Study on a New Type of Walking Training System with Human Compatibility

Yasuhiro Hayakawa[1,*], Yuuta Kimata[1,*]

[1]National Institute of Technology Nara College, Department of Control Engineering, 22, Yata-cho, Yamatokoriyama-shi, Nara, 639-1080, Japan

***Corresponding author: E-mail: hayakawa@ctrl.nara-k.ac.jp; Tel.: (+81) 743-55-6119**

DOI: 10.5185/amlett.2020.041495

With the aging of society, accidental falls among the elderly are increasing. The main factor is the deterioration of balance due to the decrease in physical ability. Another key factor with elderly people is that the position of the body's center of gravity tends to sway from side to side while walking. To find a way to cope with falls in the elderly, we have developed a new gait training system that handles the central gap of gravity position with soles. Here, a new element consisting of silicone rubber and foam rubber is used for the insole of the shoe. By using this element, it is possible to measure the foot pressure distribution and adjust the change in element stiffness. Further, the measured data of the insole can be displayed on the terminal device. Also, this data can be stored on the server. Moreover, by operating the terminal device, the insole element is pressurized and the stiffness of the element can be adjusted. Further, the developed system enables real-time measurement of changes in foot pressure distribution during walking. In this paper, we show that the difference in walking patterns can be clarified.

Introduction

The number of Japanese elderly is increasing and is expected to reach about 40% by 2060 [**1**]. This means that about one in every 2.5 people in Japan is over 65 years old. As the result, the proportion of elderly people caring for the elderly increases, and the burden on caretakers increases. With these developments, efforts to promote the independence of the elderly are being carried out socially. This promotes health and independence for the elderly. In particular, while the elderly are walking, the number of accidental falls of the elderly is increasing [**2**]. The major causes of falls are poor physical fitness and poor center of gravity due to weakness in lower limbs [**3**]. Against this background, a variety of home care and support devices have been developed to effectively prevent accidental falls, such as supporting lower limb movement and lower limb orthoses [**4-10**]. However, these devices may be too large to use every day, or users may find it uncomfortable and hate continuous use. In short, there are few devices to help elderly people walk safely, easily and without stress.

This study focuses on shoes worn daily during walking, both to assist walking and to prevent falls. We propose continuous and daily walking training that detects and corrects the center of balance during walking. The shoe insole uses a sponge core soft rubber actuator (SCSRA) consisting of open-cell foam sponge coated with silicone rubber. SCSRA changes stiffness by internal pressure. Also, by changing the stiffness of the insole, it is possible to detect the pressure distribution on the sole while promoting correct walking. In short, the advantages of the developed shoes have two functions. One is to measure the distribution pressure acting on the insole. The other function is to control the stiffness of the insole by adjusting the internal pressure. In other words, the insole part of the shoe that was developed has the function of both a sensor and an actuator. This is very different from previously developed shoes. Besides, the pressure distribution measurement results on the insole are displayed graphically on both the smart glass and the terminal tablet. Furthermore, the stiffness of the specified element of the insole can be controlled by the touch panel operation of the terminal tablet. As the result, it is possible to directly stimulate the soles of the subjects and provide balanced instruction.

In this study, we evaluate the difference in walking from the pressure distribution data on the sole by using the developed walking system. Then, the effectiveness of the system is clarified from some experimental results.

High – Performance Shoes

Sponge-Core Soft Rubber Actuator (SCSRA)

This section describes the rubber element (SCSRA) used for the insole. **Fig. 1** shows the structure of SCSRA. The sponge is coated and sealed with silicone rubber and has a tube to supply and exhaust air. Therefore, the stiffness can be changed by adjusting the internal pressure. Since the rubber element is sealed, the internal pressure changes due to external force. Thus, SCSRA is used for both pressure detection and walking assistance. Also, the actuator is made of a soft material. Therefore, it is more suitable for use on human skin than other actuators made of plastic or metal. Durability tests have confirmed that SCSRA can withstand up to 84.2 kPa in a sealed state. Therefore, it has sufficient pressure resistance to be used as an insole [**11**].

