CAREER: Bio-inspired Multi-joint Design and Control of Wearable Robots

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Problem Statement

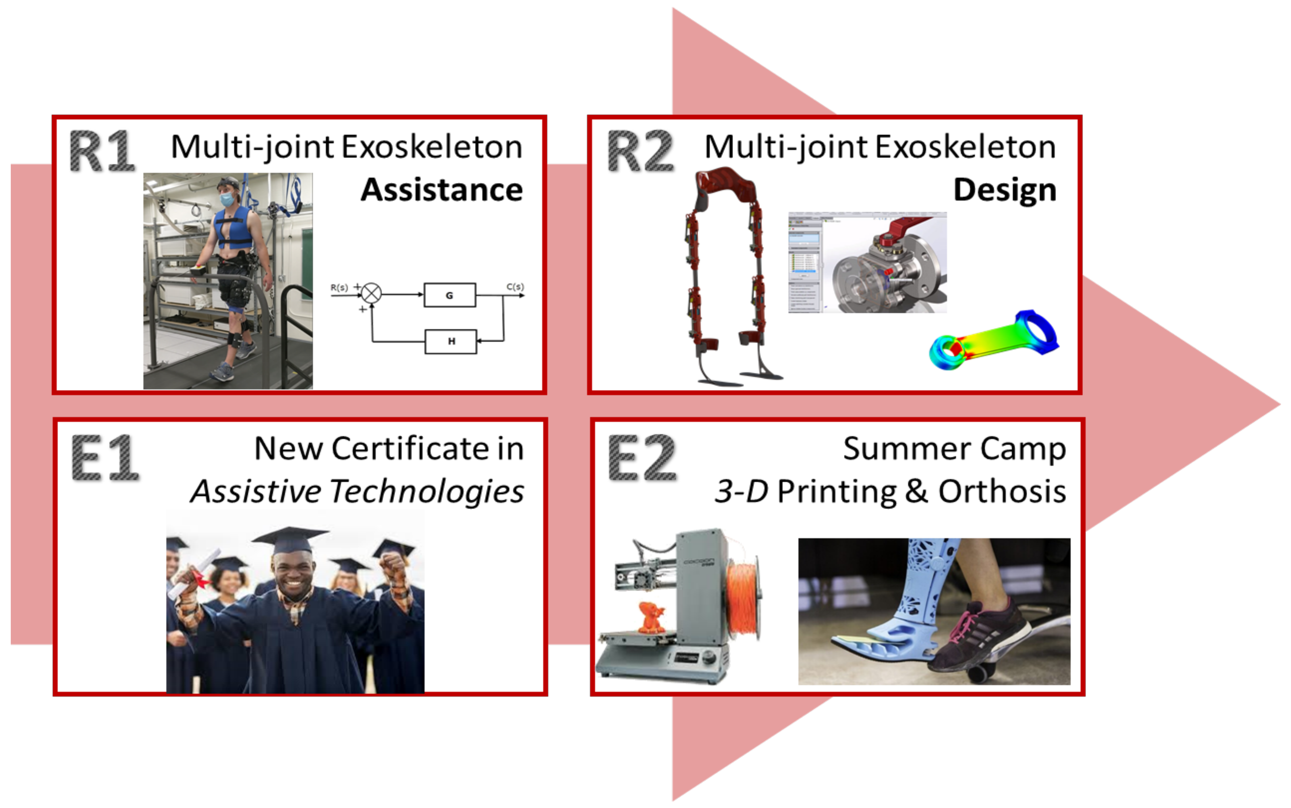
Existing powered exoskeletons are heavy and inefficient, which largely prevents them from being used in real life. Human ambulation is highly efficient because of the passive dynamics of the leg and the elastic properties of the muscles, and also because many muscles span multiple joints, actively transferring energy between joints. In contrast, powered exoskeletons are typically designed and controlled considering each actuated joint as a separate unit, independent from the others, even when multiple joints are actuated.

Solution Statement

Develop **energy-conserving mechanisms and control algorithms** inspired by the multi-joint configuration of the human musculoskeletal system and the natural gait dynamics.

Central Hypothesis

Optimizing the dynamic exchange of energy between multiple joints will result in superior powered exoskeletons—in terms of size, weight, and performance—compared to considering each actuated joint separately.



