A Spine-Inspired Soft Exoskeleton for Lifting Assistance

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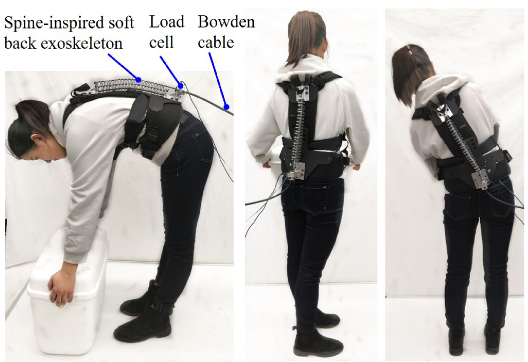
Back injuries, which represented 17.3% of all injuries in 2016, are the most prevalent work-related musculoskeletal disorders [1]. Over the last two decades, various studies have demonstrated that industrial exoskeletons can decrease total work, fatigue, and load while increasing productivity and work 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 (e.g., erector spinae muscle, and lumbar vertebral compression and shear forces).



(a) Flexion (b) Lateral flexion (c) Rotation

Fig. 1 Spine-inspired soft exoskeleton. It assists human in stoop lifting while imposing no restriction on natural movement, allowing the wearer to flex (a), lateral flex (b) and rotate (c).

To address the challenges above, we present a spine-inspired soft exoskeleton (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. When the cable is pulled, the top disc pulls the human back. Another cable placed in the center of the discs ensures the overall mechanism integration and tightly coupled together. An elastic belt is used to connect the shoulder brace and the waist brace. 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 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 mean of assistive force reference is annotated with a dashed blue line, the mean of actual assistive force is annotated with a red line, and the light blue area represents one standard deviation. 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.

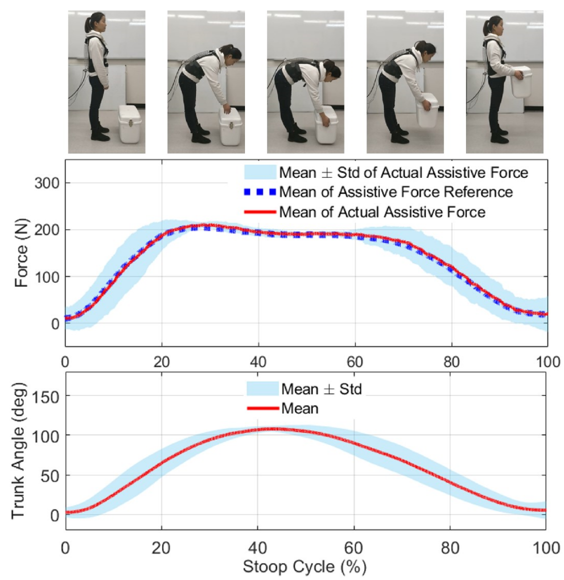


Fig. 2. Assistive force tracking performance and trunk angle measurement during stoop. It was tested in three subjects, and each subject performed ten stoop cycles. Even under trunk movement variability (bottom), assistive force controller tracked force reference with 6.63 N (3.3% of the peak force) root mean square (RMS) error.

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