2019 IEEE 5th International Conference on Mechatronics System and Robots

Walk Measurements Using a Novel Rollator with a Free Rotating Chest Pad and an Analysis of its Effectiveness in Walk Assistance

Jian Huang
Faculty of Eng., Kindai Univ.
Higashi-Hiroshima City, Japan
e-mail: huang@hiro.kindai.ac.jp

Noriho Koyachi
Faculty of Eng., Kindai Univ.
Higashi-Hiroshima City, Japan
e-mail: koyachi@hiro.kindai.ac.jp

Hiroaki Ashida
Graduate School, Kindai Univ.
Higashi-Hiroshima City, Japan
e-mail:1833850019u@hiro.kindai.ac.jp

Takashi Harada
Faculty of Science and Eng., Kindai Univ.
Higashi-Osaka, Japan
e-mail: harada@mech.kindai.ac.jp

***Abstract*—In recent years, many types of commercial rollators or gait-training devices are widely used by elderly people for their daily activities to avoid being bedridden and suffering dementia. However, the effectiveness of most of these commercial devices has not been investigated thoroughly. In this study, a novel rollator with a freely rotating chest pad integrated with two angular sensors and two load cells was developed. Walk measurements were carried out on four young healthy students who performed walk tests using the developed rollator. Two goniometers attached on the exteriors of both knees of the subject were also used to measure the knee extensions. The results of the pressing forces measured by the load cells, angles of pad rotations, and the knee extensions were demonstrated and frequency analyses of the obtained results were performed. The relationships between the pad rotation, body posture, and knee extensions were investigated and the effectiveness of the proposed device in walk assistance was discussed.**

Keywords-rehabilitation robot, walk measurement, gait analysis, walk assistance, rollator.

I. Introduction

The elderly population suffering from diseases in their lower limbs has increased rapidly in recent years according to a report by the Ministry of Health, Labor and Welfare [1]. The development of various gait training equipment is highly anticipated to prevent the elderly individuals from being bedridden and suffering dementia. Some commercialized devices have been released in recent years to provide walking support to elderly individuals [2]-[5]. However, owing to the high price and unavailability, only a limited application of these devices has been achieved. Furthermore, the effectiveness of the commercialized gait-trainers in walking assistance has not been thoroughly investigated [6]-[8].

To enhance the effectiveness of the gait-training, a rollator with a freely rotating chest pad was developed in our previous study [9]-[12]. With this rollator, the waist swaying motion of the user can be induced naturally using the freely rotating mechanism enabling the user to easily take his first step. In our previous studies, a specially conditioned space was required for a motion capturing system to measure the body movement of the user during the walk [9]-[12]. Therefore, this system demonstrated some drawbacks, as the desktop computer used for data acquisition limited the walk distances.

In this study, a compact data acquisition system was configured by developing a peripheral interface circuit with a microcomputer board of Arduino Due so that the system can be mounted on the rollator. Instead of using the motion capturing system to obtain the body movement of the user during his walk, two goniometers were attached onto both the knees of the user to extract information on his knee extensions. Walk measurements for four young subjects were conveniently conducted in the corridor and only one cable for power supply was connected to the rollator. The relationships between the pad rotation, body postures, and the knee extensions were also investigated and discussed by using a frequency analysis for the obtained data.

II. System and Methods

A. Proposed Rollator and Data Acquisition System

The developed new rollator along with the compact data acquisition system is shown in Fig. 1. Two rotation sensors (CPP-45B, Midori co.) were mounted on the back of the pad. One was used to measure the pad rotation, while the other was for pad inclination. Two load cells were also layered in the chest pad to measure the pressing force produced by the user's body weight [13]. Swaying motion of the upper body of the user induced by rotation of the chest pad is considered as an important assistance during the gait training.

