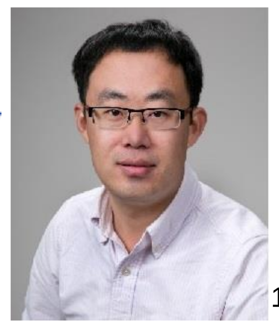
Soft Wearable Robots for Injury Prevention and Performance Augmentation



Shuangyue Yu[1], Xiaolong Yang[1], Tzu-Hao Huang[1], Sainan Zhang[1], Hang Hu[1], Alessandra Carriero[2], Yingli Tian[3], Young Soo Park[4] and Hao Su[1]

[1]Biomechatronics and Intelligent Robotics lab, Department of Mechanical Engineering, City University of New York, City College, New York, NY, 10031, USA

[2]Department of Biomedical Engineering, The City University of New York, New York City, NY 10031 USA

[3]Department of Electrical Engineering, City University of New York, City College, New York, NY, 10031, USA

[4]Applied Materials Division, Argonne National Laboratory, Lemont, IL, 60439, USA

Website: http://haosu-robotics.github.io

Email: hao.su@ccny.cuny.edu

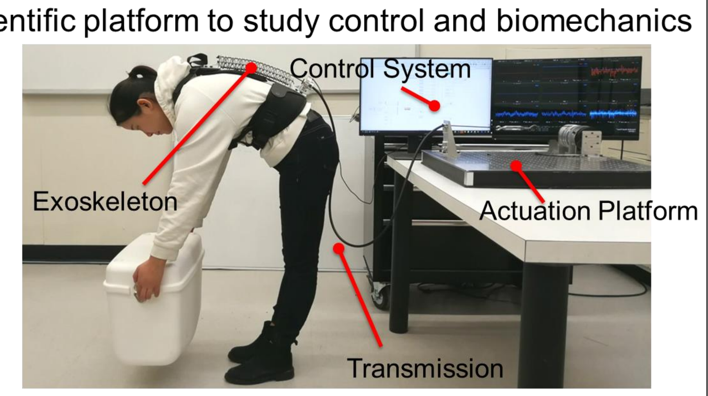
Motivation / Introduction

- More than $15 billion yearly due to physical overexertion of workers.
- Exoskeletons have potential to mitigate the injury incidence and augment human.
- Are of high interest to occupational safety and health agencies and compensation insurers.
- Current devices suffer from drawbacks: bulkiness, discomfort and inadaptability to different users.

Tethered and Portable Soft Exoskeleton Systems

Tethered System: lightweight, scientific platform to study control and biomechanics

Specification Table	
Motor Torque	2Nm
Motor Speed	1500 RPM
Output Torque:	72 Nm
Output Speed:	4.4 rad/s
Range of Motion:	130 degree
Gear Ratio	36:1
Total Weight:	< 1 kg

