# User-Adaptive Variable Impedance Control of a Wearable Upper-Extremity Exoskeleton Robot with Safety Guarantees

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## Challenges in Physical Human-Robot Interaction (pHRI)

· Primarily focused on designing robots that are energetically dissipative to the human users in order to secure coupled stability, but at the expense of system transparency and agility.

· Safety has been mainly considered in the context of collision avoidance without considering other factors important for the prevention of musculoskeletal disorders (MSDs).

## Scientific Impact

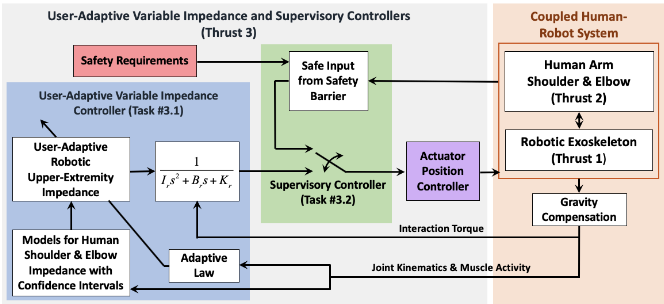
· The proposed human-in-the-loop controller will transform the way coupled stability in pHRI is achieved, letting the robot be less conservative to improve agility/transparency of the human-robot system without compromising its stability.

· The proposed supervisory control can lead to a paradigm shift towards a controller-centric approach to ensuring safety in pHRI to complement safety considerations through mechanical design.

## Solution

· A **user-adaptive variable impedance controller** will enhance transparency and agility of the coupled human-robot system by incorporating the user's intent of movement and estimates of human mechanical impedance.

· A high-level **supervisory controller** based on the synthesis of robust controlled invariant safety sets will prevent the coupled human-robot system from reaching any unsafe configurations.



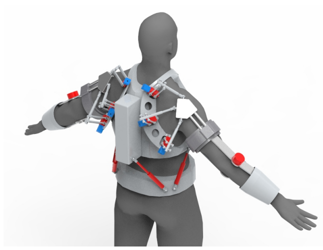



Illustration of the wearable upper-extremity exoskeleton robot with a *hybrid* (parallel and serial) actuation mechanism.

## Broader Impact on Society

· Potential to reduce work related MSDs, while increasing productivity and decreasing healthcare cost of industrial workers and employers.

· Potential to benefit human-robot systems in clinical and military applications.

## Broader Impact on Education

· Mentoring underrepresented undergraduate students and high school students in the local community.

· Developing a new graduate-level course on "Adaptive and robust control."

· Outreach activities for K-12 students.

## Quantification of Broader Impact

· This research has a potential to decrease the workers' likelihood of developing new MSDs or exacerbating existing MSDs, which account for 33% of all worker injury and illness cases, incurring a loss of more than $200 billion annually.

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