A Portable Powered Soft Exoskeleton for Shoulder Assistance During Functional Movements: Design and Evaluation

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OVERVIEW

- Work-related musculoskeletal disorders significantly impact workforce participation, creating socio-economic challenges for individuals and society. Upper-limb wearable robots have emerged as a potential solution, but shoulder assistance remains difficult due to its complex anatomy and high mobility.
- 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 soft shoulder exoskeleton and evaluated its performance using tangible metrics. Preliminary results indicate the potential of our robot to assist in daily functional movements and mitigate work-related injuries.

OUR MOST LIGHTWEIGHT AND PORTABLE SHOULDER EXOSKELETON

Exoskeleton Hardware

- We created our wearable robot that provides high torque assistance for 2 DoFs human shoulder joint movements (flexion/extension, abduction/adduction) for heterogeneous users with different levels of impairments.
- Our robot has a modular design and can be used for bilateral or unilateral assistance (e.g., stroke is hemiparesis and requires unilateral assistance).
- The customized exoskeleton actuator is mounted on the back waist to minimize weight penalty caused by loads on distal body parts.

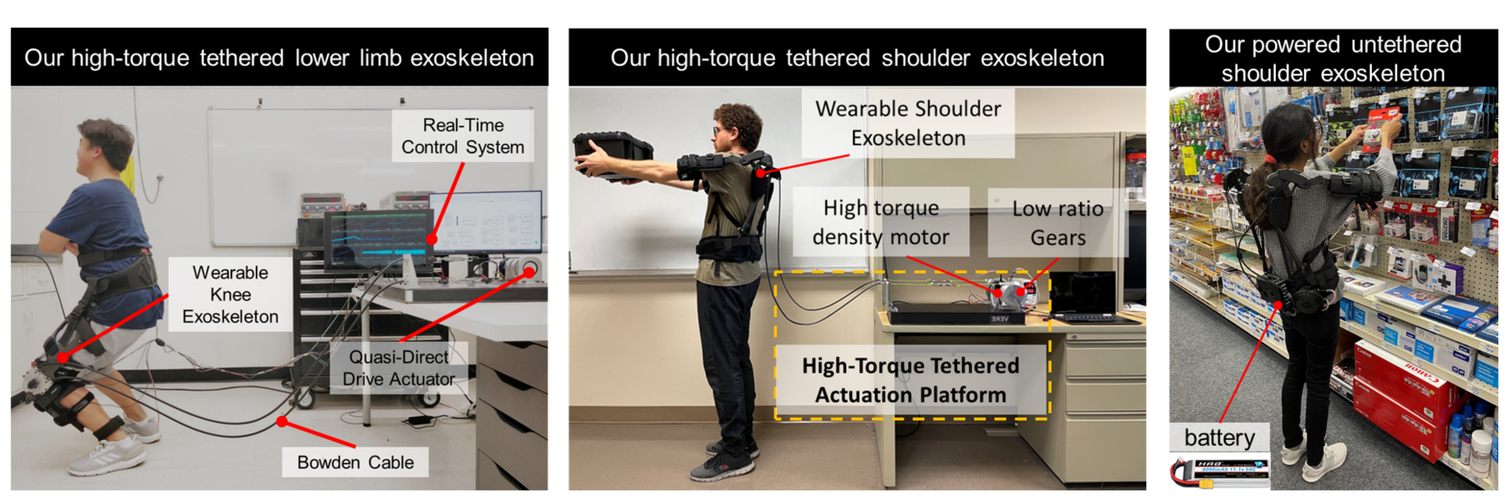


Figure 1. Evolution of exos design: transition from lab-based to real-life workplace oriented.

