

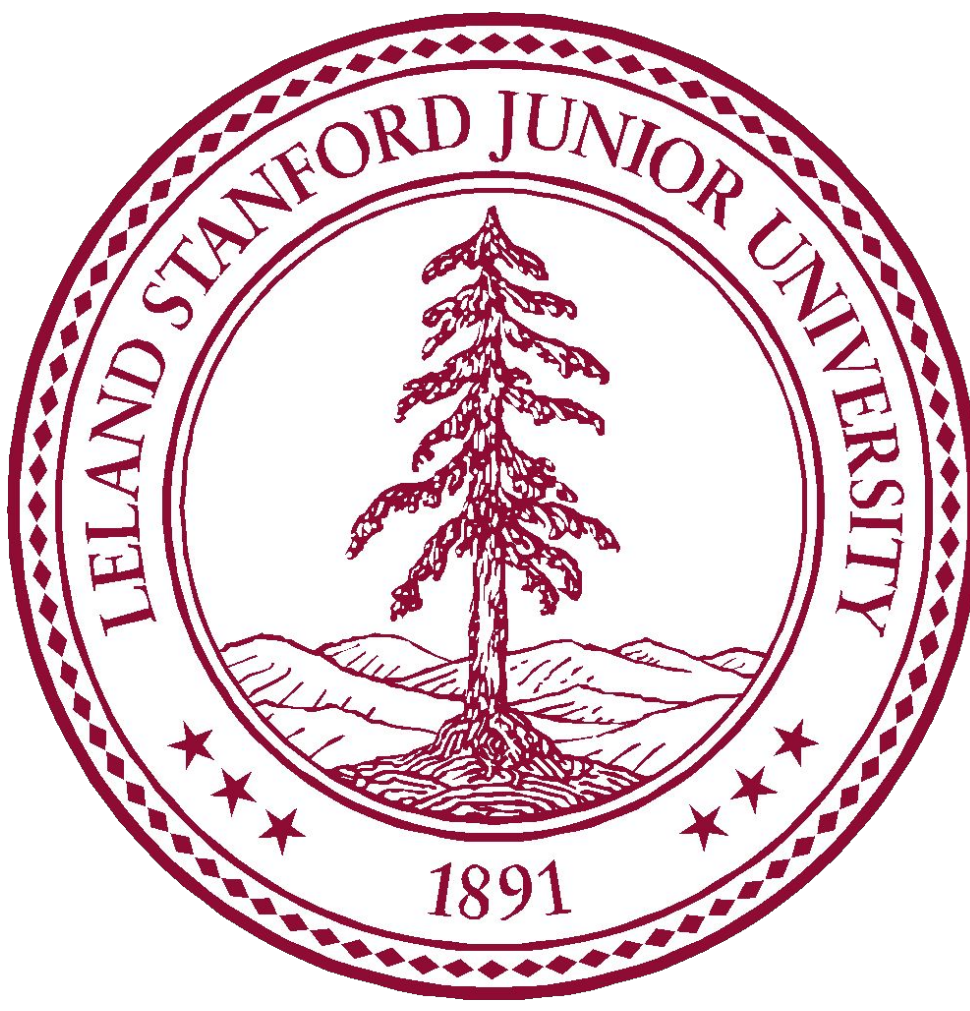
Restoring Limb Awareness Using sEMG-Driven Haptic Feedback for Post-Stroke Proprioceptive Loss

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Introduction

- **Proprioception** is the body's ability to sense its own position, movement, or force ***6th sense***.
- **Post-stroke proprioceptive loss** is common, affecting **motor coordination** and **limb awareness**.
 - **800,000** people suffer a stroke each year in the US¹.
 - **~50-60%** of these individuals experience **impaired proprioception** after².
- Impaired proprioception increases the risk of **falls**, **joint instability**, and **delayed motor recovery**³.
- Current **rehabilitation methods** focus on strength and motion but fail to target proprioception directly.
- Prior studies have demonstrated that **haptic feedback** (vibration-based signals) **counteracts proprioceptive loss**⁴.
- Our design uses **sEMG—surface electromyography—sensors** to detect **movement intent** and delivers **real-time haptic feedback** to the forearm, reinforcing **sensorimotor pathways** to enhance proprioception.

