A Soft Back Exoskeleton for Lifting Assistance in Spinal Cord Injury Individuals

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

***Abstract*— Back injuries are the most prevalent work-related musculoskeletal disorders and represent a major cause of disability. We designed a spine-inspired wearable robot that is unobtrusive and assists both squat and stoops while not impeding walking motion. The feasibility of the prototype was experimentally tested on three healthy subjects. The root mean square error of force tracking is 6.63 N (3.3 % of the 200N peak force). This continuum soft exoskeleton represents a feasible solution with the potential to reduce back pain for multiple activities and multiple forces along the human spine.**

I. Introduction

Back injuries, which represented 17.3% of all injuries in the USA in 2016, are the most prevalent work-related musculoskeletal disorders [1]. Over the last two decades, various studies have demonstrated that industrial exoskeletons can decrease total work, fatigue, and load while increasing productivity and work quality [2]. The key challenges of back-support exoskeletons lie in the stringent requirements [3] that need to augment human capability in different postures (squat and stoop lifting), during different activities (e.g., walking and lifting), for multiple joints.

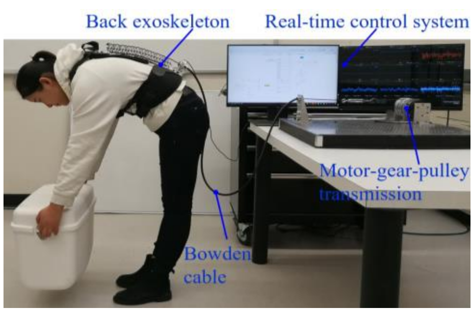

Fig. 1 Spine-inspired soft exoskeleton platform. A healthy subject wearing the exoskeleton performed stoop lifting with a 15 kg load.

II. Methods

To address the challenges above, we present a spine-inspired soft exoskeleton platform (Fig. 1) that can reduce spine loadings while not limiting natural movement. The back exoskeleton is composed of a spine-inspired mechanism, wearable structure (shoulder and waist braces) and a tethered actuation platform. Each of the twenty segments in the spinal structure of the robot is comprised of a disc that pivots on a ball and socket joint. Our spine-inspired mechanism is cable-driven; thus, it can only be pulled. A cable is threaded through holes at the edges of the discs, and when the actuator motor pulls the cable, the discs rotate about the ball joint acting as levers. The segmented nature of the spinal structure also makes the exoskeleton compliant, meaning it conforms to the curvature of a wearer's back. A cable passes through a customized load cell at the bottom of the spinal structure to measure the cable tension. This back exoskeleton provides the assistive force and permits a large range of motion in the sagittal, frontal and transverse planes.

Fig. 2 illustrates the relationship between the motor current and the actual assistive force. Fig. 3 illustrates the results of the assistive force control and the trunk angle variation during stoop tasks in three subjects for a total of 30 stoop cycles. The trunk angle was used to calculate the assistive torque by the virtual impedance model. The RMS error of force tracking is 6.63 N (3.3 % of the peak force 200 N). Regardless of motion variability indicated by the standard deviation of trunk angles during 30 stoop cycles, our controller can successfully track the desired force with high force accuracy.

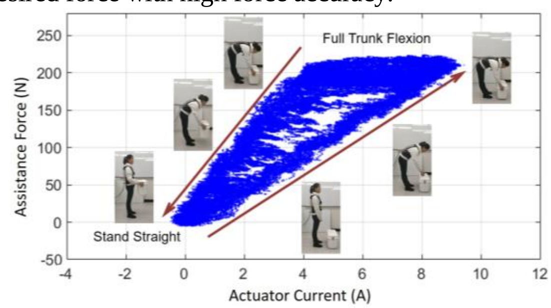

Fig. 1 The desired and actual assistive force during the stoop lifting. It demonstrates the hysteresis property due to the Bowden cable transmission mechanism.

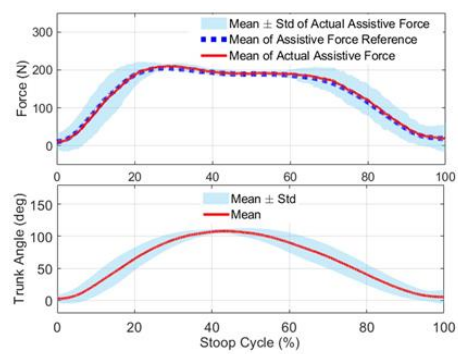

Fig. 3 Assistive force tracking performance and trunk angle measurement during stoop. It was tested in three subjects, and each subject performed ten stoop cycles.

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

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

III. References

[1] Liberty Mutual Insurance Company, *Safety Index*, 2017.

[2] De Looze MP, et al. *Ergonomics*, 2015.

[3] S. Toxiri. et al. *In International Symposium on Wearable Robotics*, 2018.