Sensor-Placement-Agnostic Sonomyography: Toward Continuous High-Dimensional Control by Users with Tetraplegia

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We present and characterize a **novel, ultrasound-based signal extraction method** that allows **users with tetraplegia** to continuously control devices using **arbitrary motions** measured from **arbitrary sensor locations**.

Problem

- **Spinal cord injury (SCI) survivors** (>300k in US [1]) and other individuals with tetraplegia could benefit from **continuous control interfaces to operate high-DOF assistive robotic devices.**
- Current biosensing interfaces require **precise sensor placement** and **extensive user-specific training data** (e.g., [2, 3]) and provide only **low-DOF control** (e.g., [3–6]), limiting real-world assistive applications.

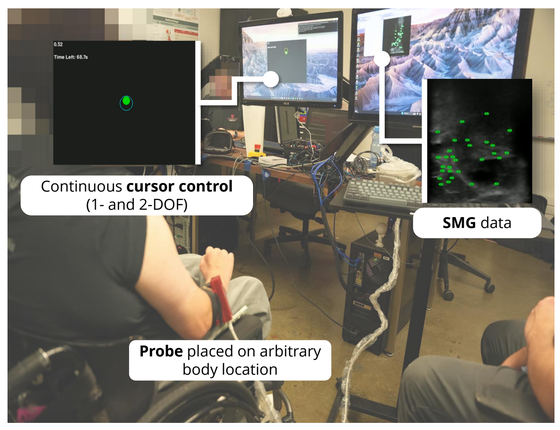
→ **GOAL**: Develop a biosignal-based control system that is **sensor-location-agnostic** and provides **multiple continuous signals**.

***Target control platform**: Hello Robot Stretch 3 [7]*

Contributions

We present a **novel sonomyography (SMG) system** that:
- can be placed anywhere on the body;
- provides continuous 1-DOF control after minimal 3-point calibration; and
- provides preliminary continuous 2-DOF control after equally minimal calibration.

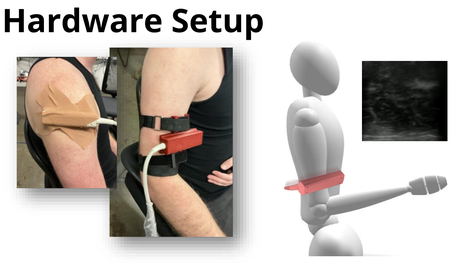
We characterize 1- and 2-DOF **system performance**:
- by 3 SCI survivors and 6 uninjured individuals;
- at 6 sensor placements across the arm, neck, and upper torso;
- objectively via performance evaluation; and
- subjectively via user feedback.



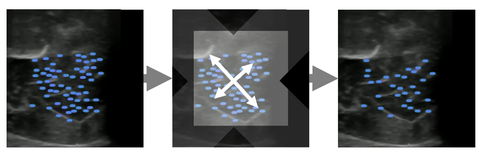
System Design

***B-mode ultrasound signals** are captured from an arbitrary body location*

Hardware Setup



Feature Extraction & Preprocessing

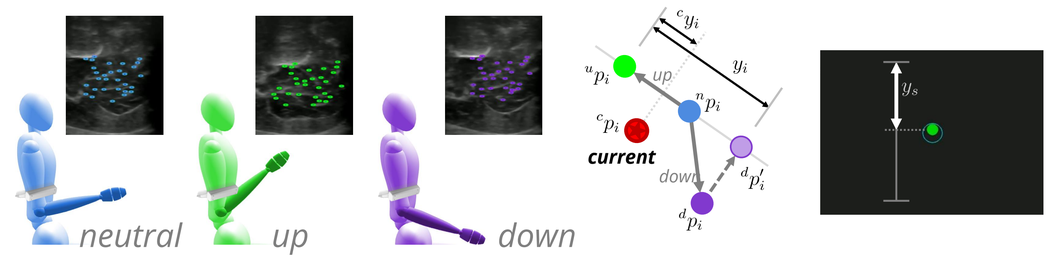


initial point selection (~60) → *truncation & PCA-based resampling* → *final tracked points (~30)*

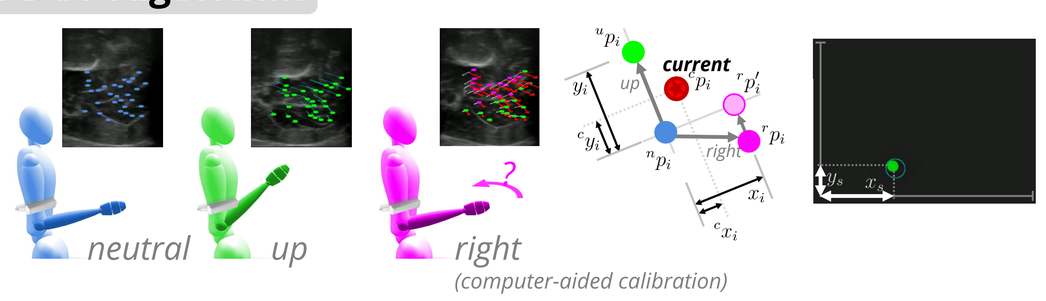
*Image features [8] are extracted, resampled for good image coverage, and tracked to quantify tissue motion using **Lucas–Kanade sparse optical flow** [9,10]*

