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)

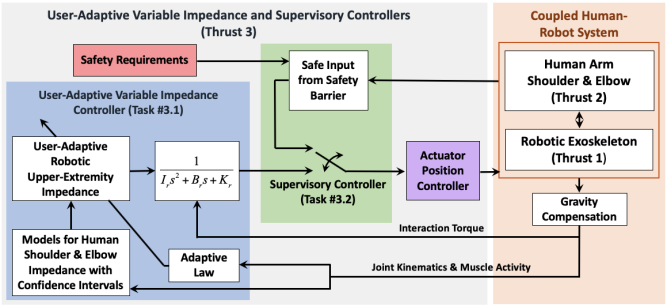
- Primarily focused on designing robots that are energetically dissipative to the human users in order to secure coupled stability, but at the expense of system transparency and agility.
- Safety has been mainly considered in the context of collision avoidance without considering other factors important for the prevention of musculoskeletal disorders (MSDs).

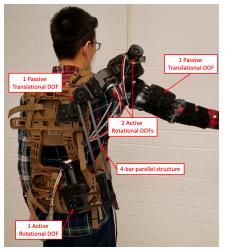
Scientific Impact

- 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

- **User-adaptive variable impedance controller**: Incorporates user intent of movement and limb/joint biomechanics to enhance transparency and agility of the coupled human-robot system.
- **High-level supervisory controller**: Synthesizes robust controlled invariant safety sets to prevent the coupled human-robot system from reaching any unsafe or awkward configurations.





Initial prototype 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.
- Redesigning a graduate-level course on "Modern Control and Estimation."
- Outreach activities for K-12 students.

Quantification of Broader Impact

- This research has the 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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