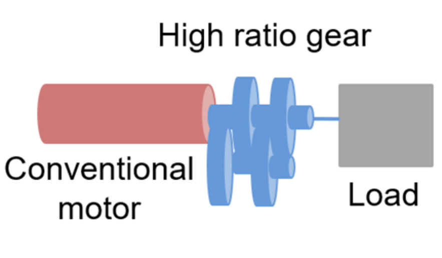
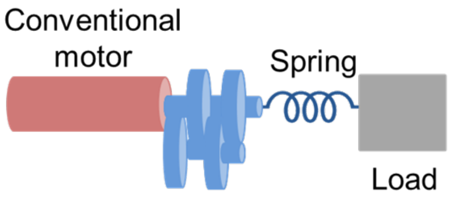
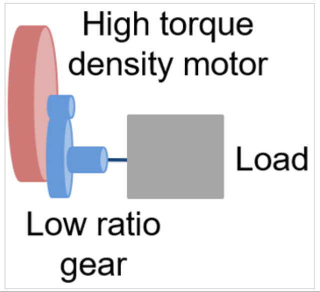
Soft Wearable Robots for Injury Prevention and Performance Augmentation (Grant # 1830613, Poster # 126)

Hao Su (PI), Alessandra Carriero (Co-PI), Yingli Tian (Co-PI), City University of New York



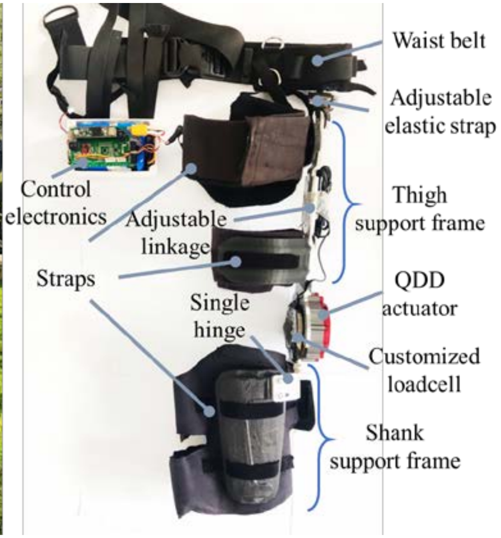
New Actuation Paradigm: Quasi Direct Drive

- High torque density motors
- High compliance and control bandwidth

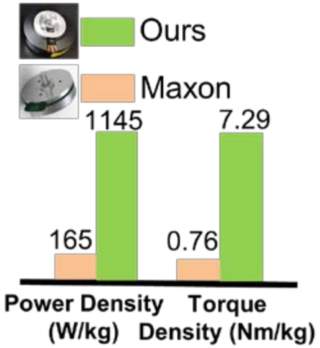
	Geared Motor with Force/Torque Sensor	Series Elastic Actuator	Quasi Direct Drive Actuator [Ours]
Compliance	Low	Medium	High
Bandwidth	High	Low	High
Efficiency	Low	Medium	High
Actuation Paradigm			

Most Lightweight Knee Exoskeleton

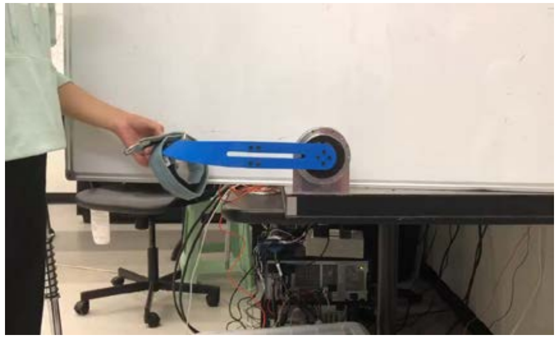
- 2.1 kg, 20 Nm
- Compliant and intrinsically safe

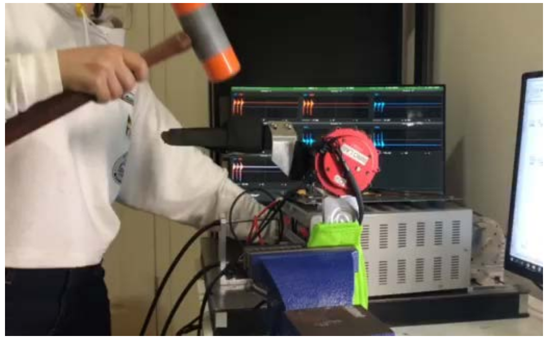
High torque motor



High compliance



High control bandwidth



Yu, et al. Quasi-direct drive actuation for a lightweight hip exoskeleton with high backdrivability and high bandwidth. IEEE/ASME Transactions on Mechatronics, 2020 (Best student paper award finalists)