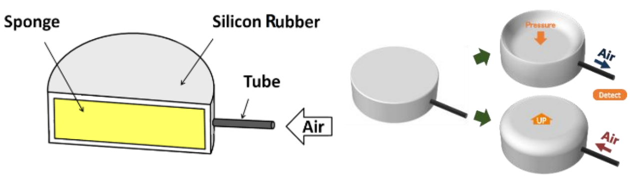


Fig. 1. Structure of SCSRA.

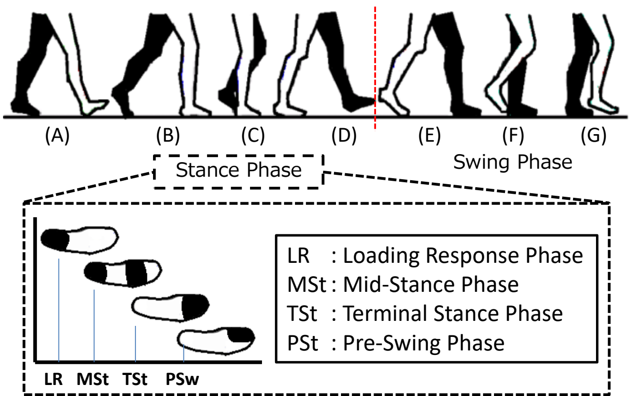


Fig. 2. Weight transfer during the stance phase of the walking cycle [**12**].

Insole

By using SCSRA as the insole material, we have developed a high-performance shoes that measure the pressure distribution on the sole and can correct the center of gravity during walking. **Fig. 2** shows the weight shift during the standings stage of the walking cycle. This determines the placement of the insole element. In other words, this figure shows that the measurements of the heel, the little finger, the ball of the thumb, and the thumb are appropriate [**12**]. Based on these results, a corresponding SCSRA was placed as shown in **Fig. 3**.

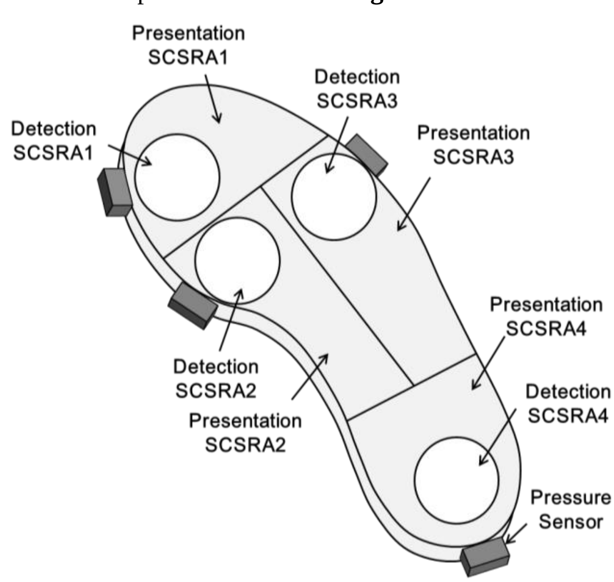


Fig. 3. SCSRA Arrangement.

High-Performance Shoes

The high-performance shoes shown in **Fig. 4** consists of the insole described in the previous section, and an electrical circuit that measures pressure distribution, processes data, and aids in gait correction [**13-14**]. These are divided into shoes weighing 720g and thin pads weighing 180g. SCSRA also has a small pressure sensor to measure internal pressure.

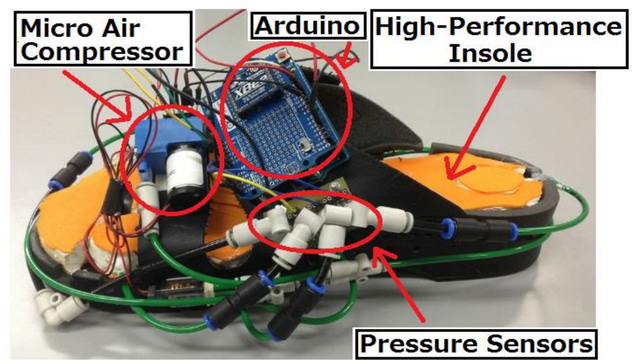


Fig. 4. High-Performance Shoes used in walking training.