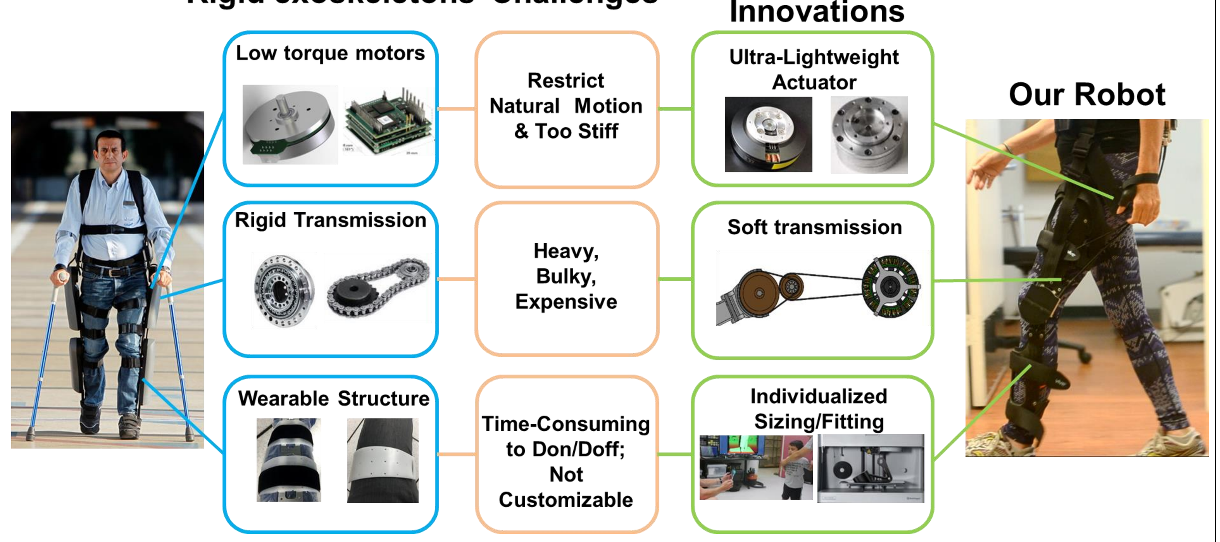


Portable System: high performance, versatile assistance in the field

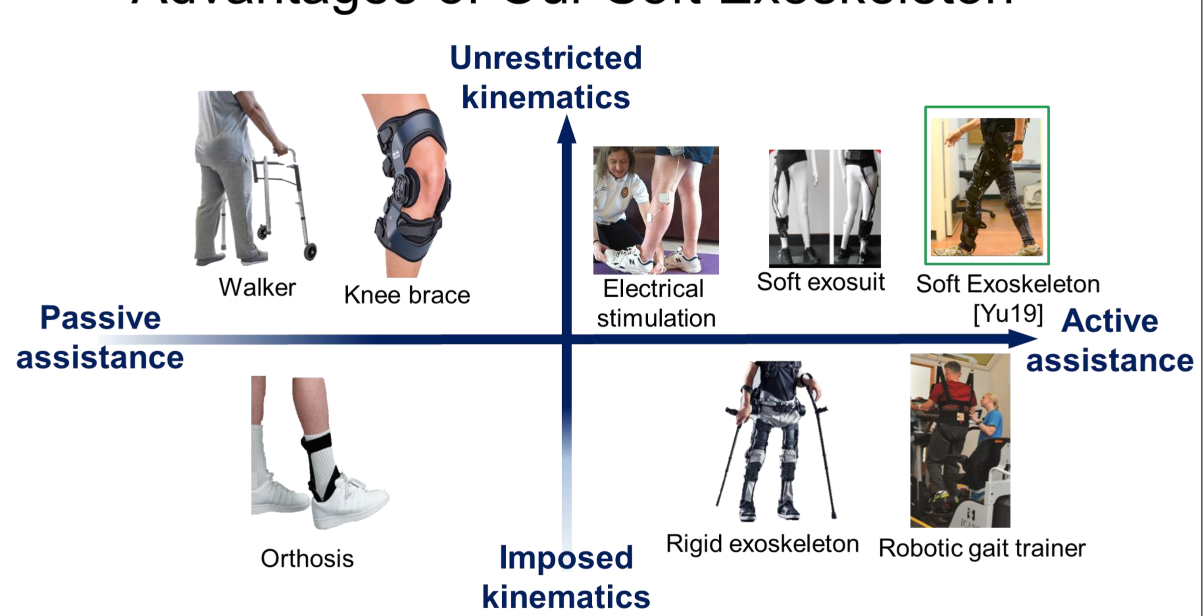
Specification Table	
Motor Torque	2 Nm
Motor Speed	1500 RPM
Output Torque:	45 Nm
Output Speed:	19.6 rad/s
Range of Motion:	130 degree
Gear Ratio	8:1
Total Weight:	3 kg

Soft Exoskeleton Innovations

Paradigm Shift of Wearable Robots



Advantages of Our Soft Exoskeleton



Reference

[1] Esquenazi A. The ReWalk powered exoskeleton to restore ambulatory function to individuals with thoracic-level motor-complete spinal cord injury. American journal of physical medicine & rehabilitation, 91(11), pp.911-921, 2012.

[2] Kang I. The Effect of Hip Assistance Levels on Human Energetic Cost Using Robotic Hip Exoskeletons. IEEE Robotics and Automation Letters. 2019 Jan 4;4(2):430-7.

[3] Kim J. Reducing the metabolic rate of walking and running with a versatile, portable exosuit. Science. 2019 Aug 16;365(6454):668-72.

[4] Yu S. Design and Control of a High-Torque and Highly-Backdrivable Hybrid Soft Exoskeleton for Knee Injury Prevention during Squatting. IEEE Robotics and Automation Letters.

[5] Yang X. Spine-Inspired Continuum Soft Exoskeleton for Stoop Lifting Assistance. IEEE Robotics and Automation Letters, 2019

[6] Wang J. Comfort-centered design of a lightweight and backdrivable knee exoskeleton. IEEE Robotics and Automation Letters, 3(4), pp.4265-4272, 2018.