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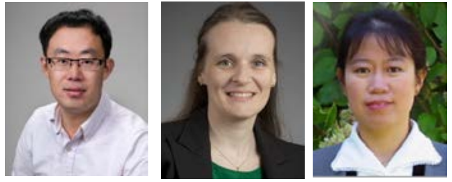
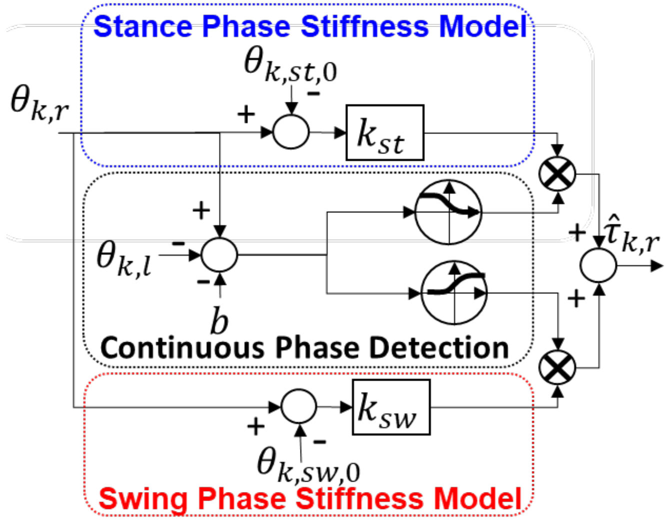
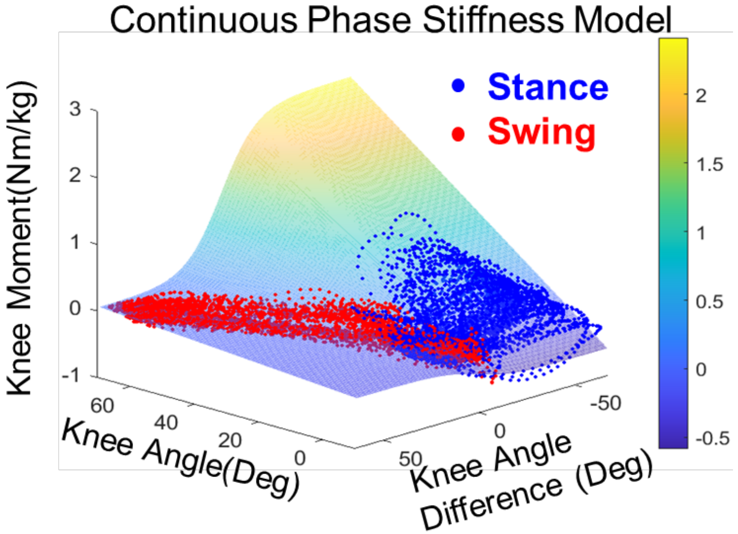


Model-based Torque Estimation for Continuous Control

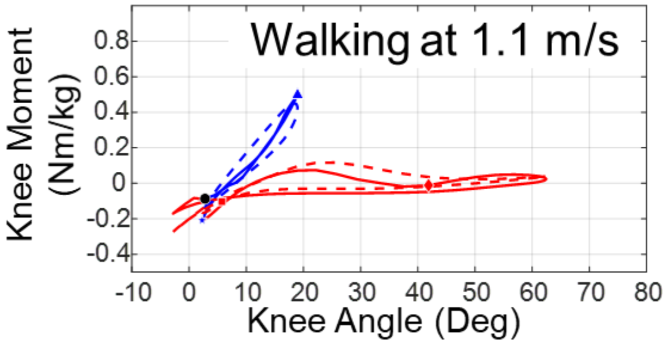
- Discrete control → continuous control (stiffness-inspired)
- Simple, analytical, adaptive to walking speeds

