Assistive Chair to Support Hip Rising of Elderly People Improves Body Movement of Sit-to-Stand Motion ⋆

Hiroki Kogami * **Qi An** * **Hiroshi Yamakawa** * **Ningjia Yang** *
Yusuke Tamura * **Hiroshi Yamasaki** ** **Fady S. Alnajjar** **
Shingo Shimoda ** **Makoto Kinomoto** *** **Noriaki Hattori** ****
Kouji Takahashi **** **Takanori Fujii** **** **Hironori Otomune** ****
Ichiro Miyai **** **Shu Ishiguro** † **Takashi Saigusa** ‡
Yoshikazu Nozaki ‡ **Haruhisa Maruyama** § **Atsushi Yamashita** *
and Hajime Asama *

* *Graduate School of Engineering, The University of Tokyo, Tokyo, 113-8656, Japan (e-mail: kogami@robot.t.u-tokyo.ac.jp).*
** *Intelligent Behavior Control Unit, RIKEN CBS-TOYOTA Collaboration Center, RIKEN Center for Brain Science, Aichi, Japan.*
*** *Osaka Developmental Rehabilitation Center, Osaka, Japan.*
**** *Neurorehabilitation Research Institute, Morinomiya Hospital, Osaka, Japan.*
† *S Care Design Laboratory Inc., Hyogo, Japan.*
‡ *Green Peas Corporation, Kanagawa, Japan.*
§ *Re Corporation, Kanagawa, Japan.*

Abstract: The number of elderly people with declined physical function has increased, and supporting independent living for them is important. This study focuses on sit-to-stand motion since it is an important daily activity. The assistive robot is needed to assist the elderly's sit-to-stand motion without interference in the motion. Meanwhile, the physical therapists improve muscle activity of hemiplegic patient by teaching the patient the timing of motions. Thus, this study proposes the assistive chair using skills of the physical therapist for the sit-to-stand motion to support. The seat of the chair rises when the user starts bending forward and stimulates the hip muscles. The three healthy elderly people were measured with and without the assist by the chair. Here we show that the assistive chair was able to estimate the timing when the upper body of subjects started to bend forward. Furthermore, we found that the assistive chair intervention reduced the amount of forward displacement of the elderly's center of mass. These results imply that the assistive chair teaches the timing of switching the center of mass from forward to upward without pushing too much and improves the sit-to-stand motion of the elderly.

Keywords: Robotics, Bionics, Mechanical Engineering, Sit-to-stand and Assistive Device.

1. INTRODUCTION

Recently, the aging society has been a big problem around the world. United Nations (2017) reported that the proportion of the world population aged 60 or over will exceed 20% in 2050. This research focuses on sit-to-stand motion since it is an important activity in daily life. Gross et al. (1998) found that elderly people have half the strength of their lower extremities than younger people. The declined physical ability makes it more difficult for elderly people to perform the sit-to-stand motion. Furthermore, that may cause staying in bed which leads to a further decrease in muscle strength. Thus it is needed to support the sit-to-stand motion of elderly people to maintain quality of life.

Various devices have been developed to support the sit-to-stand motion of elderly people. Tsukahara et al. (2010) assisted the sit-to-stand motion using an exoskeleton robot that compensated the joint torque of the lower limbs. Shiraishi et al. (2016) and Hiyama et al. (2017) developed a chair-type support device that assists the motion by pushing the buttocks on the seat. Furthermore, Chugo et al. (2006) developed a device composed of a support bar and bed system that can move up and down to support the remaining muscles of elderly people. It is important to understand the mechanism of the sit-to-stand motion to support the elderly without disturbing their movement.

We investigated the sit-to-stand motion of hemiplegic stroke patient and the improvement of their motion by rehabilitation. Kogami et al. (2018) found that a physical therapist pinched the buttocks and stimulated the gluteus maximus muscles to promote the extension of the hip joint at the instant of the seat-off. As a result, the

⋆ Research supported in part by the JSPS KAKENHI Grant 2612005, 16H04293, 18H01405 and by the Precise Measurement Technology Promotion Foundation.

muscle activity contributing to hip rising ameliorated and the motor function of the patient improved. Thus, for those who are not able to properly adjust the timing of muscle activity despite sufficient muscle strength, a physical therapist teaches the timing of the movement corresponding to lift-off from the chair.

The objective of this research is developing an assistive device for sit-to-stand motion with the skills of the physical therapist. We aim to design a chair type device in order for the elderly to use them in daily life. In addition, we discuss the effect of using the assistive device by conducting the evaluation experiment with elderly people.

