Restoring Functional Upper Limb Movements with Powered Soft Shoulder Exosuits for individuals with Amyotrophic Lateral Sclerosis

Weibo Gao[1], Antonio Di Lallo[1], Jason Huang[1], Hao Su[1,2]

[1]Department of Mechanical and Aerospace Engineering, North Carolina State University
[2]Joint NCSU/UNC Department of Biomedical Engineering, North Carolina State University and University of North Carolina at Chapel Hill

Website: http://haosu-robotics.github.io
Email: hao.su796@ncsu.edu

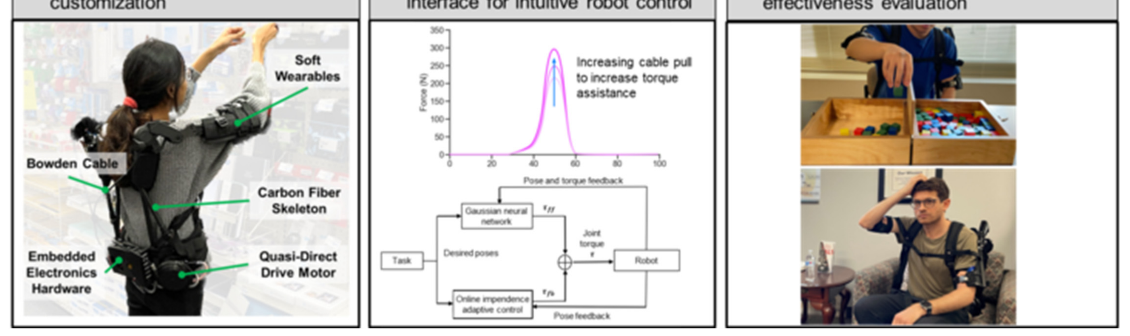
Project Overview

- The goal of this project is to accelerate the development and translation of modular portable soft exosuits (powered orthosis) for ALS individuals with residual movements and investigate their efficacy in restoring physical functions in clinic and home settings.
- Preliminary results indicate the potential of our robot to assist in daily functional movements.

Aim 1: Hardware Optimization
- Robot evaluation on ALS to gain feedback
- Robot hardware improvement and customization

Aim 2: Control and App Design
- AI-powered adaptive controller design for smart assistance
- Mobile applications with user interface for intuitive robot control

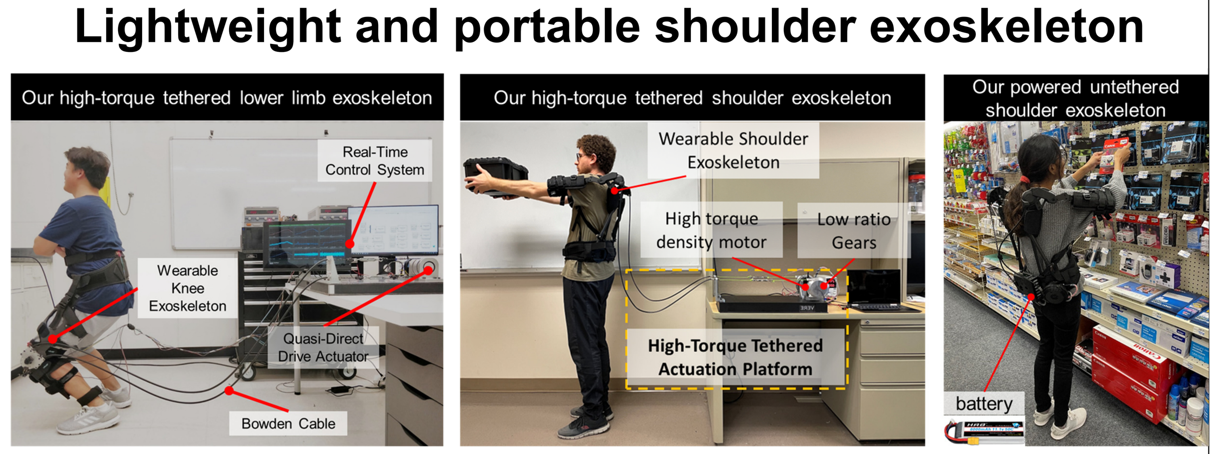
Aim 3: ALS User-Centric Evaluation
- Lab-based standard test for robot manipulation evaluation
- At-home functional test for robot effectiveness evaluation



