Soft Wearable Robots for Injury Prevention and Performance Augmentation

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Biomechatronics and Intelligent RObotics

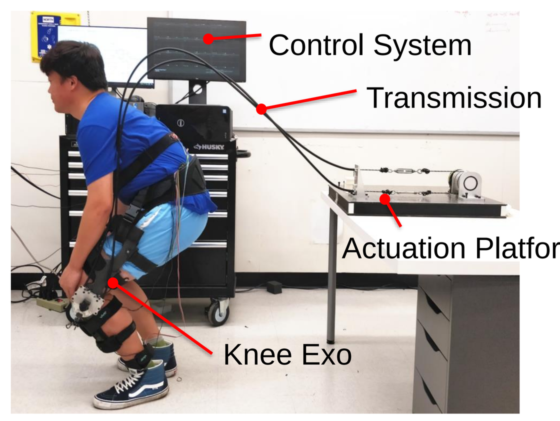
Motivation

- 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
Motor Voltage	42V
Gear Ratio	36:1
Output Torque:	**72 Nm**
Output Speed:	**4.4 rad/s**
Range of Motion:	**130 degree**
Total Weight:	**< 1 kg**

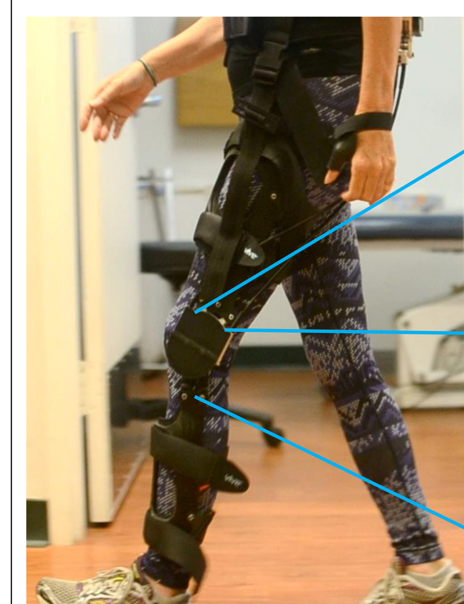


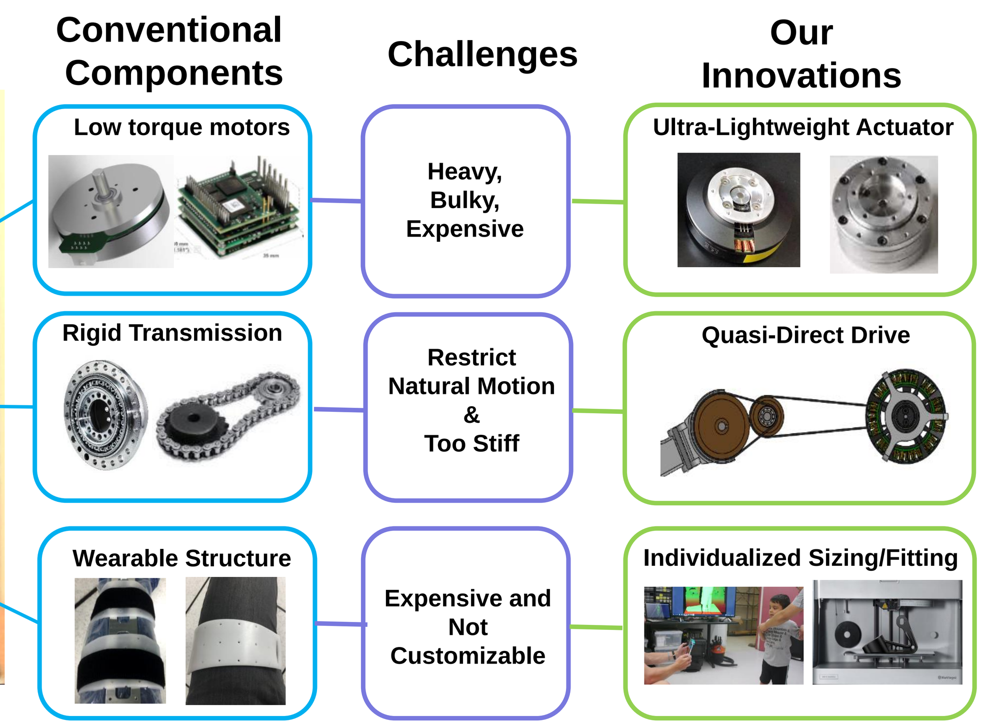
Portable System: lightweight, high torque, soft but strong, versatile assistance in the field