In order to achieve a compact data acquisition system which can be mounted on the rollator, a microcomputer board of Arduino Due is introduced in this study as shown in Fig. 2. The Arduino Due is a compact and high processing power microcontroller board based on the Atmel SAM3X8E ARM Cortex-M3 CPU. Two channels of analog inputs of Arduino Due were initiated for the pad rotation and inclination. Moreover, two channels were initiated for the two load cells, and four channels were initiated for the two goniometers. The duration of each walk was approximately 30 seconds, and the sampling time interval of the A/D input was considered to be 6 ms in our study based on the capacity of the RAM in the Arduino Due [14].

978-1-7281-2223-6/19/$31.00 ©2019 IEEE

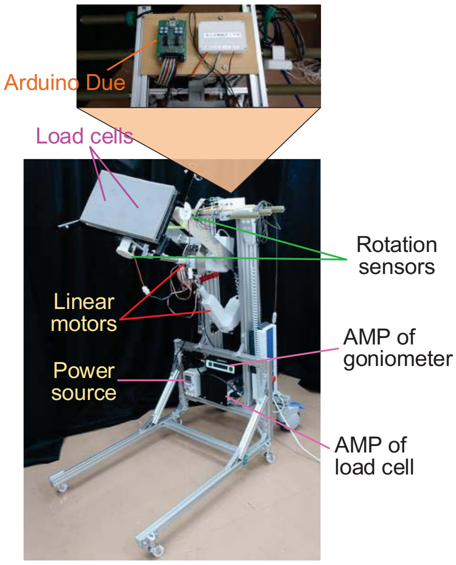


Figure 1. System configuration of the developed rollator

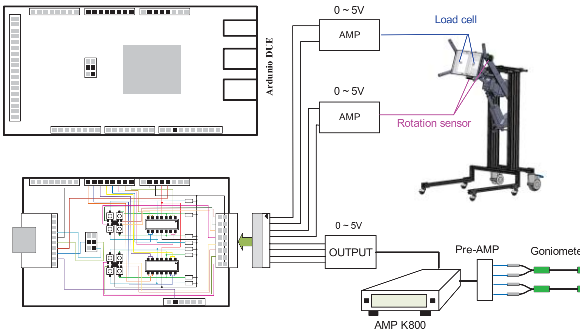


Figure 2. Configuration of the data acquisition system using Arduino Due .

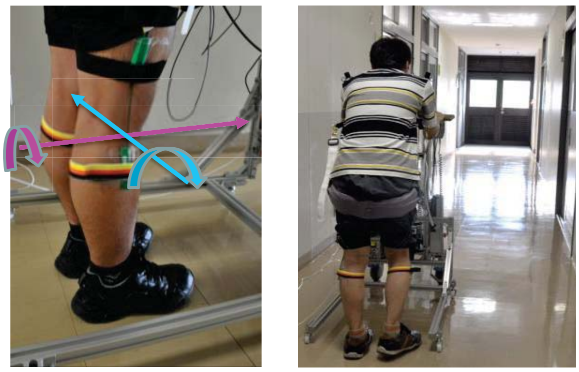


Figure 3. A scene taken from the walk test s in the corridor

B. Measurement Method

As shown in Fig. 3, two goniometers (SG150, Biometrics Ltd) were attached to the exteriors of both the left and the right knee joints to measure the knee extensions during the walk tests. A belt was fastened around the subject's thighs and hooked onto the handles of the chest pad. To facilitate the measurement, the subject was asked to put his chest in close contact with the chest pad when performing the walking tests. Measurements were carried out on four healthy subjects, each of them aged 21, with informed consent following the preliminary explanations of the measurement procedure.

III. RESULTS AND DISCUSSION

A total of four trials of walk tests were conducted for each subject. Two of these were conducted when the chest pad was in a rotatable state, while the other two were performed when the pad was fixed. Using the developed compact data acquisition system in this study, the measurement space was easily determined and the walk distance was extended to approximately 10 m. This is approximately five times of the distance achieved in our previous study.