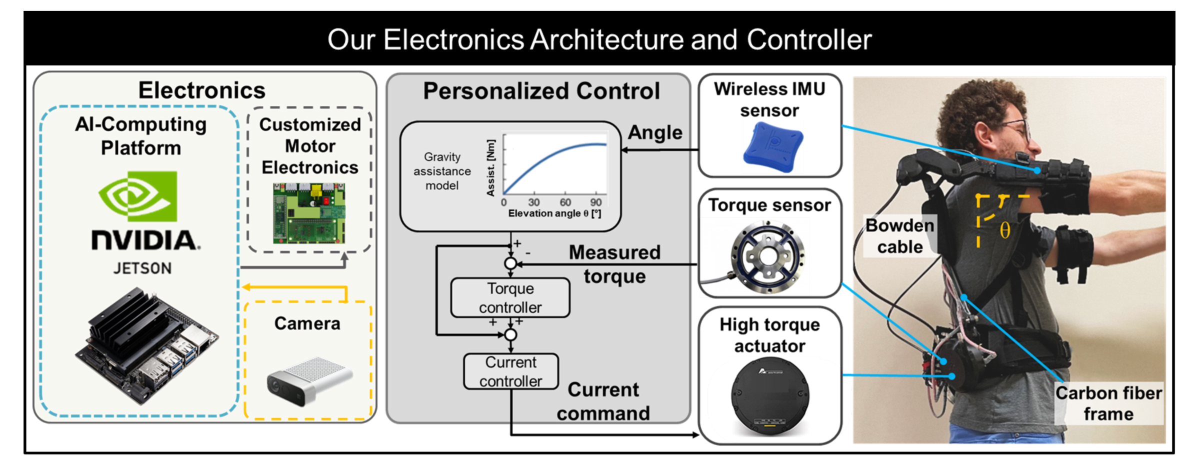
Design evolutions towards real-life settings

	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,…

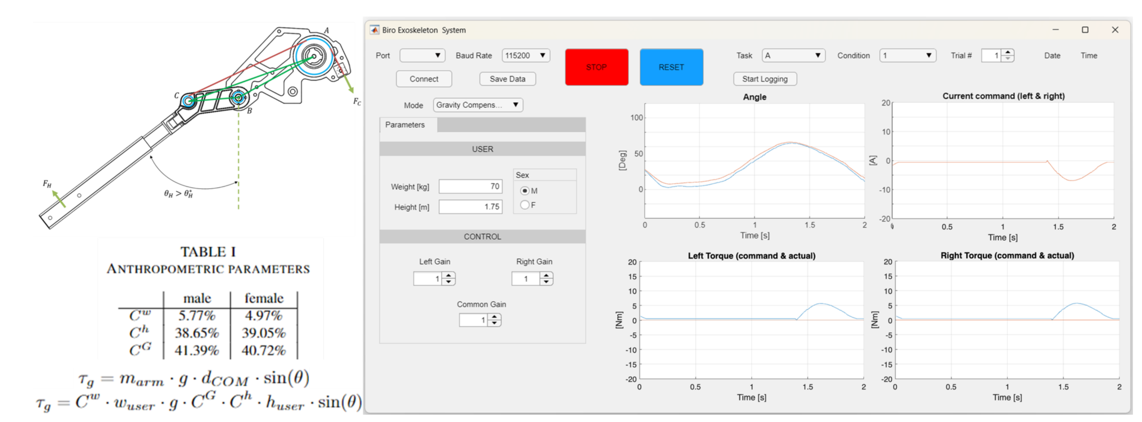
Figure 2. Improvements on our robot to enhance it practicalities in real-life workspace.

Controller and Software

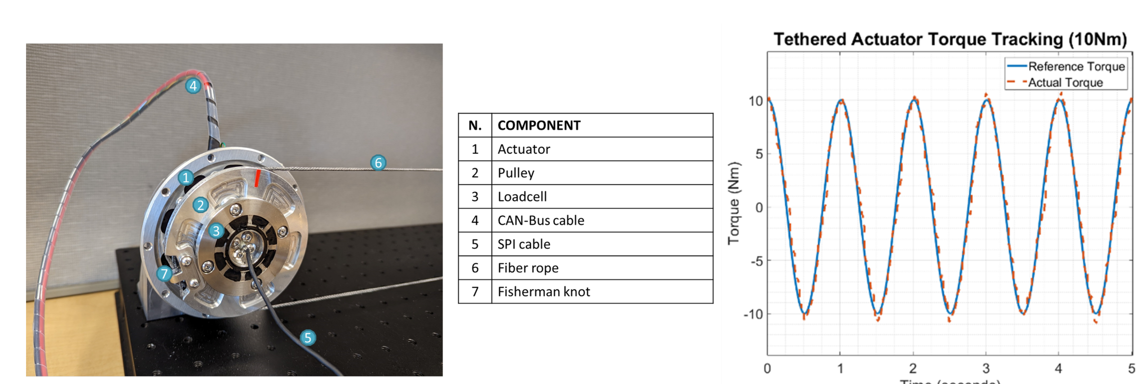
- Our customized high-torque density motor and compact customized electronics maximize the protability and can handle AI computation workloads with various interfaces for multi-sensor infusion.



