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Unleashing Fluid-driven Soft Wearable Robots

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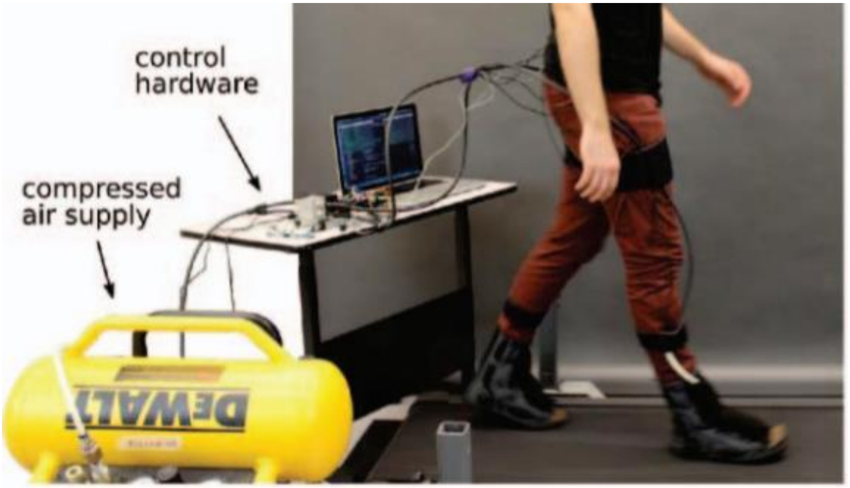
Motivation

- Human movement is characterized by **high joint torques**. Moderate level of assistance (30% of biological torque) requires forces higher than 200 N.

Walking (1.1m/s)	*Hip*	*Knee*	*Ankle*
Biological (70.9kg)			
Peak Torque (Nm)	64	35	92
Desired (30% of Biological)			
Peak Torque (Nm)	19.2	10.5	27.6
Moment Arm (m)	0.08	0.05	0.07
Peak Force (N)	240	210	394

- Conventional hardware of soft actuators for wearable robots requires a complex assemblage of motor, pump, valves and sensors, often resulting in **large and bulky systems**.