SCSRA has a small 3 port 2 position air solenoid valve for controlling the element internal pressure. In addition, the electrical control circuit includes a wireless communication module BLE (Bluetooth Low Energy) Nano V2 and a micro air pump mounted on a thin pad to change the internal pressure. **Fig. 5** shows the proposed total system.

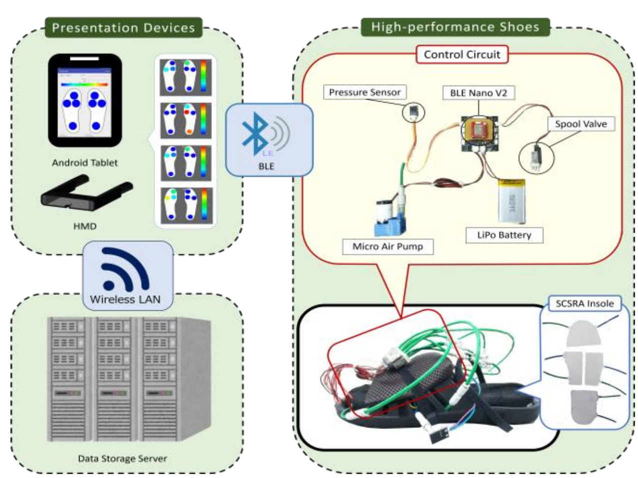


Fig. 5. Proposed Total System.

Insole for walking assistance

The purpose of the walking aid system is to automatically change the stiffness of the insole when a certain pressure value is exceeded. Also, the goal is to enable the user to perform independent walking training that stimulates the soles to walk correctly. **Fig. 6** shows the proposed configuration of the proposed walking assistance system. In system operation, the pressure value from SCSRA is sent to the electrical circuit. When the pressure value exceeds 10KPa, the solenoid valve connected to SCSRA turns on. Next, the air from the micropump is charged to SCSRA via the tube. As the result, the stiffness of SCSRA increases. When the pressure falls below the threshold, the valve is turned off and the air inside the SCSRA is released to the atmosphere. As the result, the stiffness of SCSRA becomes soft. In this experimental setup, the validity of the measurement system has been confirmed by basic experiments.

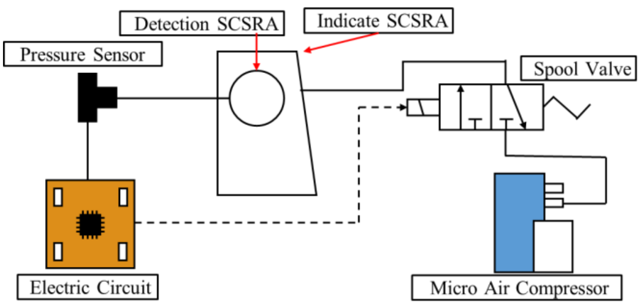
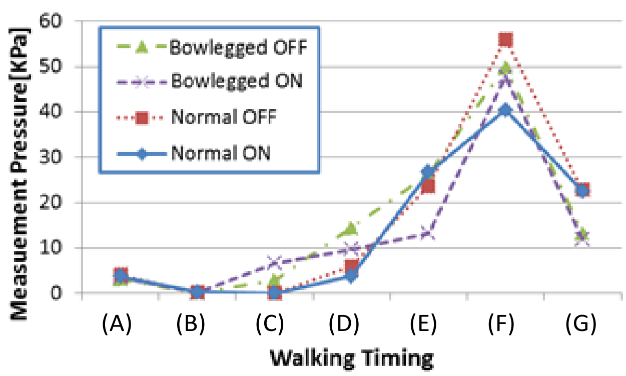
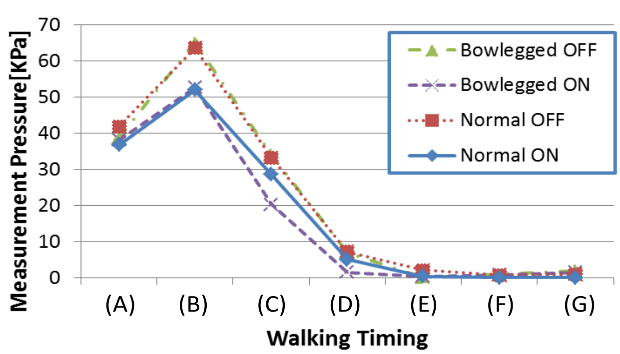