Scientific Impact

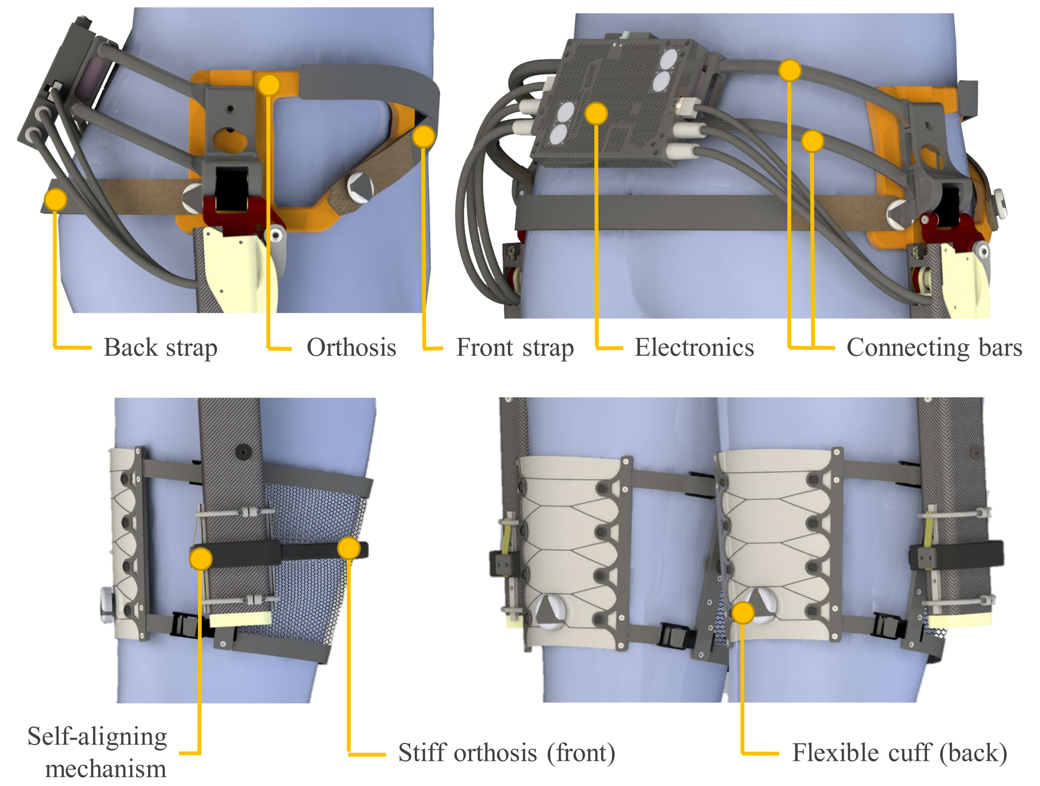
The intellectual merit of this proposal is the optimization of energy exchange across multiple joints for the design and control of powered exoskeletons inspired by human ambulation. Cumulatively, this research has transformative potential, enabling wearable robots to break the barrier of laboratory use and transition into real life, improving our productivity, health, and independence.

Broader Impact

Societal Impact: enabling the development of a new generation of powered exoskeletons that will provide greater mobility and independence to individuals with physical impairments--Thirty-three million Americans. **Educational Impact**: increasing diversity in STEM by recruiting from underrepresented groups, especially those with physical disabilities.

Results

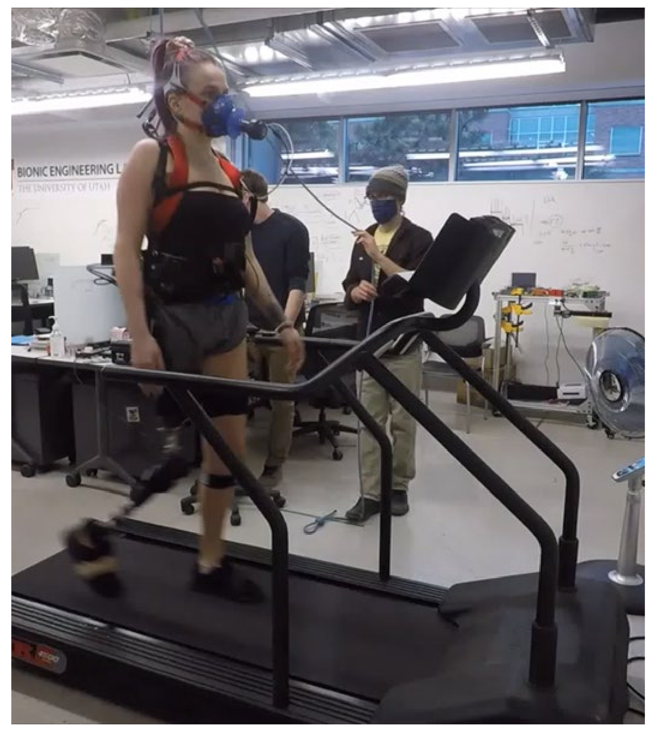
We have developed the powered hip exoskeleton with the highest assistive torque to weight ratio in the field. This exoskeleton can produce high nominal torque (41.9 Nm repetitive peak torque), high backdrivability (0.16 Nm back-driving torque), high bandwidth (23.8 Hz), and high control accuracy (2.1% steady-state error).