2. DEVELOPMENT OF ASSISTIVE CHAIR

2.1 Function of Assistive Chair

The physical therapist stimulates the muscles in the buttocks of the hemiplegic patient when the upper body of the patient begins to bend forward. Since the physical therapist feels the center of pressure (COP) shifting forward of the patient by his or her hand, the assistive chair is designed to detect the user's upper body tilt. To use the assistive chair in a daily life, it is desirable not to attach sensors on the user's body. Therefore, the pressure sensor is placed under the seat to estimate the start of the upper body to tilt. The center of the seat pressure moves forward when the upper body bends forward. The pressure sensor under the seat can identify the time when the upper body of the user starts to bend forward.

The physical therapist taught the timing of leaving the seat by lifting the patient's hip. In other words, the timing to switch the center of mass movement from the forward direction to upward direction is taught by the physical therapist. In the assistive chair, the surface that contacts the hip rises and teaches the timing of leaving the seat.

2.2 Design of assistive chair

We developed an assistive chair as shown in Fig. 1. Six pressure sensors are located under the surface of the seat. These sensors detect when the subject's upper body bends forward. The surface that contacts the gluteus maximus muscles is elevated by two gas cylinders up to 160 mm in 2 seconds to push the user's hips. The support surface is stabilized when the user is at rest, and it starts moving upward when users start bending forward.

2.3 Control of rising timing

The pressure sensor estimates the forward movement of COP of the seat when the user's upper body starts to bend forward. The longitudinal of COP, d is calculated by (1).

$$d = \frac{\sum_{i=1}^{n} F_i \cdot x_i}{\sum_{i=1}^{n} F_i}, \quad (1)$$

where $F_i(i = 1, ..., n)$ indicates the value of the pressure sensor S_i whose coordinate is x_i as shown in Fig. 2.

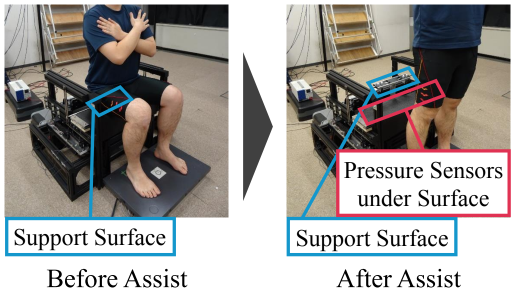


Fig. 1. Assistive Chair. support surface lifts user's buttocks.

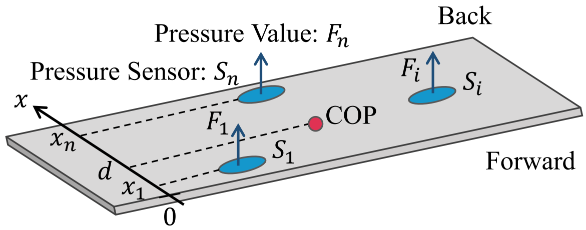


Fig. 2. Definition of the longituidinal of COP. n pressure sensors are arranged on the chair seat.

To estimate the timing of hip rising, the variance of d of the user at rest is used. The average value of d at rest is $\overline{d}$, the standard deviation is σ, and the threshold value is $\overline{d} + \alpha\sigma$ as shown in Fig. 3. Start of sit-to-stand motion is determined to time t_0 when d exceeds the threshold. When the assistive chair detects the timing, it starts pushing upward.

3. EXPERIMENT FOR EVALUATING ASSISTIVE CHAIR

3.1 Evaluation Indices

This experiment investigated whether the support surface could start pushing the hip of the user similar to that of the physical therapist pushing the hips of the hemiplegic patient. Using the motion capture system (Motion Analysis. Corp.), this study compared the movements of the great trochanter of subjects and the support surface in order to verify if the assistive chair could push the user in appropriate timing.

Furthermore, this experiment measured the physical movement of subjects and investigated the center of mass (CoM) and joint angles. The hemiplegic patient tends to move their CoM more forward than healthy people in the sit-to-stand motion. However, the patient did not bend the upper body deeply and the CoM trajectory of the patient turns upward owing to the intervention by the physical therapist [Kogami et al. (2018)]. Therefore, this study investigates how the CoM trajectory of subjects changes and whether subjects bend the upper body deeply when they are supported by the assistive chair.

The body movement during the sit-to-stand motion of subjects was measured by the motion capture system. Twenty two points were measured at 100 Hz based on the Hellen-Hayes marker set designed for measurement of lower extremity movements. The marker data were low

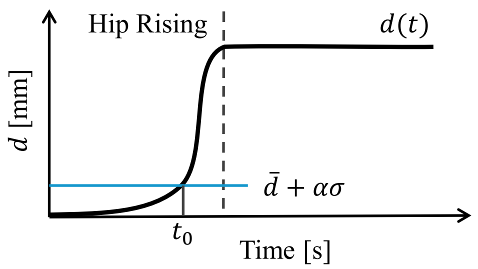


Fig. 3. Definition of t_0. The timing when d exceeds the threshold is defined as t_0.