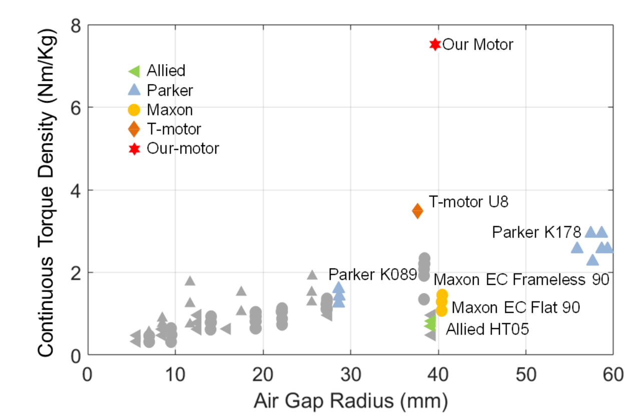
New Actuation Paradigm for Co-Robot

Exoskeletons				
Reference	[1]	[2]	[3]	Ours [4]
Actuation Paradigm	Conventional actuation	Series elastic actuation	Conventional actuation & textile wearable	Quasi direct drive actuation
Nominal Torque (Nm)	High (35)	High (30)	Low (5.9)	Medium (16)
Peak Torque (Nm)	High (70)	High (60)	Medium (32)	High (45)
Device Mass (kg)	High (23)	Medium (7)	Medium (5)	Low (3)
Bandwidth (Hz)	Low (5)	Low (5)	High (20)	High (44)
Backdrivability (Nm)	Low (30)	Medium (9)	Medium (N/A)	High (0.4)
Torque Density (Nm/kg)	Low (3)	Medium (8.6)	Medium (6.4)	High (16)

Motor Torque Density Comparison

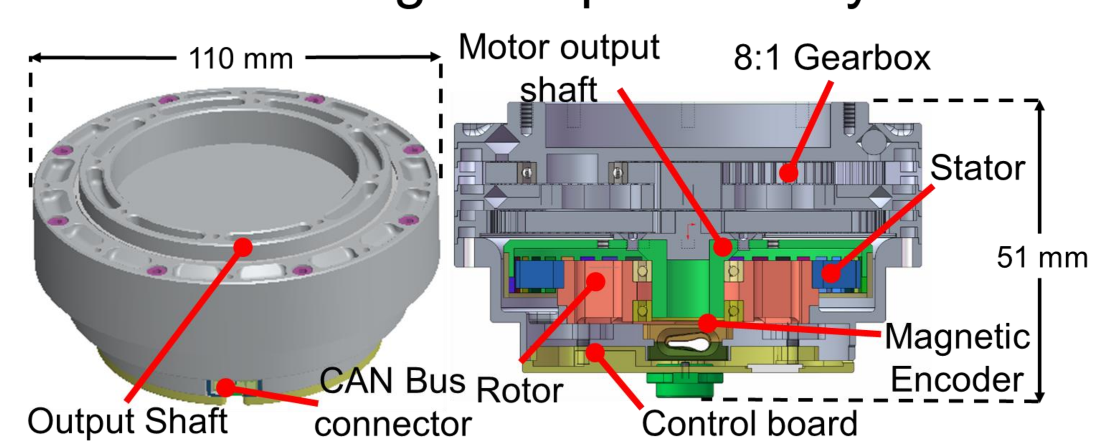
- Our custom-designed motor has the **highest torque density**

Property	Our motor	EC-90 Flat
Motors:		
Mass(g):	244	648
Nominal Power(W):	314	107
Nominal Voltage(V):	42	48
Nominal Current(A):	7.47	2.12
Nominal Torque(Nm):	2	0.5
Nominal Speed(RPM):	1500	2080
Nominal Speed(rad/s):	157	217
Power Density(W/Kg):	1145	165
Torque Density (Nm/Kg):	7.29	0.76