Fig. 6. Walk-assistance configuration.



(i) LeftP.D.SCSRA4



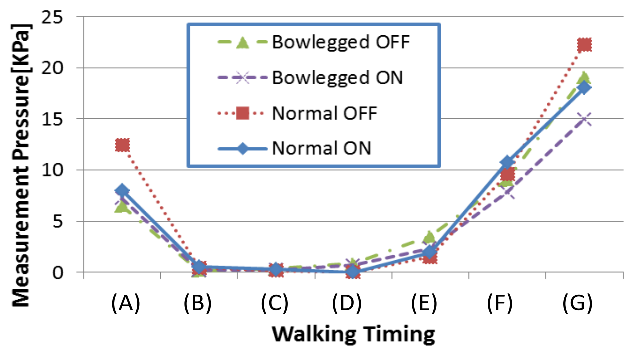
(ii) Right P.D.SCSRA4

Fig. 7. Transition of instantaneous pressure at the heel.

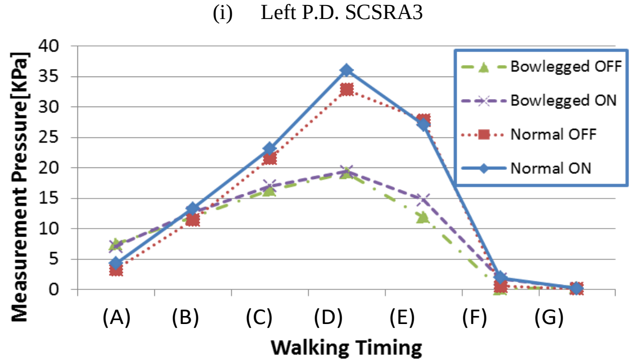
Walking measurement experiment

Instantaneous pressure measurement results

To confirm the effectiveness of the proposed high-performance shoes, we performed a walking measurement experiment. Pressure distribution was measured on a treadmill for 10 seconds with two walking patterns (normal and bowlegged) at a constant speed of 2 km / h with the assist system on or off. **Fig. 7**, **Fig. 8** show the instantaneous pressure transitions at SCSRA4 (heel) and SCSRA3 (little toe). These results occur when the assist system is turned on or off in two walking patterns (normal or bowlegged). The vertical axis indicates the obtained pressure, and the horizontal axis is the walking phase (A)-(G) corresponding to Fig. 2. The pressure was biggest at the tread stage (**Fig. 7**: (i) (F) and (ii) (B)) in the heel transition pattern for both normal and bowlegged gait. Turning on the assist system in both of these two patterns reduced the pressure value in SCSRA. The pressure change is more gradual when the subject is bowlegged walking with his left foot.



(i) Left P.D. SCSRA3



(ii) Right P.D.SCSRA3

Fig. 8. Transition of instantaneous pressure at the little toe.

In normal walking and bowlegged walking, the maximum pressure occurs when another foot in the swing phase crosses in front of the foot supporting the subject's weight in the little toe transition pattern (**Fig. 8**: (i) (G) and (ii) (D)). For both gait patterns in the left foot gait phase (G), when the system is powered on, the pressure decreases compared to when it is off. Thus, in normal walking on the left foot, the same characteristics occurred in both (G) and (A). In the right foot bowlegged walking, the pressure when turning on the system was lower than the value during normal walking. With respect to the right foot bowlegged walking, some experimental results show that the pressure value when the assist system was turned on increased more than when the system was turned off. These results indicate that the change in heel hardness supports the heel when one foot is kicked back. Therefore, foot pressure was easily increased by shifting forward of the foot.

