Soft Exo-Skeletal Arm for C4-C5 Trauma Induced Spinal cord Injuries

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Introduction: In the United States there are between 236,000 and 327,000 people with spinal cord injuries related to trauma [1]. We have designed a soft exoskeleton arm prosthetic for flexing and extending the elbow of a person with traumatic spinal cord injuries to the C4-C5 vertebra. Users with spinal cord injuries related to C4-C5, often have great difficulty, and are sometimes incapable of flexing and extending their elbow and of supinating and pronating their forearm [2]. Our exo-musculature orthotic brace is designed to follow the natural motion of the elbow without necessitating any rigid pin joints for support similar to the approach for a shoulder rehabilitation device in [3]. This is implemented using cable-driven series elastic actuators (SEAs) to actuate the user's elbow through its natural motion. The orthotic brace uses surface electromyography (sEMG) sensors at the shoulder and upper arm to control torque for both flexion and extension by learning the correlation between the user's sEMG signal and elbow movement.

Materials and Methods: The brace was constructed to provide assisted motion for a disabled lower arm as shown in Fig. 1. The brace is designed to be a soft-shell brace constructed from a neoprene sleeve with two ABS plastic attachment points for the bicep flexion and four attachment points for tricep extension. This system implements a motor driven cabling system, which use Bowden cables to actuate the brace from motors mounted in the backpack. The cable selected for the Bowden cables was Dyneema, which was collected by four threaded spools. The bottom two-attachment points include four series SEAs which control and adapt the cable force for the system. The mounting points are placed around the arm in locations that place minimal stress on the elbow and preserve natural motion. The arm's four separate cables act in antagonistic motions to each other. A motion control system for actuating the cables resides in a wearable backpack as shown in Fig. 1, and the controller uses a hybrid position/force model, which accounts for both a desired force and position. The force commands sent to the controller are determined based on learned motions from the user's own EMG signals gathered from the shoulder and upper arm through five surface electrodes. Machine learning is applied to learn user's intended motion, which will output desired torque and velocity to elbow's motion control system by classifying the EMG signals in real time. Currently linear classifiers, neural networks, and support vector machines are being used. The control system in the backpack is lightweight and battery powered. The system uses a Raspberry Pi CPU for high-level operations and two Mbed microprocessors with custom interface circuit boards as motor controllers and sEMG sensor interfaces.

Figure 1. ExoMuscular Orthotic: User wears soft robotic brace with sensor wires and Bowden cables running to a backpack that holds the motor assemblies and electronics.

Results and Discussion: A soft, exo-musculature brace capable of driving the arm with two antagonistic pairs of cables controlled through the use of SEAs with integrated sEMG sensing was constructed. The brace will be able to operate in two modes: *training* and *running*. The first mode is essentially a calibration mode, which determines the force of the users arm and the user's range of motion. In this mode, the physical therapist will be able to adjust the arm position either through a passive motor controller or a GUI interface to move the arm about the user's range of motion in steps. The sEMG classifiers being used can report eight separate torque states with 90-95% accuracy. The second mode is the normal running mode where the user manipulates their arm with their own sEMG signals. The brace while attached has been shown to be able to lift a person's arm.

Conclusions: The described brace has been constructed and the initial intention-based controller implemented. This work is related to our previous developments in developing a sEMG controlled soft exo-musculature glove intended for stroke rehabilitation [4], and we look to integrating the systems and performing human trials.

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