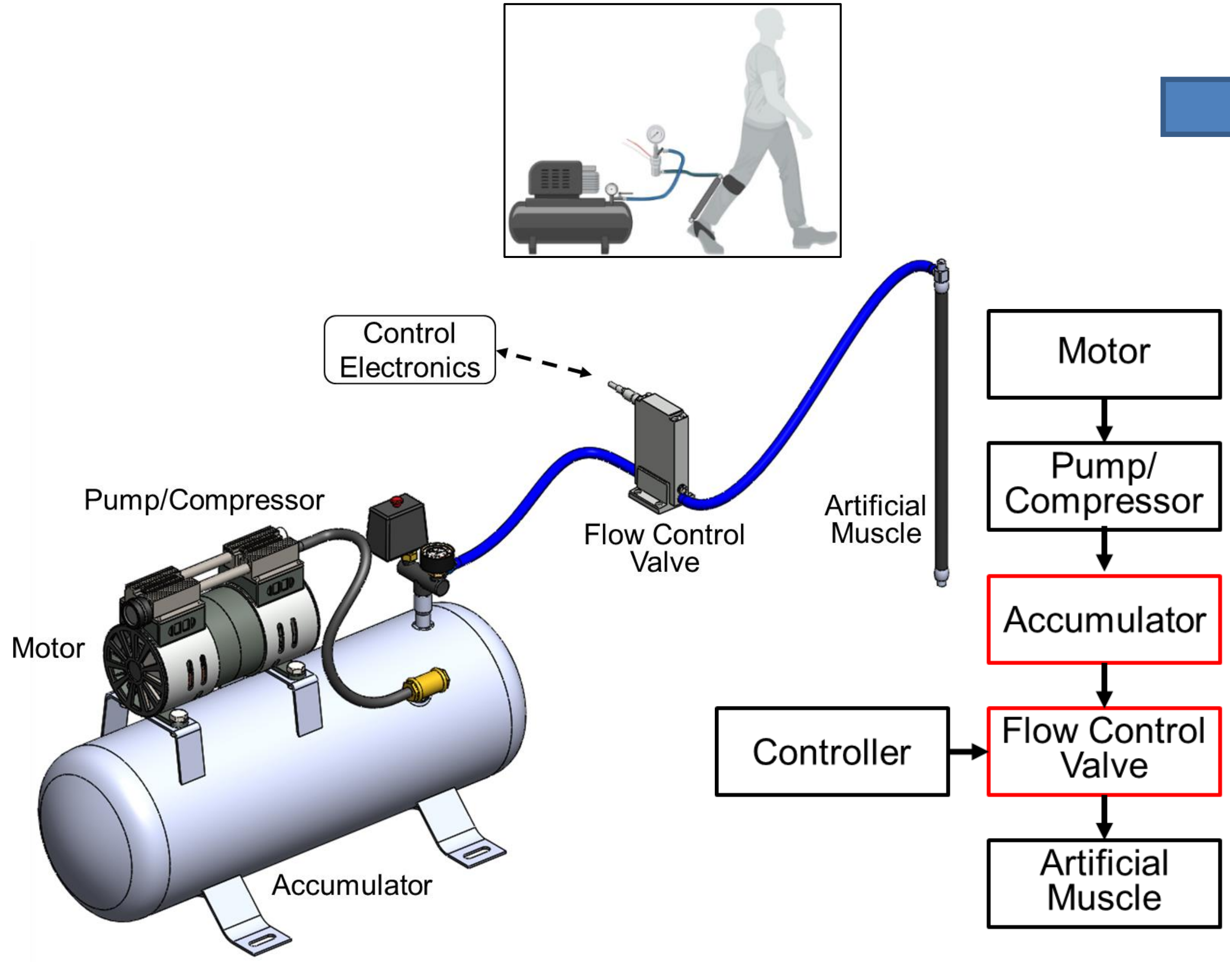


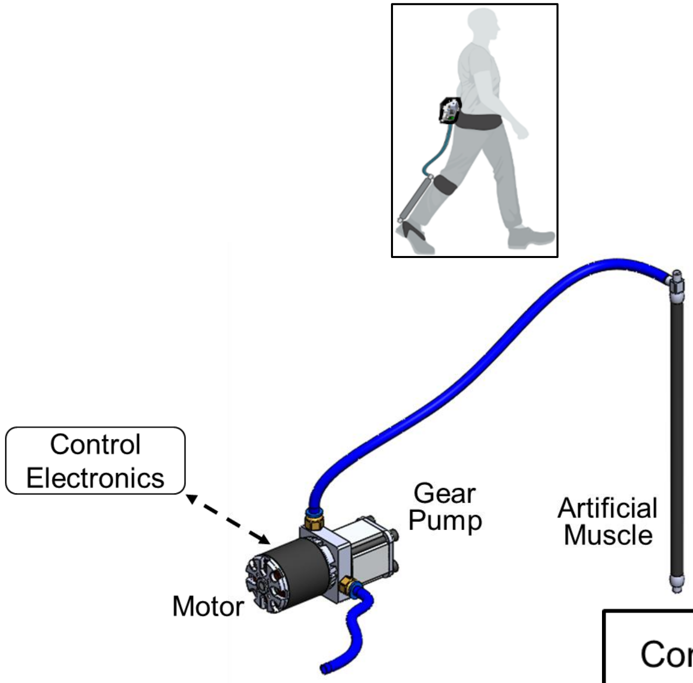
Need for forms of actuation that enable untethered and high force soft robots

Di Lallo A, Yu S, Slightam J, Gu GX, Yin J, Su H. Untethered Fluidic Engine for High-Force Soft Wearable Robots. Advanced Intelligent Systems 2024. In Press
Chung J, Heimgartner R, O'Neill CT, Phipps NS, Walsh CJ. Exoboot, a soft inflatable robotic boot to assist ankle during walking: Design, characterization and preliminary tests. In2018 7th IEEE International Conference on Biomedical Robotics and Biomechatronics (Biorob) 2018 IEEE.