Needs Statement

A way to **restore proprioceptive feedback** in **post-stroke adults with arm impairment** in order to **improve motor coordination**.

Need Specifications

Need Specification	Measurable Output	Need-to-Have	Nice-to-Have
Accurate Signal Detection	False negative rate	≤ 10% are false negatives	≤ 5% are false negatives
Tactile Feedback System	Patient feedback	2 (1-3 scale)	3 (1-3 scale)
Latency	Time from intent to feedback	≤ 500 milliseconds	≤ 200 ms milliseconds
Multi-Muscle Detection	Muscle groups monitored	1	~2
Haptic Intensity Variation	Vibration amplitude (G-force)	≥ 2x difference (0.5 G → 1G)	≥ 3-5x difference (0.3 G → 1.5 G)
Spatial Stability	Reduced arm position error	≥ 30% drift reduction	≥ 50% drift reduction

References

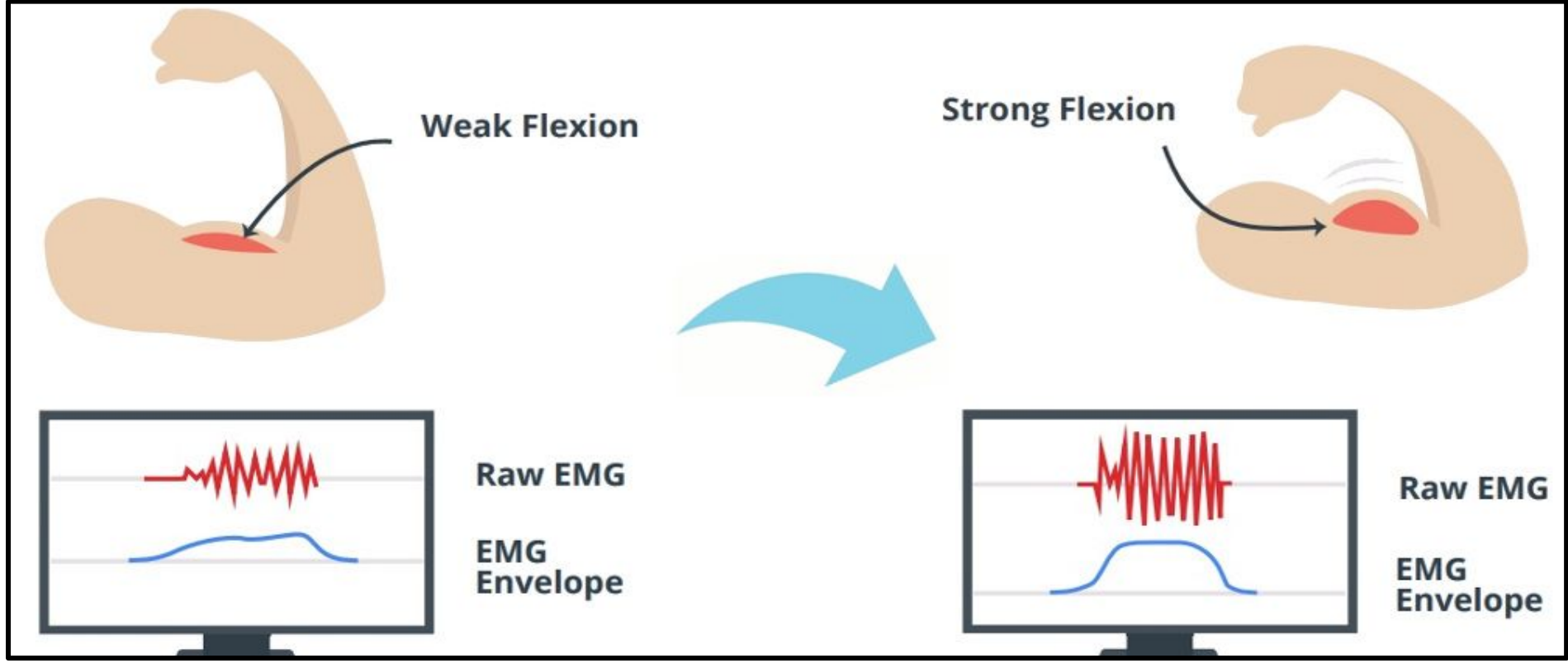
1. Tsao et al., *Circulation*, 2023
2. Tulumieri et al., *Journal of NeuroEngineering and Rehabilitation*, 2024
3. McKenna et al., *Journal of NeuroEngineering and Rehabilitation*, 2015
4. Rabin et al., *Gait & Posture*, 2013

