Study on high-performance shoes for walking training system
with human compatibility

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Abstract The number of elderly in the Japanese population has been increasing, and is expected to reach about 40% by 2060. This means that those aged 65 and over in Japan will be roughly every one in 2.5 persons. With this are increases in the need for elder-to-elder nursing and shortage in and an increased burden on care takers. These developments have resulted in efforts to promote independence among the elderly - something that has brought walking to the attention of those promoting good health and independence among the elderly. The increasing number of accidental falls among the elderly while walking. Among the main factors in falls are a deteriorating center of gravity of balance due to declining physical performance and weakening in the muscular strength of the lower limbs. Against this background, we began by presenting the specifications of the High-Performance Shoe we designed and walking training using these. We then discussed results and considerations of evaluation experiments involving younger persons. Further, we designed High-Performance Shoes that showed the status of a person’s balance while walking and an orthosis that is driven by a rubber artificial muscle actuator. In this paper, we indicate the usefulness of the proposed walking training system through some experimental results.

Keywords: Walking Training, Walking Assist, Shoes, Rehabilitation, Pneumatics

1 Introduction

In recent years, the number of elderly people has been increasing. The rate of elderly people to total population of Japan is expected to be 33 percent by 2025. Thus, we predict that the number of fall down cases of elderly people will have been increasing [1]. One of the most popular reasons with respect to fall down of elderly people is a gap of the center of walking balance which is due to power down of foot part muscle for aging. Figure 1 shows the trajectory of center of gravity position of both young people and elderly people in the walking motion. In the figure, the solid lines show the trace of the center of gravity position, and the broken lines show the center of sole of the foot. In the case of elderly people, motion of both the solid and the broken line is shaking fiercer than that of young people. Therefore, elderly people are liable to fall down. We considered that realization of walking balance without a gap of the center of gravity position of foot is one of the solutions of fall down accidents [2].

In this study, we focus on shoes to be worn daily in walking aimed at both assisting walking and preventing falls. We propose training in walking that is continues and daily that detects and corrects the center of balance during walking. To add detection of staggering, we use both a sponge-core soft-rubber actuator (SCSRA) consisting of open-cell foam sponge coated in silicon rubber and rubber artificial muscle actuators. The SCSRA changes stiffness with inner pressure. Equipping insoles, with it means that it can be uses for both detecting the pressure distribution of the foot sole while prompting correct walking by changing the stiffness of the insole. We also develop a means of walking status presentation that confirms walking status on a display in real time. Further, we develop a walking assist orthosis which is driven by a rubber artificial muscle actuator. In this paper, characteristics of each device are cleared through some experimental results.

Fig. 1 Trajectory of Gravity Point
2 HIGH-PERFORMANCE SHOES

2.1 Sponge-Core Soft Rubber Actuator (SCSRA)

We introduced the SCSRA for the insole. Figure 2 shows the structure of SCSRA. Sponge is coated and sealed in silicon rubber and a tube is attached for add or remove air. Thus, it can change the stiffness along with the inner pressure. Inner pressure is also changed by external pressure. So, the SCSRA is used both to detect pressure and assist in walking. Additionally, the actuator is more suitable for use on the human skin than others composed plastics or metals, because it's made up of these soft materials. Endurance test results confirmed that SCSRA endures up to 84.2kPa when it kept hermetically-sealed, so that it has enough pressure resistance for use as an insole [3].

![Fig. 2 Structure of SCSRA](image)

2.2 Insole

Using SCSRA as insole material, we developed High-Performance Shoes that both measure the pressure distribution of the foot sole enable the center of gravity to be corrected in walking. Figure 3 shows the weight transfer during the stance phase of the walking cycle. This determines the arrangement of the insole. According to this figure, it is pertinent that the measurement of the heel, little toe, thenar and big toe [4]. Based on these, we arranged the corresponding SCSRA as shown in Fig.4.

