The Development of Cable Driven Exosuit to Assist Upper Extremity Movement

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Movement disorders of the upper extremity may be caused by traumas, degenerative deceases, stroke, aging, and other reasons (Gaponov, Popov, Lee, & Ryu, 2016). Each year, about 795,000 Americans experience a new or recurrent stroke (Virani, Alonso, Benjamin, et al., 2020). Rehabilitation is the important procedure to restore functionalities for people with movement disorders. In the past decades, robotic-based rehabilitation with improved intensity and repeatability of the treatment has been widely investigated (Pirondini, Coscia, Marcheschi, et al., 2016). Exoskeleton is the robot that has a structure resembling the human upper limb with robot joint axes that match upper limb joint axes (Lo & Xie, 2012).

Exoskeleton has been commonly used in medical and rehabilitation purposes to assist people with movement disorders. However, it is heavy and bulky. Patients must go to rehabilitation facilities to use exoskeleton and the using time is limited. There is a need to develop wearable exoskeleton (exosuit) that incorporates exoskeleton function into apparel, so the patients can wear the exosuit in their daily life. Exosuits can assist patients to move their upper extremities and provide rehabilitation function during the patients' daily activities. Bowden cable technology was used in exosuit development for upper extremity movement (Nycz, Delph, & Fischer, 2015; Gaponov, et al., 2016; Wei, Qu, Wang, Zhang, & Hao, 2018). Dyneema® (Ultra-high molecular weight polyethylene) cables were often used in cable driven exosuit (Nycz, Delph, & Fischer, 2015; Gaponov, et al., 2016).

Cappello, Binh, Yen, and Masia (2016) designed a soft frame structure of wearable exoskeleton for upper limb with a combination of stiff and unstretchable fabric, strong and stretchable fabric, and soft and stretchable fabric. The stiff and unstretchable fabric was used to anchor cable points, and provided a quasi-rigid structure for force transmission by the cables to the limb and prevent undesired deformation. The strong and stretchable fabric bore the cables sheaths and kept the unstretchable fabric snugly in place. The soft and stretchable fabric was used for the rest of the garment (Cappello, et al., 2016). Similarly, Schmidt, Duarte, Grimmer, et al. (2017) used a combination of strong inelastic textile and elastic textile to develop Myosuit, a lower body exosuit to reduce hip extensor activity in sitting transfers.

The purpose of this research was to develop prototypes of cable-driven exosuit that assist movement in the upper extremity. This exosuit research focused on assisting elbow movement of flexion and extension. The expectation of the exosuit is comfortable to wear, easy donning and doffing, and aesthetic.

The garment design was a quasi-rigid structure with a combination of stiff and stretchable fabrics. The webbing fabric (stiff and unstretchable) was used to anchor the cable. The stretchable fabric (80% nylon, 20% spandex knit fabric) provided comfort and kept unstrechable

fabric snugly in place. To save time, commercial elbow protective pads were purchased and used in the prototype development phase. Dyneema® cable was used to provide elbow movement assistance. Cables were sheathed in plastic tubing to reduce friction and embedded in textiles. Three-D printed components (the white components in Figures 1 and 2) were used to assure the path of the cable. The researchers plan to place the cable actuation and control unit (currently under development) on the back of the exosuit.

Figure 1 shows the first prototype of the exosuit. There were two cables in the prototype. The cable placed in the front of the arm was used for elbow flexion and the cable placed at the back of the arm was used for elbow extension. It was found that the exosuit prototype could assist elbow flexion movement by pulling the cable from the back where the cable actuation and control unit will be placed. However, the exosuit prototype could not assist elbow extension. When pulling the cable placed at the back of the arm, the fabric in the shoulder area would shrink, which indicated the pulling force was distributed in the shoulder rather than elbow area. To solve this problem, the researchers developed the second exosuit prototype (Figure 2) by placing self-adhesive hook and loop tapes on the back shoulder of the exosuit so that the paths of the cables can be adjusted. By adjusting the paths of the cables, especially the cable for elbow extension (the one placed at the back of the arm), the optimum cable paths have been identified, and both elbow extension and flexion movements were accomplished by pulling cables.

Figure 1. First exosuit prototype

Figure 2. Second exosuit prototype

In conclusion, exosuit prototypes that can assist elbow movement have been developed. Currently, the researchers are developing the cable actuation and control unit. After integrating the cable actuation and control unit into the exosuit, the researchers will conduct human subject test to evaluate the effectiveness of the exosuit.

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