Value Proposition

Figure 1: Virtual reality therapy



Figure 2: EMG demonstration



Selection Criteria	Improves Mobility	Restores Sensory Function	Real Skin Sensation	Personalized Feedback	Responds to User Intent	Non-Invasive	Designed for Post-Stroke Proprioception
Physical/Mirror Therapy	✓	✗	✗	✗	✗	✓	✗
VR/AR	⚠ Limited	✗	✗	✗	✗	✓	✗
Haptic Sleeves	⚠ Limited	✗	✓ (on/off only)	✗	✗	✓	✗
Our Design	✓	✓	✓ (adaptive, personalized)	✓ (real-time muscle-based)	✓ (sEMG-driven)	✓	✓

Solution Design

Combination of EMG and haptic feedback addresses critical gap in post-stroke rehabilitation techniques, which neglect sensory recovery.

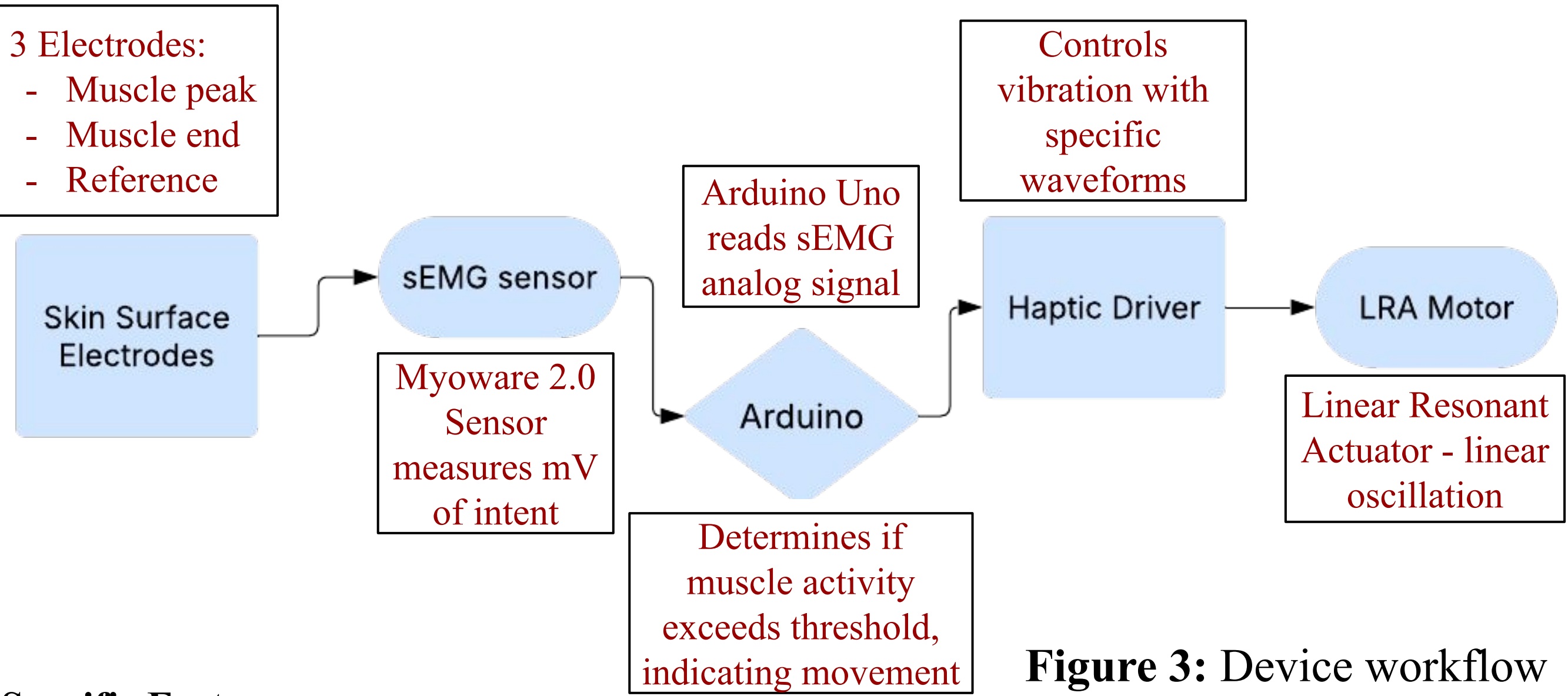


Figure 3: Device workflow

Specific Features:

- Auto-calibration of sEMG signal threshold allows for personalized therapy.
- Varying vibration intensity allows for proportional feedback based on user effort.
- Compact splint design allows for comfort and long-term use.