Upper Limb Exoskeleton Systems

- Current portable shoulder exoskeletons, often passive and spring-based, prioritize lighter designs at the expense of adaptability and smart human-centered control. Conversely, powered devices, suitable for clinical rehabilitation, are typically bulky and tethered, limiting their applicability in daily activities.
- To overcome these limitations, we developed the most lightweight, portable, powered shoulder exoskeleton.
- Our wearable robot provides high torque assistance for 2 DoF human shoulder joint movements (flexion/extension, abduction/adduction) for heterogeneous users with different levels of impairments.
- Our customized exoskeleton actuator is mounted on the back waist to minimize weight penalty caused by loads on distal body parts.

Lightweight and portable shoulder exoskeleton



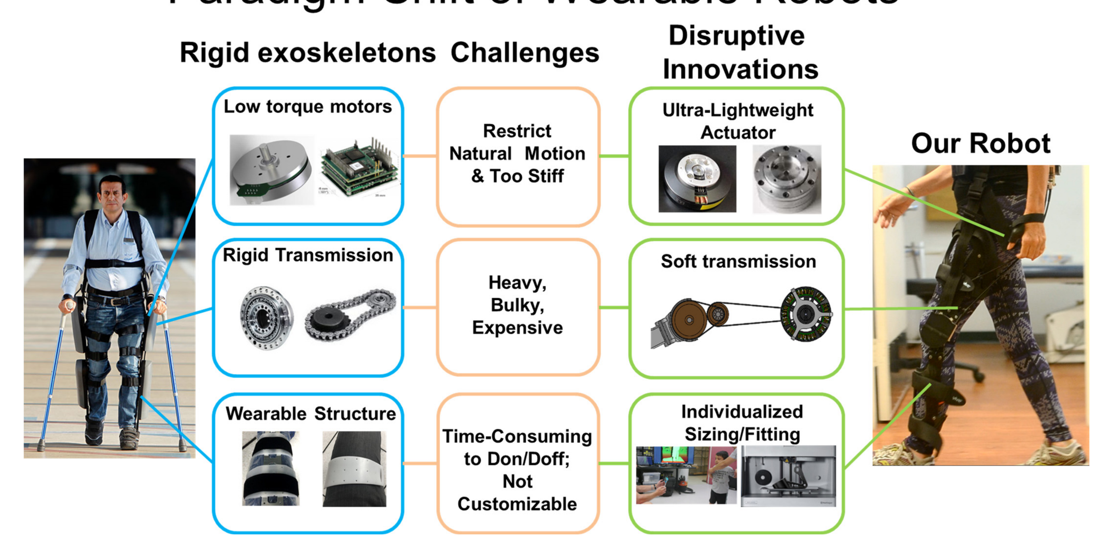
Evolution of exoskeleton design: transition from lab-based to real-life workplace oriented

Design evolutions towards real-life settings

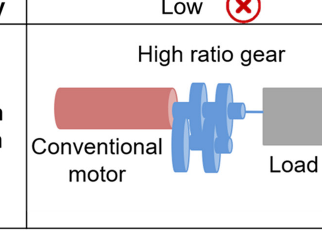
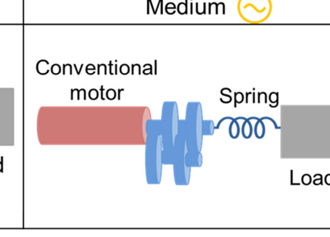
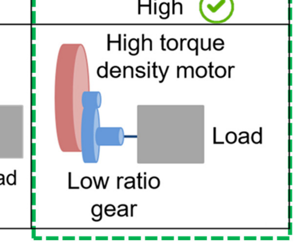
	Lab-based design	Current design	Future design
Weight	5 kg	3.5 kg	~2.2 kg
Portability	Tethered	Fully portable	Fully portable with increased comfort
Scenarios	Lab, clinic	Workplace, Warehouse, …	Workplace, Warehouse, Manufacturing factory, …
Hardware platform	Tethered to desktop PC	Wireless micro controller unit and laptop	Intuitive control via portable devices: phone, tablets,…