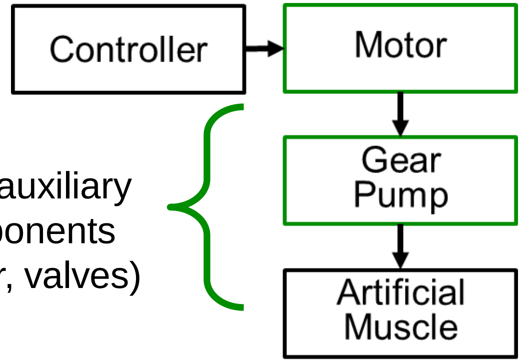
Scope of the Work

Development of a portable solution for **untethered** actuation of a soft artificial muscle with **human-scale force** capability.





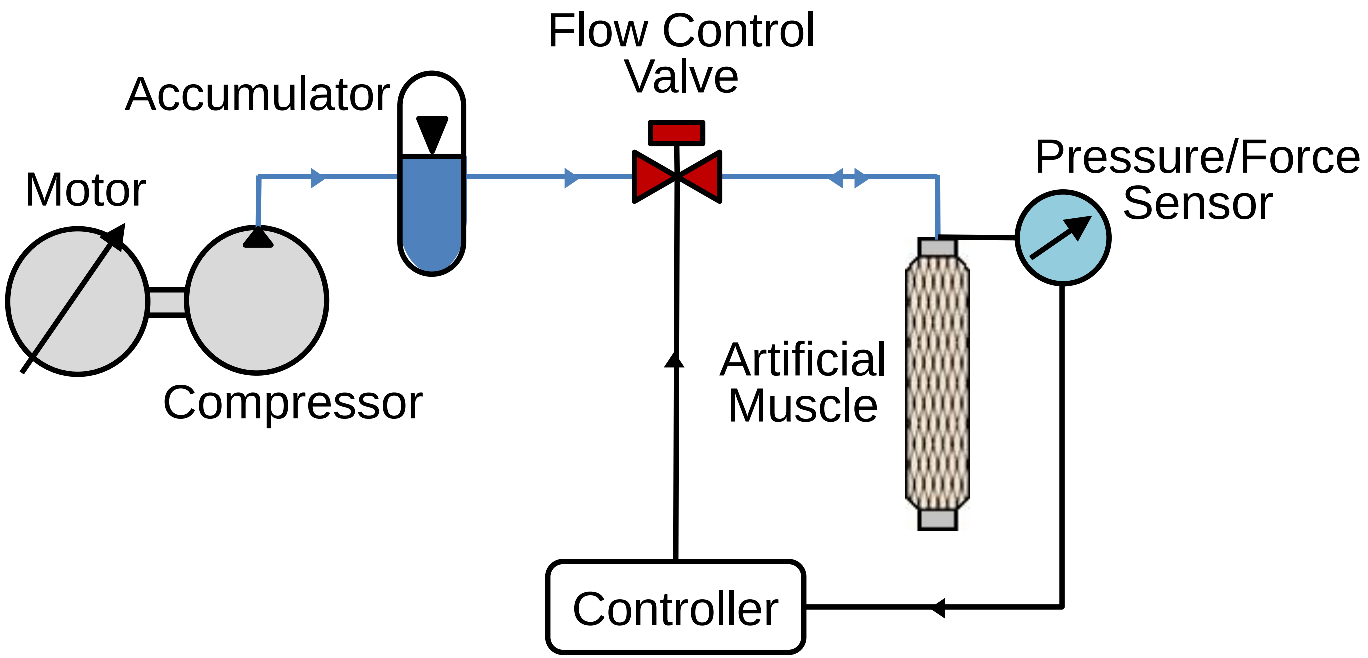
No need for auxiliary control components (accumulator, valves)



