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)

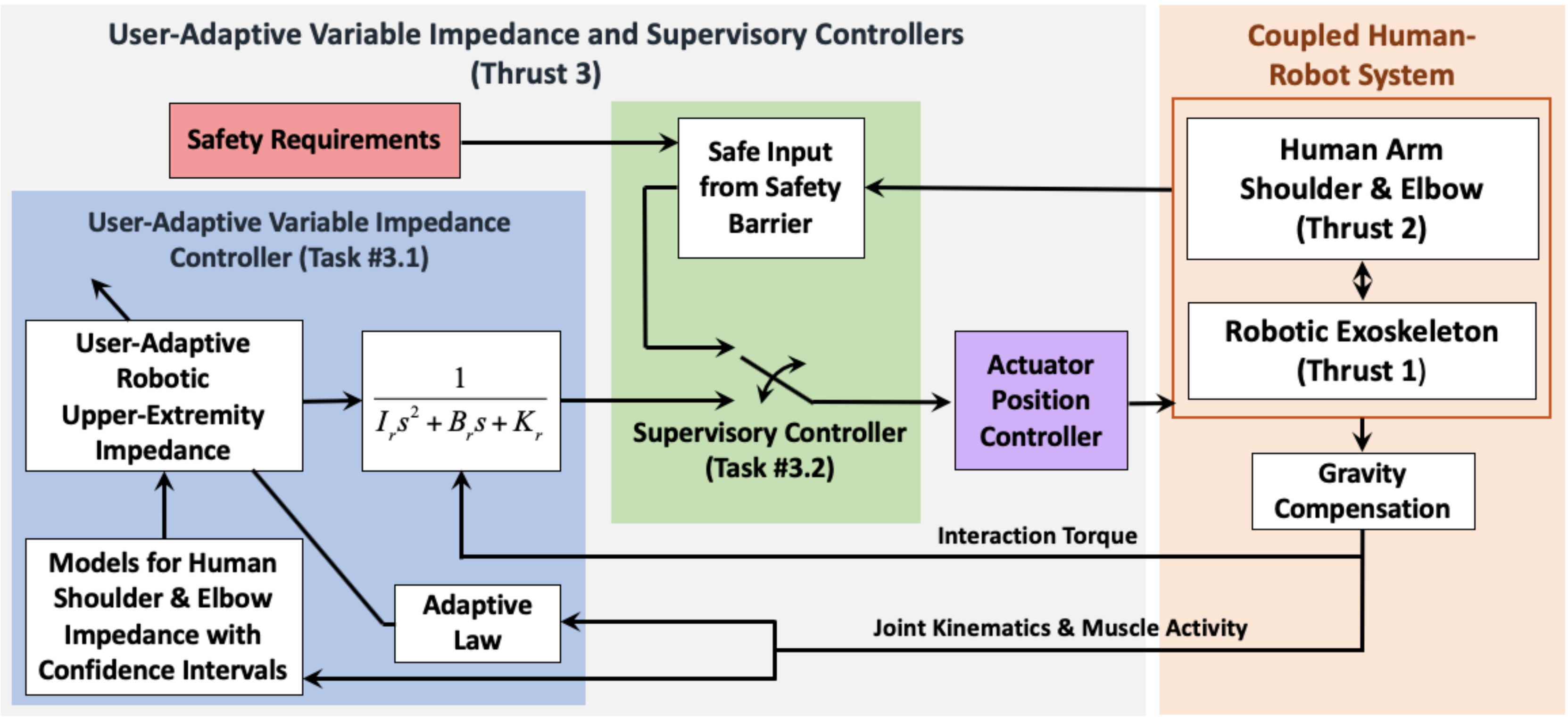
- Primarily focused on designing robots that are energetically dissipative to the human users in order to secure coupled stability, but at the expense of system transparency and agility.
- Safety has been mainly considered in the context of collision avoidance without considering other factors important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

Solution

- **Biomechanics-Based User-Adaptive Impedance Controller**: Dynamically modulate stiffness and damping of the robotic impedance controller by incorporating user intent of movement and limb/joint biomechanics
  → Improves the trade-off between stability and agility in coupled human-robot systems and reduce the human user's effort.
- **Control Barrier Function (CBF)-Based Safety Controller:** Synthesize robust controlled invariant safety sets to prevent the coupled human-robot system from reaching any unsafe or awkward configurations
  → Our proposed robust CBFs based on mixed monotonicity and duality with parameter set estimation generally outperforms adaptive CBFs in the literature while guaranteeing robust safety.

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.



Wearable upper-extremity exoskeleton robot with a *hybrid* actuation mechanism.

Broader Impact on Society

- Potential to reduce work related MSDs (accounting for 33% of all worker injury and illness cases, incurring a loss of more than $200 billion annually), while increasing productivity and decreasing healthcare cost of industrial workers and employers.
- Potential to benefit human-robot systems in clinical and military applications.

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