Specific continuous torque = $\frac{Continuous\ torque}{Mass}$

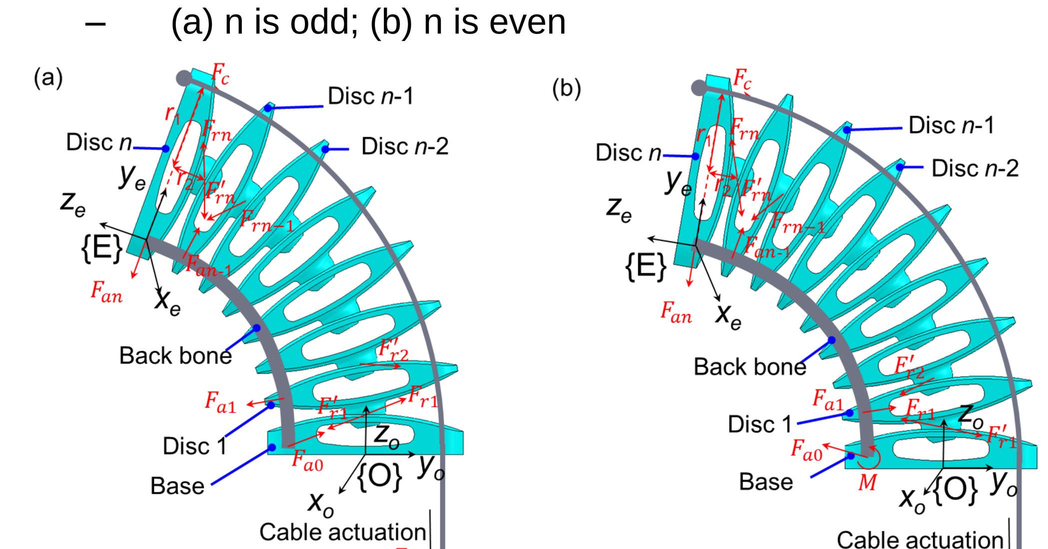
Customized High Torque Density Actuator



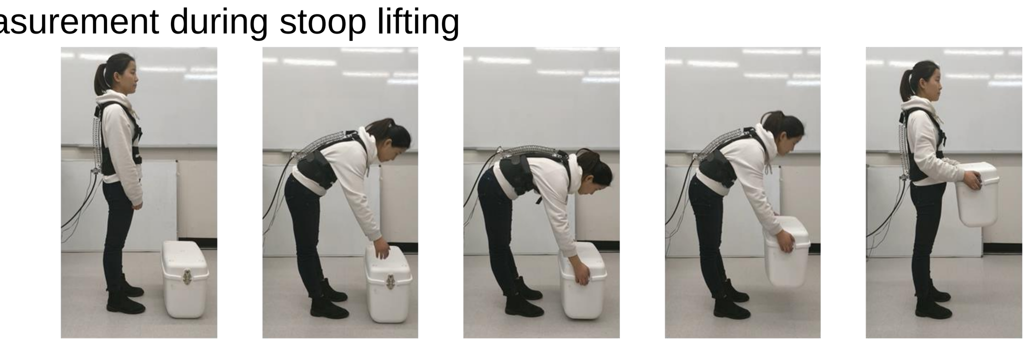
Spine-Inspired Continuum Back Exoskeleton