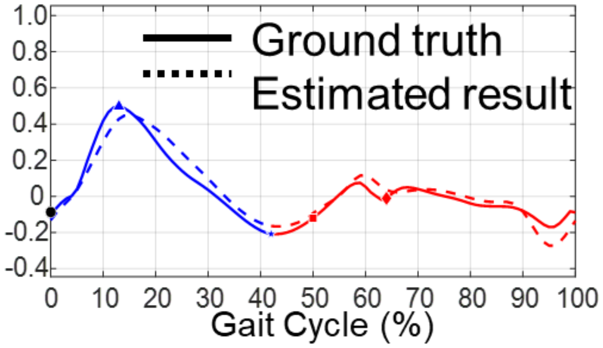




Estimated biological torque:

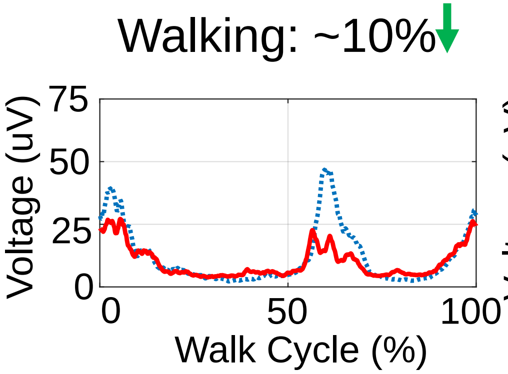
$$\hat{\tau}_{k,r} = [1 - \boldsymbol{S}(\boldsymbol{\theta}_{\boldsymbol{k,r}}, \boldsymbol{\theta}_{\boldsymbol{k,l}})]k_{st}(\theta_{k,r} - \theta_{k,st,0}) + \boldsymbol{S}(\boldsymbol{\theta}_{\boldsymbol{k,r}}, \boldsymbol{\theta}_{\boldsymbol{k,l}})k_{sw}(\theta_{k,r} - \theta_{k,sw,0})$$

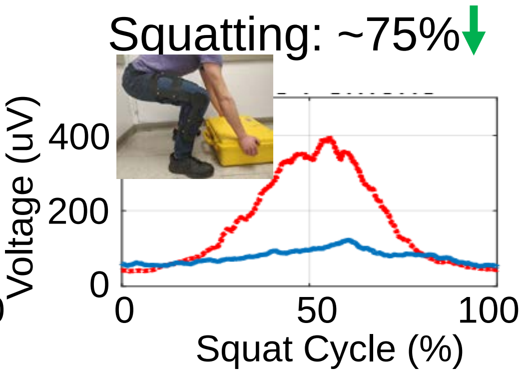




Versatile Controller

- Reduced muscle activities for walking squatting





Huang, et al. Modeling and Continuous Stiffness Torque Control of Quasi-Direct-Drive Knee Exoskeletons for Versatile Walking Assistance, IEEE Trans. Robotics, 2021 (in review)

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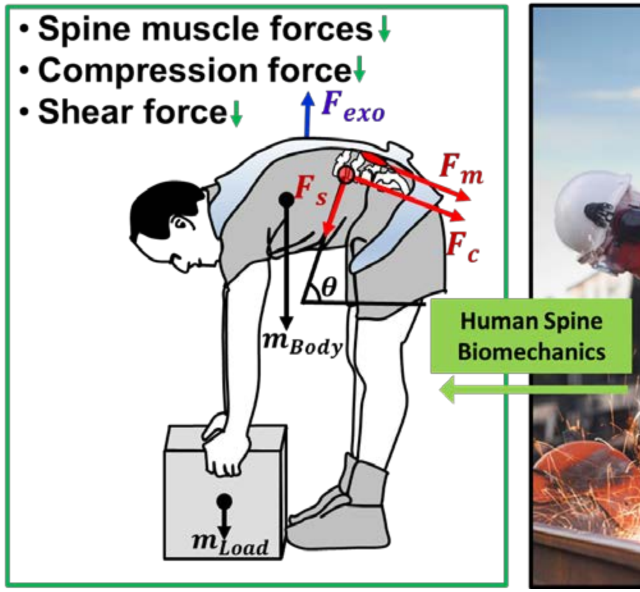
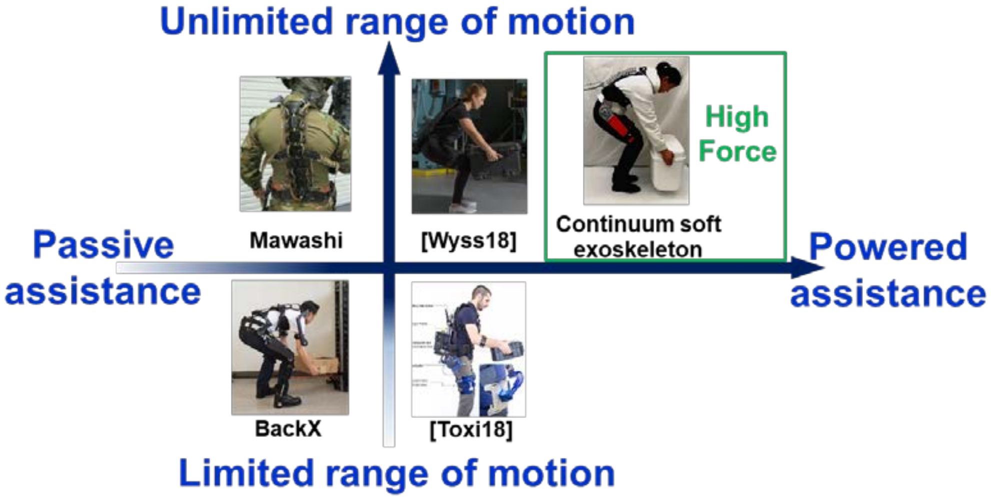
Continuum Soft Back Exosuit