Soft Exoskeleton Innovations

Paradigm Shift of Wearable Robots



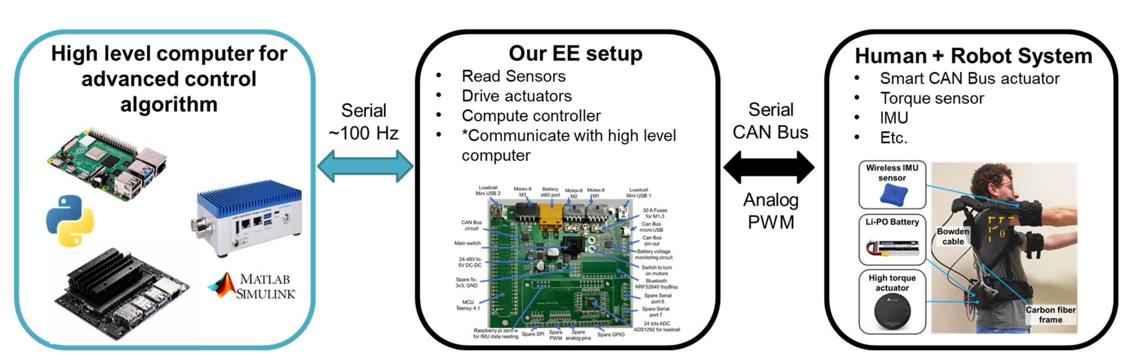
New Actuation Paradigm for Co-Robots

	Geared Motor with Force/Torque Sensor	Series Elastic Actuator	Quasi Direct Drive Actuator [Ours]
Compliance	Low	Medium	High
Bandwidth	High	Low	High
Efficiency	Low	Medium	High
Actuation Paradigm			

Portable and Expandable Electronics Architecture

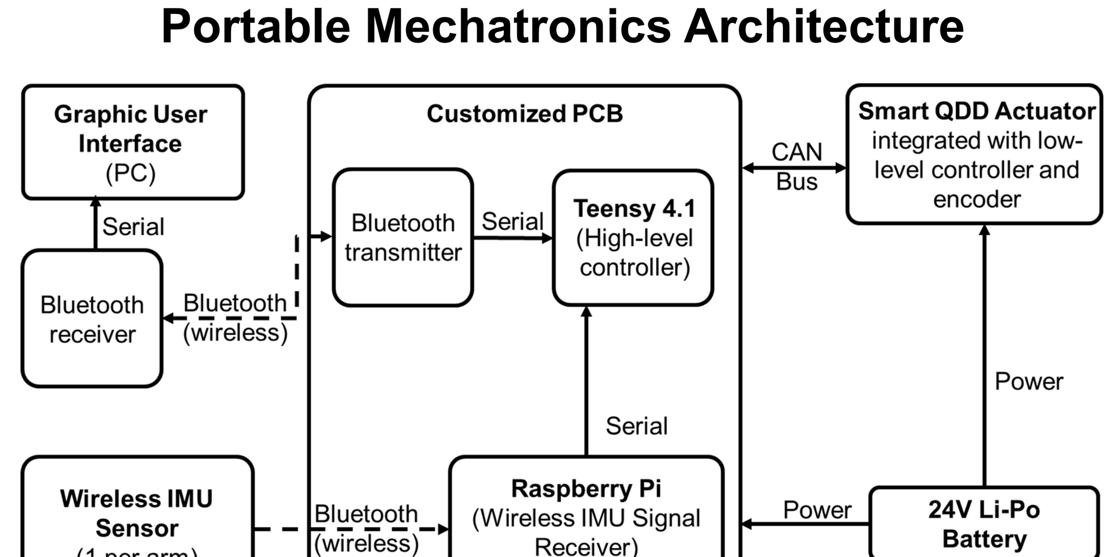
- We proposed a powerful electronics architecture using a hierarchical structure with a high-level computer and a low-level microcontroller.