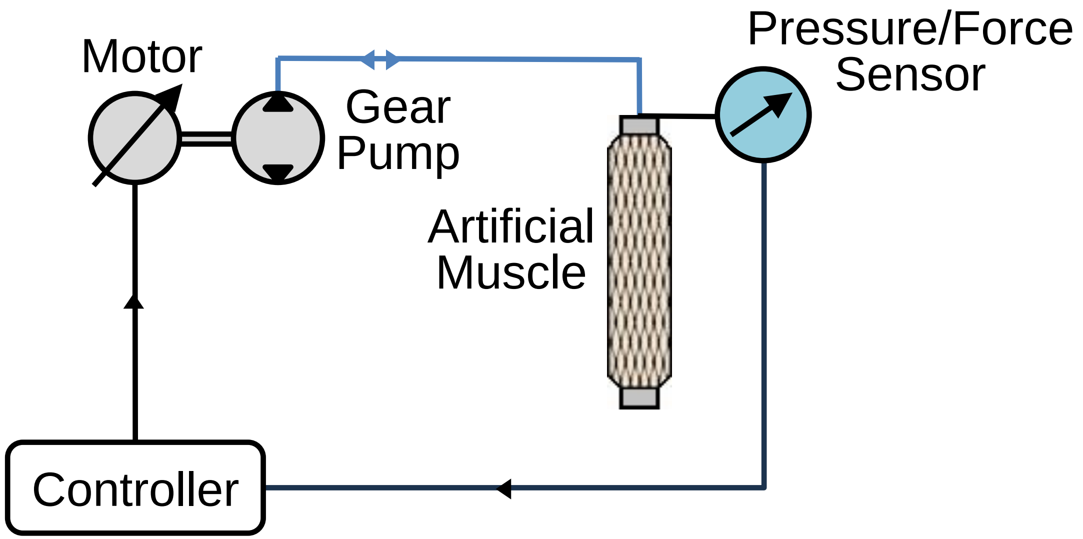
Conceptual Design

- From a valve-controlled architecture to a pump-controlled architecture, without interposition of auxiliary components (i.e., accumulator and solenoid valve) between the fluidic engine and the artificial muscle.

