Design and Analysis on a Passive Exoskeleton Assistive Device

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INTRODUCTION

Exoskeleton robotic system is a feasible solution that can help people with locomotion difficulties walk again. This system equipped around the human body can support the load and a part of the body weight, enlarging the load-bearing capacity and endurance of the biological system. The corresponding components of the exoskeleton system, such as the power capacitor and transmission, kinematic energy transmission, degrees of freedom of motions and adjustments for different wearers, are of great importance as well as the frame and ergonomic designs.

Exoskeleton robots are developed in many countries, including the US, Japan, South Korea and Israel, etc. They are oriented into different usages – both military and medical devices. University of Tsukuba proposed a commercial exoskeleton robot, Hybrid Assistive Limb, for patient walking and stair-climbing assistances. US Defense Advanced Research Projects Agency (DARPA) supported a multi-million project in "Exoskeletons for Human Performance Augmentation" and help rapid progresses in the researches and developments on exoskeleton robot field.

METHOD

This research proposes a passive exoskeleton assistive device, as shown in Fig. 1, composed of the pelvis frame, thighs, shanks and the footplates. A pneumatic cylinder serves as the power source and drives the cable-cam transmission system in the exoskeleton knee area. Eby and Kubica (2007) suggest that generating an external knee extensor torque with a powered lower-limb orthosis may reduce the sit-back failure. In this design the biological knees therefore do not provide any torque during sit-to-stand motion, however it needs some human efforts to flex the exoskeleton knee joint, storing potential energy into the pneumatic cylinder for later extension.

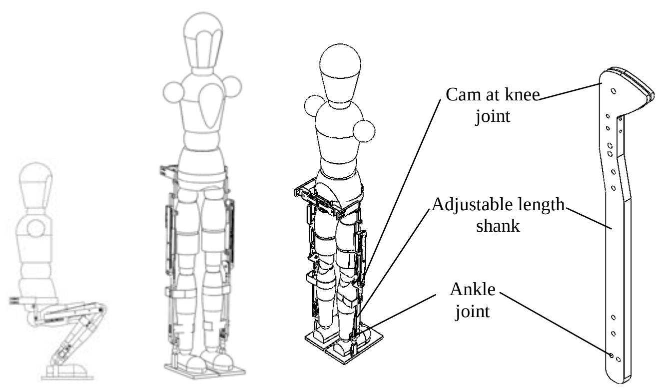

Fig. 1: The passive exoskeleton assistive device in this study.

Detail design of the proposed model is shown in Fig. 1. The piston rod of the pneumatic cylinder draws a cable wound through a cam with specific profile, providing the extension torque of the exoskeleton knee. The specific profile consists of a gradually lengthened radius from the rotation center to the edge of the cam, producing a progressively enlarged torque during the knee flexion. The proposed device acts as a knee extensor for sit-to-stance motion. A upper-body weight above the knee of 400N and the weight-assisting ratio of 100% are selected for the design purpose, providing a complete assisting force to help the patient to stand from sit without any biological effort. The maximum exoskeleton knee torque T at squat is calculated as:

$$T = Wd_1 = 400 \times 0.37 = 148 \quad \text{(Nm)}$$

where W represents the upper-body weight above the knee; d_1 is the distance between the center of mass of the upper-body and the knee joint. The cam radius ranges from 20 to 45mm in this study, preventing the cam component from extending outward from the biological leg profile and reducing the esthetics of the device when worn inside the pants. The cylinder provides the maximum force F to draw the cable wound at its maximum radius d_2 of 45mm, as derived below:

$$F = \frac{T}{d_2} = \frac{148}{0.045} = 3289 \text{ (N)}$$

A standardized commercial pneumatic cylinder providing 4kN force output at full contraction is selected in this study.

The cam profile is approximately derived by using the multi-point line smoothening technique in the CAD software. Zoss and Kazerooni (2005) suggest that the knee joint rotational ranges from 0 to 160 degrees for BLEEX exoskeleton robot. The initial radius of the cam at knee full extension is 20mm while the final radius at full flexion is 45mm, and other 4 points between the initial and final points are defined as the passing-though points of the smooth profile of the cam, as shown in Fig. 2. Arc length of the derived profile 69.99mm is also confirmed to agree with the piston stroke 70mm.

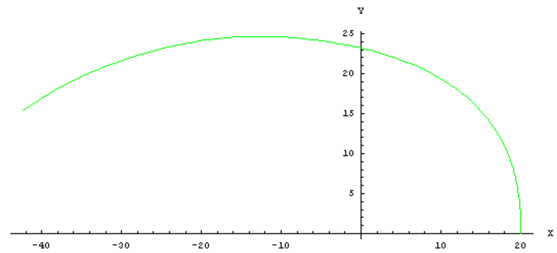

Fig. 2: Profile of the cam.

RESULTS

Relation between the knee flexion angle and the generated torque by the exoskeleton knee is shown in Fig. 3, as well as the plot of piston stroke vs. the knee torque.

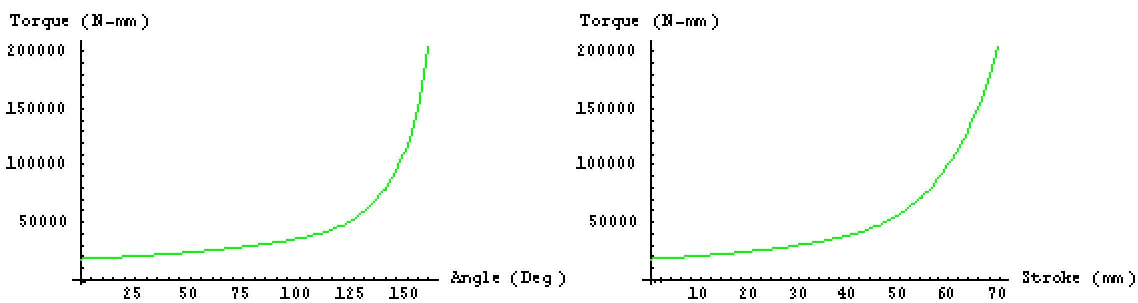

Fig. 3: Relation between the knee flexion angle/piston stroke and generated torque.

CONCLUSION

This research focuses on the design and analysis of the power and transmission system in a passive exoskeleton assistive device for sit-to-stand task. The profile of the cam in the transmission system is derived from CAD, and the final design is modified according to a standardized available product. Performance of this assistive device is theoretically verified in this study.

ACKNOWLEDGEMENTS

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