Lightweight and Backdrivable Exoskeleton Emulator for Musculoskeletal Injury Prevention

Sainan Zhang, Tzu-Hao Huang, Shuangyue Yu, Hang Hu, Chunhai Jiao, Jiechao Ma, Hao Su*, *IEEE Member*

Musculoskeletal disorders (MSDs) are leading causes of injury among various individuals [1]. Wearable robots present an attractive solution to mitigate the incidence of injury and augment human performance. Recently, there is a growing interest in wearable robots for knee joint assistance as cumulative knee disorders account for 65% of lower extremity musculoskeletal disorders. Squatting and kneeling are two of the primary risk factors that contribute to knee disorders. However, state of the art exoskeletons is excessively heavy, bulky, and cannot provide high torque.

Quasi direct-drive actuation [2] consisting of high torque motors and low gear ratio transmission mechanism represents an improved solution to obtain a lightweight structure and high torque output. Inspired by the superior performance of proprioceptive actuators for legged locomotion, we developed two knee exoskeletons using a quasi-direct actuation paradigm based on our high-torque-density motors, as shown in Fig.1.

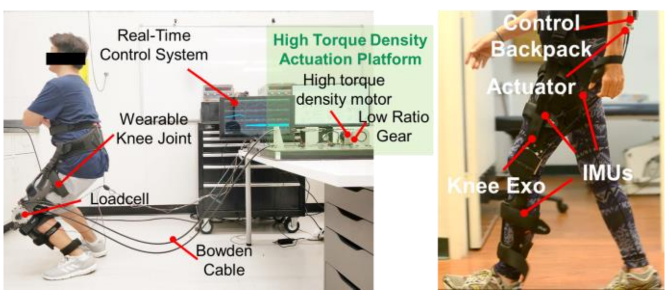

Fig. 1 (Left) tethered soft exoskeleton. (Right) portable soft exoskeleton

Table 1 Specifications of portable and tethered knee exoskeletons.

Properties	**Value**	
Actuation type	**Tethered**	**Portable**
Motor Nominal Torque	2 Nm	2 Nm
Motor Speed	1500 RPM	1500 RPM
Motor Voltage	42 V	42 V
Gear Ratio	36:1	36:1
Output Torque	72 Nm	72 Nm
Range of Motion	127 degree	127 degree
Max joint speed	4.4 rad/s	4.4 rad/s
Total Weight	1.1 kg	2.8 kg

The tethered knee exoskeleton was developed to study the biomechanics of squatting and the evaluation of control algorithms. The specifications are listed in Table 1. After the validation on the tethered knee exoskeleton, we developed a portable knee exoskeleton using the same actuation paradigm with that of the tethered one such that the lightweight and high torque output are guaranteed. It can assist onsite squat with high torque for knee injury prevention.

In Fig.1, a healthy subject performs squatting with the hybrid soft exoskeleton that uses soft cable transmission with a rigid customized wearable structure. The quasi-direct drive actuation consisting of high torque density motors and low transmission ratio gears makes the exoskeleton lightweight and highly-backdrivable. To overcome the challenges of the excessive mass and restriction of natural movement, we also present a lightweight (2.8kg) hybrid soft exoskeleton design that combines the advantages of rigid exoskeletons (high torque thanks to large moment arm) and textile-based soft exosuits (no restriction to human movement).

Experimental results in Fig. 2 demonstrate that the robot exhibits low mechanical impedance (1.5 Nm torque) when it is unpowered and 0.5 Nm torque with zero-torque tracking control. Root mean square error of torque tracking is less than 0.29 Nm (1.21% error of 24 Nm peak torque). Compared with squatting without an exoskeleton, the maximum amplitude of the knee extensor muscle activity (rectus femoris) was reduced by 75% using 50% biological torque assistance in three healthy subjects [3]. Our portable device can operate autonomously for more than 1 hour with potential as a personal mobility device.

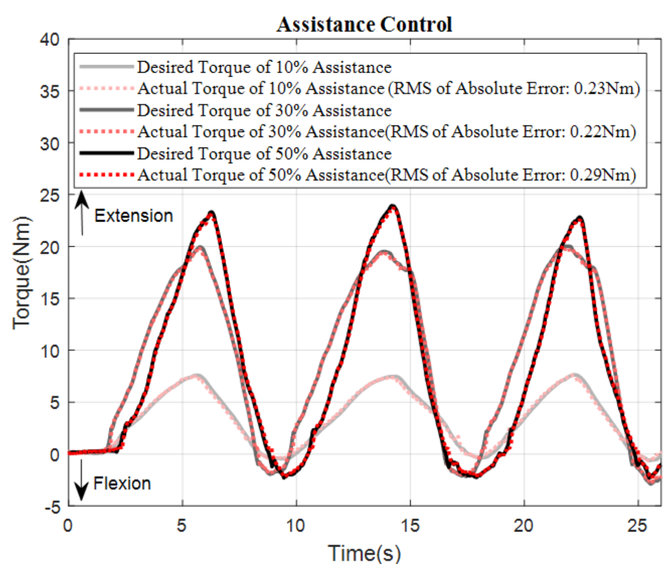

Fig. 1 The tracking performance of the 10%, 30%, 50% of knee torque assistance in three squatting cycles.

Sainan Zhang, Tzu-Hao Huang, Shuangyue Yu, Hang Hu, Chunhai Jiao, Jiechao Ma, and Hao Su are with the Lab of Biomechatronics and Intelligent Robotics, Department of Mechanical Engineering, The City University of New York, City College, New York, NY, 10023, US.

*Corresponding author. Email: hao.su@ccny.cuny.edu

Reference

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