Supernumerary Robotic Limbs (SRLs) for Next Generation Space Suit Technology

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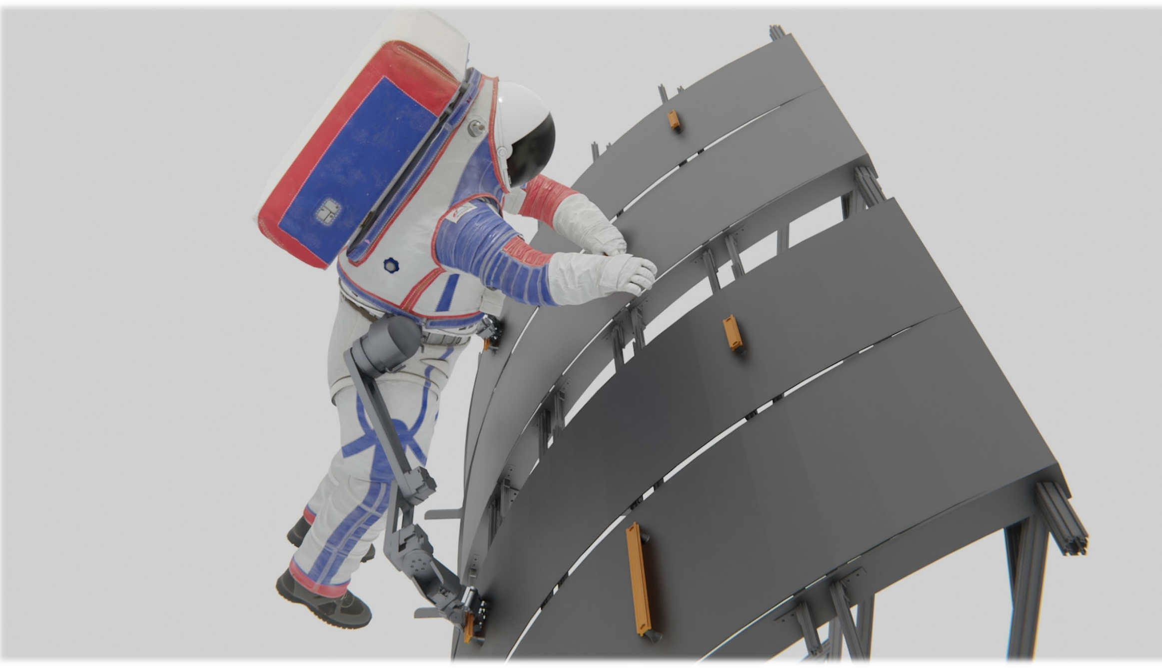
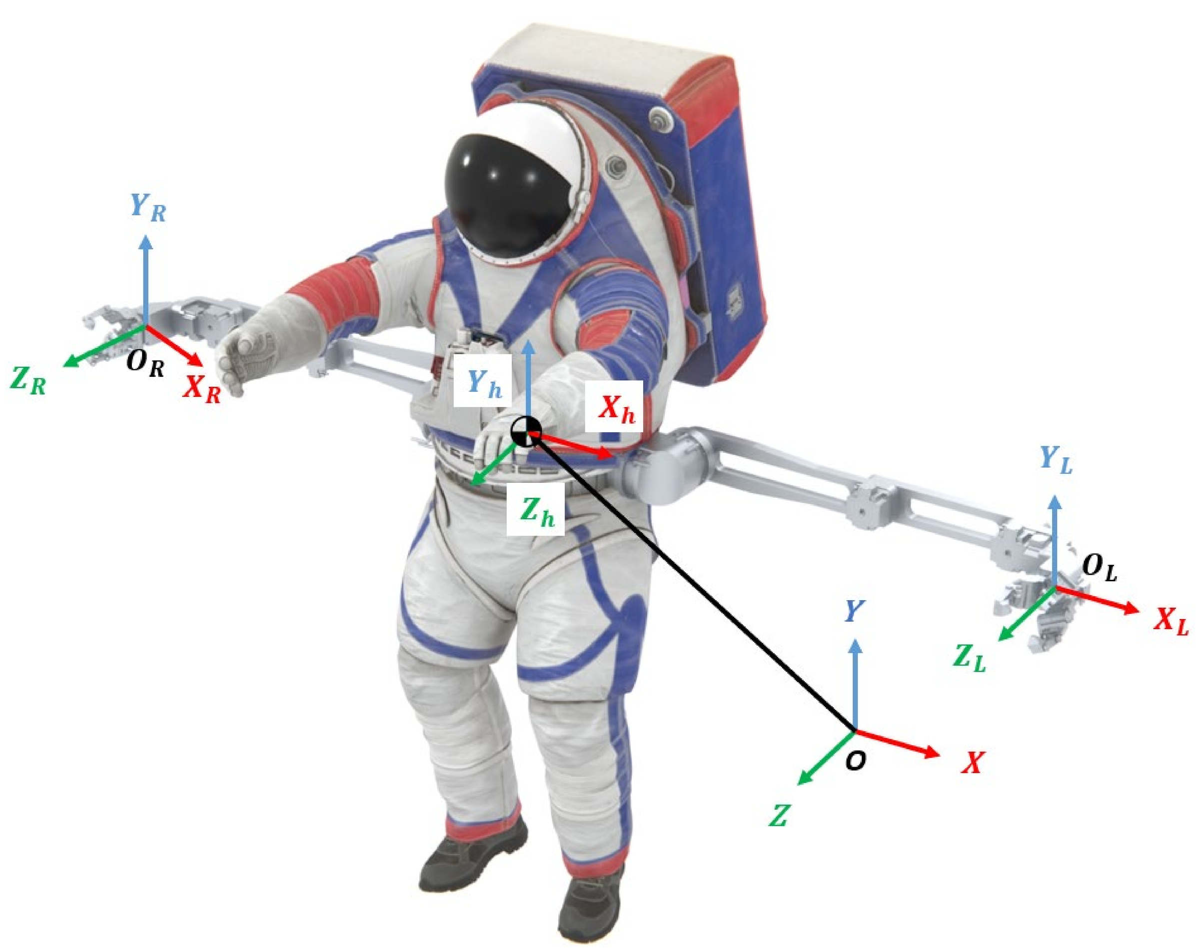




