Graduate Seminar – PhD Oral Defence

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Zoom Link : https://cuhk.zoom.us/j/5013947035
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Title: Soft Robotics Actuators for Hand Rehabilitation after Stroke

Stroke has been the leading cause of long-term disability and severely affecting the performance of Activities of Daily Living (ADL) among its survivors. Robotic devices are designed for assisting therapists in providing consistent rehabilitation training, but the drawback is primarily reflected in the bulkiness of rigid mechanical actuators that create discomfort to users and impede natural movement of fingers. Soft robotic hands/gloves have been proposed alternatively as an improvement over earlier devices in terms of the inherent compliance, lighter weight, and ability to provide customizable bending motion of soft actuators. However, major defect of current soft actuators is the incapability of providing sufficient extension torque to assist individuals who have finger joints that are influenced by exaggerated tone in flexor muscles in finger extension on actuator depressurization. The provided aid with ADL of existing soft robotic hands/gloves for those with severely impaired hand movements, as seen with stroke survivors, is very limited. Therefore, the major contributions of this study are (1) to develop a soft robotic hand that facilitates active finger flexion and extension in stroke survivors with our new actuator design, (2) to model the static and dynamic behavior of the actuator for performance characterization and control application, (3) to describe the stiffness of finger joints based on the models that present the interaction between the actuator and the phantom finger simulating post-stroke spasticity condition, and (4) to validate the efficacy of our soft robotic hand for rehabilitation applications in the clinical trials.

First, we introduce a novel design of the soft-elastic composite actuator (SECA) that allows active control of bending and extension under pressurization and depressurization, respectively. Key elements of SECA involve a silicone-based bending actuator and a torque-compensating layer, which the torque-compensating layer placed beneath offers an assistive bending moment to maintain sufficient extension torque. In free space bending, the bending angle of SECA are measured. To also consider post-stroke finger spasticity, the performance of SECA is characterized by the analytical models that quantify the input pressure and the bending angle on phantom compromised hands, i.e. mannequin fingers installed with torsion springs to mimic the increased muscle tone in flexors. From the pressure-angle relationship of SECA on the mannequin finger, we further derive the equations that calculate the stiffness of human finger joints to objectively quantify the level of post-stroke spasticity. The analytical models and the stiffness equations are well-validated experimentally and by simulations using Finite Element Analysis (FEA). They are further tested in healthy participants and stroke individuals for preliminary validation.

Furthermore, we develop a soft robotic hand using these SECAs for rehabilitation applications. Flexion and extension of Metacarpophalangeal (MCP) and proximal interphalangeal (PIP) joints of the fingers are facilitated with the devices. Preliminary clinical study with single-group design is also conducted on chronic stroke participants ($n=16$) who have received 20 sessions of 1-hour EMG-driven rehabilitation training using the soft robotic hand. Significant improvements of upper limb function are observed after the training, as shown in the improved score of Action Reaction Arm Test (ARAT, mean of increase = 2.438, $P = 0.032$), Fugl-Meyer Assessment for Upper Extremity (FMA-UE, mean of increase = 3.313, $P = 0.003$), Box-And-Block Test (BBT, mean of increase = 1.8125, $P = 0.024$), and maximum voluntary grip strength (mean of increase = 2.138 kg, $P < 0.001$). No significant change was observed in terms of spasticity with the Modified Ashworth Scale (MAS, mean of increase = -0.106, $P = 0.496$).

In this dissertation, we present the functional soft robotic hand for complete rehabilitation purposes due to the unique design of SECA. With this device, in the future, continuous measurement of the stiffness of all digits would be integrated into the training for facilitating a task-oriented rehabilitation program that may further enhance the therapeutic effects.

***** ALL ARE WELCOME *****

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