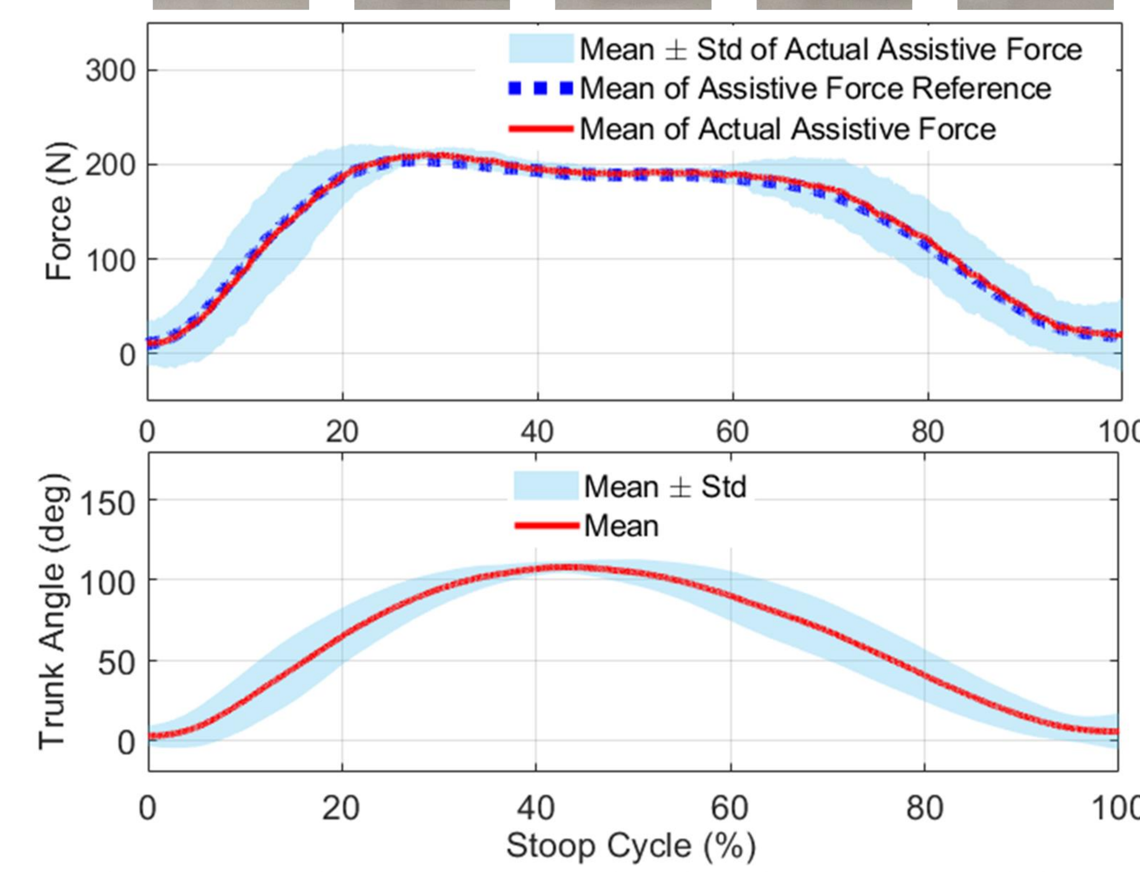
- Spine-inspired soft back exoskeleton design

- Kinetics of back exoskeleton in bending configuration
  - (a) n is odd; (b) n is even



- Assistive force tracking performance and trunk angle measurement during stoop lifting