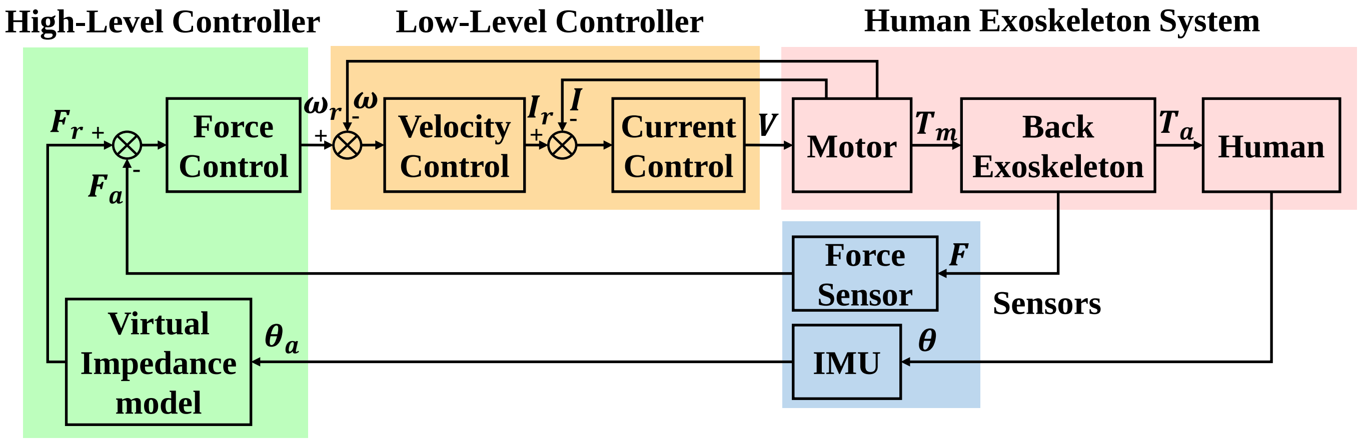
- Reduce 3 forces along spine

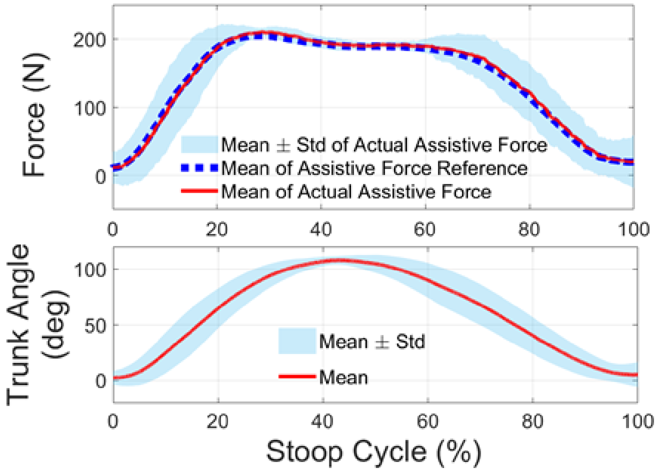




Modeling and Control

- Stoop assistance, high force output (220N)