Conventional Valve-Controlled Architecture

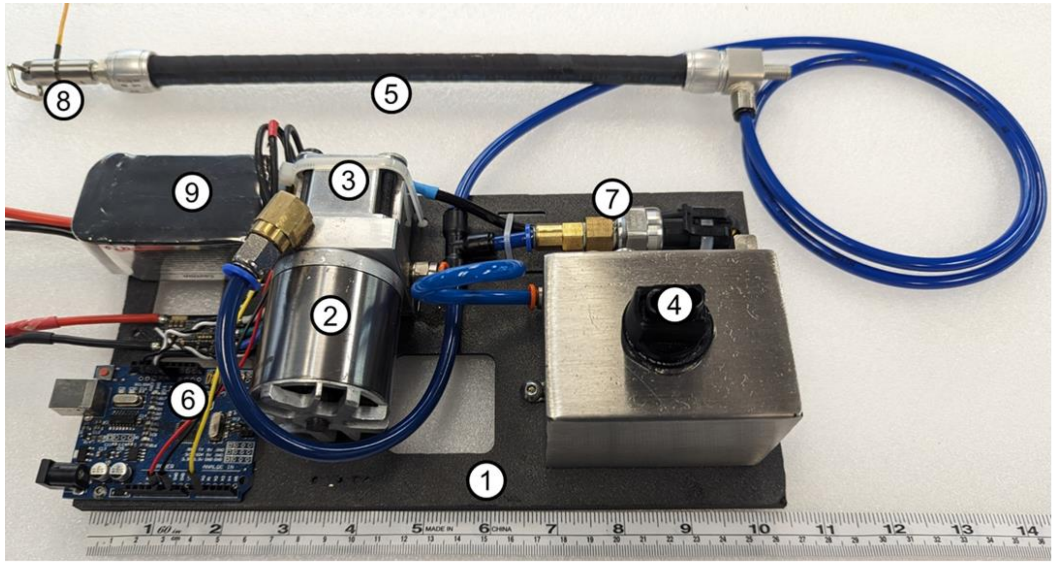


Proposed Pump-Controlled Architecture

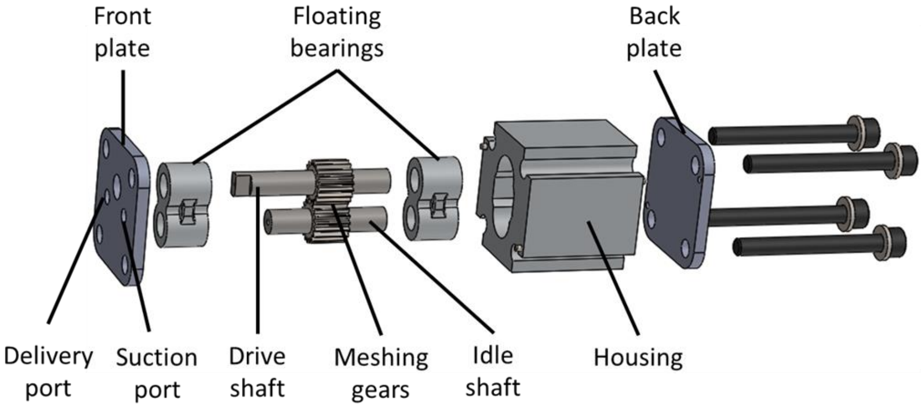


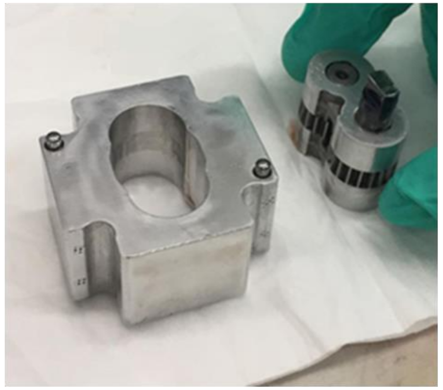
Mechatronics Design

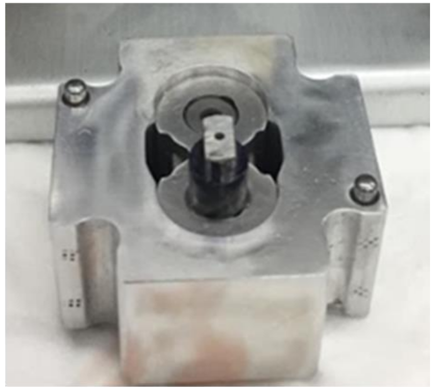
- Integrated solution combining a high-torque motor with a customized gear pump



N.	Part	Mass (kg)	Mass (%)	
	Mechanical Components			
1	Support Base	0.11	7	1.19 kg (72%)
2	Motor	0.45	27	
3	Pump	0.30	18	
4	Fluid Tank	0.25	15	
5	Soft Actuator	0.08	5	
	Electrical Components			
6	Controller	0.08	5	0.45 kg (28%)
7	Pressure Sensor	0.07	4	
8	Force Sensor	0.01	1	
9	Battery	0.29	18	
	Total			**1.64 kg**