Specification Table	
Motor Torque	2Nm
Motor Speed	1500 RPM
Motor Voltage	42V
Gear Ratio	36:1
Output Torque:	**72 Nm**
Output Speed:	**4.4 rad/s**
Range of Motion:	**127 degree**
Total Weight:	**2.5 kg**

Walking Assistance   Lifting Assistance

Soft Knee Exoskeleton Innovations

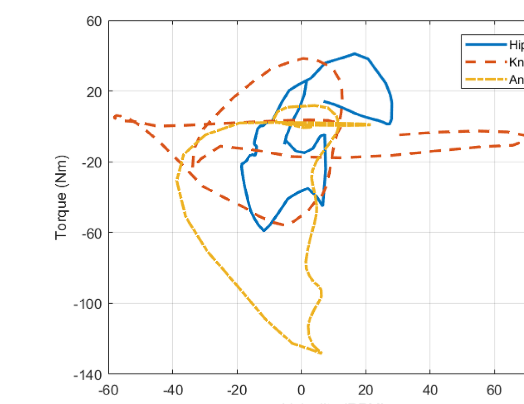




Our Actuators for Co-Robots

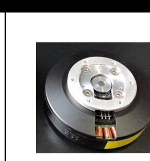
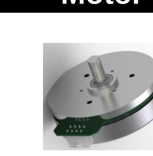
- Motion of human lower limbs
  - High torque
  - Low speed
- Conventional actuators
  - Low torque
  - High speed

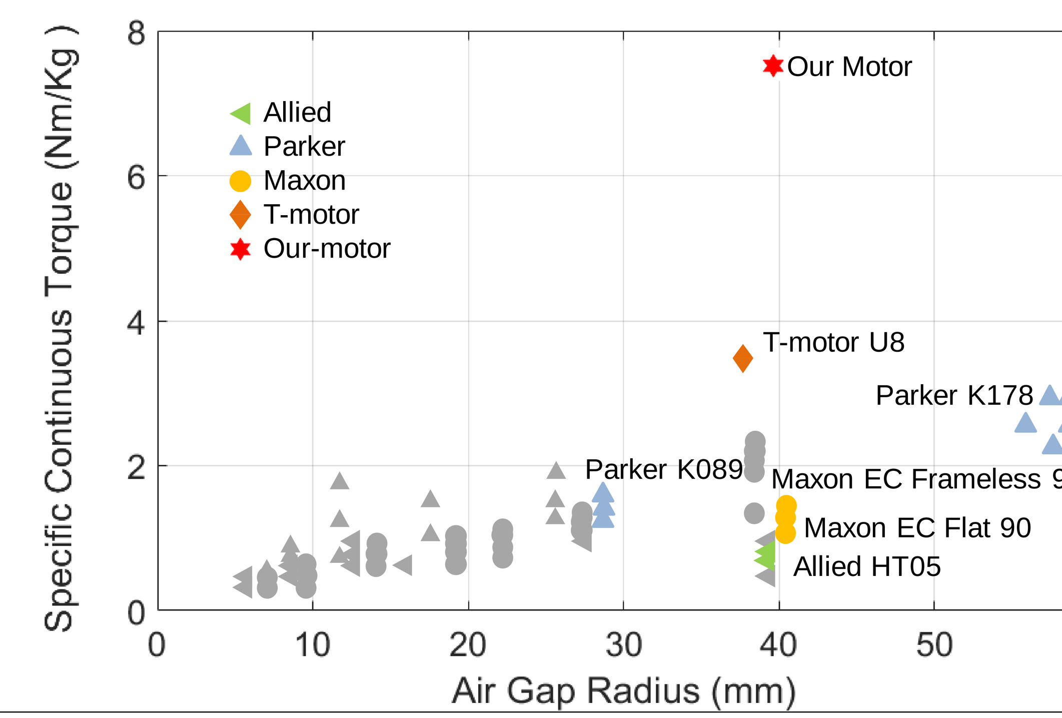
Data from OpenSim Gait 2392 Model



Joint	Hip	Knee	Ankle
Max torque (Nm)	65	40	125
Max Velocity (rad/s)	4.3	6.1	5.2

Custom-Designed High Torque Density Motor

Property	Our Motor	Benchmark Motor
Motors		
Mass(g)	274	648
Dimensions (mm)	87D * 32H	90D*45H
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



