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Hip Joint Control of PGO for Paraplegics

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Abstract. : In this study, we developed a fuzzy-logic-controlled PGO (Power Gait Othosis) that controls the flexion and extension of each PGO joint using bio-signals and an FSR sensor. The PGO driving system works to couple the right and left sides of the orthosis by specially-designed hip joints and pelvic section. This driving system consists of the orthosis, sensor, and control system. An air supply system for muscle action is composed of an air compressor, 2-way solenoid valve (MAC, USA), accumulator and pressure sensor. The role of this system is to provide constant “air muscle” with compressed air at the hip joint. With the output signal of the EMG and foot sensors, air muscles assist the flexion of the hip joint during the PGO gait.

Introduction

It is a challenging task to make the paraplegic walk without the assistance of a caregiver. RGOs (Reciprocating Gait Orthosis) have been introduced to assist the paraplegic in walking. An RGO consists of two KAFOs. of which the torso section includes a pelvic band. The patient wearing the RGO pushes the pelvic band backward with his/her trunk and one of the leg braces moves forward. Thus he/she has to keep pushing the pelvic band in order to walk. Therefore, during a gait with an RGO, the energy expenditure is excessive, and the use of RGO has not been not widely accepted[1,2,3,4].

At KOREC, a prototype of a PGO (Powered Gait Orthosis) was developed to reduce energy consumption and muscle fatigue. Each hip joint of the PGO is flexed by an air muscle operated by pressurized air, enabling the patient to walk. The air muscle behaves like a human muscle and connects one side of the torso section to the upper part of the same side of the brace. The role of artificial muscle is to assist hip flexion during the swing phase. Therefore, the patient can walk with less energy expenditure by using a PGO compared to an RGO. The PGO is a modification of an RGO, incorporating two pneumatic muscle actuators (PMA), a compressed air system, and pressure and joint angle sensors. In the present study, a PGO controlled by a fuzzy algorithm for hip flexion was evaluated in two SCI patients. In addition, hip flexion angles and foot pressure were measured and analyzed for SCI patients who used the developed PGO with a three-dimensional motion analysis system.

2.2 PGO system

The concept of the PGO driving system is to couple the right and left sides of the orthosis by specially-designed hip joints and pelvic section. The driving system of the PGO consists of the orthosis, sensor, control system. An supply system is composed of an air compressor, 2-way solenoid valve (MAC, USA), accumulator, and pressure sensor. The role of this system is to provide constant air muscle with compressed air at the hip joint (Fig. 1). It consists of two sensors and a fuzzy controller.

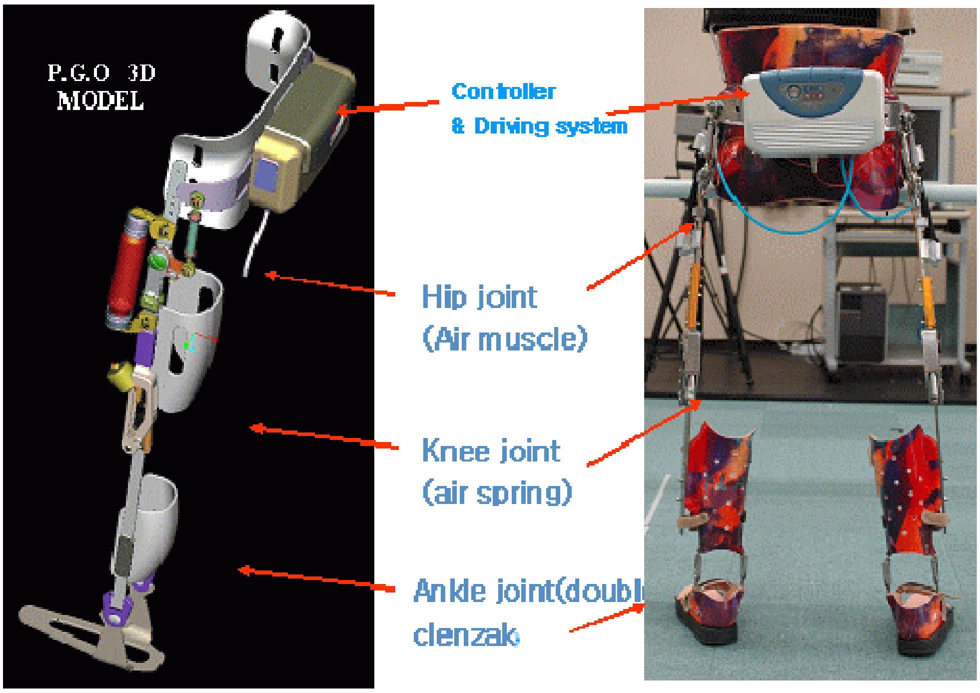


Fig 1. PGO system

3. Gait Analysis

Three subjects (39±2.8 years) participated in this study. Their heights and weights ranged from 170±1.7㎝, 60.5±7.5kg, respectively. Subjects performed the gait analysis five times per month after gait training on the PGO over a period of about three months.