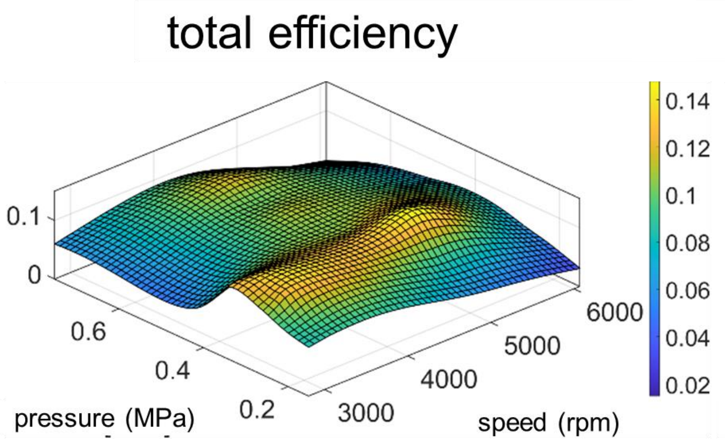
Experimental Evaluation

- Energy efficiency of the fluidic engine

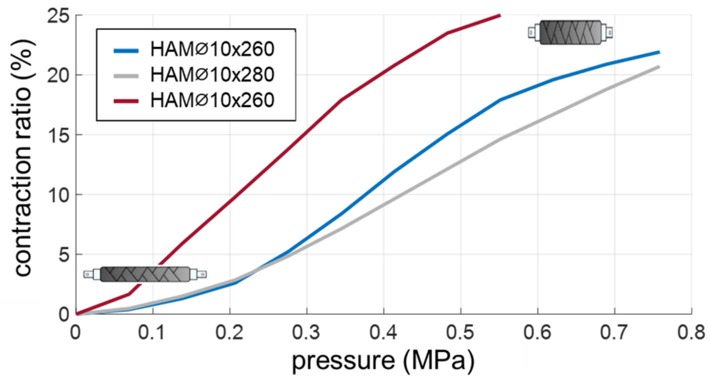
Motor-pump Efficiency

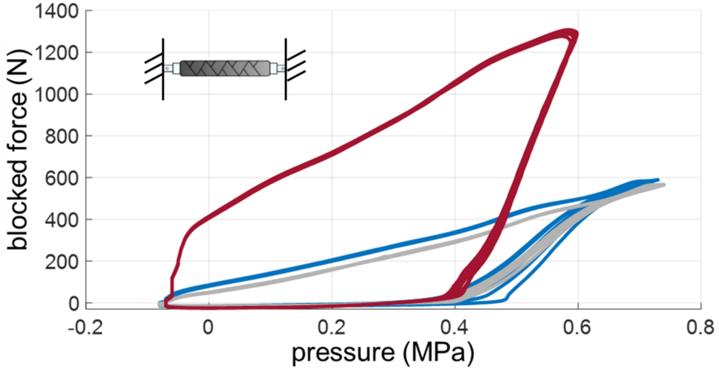
$$\eta_t = \frac{\text{Output Fluidic power}}{\text{Input Electrical power}} = \eta_\mathrm{m}\eta_\mathrm{p} = \frac{Q\Delta p}{VI}$$

Motor Efficiency	Pump Efficiency
$\eta_\mathrm{m} = \frac{\tau\omega}{VI}$	$\eta_\mathrm{p} = \frac{Q\Delta p}{\tau\omega}$