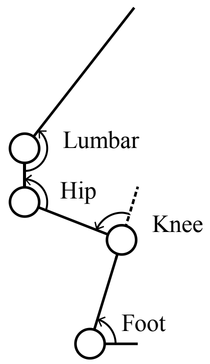


Fig. 4. Definition of joint angle. The lumbar, hip, knee and foot angle are considered.

pass filtered with a cut-off frequency of 6 Hz. Joint angle data and CoM trajectory were calculated using SIMM (Musculographics, Inc.). Four degrees of freedom of the hip joint and the joints on the right side of the hip, knee, and foot were investigated, and the angle was defined as shown in Fig. 4.

3.2 Subject and genral setup

Three elderly people (two male and one female, 67.3 ± 1.7 years old) participated in our experiment. The informed consent was obtained from all the subjects. This experiment was conducted with approval by the Institute Review Board of The University of Tokyo.

Subjects were instructed to perform sit-to-stand motion without using their arms. There were ten trials in which subjects stood up on their own and ten trials in which they were assisted by the assistive chair. Some measured trials were due to signal noises and failure to perform the sit-to-stand motion. In all the trials, the period between 1.0 s before and 2.0 s after the instant of hip rising was analyzed.

4. RESULTS AND DISCUSSIONS

The parameter, α, to determine start time of the movement in Eq. (1) was set to be 10 by trial and error. In all the three users, the threshold of COP displacement from the rest position to hip rising was about 10 mm.

Figure 5 shows one subject's average velocity of the vertical direction of the support surface and the subject's great trochanter. The blue dashed line shows the vertical velocity of the great trochanter when subjects were not

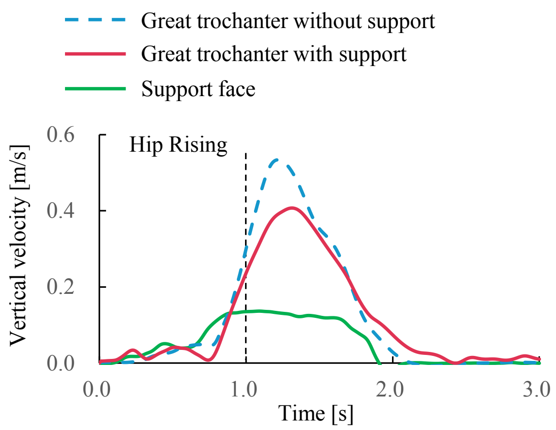


Fig. 5. Vertical velocity. The support surface followed the speed of the great trochanter before the hip rising.

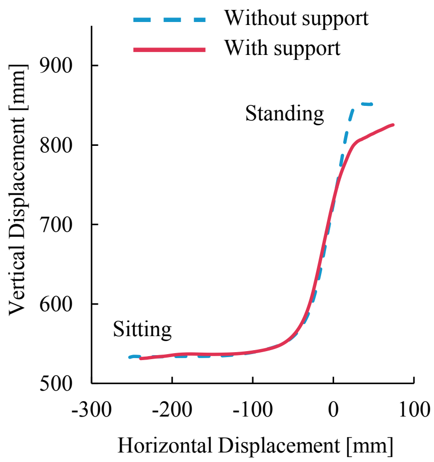
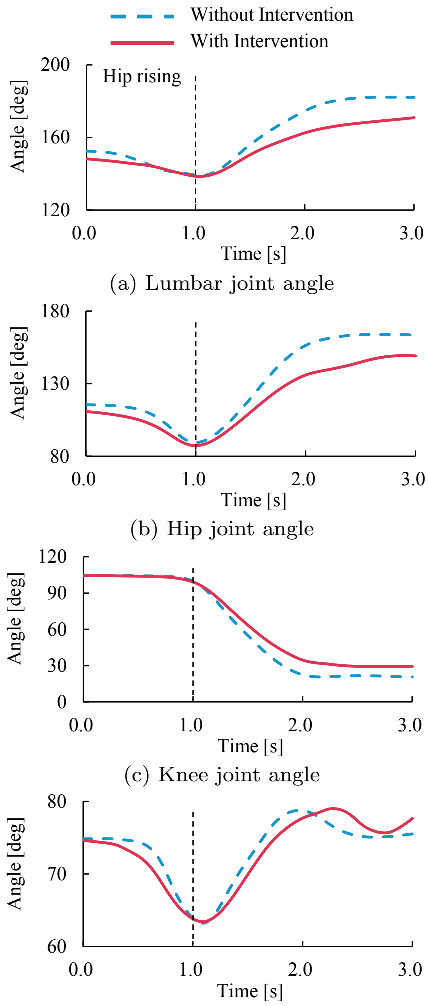


Fig. 6. CoM trajectory. This shows that the CoM trajectory became more upward with the support of the assistive chair.

supported by the assistive chair and the red solid line represents the trial when subjects were supported. The green solid line represents the vertical velocity of the support surface. It was found that the support surface followed the speed of the subject's great trochanter until the instant of hip rising. However, the speed of the support surface was slow after that. Furthermore, the maximum vertical velocity of the great trochanter is smaller with intervention than without that.