The raw data of the marker positions were passed through a filter, and analyzed with the built-in software in the three-dimensional motion analyzer system (Vicon 370; Oxford Metrics Inc., UK). To obtain kinetic data for each lower limb joint of the subjects, we measured ground reaction force using two force plates (900×600㎜, 600×400㎜ in size; Kistler Co., Swiss). (Fig. 2) Capacitance pressure sensors (Novel GmbH, Germany) were used to measure plantar pressure distributions while using the PGO.

Fig 2. Gait analysis

4. RESULTS AND DISCUSSION

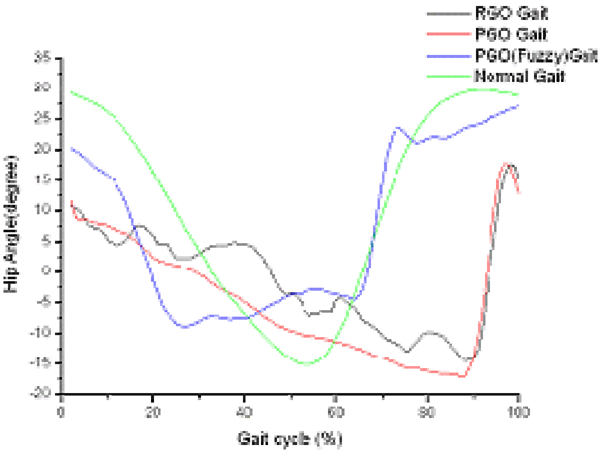


Fig 3. Hip flexion/extension angle

The aim of this study ultimately is verifying that fuzzy PGO gait is more efficient than RGO for paraplegics because the air muscle assists hip flexion power in heel off movement.

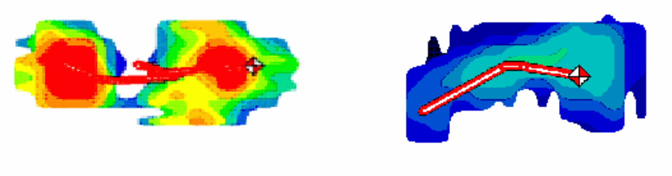
In figure 3, the gait characteristics of the paraplegic wearing the PGO and RGO are compared with that of a normal person. At heel contact in RGO and PGO gait, hip flexion angles are approximately 10 degrees, while that of a normal gait is approximately 30 degrees. The smaller hip flexion angles of the PGO and RGO gaits are due to the smaller step length. In normal gait, the duration of the stance phase and swing phase are 60% and 40% of the total gait cycle respectively. In RGO gait, the duration of the swing phase is reduced since the hip joint is flexed by the rotation of the pelvic band. The hip flexion angle fluctuates during the stance phase as the movement of the body center is unstable. On the other hand, in the PGO gait, since the hip joint is flexed by the air muscle and not by the rotation of the trunk, the movement of the center of the body appears to be more stable than that of the RGO gait. The ratio of the duration of the swing phase in PGO gait is 63±8% showing improvement from the RGO gait in which the duration of the swing phase is 79±4%. The gait speed is 61±3step/min for RGO gait and 77±2step/min in PGO gait, respectively. During gait, the pelvic tilt is normally related to the balance of the body and the amount of energy consumption.

The pelvic tilt during normal gait reduces the vertical movement of the hip joint and minimizes the vertical motion of the body center. The pelvic tilts during the PGO and RGO gaits become larger than that of the normal gait. The reason is that since there is no knee flexion during the PGO/RGO gait, larger pelvic tilt than that of the normal gait is needed for toe off. The fact that pelvic tilt during the PGO gait is relatively smaller than that of the RGO gait means that the movement of the body center is more stable in PGO gait because of the air muscle.

At the initial heel contact during the level walk of a normal person, the pressure distribution is concentrated on the heel and, at the terminal stance phase, a heavy concentration of the pressure is found in the metatasal. At mid-stance the pressure distribution is almost even.

On the other hand, during PGO gait, the pressure distribution conical shape concented on the heel and metatasal at the initial heel center and through mid-stance. In RGO gait, at the terminal stance phase the pressure hill moves back to the mid-foot as the patient tries to change weight-bearing to the other limb.

The COP (Center of pressure) during normal gait, starts from the posteriolateral of the heel at initial contact and travels almost linearly along the lateral to the midline during the mid-stance phase. It then moves to the medial part of the foot with distinct pressure concentration on the metatarsal break. However, in case of PGO gait, the COP starts from the heel and proceeds to the metatasal. Then at the pre-swing phase the COP moves to the mid-foot. The positions of the foot on which the value peak pressure are heel, metatarsal and toes. During PGO gait, the peak pressure at the heel is larger than normal gait.



(a) RGO gait (b) PGO gait

Fig 4. COP movement

5. CONCLUSION

In this paper a PGO using PMA's for SCI patients is proposed. As the hip flexion angle and the pelvic angle decreased during the gait using PGO, the patient can walk faster. A PGO controlled by a fuzzy controller was developed and found to useful. The EMG signal seems to be a good tool to detect the intention of ambulation of the paraplegic and unintentional motion of the PGO can be removed by using the EMG signal. Therefore, the proposed PGO can be a very useful assistive device for paraplegics in walking.

6. Acknowledgment

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