Yang, Huang, Hu, Yu, Zhang, Yue, Su. Spine-Inspired Continuum Soft Exoskeleton for Stoop Lifting Assistance. IEEE Robotics and Automation Letters, 2019

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- Journal (3 published, 2 in review)

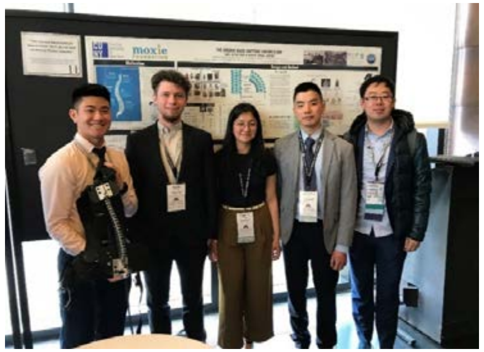
1. Yang, Huang, Hu, Yu, Zhang, **Carriero**, Yue, **Su**. Spine-Inspired Continuum Soft Exoskeleton for Stoop Lifting Assistance. IEEE Robotics and Automation Letters, 2019
2. Yu, Huang, Lynn, Sayd, Silivanov, Park, **Tian, Su**. Design and Control of a High-Torque and Highly-Backdrivable Hybrid Soft Exoskeleton for Knee Injury Prevention during Squatting . IEEE Robotics and Automation Letters (RA-L), 2019
3. Yu, Huang, Yang, Jiao, Yang, Chen, Yi, **Su**. Quasi-direct drive actuation for a lightweight hip exoskeleton with high backdrivability and high bandwidth. Trans. on Mechatronics (T-MECH), 2020. (Best student paper award finalists)
4. Huang, Zhang, Yu, MacLean, Di Lallo, Bulea, **Su**, Modeling and Continuous Stiffness Torque Control of Quasi-Direct-Drive Knee Exoskeletons for Versatile Walking Assistance, Trans. on Robotics (T-RO), 2021 (in review)
5. Yu, Huang, and **Su**. Artificial Neural Network-Based Activities Classification and Gait Phase Prediction: Application for Exoskeleton Control, Trans. on Biomedical Engineering (TBME) (in review)

Liz Salmeron
EE, senior

Gladys Castro
EE, senior

- International conferences (2 awards) + 18 undergrad student projects

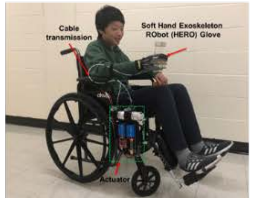
1. Salmeron, Juca, Mahadeo, Yu, and **Su**, International Conference of Wearable Robotics Association (WearRAcon), 2020 (2nd prize, Innovation Challenge)
2. Salmeron, Juca, Ma, Yu, **Su**, “Untethered Electro-Pneumatic Exosuit for Gait Assistance of People with Foot Drop”, Design of Medical Devices Conferences, 2020 (2nd prize, Three-in-Five Competition)
3. Yuen, Nogacz, Chi, Ferdousi, Yu, **Su**, “Oxeous Back-Support Exoskeleton: Soft, Active Suit to Reduce Spinal Loading”, Design of Medical Devices Conferences, 2019.
4. Yu, Perez, Barkas, Mohamed, Eldaly, **Su**, “Soft High Force Hand Exoskeleton for Assistance of Stroke Individuals,” Design of Medical Devices Conferences, 2019
5. Yang, Huang, Yu, Su, Spungen, Tsai, “Machine Learning Based Adaptive Gait Phase Estimation Using IMU Sensors,” Design of Medical Devices Conferences, 2019



https://assistiverobotcenter.github.io

Cable Drive Knee Exoskeleton

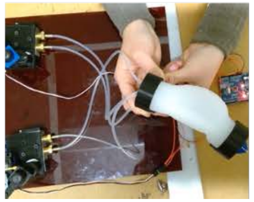
Cable Drive Exo-Glove



Jumping Robotic Leg

Soft Submersible Inspection Robot

Soft Pneumatic Fish Robot



Pediatric Knee Exoskeleton