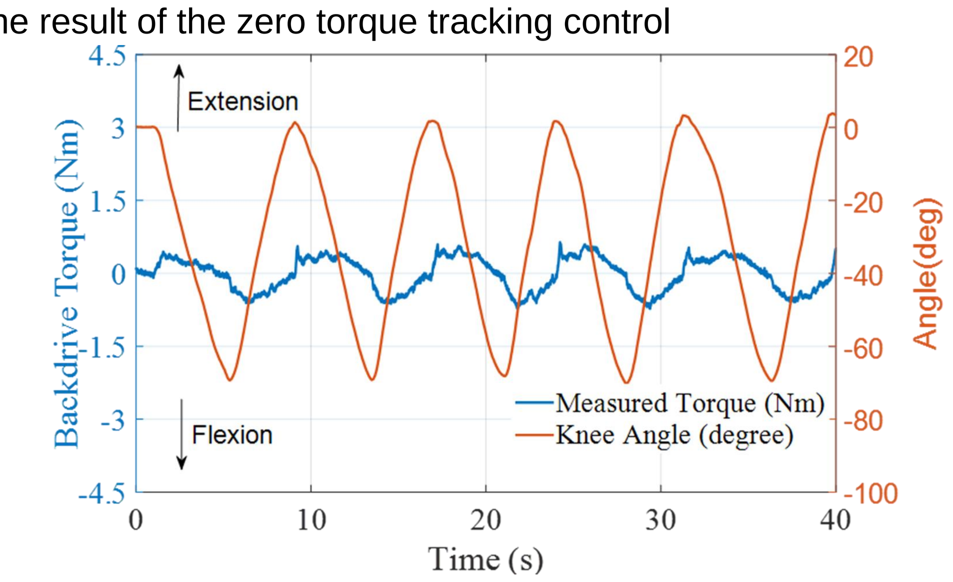




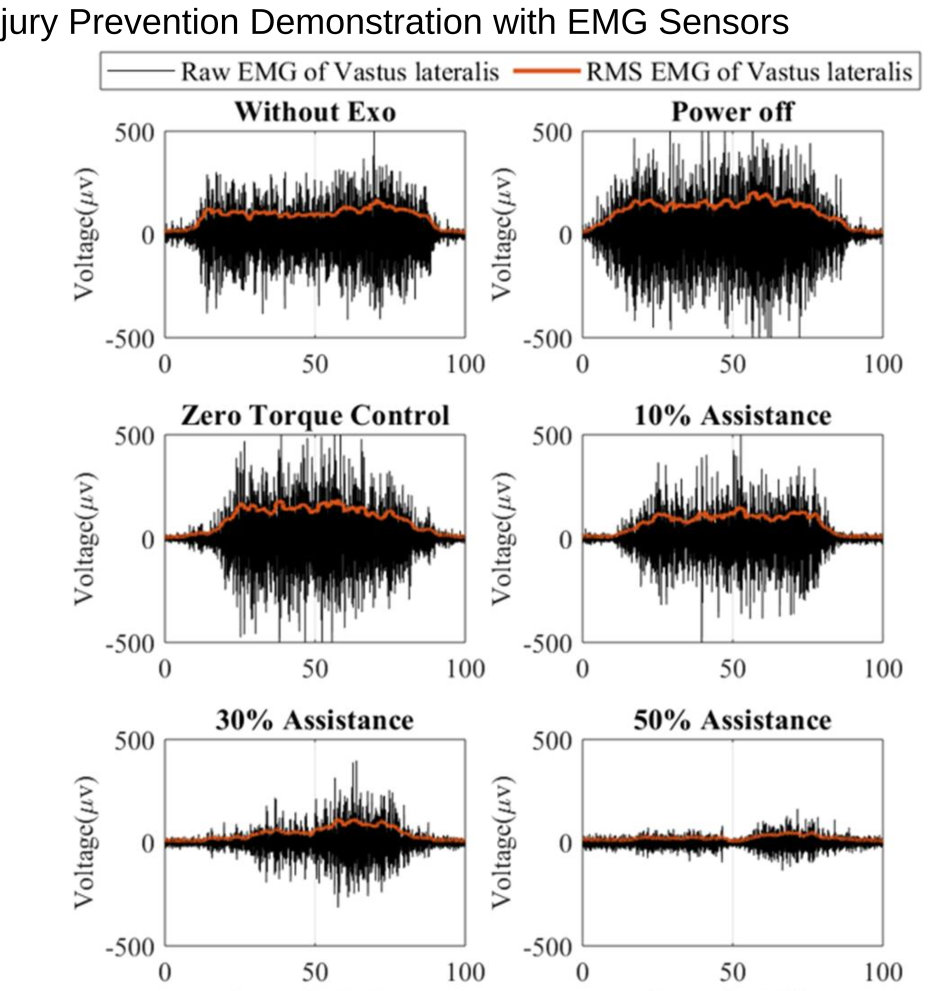
Assistive force tracking performance and trunk angle measurement during 30 stoop cycles. The actual assistive force (red line) tracked assistive force reference (blue dash line) well. The RMS error of force tracking in thirty stoop cycles was 6.63 N (3.3 % of the peak force).