System Control Architecture



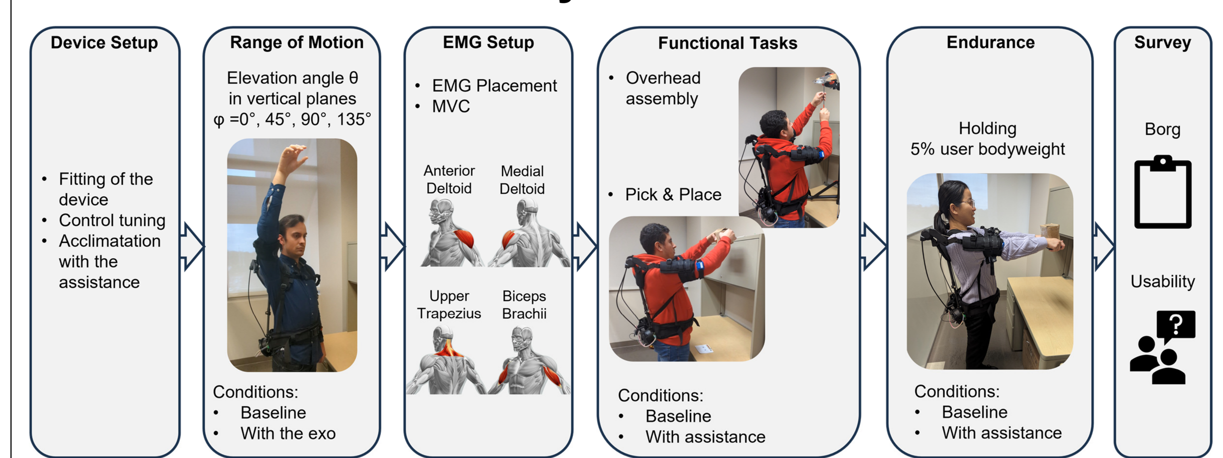
- It computes complex algorithms and improves the accuracy, speed, and efficiency of the exoskeleton's control system, leading to better performance, user experience, and safety.
- Our customized high-torque density motor and compact customized electronics maximize the portability and can handle AI computation workloads with various interfaces for multi-sensor infusion.