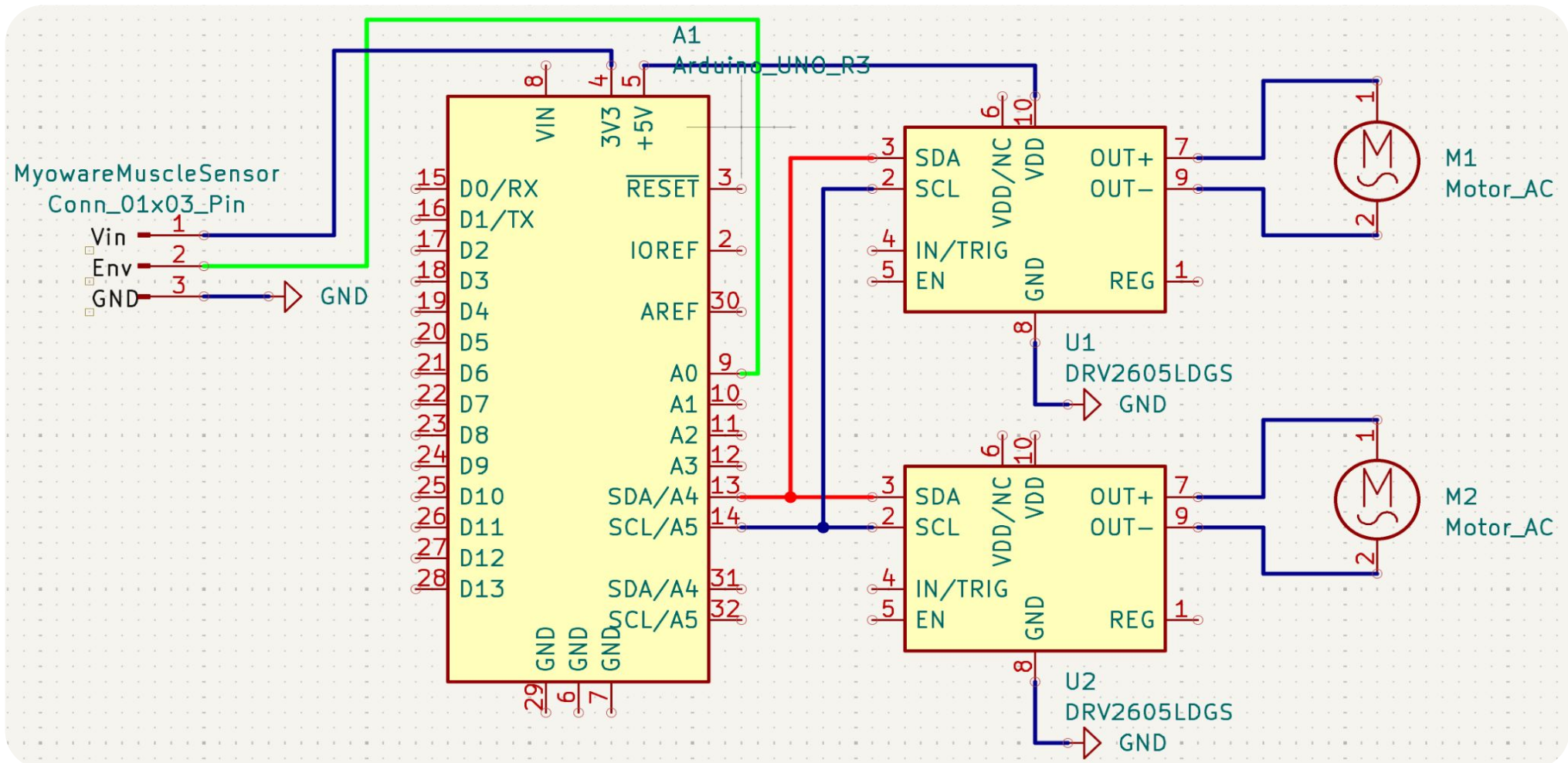


Figure 5: Circuit schematic for haptic sleeve

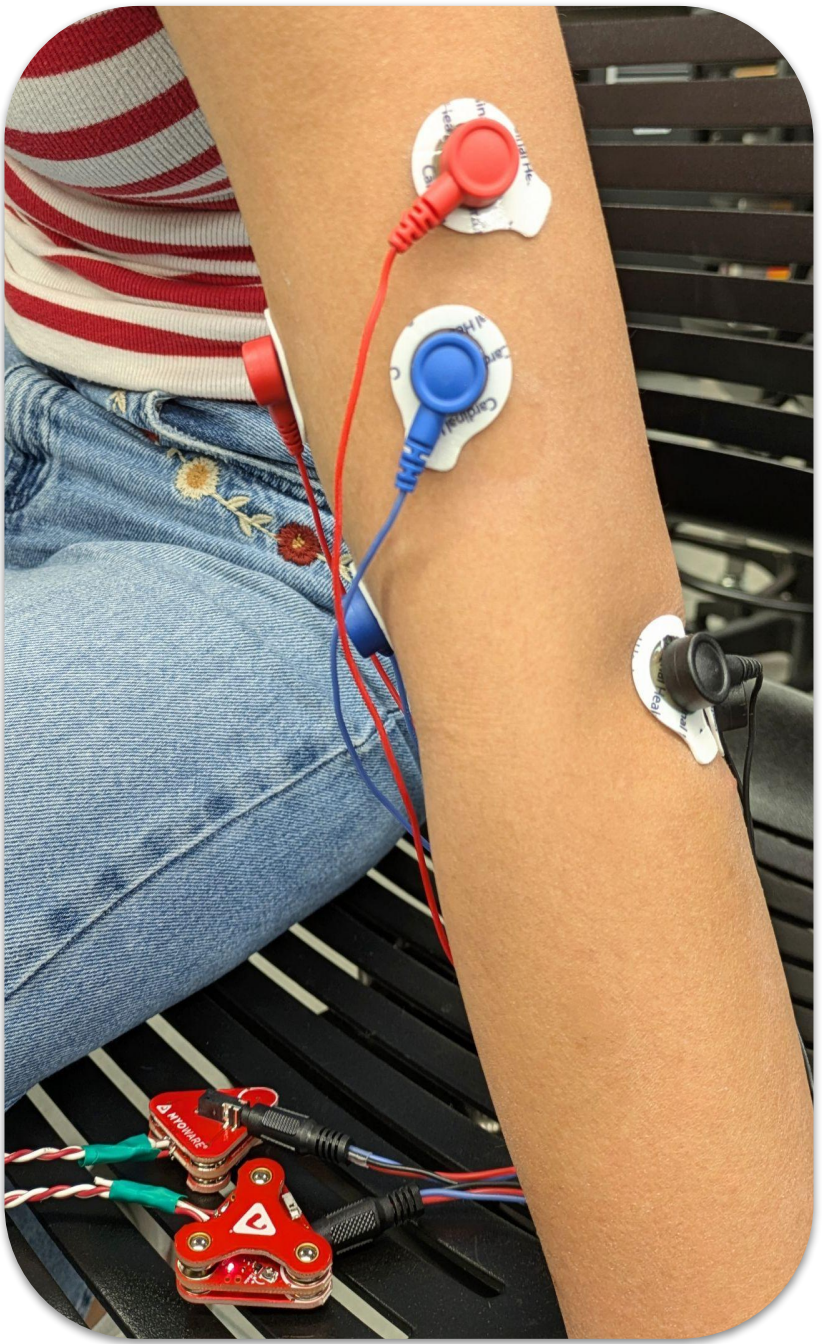


Figure 4: EMG setup

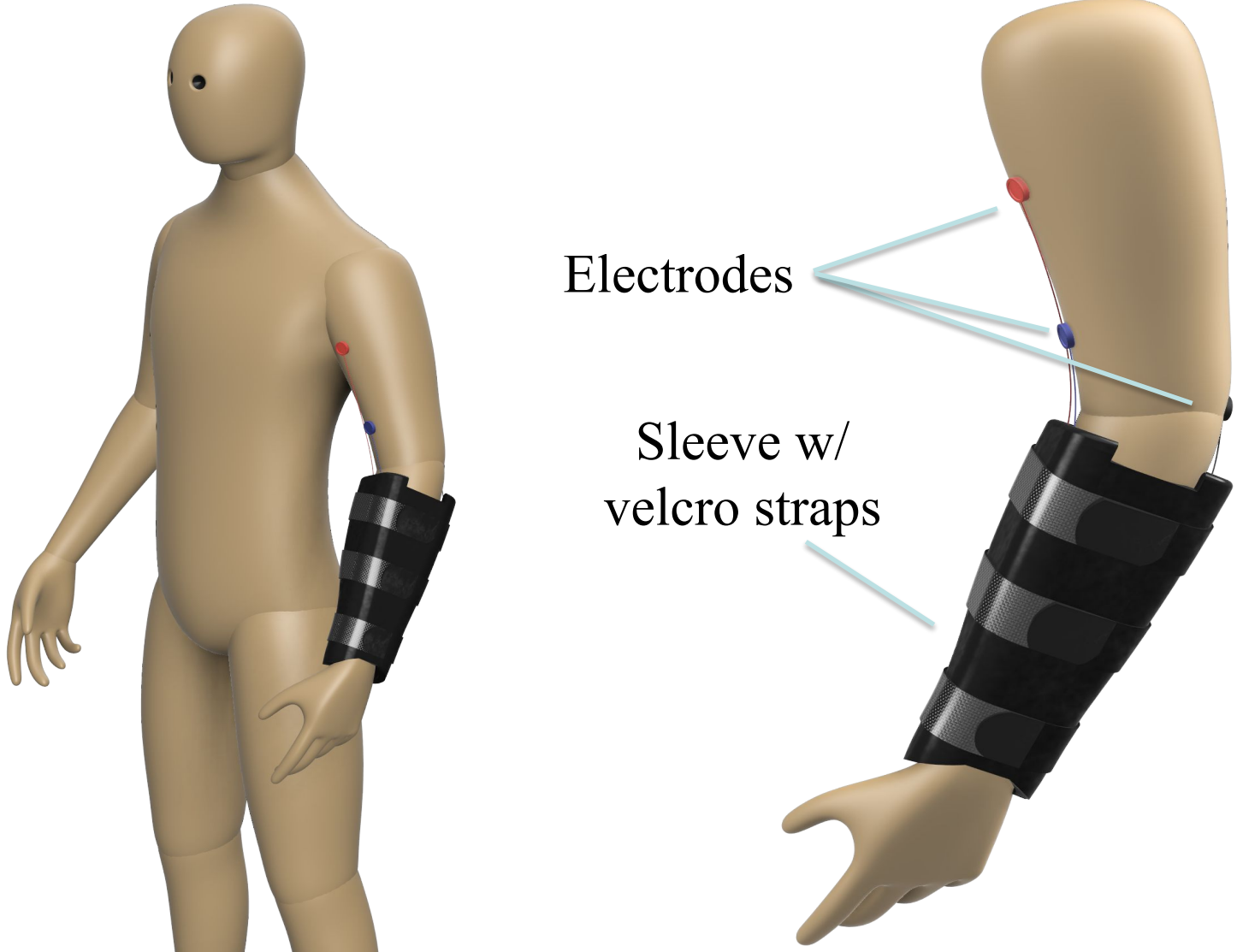


Figure 6 & 7: CAD model of haptic sleeve

Data & Results

- **Latency Test:** User 1 wears sEMG; User 2 wears haptic splint. Timer starts when User 1 moves. User 2 times perceived movement duration. Latency = difference between actual and perceived durations.

	Haptic Splint
Average	$\mu_d = 0.319$
SD	0.341
N	20
Confidence Interval	(0.159, 0.479)

- Since the confidence interval excludes 0.500 seconds (our criterion), **latency was significantly below 0.500 seconds**.
- **Angle Test:** User 1 moves to a set angle with sEMG; User 2 uses haptic feedback to match it. Error = difference between actual and estimated angles.