Assistive Torque Control during Squat

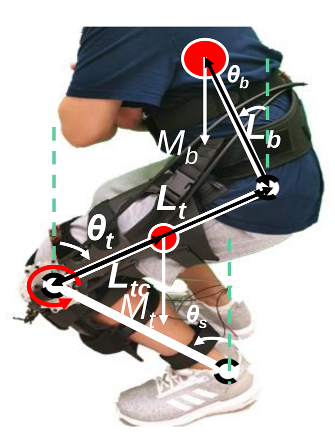
The knee joint torque (τ_k) in the quasi-static state is

$$\tau_k = -\frac{1}{2}[M_b\, g\,(L_b \sin\theta_b + L_t \sin\theta_t) + M_t\, g\, L_{tc} \sin\theta_t]$$

The desired assistive torque (τ_r) is defined as

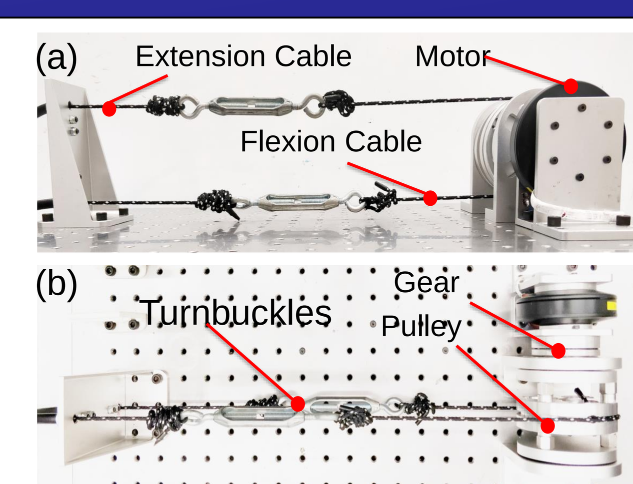
$$\tau_r = \alpha\, \tau_k$$

α is assistance rate (>0).

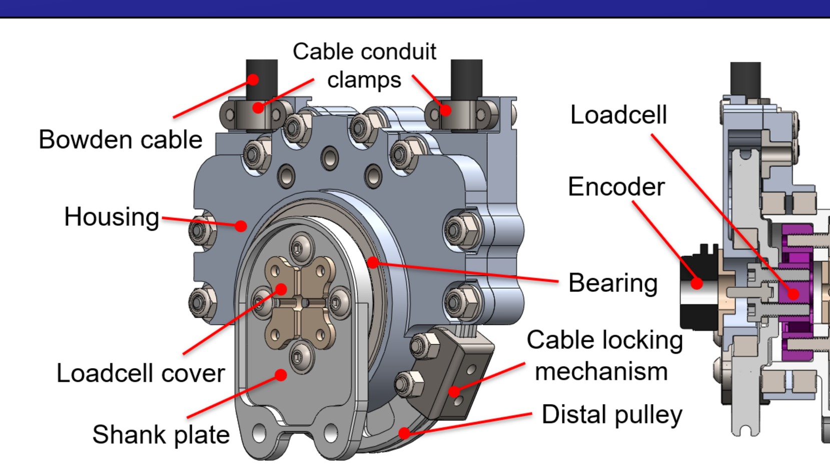


A human biomechanics model for deriving the biological knee joint torque and assistive torque.