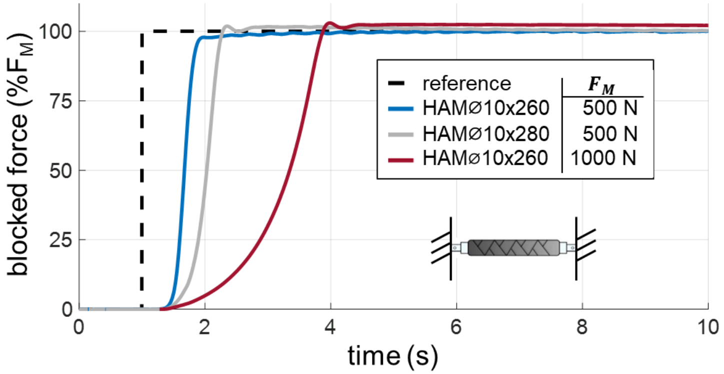


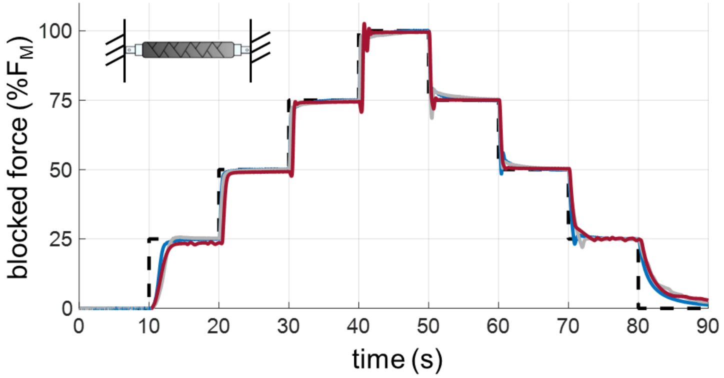
- Force-displacement characterization





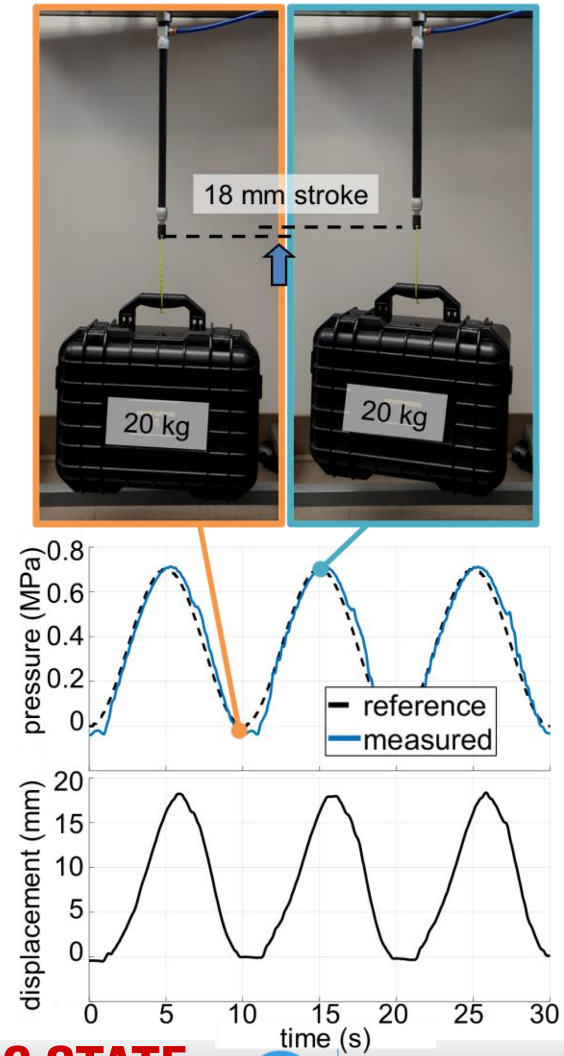
- Closed-loop force control



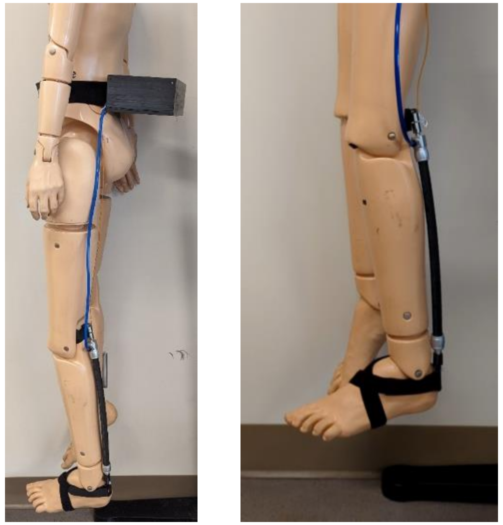


