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論　文　内　容　の　要　旨

The rapid aging of global population has brought a situation in which more and more elderly people need to be cared for by the other elderly family members or professional caretakers. Walking assistance for the elderly or the people with walking disabilities has received serious attention in the field of robotics and mechatronics in recently years. A large number of wearable robots, suits or devices have been developed over the years, usually with the purpose of assisting or augmenting human walking. Most of them are exoskeletons using electric motors with rigid links in parallel with the body that can impart torques to the joints and support compressive forces. However, exoskeletons still present some ongoing challenges, such as a heavy load, a bulky structure, high stiff rigid frames, which could be a burden for the elders with weakened muscles and the rigid frames may restrict the natural movements of the wearers.

Our long term goal is to develop a wearable assistive device that can be used for a daily life to support the elders with some weakened muscles or to lighten the muscular burdens of the healthy people during walking. In addition to have the function of lightening the burden of the wearers during walking, the devices should have low impedance, high flexibility, be comfortable and safe to wear and easy to don and doff. In a previous study, We have developed a soft artificial muscle using the plasticized polyvinyl chloride (PVC) gel which has many positive characteristics, such as being soft and lightweight, having a stable actuation in the air with a high output, a notable response rate, a low power consumption and no noise, which showed a great potential for practical applications among all the candidates of artificial muscles.

In this Thesis, we developed a novel lightweight, flexible wearable walking assistive wear using PVC gel artificial muscles. Compared to other prior motors based wearable assistive devices, the proposed assist wear had the features of no rigid mechanical structures, minimal weight, compact and high flexibility which made the assistive device possibly be wearable like a clothing. The main works concern two aspects as development of PVC gel artificial muscles and application on the walking assist wear.

For the development of PVC gel artificial muscles, we have improved the characteristics of PVC gel artificial muscles from several aspects, from the gel membranes to artificial muscle fabrication to make it almost close to the level of the

biological muscles. And we have proposed an improved method to measure the output force of PVC gel artificial muscles that can accurately measure the characteristics than the former method which made a great sense in present and future development of PVC gel artificial muscle technologies. Also we have proposed three types of modular constructions to make the PVC gel artificial muscles become robust actuation devices for different kinds of applications, which are very important elements for the standardization of PVC gel artificial muscles. Furthermore, the model of the static characteristics developed in this study which showed a good agreement with the experimental data could be an effective element for the specific design and control of the proposed modular constructions in an application.

For the application on a walking assist wear, we have proposed a novel lightweight wearable assistive wear using PVC gel artificial muscles, according to the biomechanics of walking. The assist wear is able to assist the lower limb during the swing phase, from the moment that the toe leaves the ground, providing an assistance over 10% of the maximum moment on the hip to support the motion of the hip joint until the moment of the heel initially contact to the ground, so as to reduce the burden of the leg muscles in the flexion motion. And we have designed and prototyped the walking assist wear using PVC gel artificial muscles, and developed a smart and cost effective walking motion detector and a competent controller. The characteristics evaluation experimental results of the system were almost consistent with the desired results which indicated the effectiveness of the designed walking assistance system with PVC gel artificial muscles.

And we have conducted experiments to validate the effectiveness of the walking assist wear system, founding that, with the assistance of the PVC gel artificial muscles based assist wear the walking speed increased about 10% and the average step length of the assisted leg increased about 28mm during walking. Also we obtained about 17% maximum decrease of the muscular activity for the Rectus femoris muscle, about 11% maximum decrease for the Sartorius, about 5% maximum decrease for the Hamstring with a significant difference of 1% which shows that the assist wear can reduce the burden of the muscles of the lower limb during walking.

The assist wear is compact and lightweight, showing no impedance to the natural movement of the wearer during walking, and it allowed the wearer walking freely like a clothing. Therefore, the proposed PVC gel artificial muscles based assist wear could be reasonable for a daily life use, for the advantages of a simple structure, compact and lightweight, flexible, good in fitting and easy to put on and take off.

The main contribution of this Thesis can be briefly concluded as follows:

1. A critical review and analysis of the existing artificial muscles and human assistance device technologies (Chapter 1).
2. Development and improvement of the PVC gel artificial muscle technology from several aspects to make it much more applicable in a practical application (Chapter 2).
3. Propose of a novel lightweight assist wear for a daily life support using the PVC gel artificial muscles (Chapter 3).
4. Design, construction and fabrication of a new walking assist system, including the assist wear, walking motion detector and controller (Chapter 4).
5. A comprehensive evaluation of the characterizations of the system (Chapter 5).
6. An experimental effectiveness validation with a deep analysis of the proposed novel assist wear system (Chapter 6).