Actuation Mechanism



The quasi-direct drive actuation platform

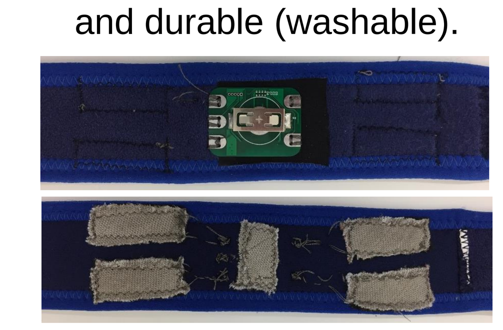


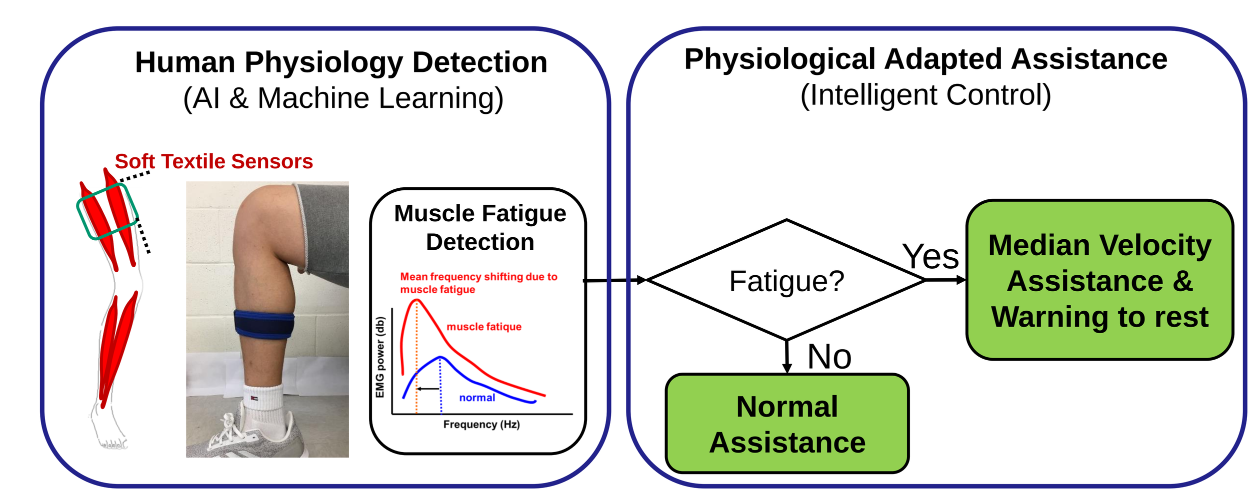
the cable driven knee mechanism for knee flexion/extension.

Fabric Physiology Sensors

Fabric EMG sensor

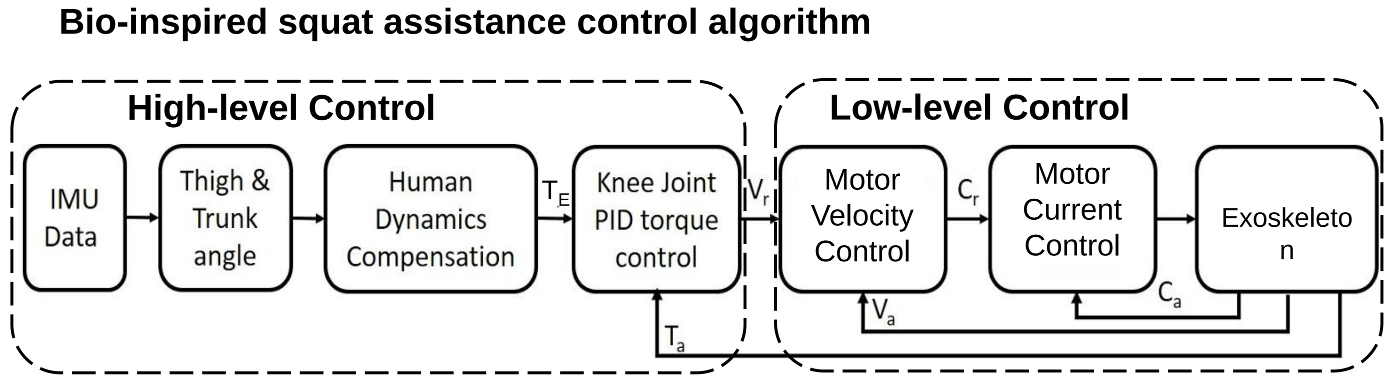
- Customized for online monitoring of wearers physiological condition.
- More conformal, comfortable and durable (washable).





Squat Assistance Strategy

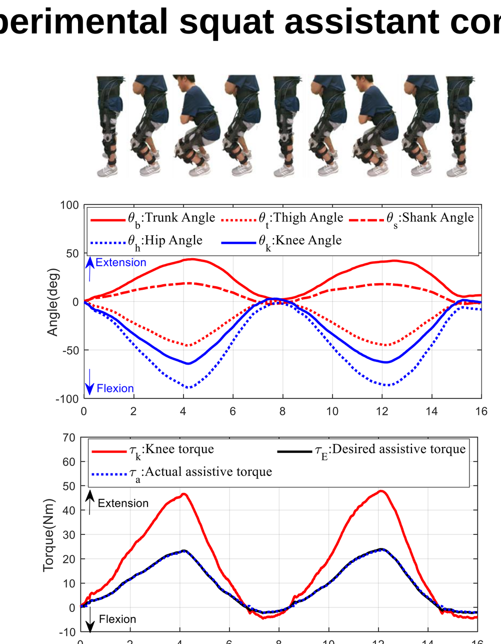
Bio-inspired squat assistance control algorithm



The high-level controller generates a reference torque profile using our generic lifting biomechanics mode to compensate for human dynamics.

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.