Portable and Versatile Knee Exoskeleton

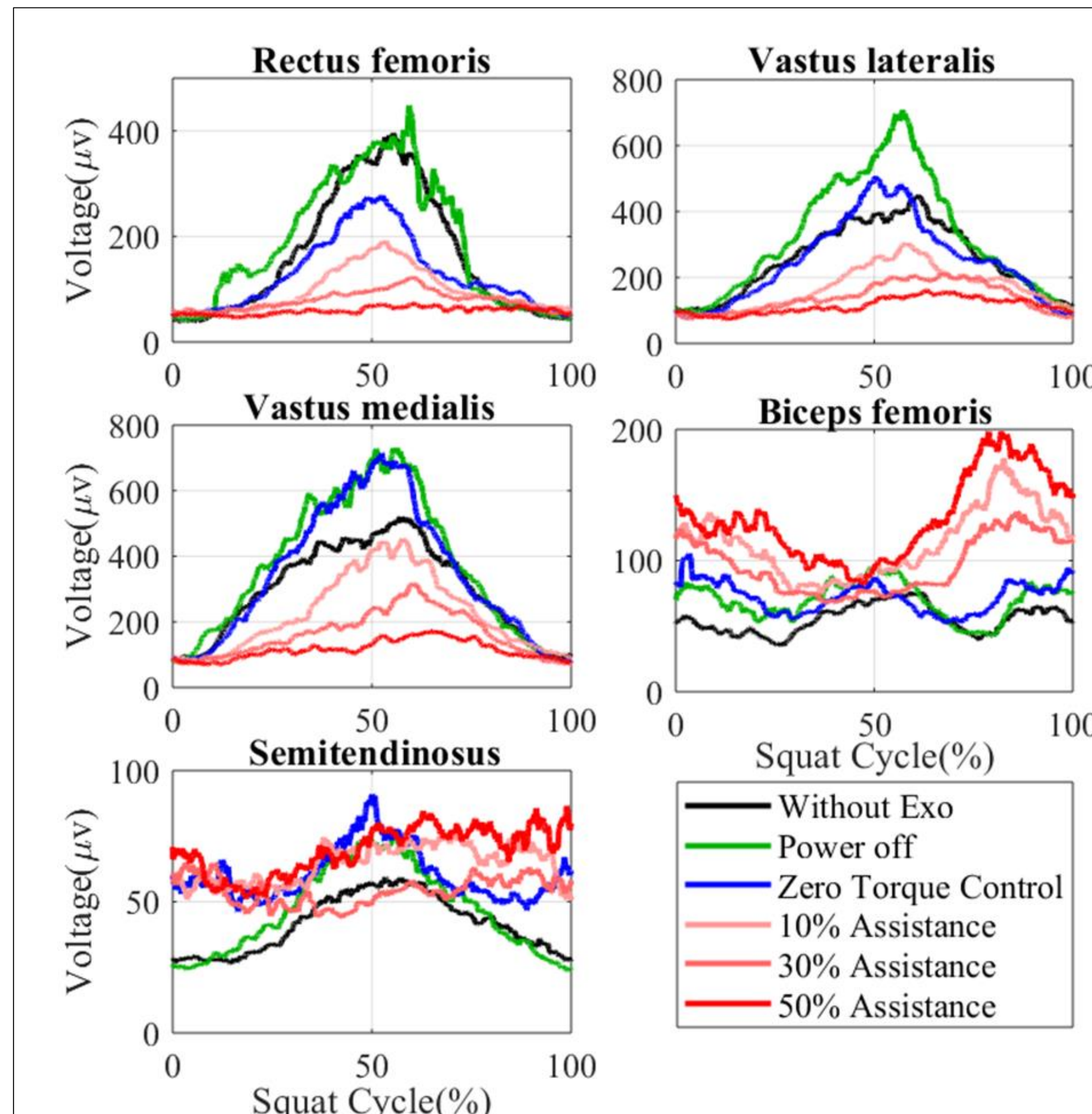
- The result of the zero torque tracking control



- Injury Prevention Demonstration with EMG Sensors



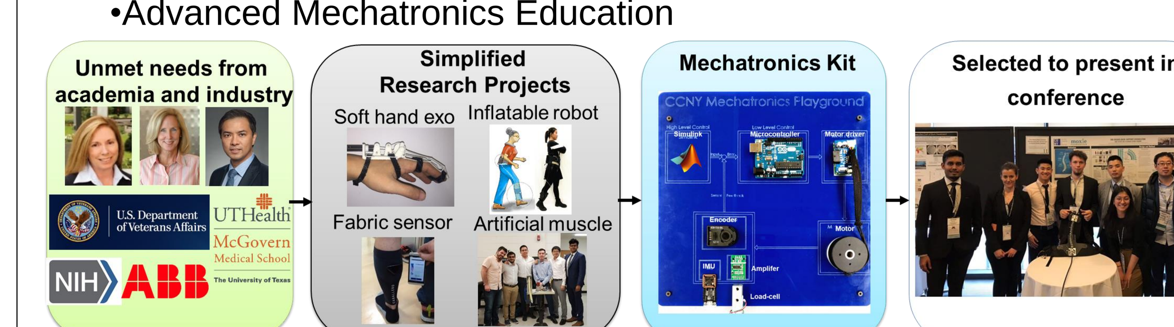
Comparison of muscle activities of one subject during squatting in the conditions of without-exoskeleton, power-off, zero torque control, 10% assistance, 30% assistance, and 50% assistance.