Motivation

Better ergonomics for Extra-Vehicular Activities (EVAs)

- **Significant risks are present concerning astronaut ergonomics/safety during EVAs**
- Space suits restrict an astronaut's mobility, leading to safety and reliability risks
- Current practices (foot-restraints) partially address the issue, but are cumbersome and time consuming to utilize

Objectives

Augment astronaut's EVA capabilities to perform:

- **Tethering and bracing anywhere**
- **Inertial Mass Reduction**

Astronaut Augmentation

Human-Robot Interaction User Interface

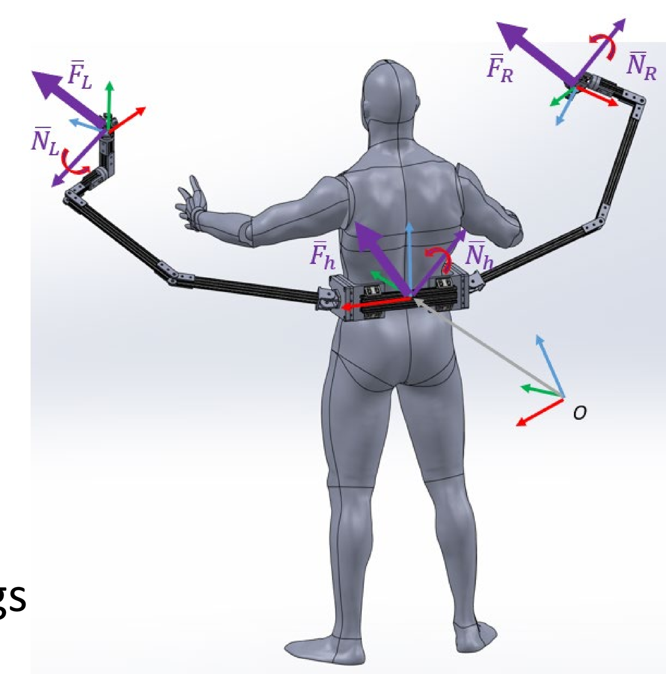
- The right and left SRLs when statically bracing the astronaut forms a closed-loop kinematic chain
- The collaborative configuration can be exploited to estimate the forces exerted by the astronaut and utilized as a control input

$$\widehat{\boldsymbol{F}_h} = -S_R \boldsymbol{F}_{\boldsymbol{R}}^{\boldsymbol{R}} - S_L \boldsymbol{F}_{\boldsymbol{L}}^{\boldsymbol{L}}$$

$\widehat{\boldsymbol{F}_h}$: Human input force estimate

$S_{R,L}$: End-Effector -> Human Centered Frame Transformation Matrices

$\boldsymbol{F}_{\boldsymbol{R,L}}^{\boldsymbol{R,L}}$: 6-axis force sensor readings at End-Effector