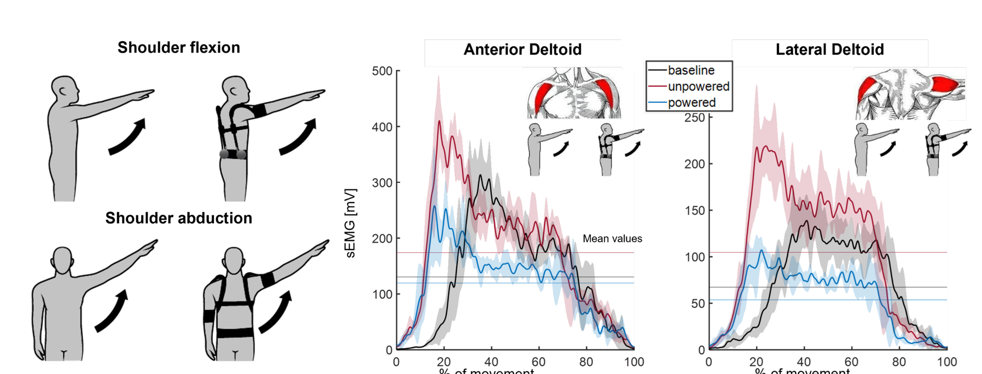
- We developed an intuitive control algorithm synergistic with human intention by detecting shoulder angles while arm elevation via wearable sensors and provide assistance by counterbalancing gravity forces .



PRELIMINARY RESULTS

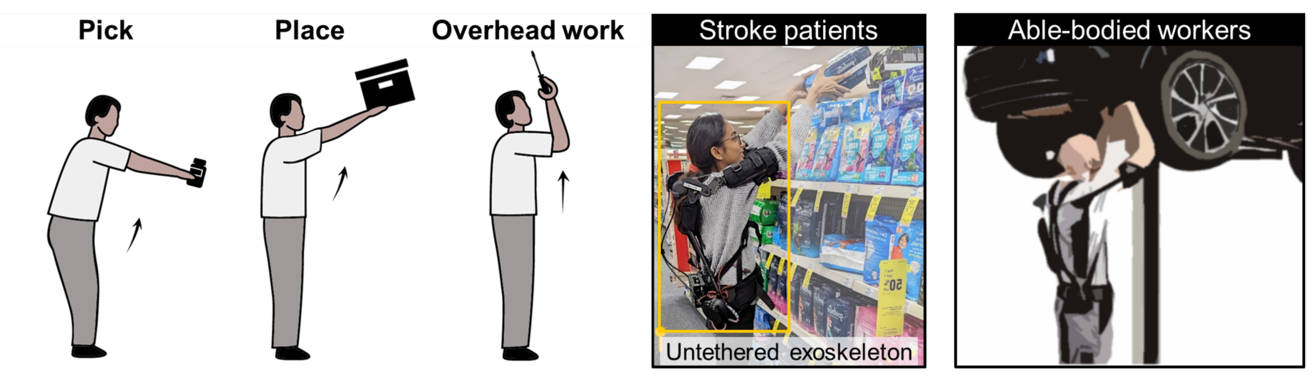


- We minimized deflection angle and applied pretension force to reduce friction and backlash in the Bowden cable system.
- Our biomechanics model-based control enables high accuracy in torque tracking, with a root mean square error of only 1.4% of the reference peak torque set at 10 Nm.



- The robot reduced muscle activation by 30% for the anterior deltoid and 52% for the lateral deltoid of able-bodied subject, showcasing its potential to decrease injury risk for able-bodied workers and aid upper-limb movement in individuals with impairments.

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.
- We plan to conduct in-field tests with our exo in both retail stores (with patients) and warehouses (with able-bodied workers) 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.
- This software will be compatible with multiple operating systems to enable accessibility from a variety of devices, like computers, tablets, and mobile phones.

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