Experimental squat assistant control

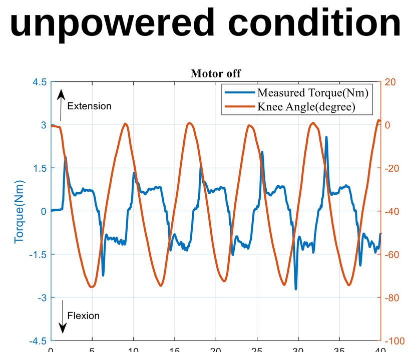


(Top) segment angles; (Bottom) the biological knee, desired and actual assistive torques.

Experimental Results

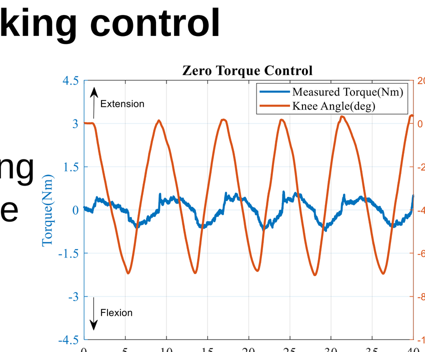
Backdrivability in unpowered condition

Resistive torque characterization during squatting

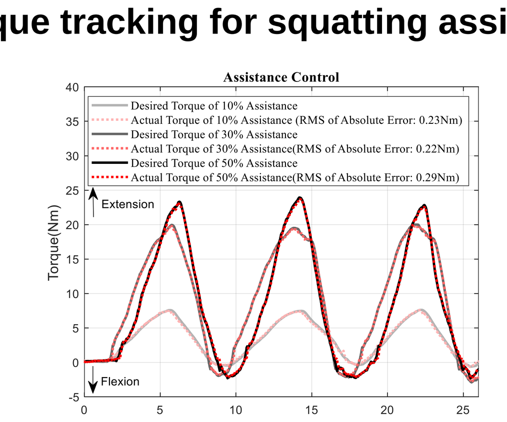


Zero torque tracking control

Zero torque tracking control reduces the mechanical resistance

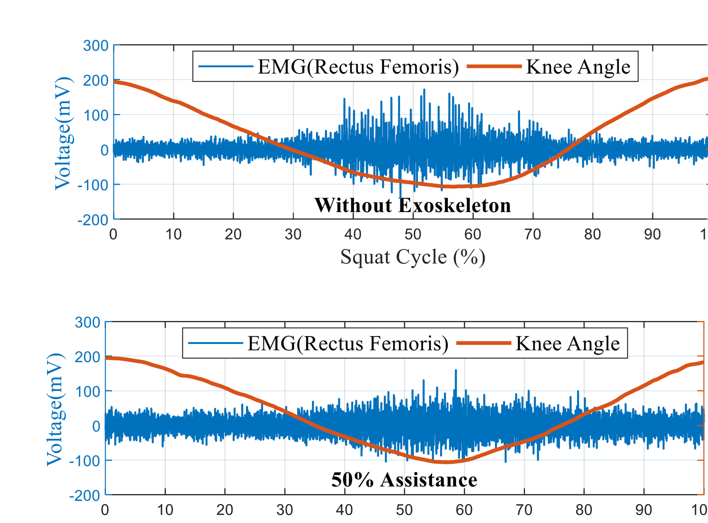


Torque tracking for squatting assistance



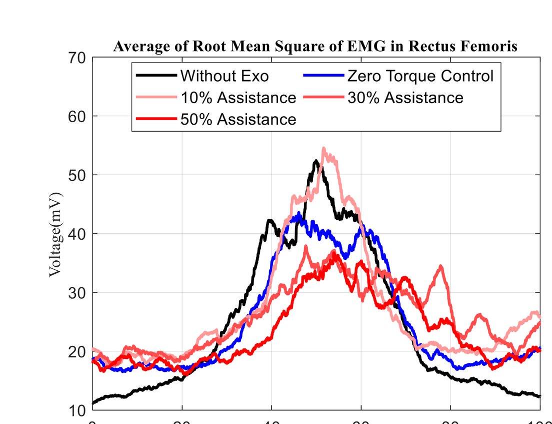
The tracking performance of the 10%, 30%, 50% of knee torque assistance in three squatting cycles. The RMS of the absolute error between the desired and actual torque trajectory is 0.3 Nm, 0.22 Nm, and 0.29 Nm.

Injury Prevention with EMG Sensors



Result for the squat without exoskeleton and squat with 50% assistance.

Processed data from fabric EMG sensor for different assistance percentage.



The average of RMS EMG in 5 squat cycles.