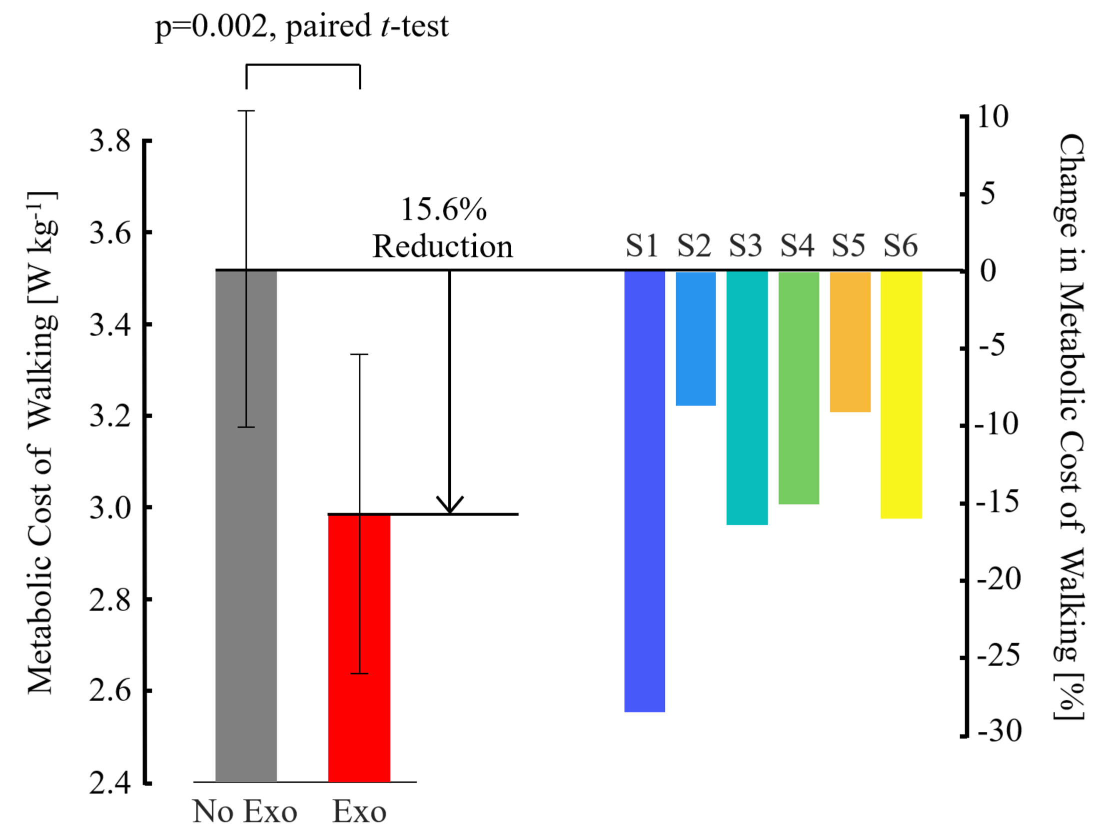


			Measured During Ambulation		
Exoskeleton	Actuator Weight [kg]	Total Weight [kg]	Average Peak Torque [Nm]	Actuator Torque Density [Nm/kg]	Exoskeleton Torque Density [Nm/kg]
Utah	**0.567**	**2.7**	**41.9**	**73.9**	**15.52**
Harvard* [21]	1.337	5.0	38.1	28.5	7.62
CUNY [4]	0.777	3.4	20	25.7	5.88
Samsung [9]	--	2.8	10.9	--	3.89
NCSU+[16][17]	1.5	9.2	34.3	22.9	3.73
ASU [18]	1.135	2.95	9	7.9	3.05
SSSAº [20]	1.2	4.2	10	8.3	2.38
Honda [8]	--	2.8	6	--	2.14
Georgia Tech [14]	1.5	7	14.1	9.4	2.01
Panasonic# [22]	0.58	9.3	10	17.2	1.08

M.K. Ishmael, D. A. Archangeli, and T. Lenzi, *"A Powered Hip Exoskeleton with High Torque Density for Walking, Running, and Stair Ascent"*, IEEE/ASME Transactions on Mechatronics, 2022 https://doi.org/10.1109/TMECH.2022.3159506

We have shown that our powered hip exoskeleton significantly improves amputee metabolic walking economy by 15.6% ± 2.9% (mean ± standard error). The observed metabolic cost reduction is equivalent to removing a 12-kg backpack from a nonamputee individual. This is the first technology showing walking economy improvements in individuals with above-knee amputation since the introduction of microprocessor-controlled prostheses in the 1990s.





M.K. Ishmael, D. A. Archangeli, and T. Lenzi, *"Powered Hip Exoskeleton improves walking economy in individuals with above-knee amputation"*, Nature Medicine, 27, pages 1783–1788 (2021) https://doi.org/10.1038/s41591-021-01515-2