Portable Mechatronics Architecture

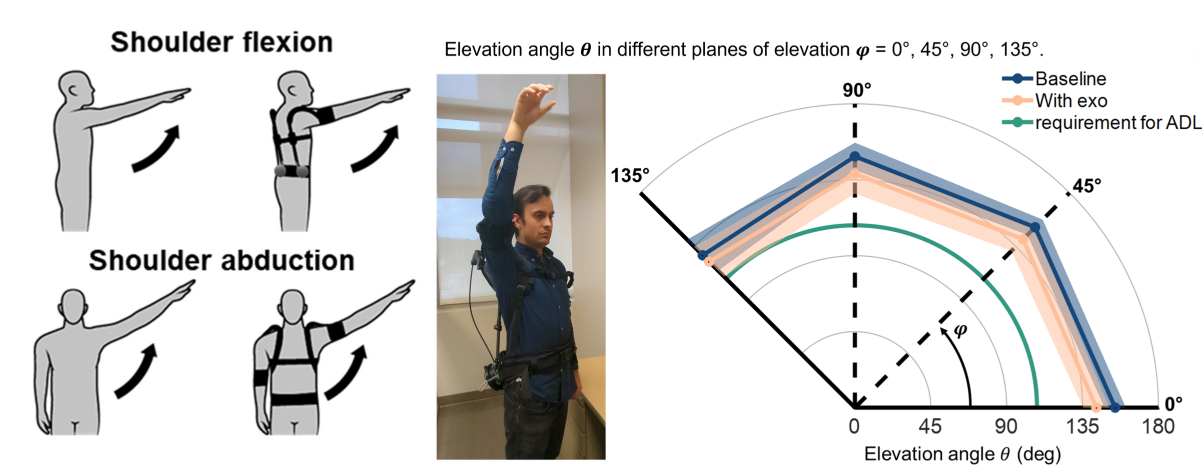


Preliminary Results

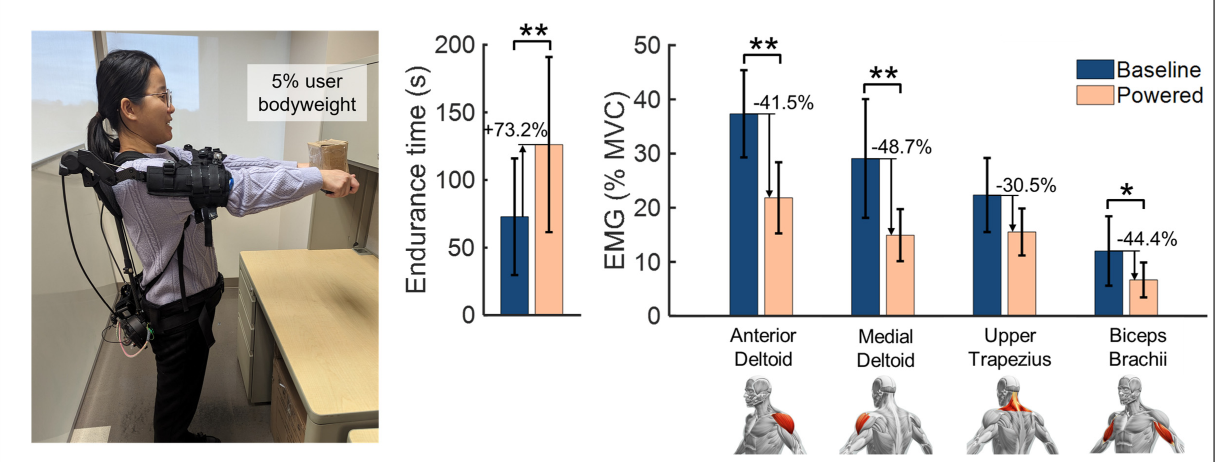
Study Protocol



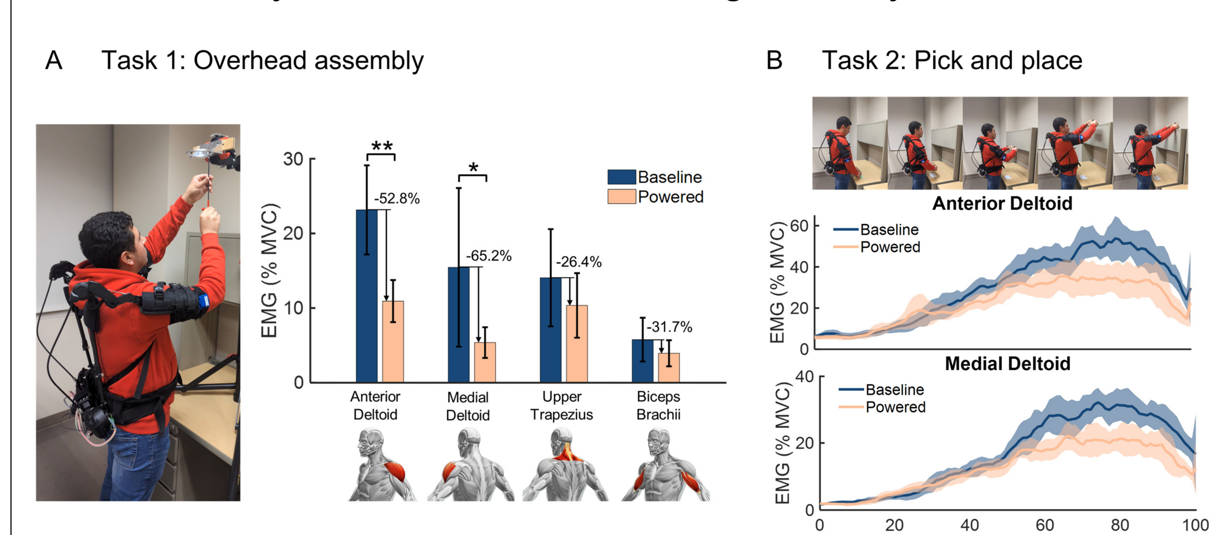
- The robot can assist both shoulder flexion, and abduction.



- Wearing the exoskeleton resulted in a slight reduction of the range of motion compared with the baseline condition (not wearing the device), but it did not compromise the possibility of performing most activities of daily living.