 - H_0 : Haptic feedback does not improve angle estimation accuracy ($\mu_1 = \mu_2$).
 - H_A : Haptic feedback improves angle estimation accuracy ($\mu_1 < \mu_2$).

	Control	Haptic Splint
Average	$\mu_2 = 33.222$	$\mu_1 = 14.158$
Standard Deviation	26.471	12.235
N	9	19
P-Value	N/A	0.0337

- Because the p-value is less than 0.05, we can reject the **null hypothesis**, showing the **haptic sleeve does enhance accuracy** and improves proprioceptive loss.
- **Drift Test:** Constantly buzz ulnar (funny bone) nerve to impair left arm. Measure arm drift over 1 minute without sleeve, then with sleeve. Compare start-to-end position displacement.

	Impaired	Impaired & Sleeve
Total Displacement	3.6 inches	1.4 inches
Average Drift Rate	1.52 mm/sec	0.93 mm/sec
Position Offset	2.4 inches	0.8 inches

- The haptic sleeve **reduced arm drift by ~60%**, demonstrating that **tactile feedback compensates for impaired proprioception** by providing external spatial cues.
- **Achieved all need-to-have specifications:**
 - ≤ **1%** of tests led to false negatives (**surpassed nice-to-have**)
 - **3** on scale of 1-3 of tactile feedback system (**met nice-to-have**)
 - Latency confidence interval was **(0.159, 0.479)** (**met need-to-have**)
 - Measured **2 muscle groups**—bicep and tricep—(**met nice-to-have**)
 - Haptic intensity ≥ **2x difference** (**met need-to-have**)
 - Drift reduction of **60%** (**surpassed nice-to-have**)

Next Steps

- Add pressure/force sensors to validate muscle movement derived from EMG signals for closed-loop feedback between intent and outcome.
- Develop mobile app for muscle activation visualization, proprioception tracking, and feedback customization, plus train ML model to distinguish intentional movement from noise.

Acknowledgements

Thank you to our TAs—John Heath, Arvie Violette, Gokul Kannan, Clifford Palmer, Tim Jing, and Brooke Ruszkiewicz—for their continuous support. Thank you to Dr. Karen Allendoerfer, Dr. David Hartmann, Dr. Neelam Goyal, Dr. Prashanth Venkataraman, Dr. Ava Chen, and all of the guest lecturers for their advice. Thank you to Dr. PJ Utz and Dr. Cindy Lamb for leading this program. Finally, thank you to SIMR and the Stanford Bioengineering Department for giving us the opportunity to conduct research and design an impactful device for post-stroke adults.