The average trajectory of the one subject's CoM in the sagittal plane is shown in Fig. 6. The dashed and solid lines respectively show the trajectory of the CoM without and with support by the assistive chair. The zero point of the CoM was the start position of the subject's ankle. The figure shows that the amount of forward displacement of CoM decreased when subjects were supported by the assistive chair.

The average joint angles of lumbar, right hip, knee and ankle from one subject are respectively shown in Fig. 7. The blue dashed and the red solid line indicates the cases without and with support by the assistive chair, and the black dashed line indicates the instant of hip rising. To investigate changes in the angle of the forward bending, all the subject's average value of the minimum angle of each trial for the hip joint was 86.2 ± 4.1 deg without



(a) Lumbar joint angle

(b) Hip joint angle

(c) Knee joint angle

(d) Foot joint angle

Fig. 7. Average joint angle. The intervention of the assistive chair reduced the anteflexion of the upper body but the extension was prolonged.

the support of the assistive chair and 85.4 ± 8.7 deg with the support. The minimum angle of the hip joint became smaller in the case with the support than without it, but there was no significant difference because of a result of the t-test, $t(32) = 0.43$, $p = 2.0 > 0.05$. In other words, it was found that subjects bent their body more forward when the developed system assisted them. Moreover, the changes in the all joint angle became slow. This means that the duration of body extension became longer in the case with the assist by the chair than without it. This may cause the subject's further bending forward.

The assistive chair was able to estimate the timing when the subject's upper body bent forward, and the assistive chair pushed the subject's buttocks slightly. However, the support of the assistive chair did not reduce the subject's upper body flexion before the instant of hip rising. Moreover, the time to upstand after the instant of hip rising was longer with the intervention of the assistive chair than without that. It is suggested that the rising speed of the support surface of the assistive chair is slow as the cause of the time to extend the whole body. The subject may have adjusted to the speed of his or her hip rising to one of the support surface of the assistive chair. As a result, the speed of hip rising may have slowed down and subjects bent their upper body deep. To confirm this interpretation, it is necessary to increase the rising speed of the support surface or change the method to push the subject's hip. It is needed to improve the assistive chair to reproduce the skill of the physical therapist.

To need further improvement of the assistive chair developed by this research was confirmed by performing the experiment for the elderly people with declined physical function compared to the young. The rising speed of the support surface needs to be adjustable to the individual person, and it needs to be verified whether the muscle activity of the user is improved accordingly.

5. CONCLUSION

This study developed the assistive chair to support the sit-to-stand motion of elderly people. The assistive chair pushes up the buttocks of users according to their motion without the sensors attached to the body. We conducted an experiment to evaluate the effect of the assistive chair. Here we have shown that the elderly people performed the sit-to-stand motion with bending forward marginally deeply owing to the assistive chair and the skills of therapists were not replicated. Future work will be needed to address the improvement of the rising speed of the support surface and the evaluation by electromyogram of the muscles related to the sit-to-stand motion.

REFERENCES

Chugo, D., Kaetsu, H., Miyake, N., Kawabata, K., Asama, H., and Kosuge, K. (2006). Force assistance system for standing-up motion. In *2006 International Conference on Mechatronics and Automation*, 1103–1108.

Gross, M., Stevenson, P., Charette, S., Pyka, G., and Marcus, R. (1998). Effect of muscle strength and movement speed on the biomechanics of rising from a chair in healthy elderly and young women. *Gait & Postures*, 8(3), 175–185.

Hiyama, T., Kato, Y., and Inoue, T. (2017). Sit-to-stand assistance system based on using emg to predict movement. In *2017 26th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, 81–87.

Kogami, H., An, Q., Yang, N., Yamakawa, H., Tamura, Y., Yamashita, A., Asama, H., Shimoda, S., Yamasaki, H., Itkonen, M., et al. (2018). Effect of physical therapy on muscle synergy structure during standing-up motion of hemiplegic patients. *IEEE Robotics and Automation Letters*, 3(3), 2229–2236.

Shiraishi, R., Kawamoto, H., and Sankai, Y. (2016). Development of sit-to-stand and stand-to-sit training system for hemiplegie patients. In *2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 4567–4572.

Tsukahara, A., Kawanishi, R., Hasegawa, Y., and Sankai, Y. (2010). Sit-to-stand and stand-to-sit transfer support for complete paraplegic patients with robot suit hal. *Advanced Robotics*, 24(11), 1615–1638.

United Nations (2017). *World Population Prospects: The 2017 Revision.* United Nations, Department of Economic and Social Affairs, Population Division.