*3-point user-defined calibration enables **1- or 2-DOF control***

1-DOF Algorithm



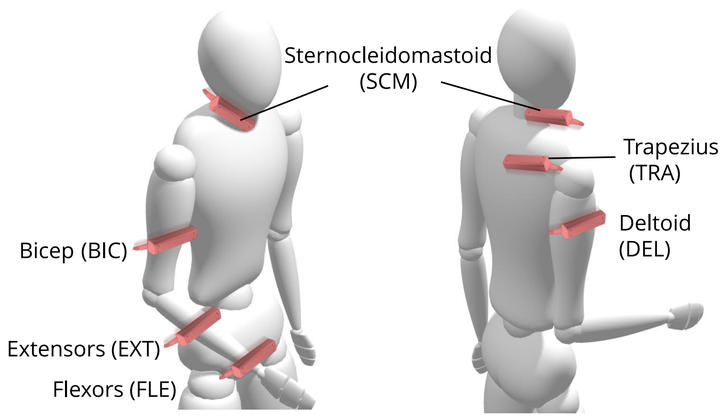
2-DOF Algorithm



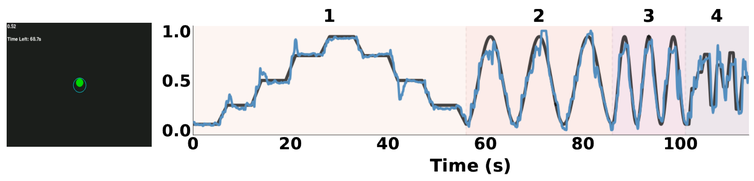
(computer-aided calibration)

Preliminary System Evaluation

Our system was employed by a preliminary cohort of **3 SCI survivors** and **6 uninjured individuals**. The ultrasound probe was placed on **6 different locations** on the upper body:

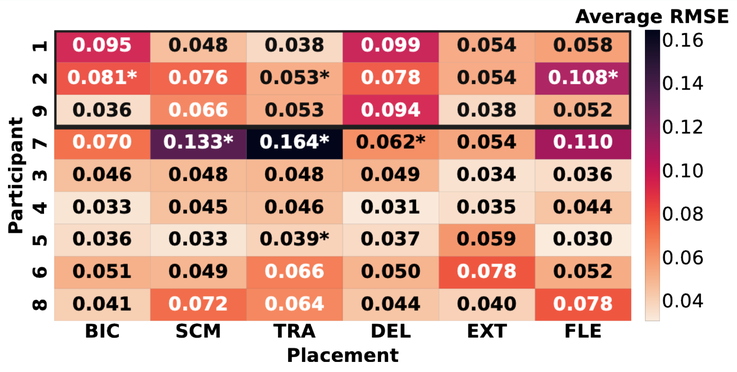


After calibrating the system, participants were asked to complete **1- and 2-DOF cursor trajectory tracking tasks**:



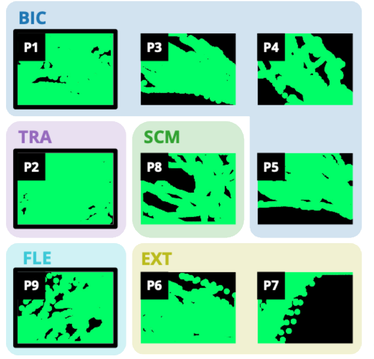
1-DOF Evaluation

- Signal modulation was feasible for all sensor locations.
- **SCI survivors did not report an RMSE meaningfully greater** than that of uninjured participants for any sensor placement.
- SCI survivors could modulate motion even for locations where they had **no volitional muscle control**.

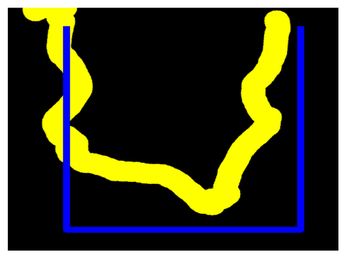


2-DOF Evaluation

- Workspace traversal was possible for **all participants**.
- Some participants were able to draw, showing feasibility of **intentional multi-DOF continuous signal modulation.**



***Block U drawing task** (participant 8, placement SCM) →*



*← **Workspace traversal** (all participants, self-selected placement)*

Qualitative Feedback

- SCI users cited **intuitive control**, **low fatigue**, and minimal interference with **trunk balance** as top priorities.
- Users' preferred sensor locations were **heterogeneous**.
- The system was enjoyable to use and entertaining; one user even expressed **feeling like a Jedi**.
- Users agreed that the system has great potential for in-home robotic assistive devices.

Conclusions

Users' varied preferences and consistent performance of the trajectory following tasks demonstrates the **importance and feasibility of a sensor-placement-agnostic system that utilizes a continuous, multi-DOF SMG signal**.

Current Extensions

Continuous high-DOF device control will require improvements in both algorithms and hardware, such as:
- improving **ultrasound attachment methods** and **probe form factor**; and
- **integrating additional signals** (e.g., sEMG) to **reduce drift** and **enhance signal stability**.

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*These authors contributed equally to this work.

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Works Cited: