A Modular Platform for Customizable Biosignal-Based Control of a Simulated Assistive Robot

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Introduction: Spinal cord injury (SCI) survivors and others with impaired upper-body motor capabilities could benefit from the ability to control high-degree-of-freedom (DoF) assistive robot manipulators. However, these potential users exhibit diverse levels of motor function [1]. Current platforms do not generally support this heterogeneity of capabilities, often assuming volitional control of a specific muscle or group of muscles [2–5] that a given user may or may not be able to activate.

To address the need for interfaces agnostic to specific neuromotor function, our team has developed a sonomyographic (SMG) interface that can be placed anywhere users can generate measurable tissue motions [6], which we aim to employ alongside other biosensing modalities like surface electromyography (sEMG) to generate intuitive control schemes for robot manipulators. However, the best way to map these biosignals to robot DoF remains poorly understood, and existing systems remain slow, data-hungry, unreliable, and user-specific [7,8]. To enable comprehensive exploration of many possible control algorithms, we present a modular ROS-based platform allowing SMG, sEMG, and other signals to be mapped and re-mapped to a virtual mobile robot manipulator as shown in Figure 1 without modifying core system architecture.

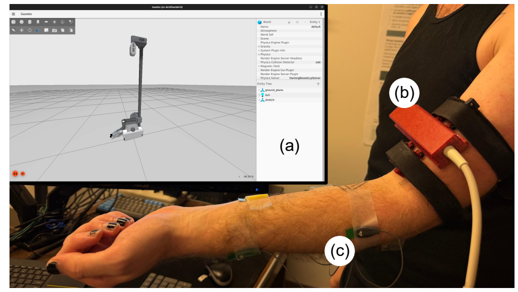

Figure 1: Example use of our modular ROS-based platform enabling users to control joint states of a virtual Stretch 3 robot (a) using SMG (b), while cycling through different robot control motions via sEMG (c) triggering.

Methods: The architecture of our control platform is shown in Figure 2. Windows-specific hardware data — SMG (Telemed ArtUs EXT-2H) and sEMG (Delsys Trigno Quattro) — are streamed via TCP/IP to an Ubuntu machine hosting a ROS 2 network, which connects sensor data streams to a simulated mobile robot manipulator (Hello Robot Stretch 3) in Gazebo. Components are containerized via Docker, both to enable strict version control and to separate data streaming components from controller elements that don't require network access.

To demonstrate the capabilities of our modular platform, we developed a naive controller that uses both SMG and sEMG signals to control the simulated robot, as illustrated in Figure 1. Leveraging the relative performance of SMG and sEMG for continuous and discrete control, respectively, we map sensor streams to robot motion as follows. A continuous SMG control signal is defined after 3-point calibration as described in Sueltz et al. [6] (in the Figure 1 example, roughly corresponding to elbow flexion motion), which is then mapped to the full range of one of four robot motions: 1) vertical movement (lift joint), 2) horizontal movement (arm joints), 3) wrist yaw, or 4) end-effector opening/closing. Users cycle through these motions by activating an sEMG signal above a programmed threshold (in Figure 1, by executing a grasp or wrist flexion motion).

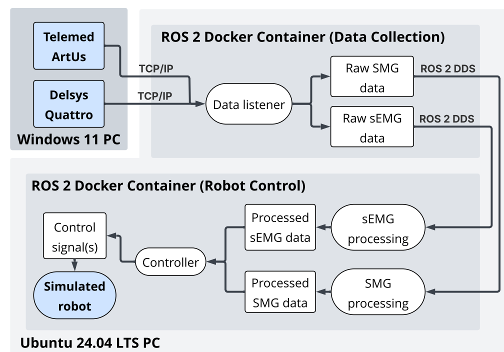

Figure 2: Complete, modular software architecture detailing the flow of data from SMG and sEMG biosensor hardware to Stretch 3 simulated robot.

Results & Discussion: A pilot user was able to activate both SMG- and sEMG-based control signals using our naive controller with minimal calibration, illustrating the utility of our complete control platform, and found even this "switched" system reasonably intuitive to control. This proof-of-concept illustrates the readiness of the platform for future expansion, enabling the study of research questions regarding biosensor placement, signal processing, and control mapping to robot DoF. The modular system structure, with specific control mappings defined at the end of the pipeline and sensor-location-agnostic signal extraction methods, makes the system well-suited to future investigation of control schemes that embrace the heterogeneity of motor function in the SCI population. Most immediately, we aim to use our system to test more sophisticated control approaches than the simple position controller tested. We hypothesize that a velocity controller will be more intuitive for users and decrease cognitive load. We also aim to expand the controller to allow simultaneous control of multiple robot motions, such as horizontal and vertical movement.

Significance: With the ability to quickly test a wide range of sensor placements and robot control schemes, we can work alongside members of the SCI community to develop intuitive, practical control methods. The improvements we make to control system utility have the potential to enable SCI survivors and others with motor impairments to control more dexterous, capable assistive robots and other complex devices, providing them with tools to enhance their independence and quality of life. The platform has been open-sourced to promote further development in biosensor-based robot control.

Acknowledgments: We acknowledge the assistance of Gabriel Parra in interfacing with the Delsys API and Gavin Sueltz for his work on SMG signal processing.

References: [1] Sheldon et al. (2025), *World Neurosurgery*. [2] Nazari and Zheng (2023), *Sensors*. [3] Henderson et al. (2013), *Technology Disability*. [4] Mougharbel et al. (2013), *Science and Information Conference*. [5] Kiguchi and Hayashi (2012), *Transactions on Systems, Man, and Cybernetics—Part B: Cybernetics*. [6] Sueltz et al. (2026), *Rocky Mountain American Society of Biomechanics*. [7] Madduri et al. (2023), *Current Opinion Biomedical Engineering*. [8] Arnau et al. (2022), *Journal of Neural Engineering*.