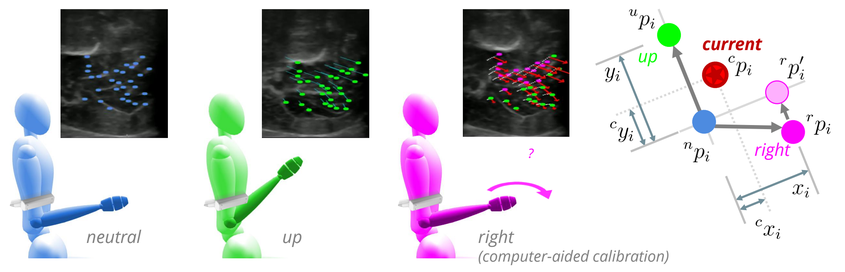
Spinal cord injury (SCI) survivors exhibit **heterogeneous capabilities** [1], and could benefit from control of high-DoF assistive devices. We have developed a preliminary SMG interface[2] enabling 2-DoF control, but the existing system experiences strong signal coupling and unreliable calibration.

→ **GOAL:** Develop robust, multi-DoF, sensor-location-agnostic SMG signal extraction algorithms to enable control of high-DoF assistive robots.

Previous System[2]



Paper TuO5T2.5 *(Sueltz et al. 2026)* [2]

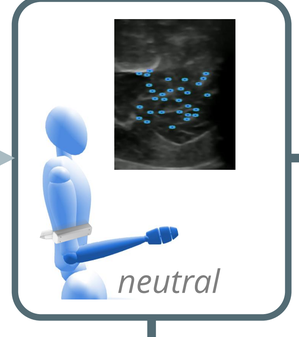


Our preliminary 2-DoF system prompted a user to define an "up" pose and then aided them in finding a sufficiently orthogonal "right" pose. For many users, a "right" pose was challenging to locate, and even when found, the control output had significant signal coupling.

Signal Extraction Methods

SMG image capture

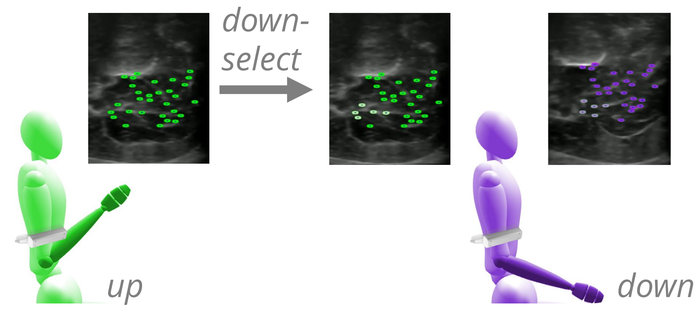
Feature Extraction & Preprocessing[2]



Workspace exploration is currently unstructured; future optimization of this procedure could improve consistency of results.

Feature Grouping

VERTICAL



HORIZONTAL . . .

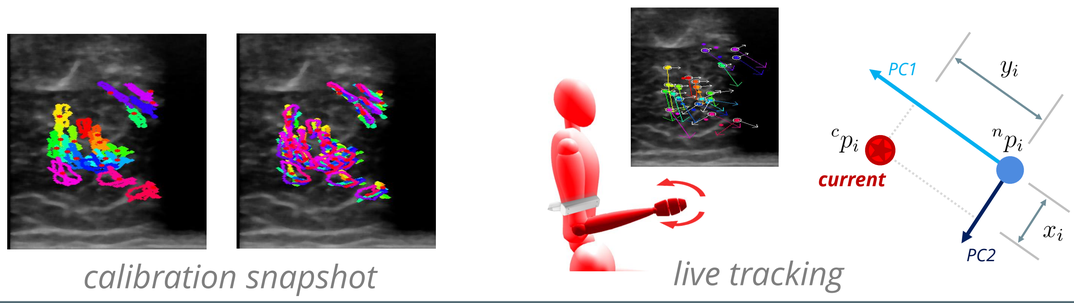
(same as above for left and right)

y_s

x_s

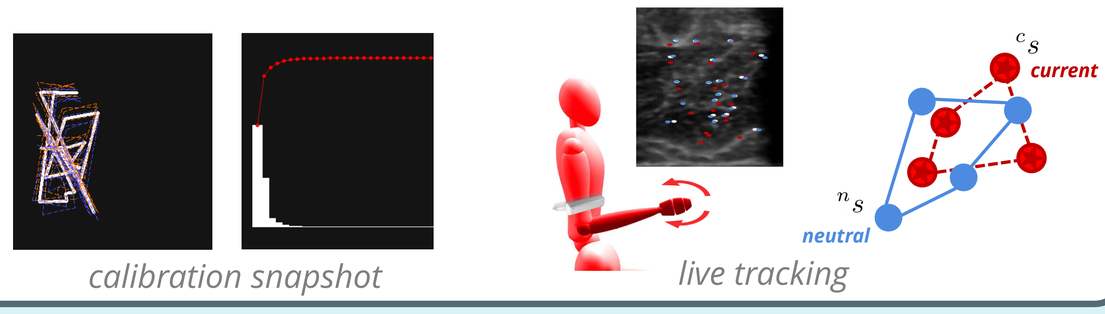
Feature Grouping method experiences substantial signal coupling between x_s and, y_s, making it difficult to exert purely vertical/horizontal control.

Pointwise PCA



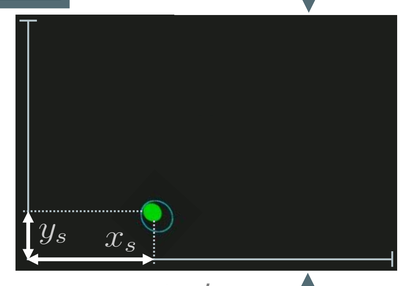
Pointwise PCA method assumes that the first principal component for each point should be mapped to "up", regardless of points' relationship to each other, causing signal conflict/coupling across points.

Aggregate PCA



Aggregate PCA method requires fewer underlying assumptions about relative feature motions and showed the most consistent calibration output, leading to best performance.

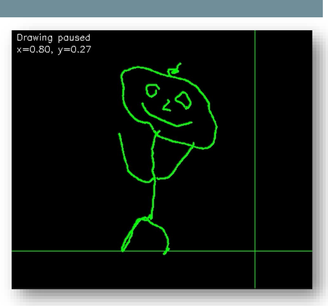
(x_s, y_s)



(x_s, y_s)

Results / Conclusions

Qualitative performance by pilot users on cursor control drawing tasks was promising, especially using our **Aggregate PCA method** (example shown).



Current Extensions

We are currently designing user studies to **evaluate the efficacy of these algorithms across user capabilities and sensor locations** and **establish signal characteristics that determine performance**.

These algorithms will ultimately form the basis of **controllers for high-DoF assistive devices** like the Stretch 4 robot.

Poster SuPO1P.12 *(Athithan et al. 2026)*

Poster MoPO1P.13 *(Wynn et al. 2026)*

Acknowledgments / Sponsors

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The authors thank Gavin Sueltz, for his work on SMG signal processing.

[1] Sheldon et al. (2025), *World Neurosurgery*.
[2] Sueltz et al. (2026), *BioRob*.