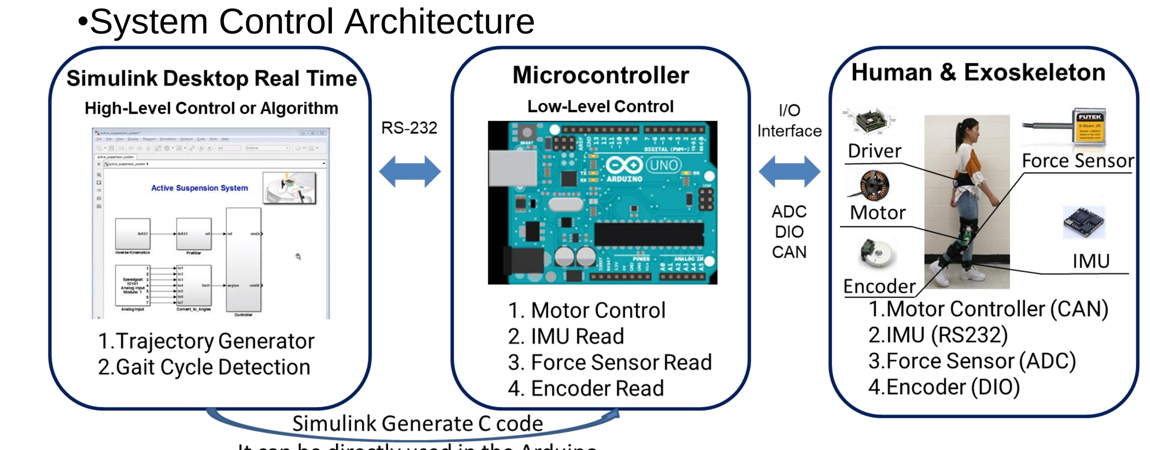
Muscle activities of rectus femoris, vastus lateralis, (the major knee extensor muscle) under different assistive control levels. It shows the average of EMG in 15 squat cycles (three healthy subjects with 5 cycles each).

Lowering Barriers To Learn Robotics

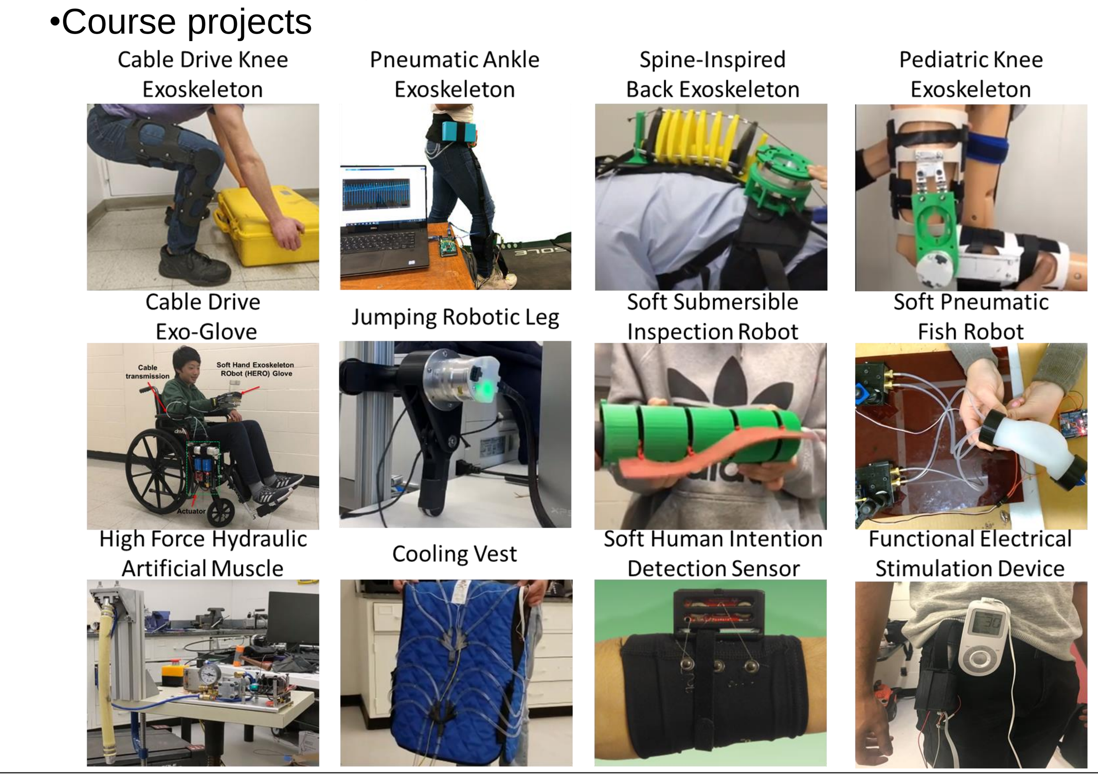
- Advanced Mechatronics Education



- System Control Architecture



- Course projects



This work is supported by the National Science Foundation grant NRI 1830613 and Grove School of Engineering, The City University of New York, City College.