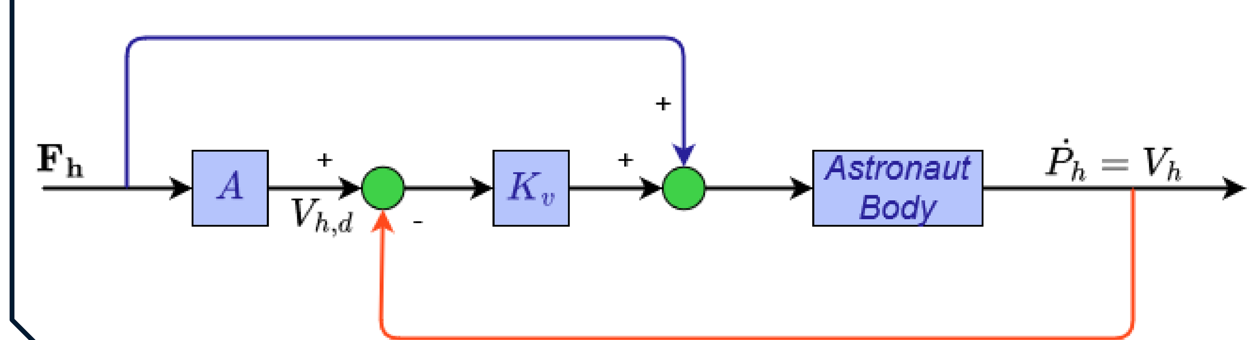


Control

- An admittance controller with force feedforward creates the **Admittance Control Synthesis Scheme (ACSS)**

$$V_h = \left[{K_v}^{-1} M s + I\right]^{-1} (1-\eta) \boldsymbol{F}_{\boldsymbol{h}}$$

- Mass term attenuated by gain matrix K_v
- Disturbance rejection of entire human-robot system tunable by η



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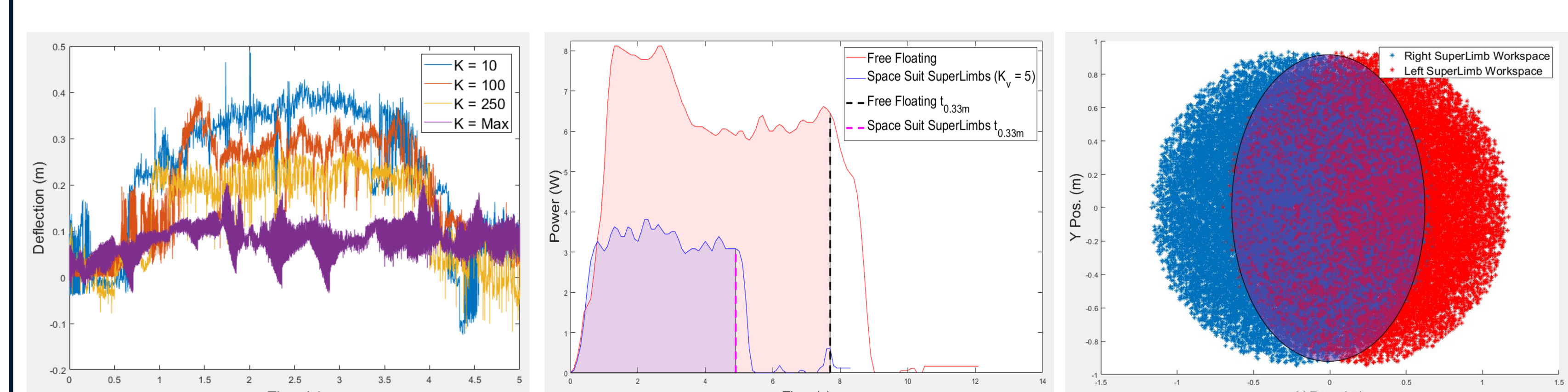
Experimental Design and Results

Experimental Design

- Prescribed pushing of prototype Center of Mass (CoM) to measure deflection with varying compliance control gains
- Measure work required to translate prototype CoM 1 m with varying admittance control gains

Results



- Static bracing effective and tunable by **disturbance rejection**
- Effective inertial felt by astronaut attenuated with SRLs
- Working envelop of astronauts expanded by SRL workspace

Conclusions

Space Suit SuperLimbs is a novel approach to human-robot collaboration. With two SRLs rigidly fixed to an astronaut's body in a micro-gravity environment, the astronaut can **be safely tethered anywhere during an EVA**, shown by the effectiveness of the manipulators to statically brace their body and expand their working envelop. In addition, the **astronaut's effective inertial mass can be attenuated** through implementation of the ACSS, thus **reducing energy consumption** during transfer operations between worksites.