Development of a Hybrid Power Assist Orthosis with FES

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Abstract

In the past various methods to restore motor functions in persons with spinal cord injury (SCI) have been developed. Functional electrical stimulation (FES) methods and wearable power assist suits with actuators have been proposed in the areas of medical sciences and engineering respectively. However, complete restoration of motor functions in persons with SCI has still not been successful. In this paper we describe the development of a new hybrid power assist orthosis with FES and actuators for restoration of the lower extremity motor functions in persons with SCI. The main features of the orthosis are the compensation of moment produced by FES and controllability of FES output moment by using actuators. The developed orthosis has been experimentally evaluated by measuring and comparing the moment at the knee joint with only FES, with only actuators and with both FES and actuators. The results prove that the developed orthosis can provide very good assistance to persons with SCI and also controllability of the variation of output FES moment.

1. INTRODUCTION

Functional electrical stimulation (FES) is normally applied to persons with spinal cord injury (SCI) to restore their motor functions. Minato et al. [1] reported that a hybrid FES with the medical single hip joint Knee-Ankle-Foot Orthosis improved the step length and the step cadence in comparison with the only use of orthoses. However the gait velocity and the oxygen consumption with hybrid FES were not improved substantially [2]. Therefore, FES usage has been confined to rehabilitation and there is no effective cure for persons with SCI in spite of remarkable progress in medical technology in recent years.

On the other hand, various wearable power assist suits with actuators have been developed in the field of engineering [3] [4]. These power assist suits assist the muscular force of healthy persons, but most of them have not yet been developed. Due to these reasons, a restoration method of motor functions in persons with SCI has not been developed. This study proposes a new hybrid power assist orthosis with FES and actuators to restore the lower extremity motor function in persons with SCI. The hybrid system reduces possible to reduce muscle fatigue, caused by too much stimulation of FES, by using actuators. In addition, the system compensates uncertain muscle power output by FES. The objective of this study is to develop a hybrid power assist orthosis and experimentally verify its effectiveness.

2. METHODS

2.1. Specification of the Hybrid Power Assist Orthosis

Figure 1 shows the front view and side view of the designed orthosis and Table 1 shows its specification. The orthosis is designed for a healthy person (age 23 years, height 174 cm, weight 59 kg) and its weight including four actuators is 9.2 kg. The wearer does not feel the weight because the structure is supported by the orthosis foot region that is resting on the ground.
The orthosis has two novel mechanical features. One is the use of parallel linkages instead of gearing systems or timing belt systems in order to transmit the actuator power to the knee and hip joints (Fig. 2, Fig. 3). This structure results in a more compact size compared to that of other power transmission devices. The second feature of our orthosis is that it is mounted from the front of the body. In general, most orthosis are designed to be mounted from the back of the body, based on the principle of three-point fixation for standing postural stability. However, in the case of our orthosis, the actuators attached to the orthosis ensure standing postural stability. Therefore, we designed the orthosis to be mounted from the front of the body in order to enable a person with SCI to wear it even while sitting in a wheel chair. Consequently, these features make our orthosis practical in daily life.

2.2. Experimental Procedures

We measured the moment at the knee joint for a healthy person (age 23 years, height 174 cm, weight 59 kg) to verify the effectiveness of the hybrid power assist orthosis. The experimental set-up is shown in Fig. 3. A load cell attached to the distal limb recorded tensile force $F$, and the joint moment $M$ was obtained by multiplying $F$ with the lever arm length $l_F$. In addition, the knee moment was measured at an angle of 45° of knee extension.

![Figure 2: Experimental set-up](image)

![Figure 3: Geometrical definition](image)
3. RESULTS

Figure 4 shows the output of the knee joint moment in each of the three steps. There is little difference between the maximum knee joint moment in Fig. 4 (b) (31.6 Nm), which is measured data with FES only, and (c) (31.9 Nm), which is measured data with FES and actuator assisting. In terms of the stimulation voltage the value in (c) is about 60 % of the value in (b). This indicates that the actuator moment can compensate for the joint moment produced by FES. In addition, this data also shows that the output with the actuator and FES (c) increased moderately compared to the output of FES only (b) (shown by the circle in orange dot line in Fig. 4). These results indicate that we can reduce the influence of the FES output uncertainty by controlling the actuator’s output.

![Figure 4: Knee joint moment measured in three experimental conditions: (a) actuator’s assist, (b) FES, (c) hybrid assist with actuator and FES](image)

4. DISCUSSION AND CONCLUSIONS

The goal of our study is to restore the motor function of the lower extremity of persons with SCI to enable walking and standing. We developed a hybrid power assist orthosis with FES and actuators and proved the effectiveness of the orthosis in this paper. The effectiveness of the orthosis was experimentally verified at the knee joint, but similar result is also expected at the hip joints. The results proved that the proposed hybrid system is much more effective than only use of FES. Especially, in terms of controllability of the variation of FES output, we can think that the system has large effectiveness on the control of leg exercise. This effectiveness contributes to the reduction of muscle fatigue induced by FES and improves the movement of persons with SCI.

There are two further issues that must be solved in order to restore the motor functions of lower extremity. The first issue is how to control the uncertainty of the output of FES. In order to solve this problem, it is necessary to develop a real-time monitoring method of the joint moment. Therefore, we will apply a force sensor in our orthosis. The measured data from the sensor will make it possible to know the interference between the output of FES and the actuator in order to estimate the output of FES. This data would also be useful to solve the second issue. The second issue is how to control FES and the actuators without interference, as is necessary to control both FES and actuators in cooperation. We think that impedance control is an effective method to solve the issue because this method includes both position control and force control. The force sensor will also be used for the impedance control of the orthosis. At present we are investigating the best way to control the orthosis in order to solve the above two issues.

References