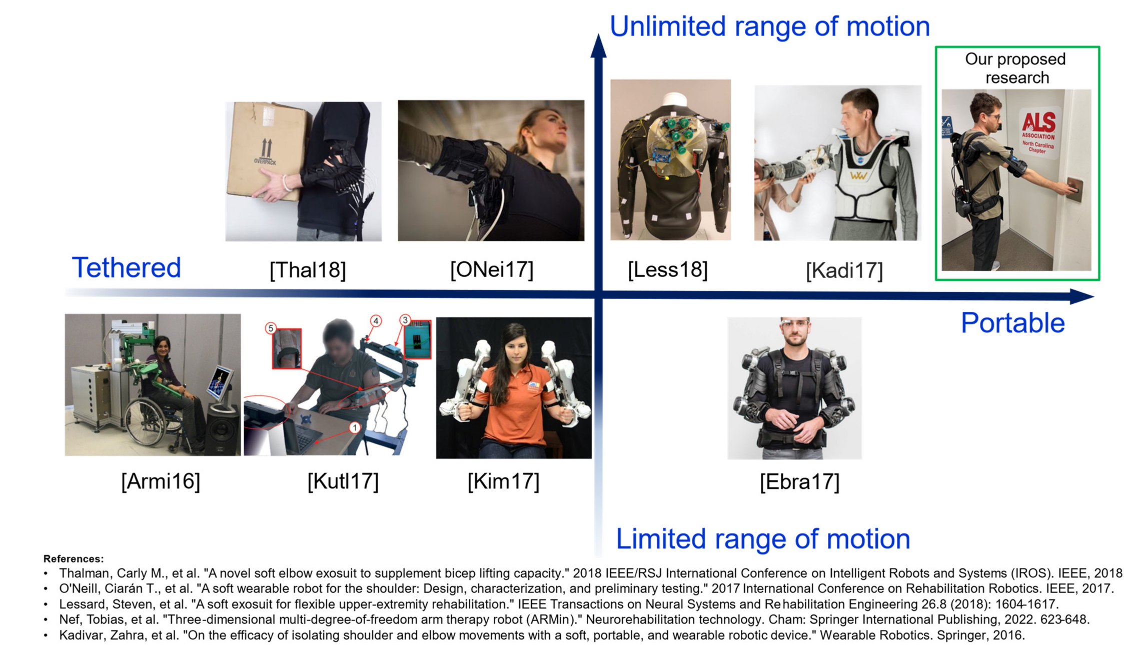


- The average endurance time increased from 73 s to 126 s (+73.2%) with assistance compared to not wearing the device. This result is supported by the fact that on average, the activity of recorded muscles significantly decrease



- For all the recorded muscles, muscle activity was reduced with exoskeleton assistance compared to the baseline condition without wearing the device. Average EMG reductions due to assistance were 52.8%, 65.2%, 26.4%, and 31.7% for anterior deltoid, medial deltoid, upper trapezius, and biceps brachii, respectively

Transition to Practice



- Despite the advances in assistive technologies, it is unclear whether upper-limb wearable robots can be truly useful in real-life workplaces.
- To this end, we will conduct in-field tests with our exoskeleton in both retail stores (with stroke survivors), warehouses (with able-bodied workers), at home (with ALS individuals) to establish the facilitate transitions to reality

- We will develop an application that can be utilized on tablets and cell phones with a graphic interface including an expert panel for analysis and remote control, and a user panel for intuitive control.

Publications

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4. Gao W, Di Lallo A, Su H, "A Portable Powered Soft Exoskeleton for Shoulder Assistance During Functional Movements: Design and Evaluation" International Symposium on Medical Robotics (ISMR), Georgia, USA, 2023.
5. Huang J, Gao W, Di Lallo A, Su H, "Design of Lightweight and Portable Soft Shoulder Exoskeleton in Community Settings" IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Michigan, USA, 2023.
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7. Luo S, Jiang M, Zhang S, Zhu J, Yu S, Dominguez Silva I, Wang T, Rouse E, Zhou B, Yuk H, Zhou X. Experiment-free exoskeleton assistance via learning in simulation. Nature. 2024 Jun 13;630(8016):353-9.