![Fig. 3 Weight transfer during the stance phase of the walking cycle](image)
2.3 High Performance Shoes

Our High-Performance Shoes, shown in Fig. 5, consist of an insole which is described in section 2.2, an electrical circuit that measures pressure distribution, processes data and assists walking correction[5][6]. These are separated into the shoes, which weigh 720g, and a thin pad, which weighs 180g. SCSRAs have small pressure sensors for measuring inner pressure. SCSRAs have small three-port two-position air solenoid valves for controlling of inner pressure. Further, the electrical control circuit has the BLE (Bluetooth Low Energy) Nano V2 that is a wireless communication module, along with micro air pump for changing inner pressure mounted on the thin pad.

![Fig. 4 SCSRA Arrangement](image)

![Fig. 5 High-Performance Shoes used in walking training](image)
(a) Communication System

(b) Walking Training System

Fig. 6 Proposed Total System
3 WALKING TRAINING SYSTEM

3.1 System Constitution

Figure 6 shows the constitution of walking training system that we developed in this study. The proposed system is constructed with High-Performance Shoes, Android Devices and the BLE Nano V2. By using the High-Performance Shoes, it is possible to show the status of walking balance. This system purposes realization of steady walking through walking training using High-Performance Shoes. The active flow of the proposed system is explained in Fig.6.

First, a patient wears both the High-Performance Shoes and an Android-Powered Head-Mounted Display (HMD). Second, the subject does walking training. At this time, the High-Performance Shoes measure the distribution pressure of the sole by using the measurement circuit on the shoes. Then, the subject can see walking state by using the android application for walking state presentation. From the walking pattern, the High-Performance Shoes system shows some positions on the insole where the subject should put as the center of gravity position of each foot by changing the stiffness of the insole.

3.2 Orthosis for Walking Assistance

In order to support the lower limbs motion, the orthosis using rubber artificial muscle is used to lift up the thighs. The orthosis is shown in Fig.7. The muscle is driven by CO2 Gas (Fig.8). The weight of CO2 Gas Regulator is 169 g and the tank is 294 g.

![wearable walking assist device](image1)

Fig.7 wearable walking assist device

![CO2 Gas Regulator and Tank](image2)

Fig.8 CO2 Gas Regulator and Tank
3.3 Walking Assistance using an orthosis with a rubber artificial muscle

In this section, we indicate an effectiveness of the proposed wearable walking assist orthosis to support the elderly people using a rubber artificial muscle (rubber actuator) as shown in Fig.7. The assistane system has high-value-added walking training system whose joint is driven by the rubber actuator. Their walking speed and step can be improved by supporting a flexing action of hip joint. The device is required to have a lightweight, simple structure, and portability. Therefore a pneumatic rubber artificial muscle which has a lightweight and high power-weight ratio is used as an actuator. Further, CO2 gas cartridge tank is used to realize a portability instead of air compressor as air pressure source.

Through some experimental results, effectiveness of support force to lift up the thighs is indicated under the condition that there are three inner pressure patterns of rubber actuator (500kPa, 400kPa, 250kPa). Each experimental result is shown in Fig. 9-Fig.10. In these results, both myogenic potential and hip joint angle are measured when subject wearing the wearable walking assist device walks on a treadmill. The number of subject is five students (healthy adult males). From some experimental results with respect to both walking speed and step, similar waveforms are obtained. When the assist function is on state, the average maximum value of myogenic potential decreases as compared with turned off state. In other words, it became clear that this device can perform similar walking even with small muscular strength. Therefore, it can be said that the wearable walking assist device has an ability of walking assistance function.

![Fig.9 Myoelectric potential](image1)

![Fig.10 Hip joint angle](image2)

4 CONCLUSIONS

We have discussed the background, development and results for the High-Performance Shoes we developed in this study. These shoes detect and help correct the pressure distribution on the sole of the foot, helping to correct walking balance and to minimize falls in elderly through walking training. Results of experiments for evaluating the effectiveness of the proposed system showed that kicking up support and correction of human body center.
Although our shoes had a certain effectiveness in support in walking by younger person’s. However, these shoes have some problems to conduct walking experiments by elderly people such as weight of the walking assist devices, ease to wear and so on. Therefore, we have been improving in order to reduce size and weight and become easy to wear. After these improvements, we plan to conduct walking experiments involving pseudo elderly persons. Furthermore, we also plan to conduct walking experiments and sensory evaluation involving the elderly at welfare and rehabilitation facilities.

REFERENCES