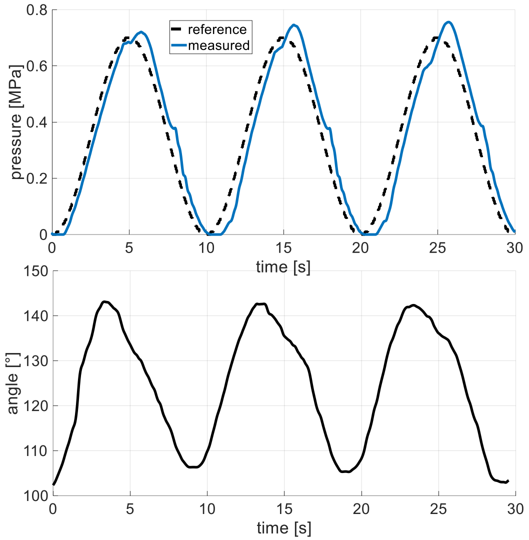
Proof-of-Concept Demonstrations

High Force

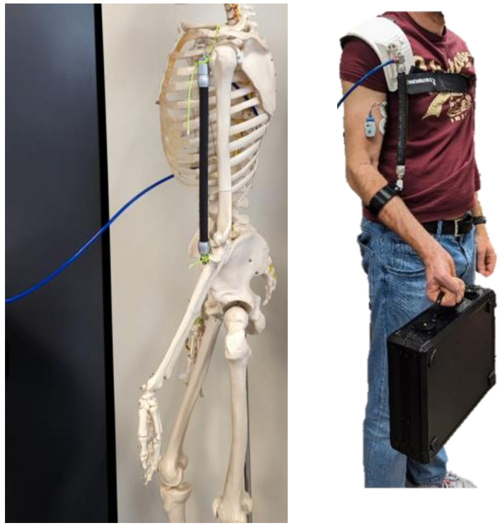


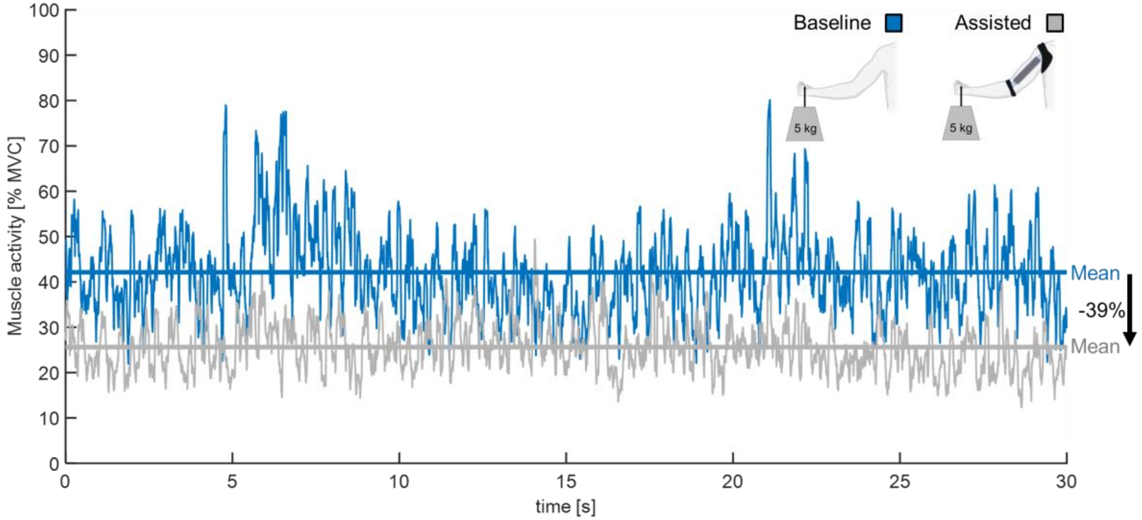
Lower limb assistance





Upper limb assistance





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