This indicates that the assist system has a correction effect on the center of gravity of the sole of the foot and that a decrease in the pressure value of the little toe tends to increase the value of the ball of the foot. Thus, we concluded that using the proposed support system could prevent outward stagger during gait training.

Conclusion

In this study, we developed high-performance shoes using a new rubber element and clarified its characteristics by some experiments. Our shoes have had a certain effect in supporting the walking of young people. However, these shoes have some problems in performing walking experiments with the elderly, such as the weight and ease of putting on the shoes. To solve this problem, we will make improvements to reduce size and weight and make it easier to wear. After these improvements, we plan to conduct walking experiments on the quasi-elderly. Also, we plan to conduct walking experiments and sensory evaluations for elderly people at welfare and rehabilitation facilities.

Keywords

Walk assistance, high-performance shoes, rehabilitation, fall.

Received: 29 October 2019
Revised: 29 January 2020
Accepted: 19 February 2020

References

1. Cabinet office, Government of Japan, Director General for Policies on Cohesive Society, H.26 Aged Sciety White Peaper, **2014**, Chapter 1, Section 1-2.
2. Ministry of Health; Labour and Welfare, Comprehensive Survey of Living Conditions.
3. Takamichi Takashima; Study of the dynamic model analysis of the human foot complex during gait and its applications, Waseda Univercity, **2003**, pp40-41.
4. Ikehara; Tanaka; Tamiya; Fukuya; Development of elderly people's walking support system, Robotics and Mechatronics Conference **2006**, 06-4, 1P1-A09.
5. Eiichirou Tanaka; Tadaaki Ikehara; Hirokazu Yusa; Yusuke Sato; Tomohiro Sakurai; Shozo Saegusa; Kazuhisa Ito; Louis Yuge; *Journal of Robotics and Mechatronics*, **2012**, *24*, 5.
6. Hiroshi Kobayashi; Takuya Hashimoto; So Nakayama; Kazutaka Irie; *Journal of Robotics and Mechatronics*, **2012**, *24*, 2.
7. Hiroyuki Inoue; Toshiro Noritsugum; *Journal of Robotics and Mechatronics*, **2010**, *22*, 2.
8. Motonobu Sato; Eiichi Yagi; Kazuo Sano; *Journal of Robotics and Mechatronics*, **2013**, *25*, 6.
9. Moufawad el Achkar C.; Lenoble-Hoskovec C.; Paraschiv-Ionescu A.; Major K.; Büla C.; Aminian K.; *Gait Posture*, **2016**, *44*, 12.
10. Farzin Dadashi; Benoit Mariani; Stephane Rochat; Christophe J. Büla; Brigitte Santos-Eggimann; Kamiar Aminian; Gait and Foot Clearance Parameters Obtained Using Shoe-Worn Inertial Sensors in a Large-Population Sample of Older Adults, Sensors (Basel). **2014** Jan; 14(1): 443–457., Published online **2013**, Dec 27.
11. Yasuhiro Hayakawa; Kensuke Morishita; Mina Aichi; Ryuuji Tsuda; Development of a Pneumatic Silicon Outer Fence Mold Actuator, The Japan Society of Mechanical Engineers, C, Vol.70, No.690, **2004**, pp.433-439.
12. Perry Jacqueline; GAIT ANALYSIS Normal and Pathological Function Second Edition, **2007**, pp.2-47.
13. Yasuhiro Hayakawa; Shogo Kawanaka; Kazuma Kanezaki; Shigeki Doi; Development of Walking Training System using High-Performance Shoes, Robotics and Mechatronics Conference, **2014**, 1A1-A01.
14. Yasuhiro Hayakawa; Shogo Kawanaka; Kazuma Kanezaki; Shigeki Doi; Study on Presentation System for Walking Training using High-Performance Shoes, Robotics and Mechatronics Conference, **2015**, 1P2-L10.