A. Measurement Results

The rotation angle was set to 0° before the walk test were initiated. The analysis results of the relationship between the pad rotation and the pressing force of the body weight are demonstrated in Fig. 4, where F1 and F2 are the pressing forces measured from the left and the right cells, respectively. From Fig. 4, we observe that the pressing forces, F1 and F2, change rhythmically with the forward motion. A large rotation of the chest pad is generated proportional to the variation in the press forces, as shown in Fig. 4(a) and (b). This indicates that the swaying motion of the upper body of the user was induced by the rotation of the chest pad.

The analysis results of the relationship between the pad rotation and knee extensions are summarized in Fig. 5. The sample results obtained when the pad rotation was mechanically terminated during the walk tests are provided in Fig. 4(c) and Fig. 5(c), for comparison purposes. As depicted in Fig. 5, the knee extensions vary rhythmically with the alternate change in the pressing force of the body weight on the chest pad. This indicates that the subject bent his knees while adjusting his upper body to push the chest pad towards the direction of the walk.

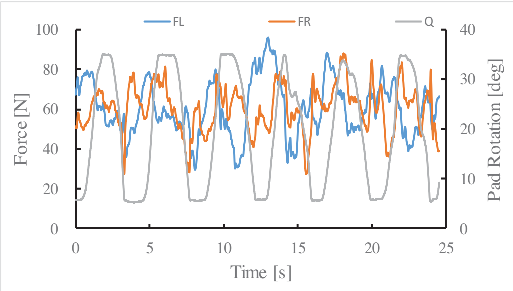
In contrast, a comparison of the results obtained when the chest pad was rotatable indicates that the pressing force obtained with the fixed pad remains almost unchanged, as shown in Fig. 4(c), and the knee extensions vary quickly in this case, as shown in Fig. 5(c).

B. Results of the Power Spectrum

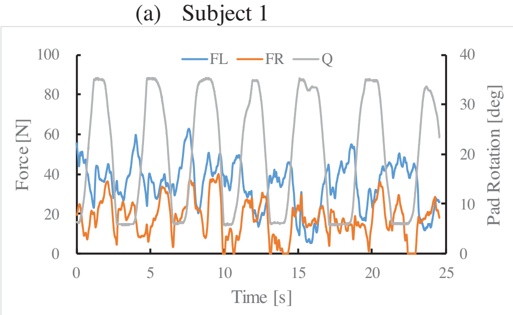
Generally, discrete Fourier transform X_k of a time-series data $x(n)$ $(n=0,1,2,3,\cdots,N-1)$ is calculated using the following equation:

$$X(k)=\frac{1}{N}\sum_{n=0}^{N-1}x(n)e^{-i\frac{2\pi n}{N}k}\ . \tag{1}$$

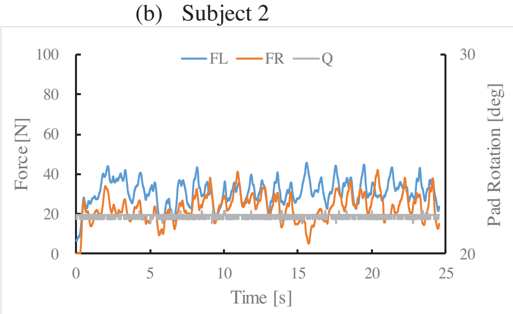
The power spectrum $S(k)$ can be obtained using the following equation:



(a) Subject 1

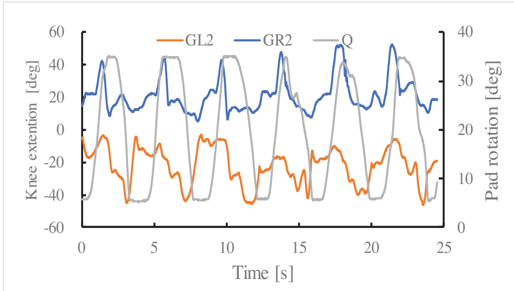


(b) Subject 2

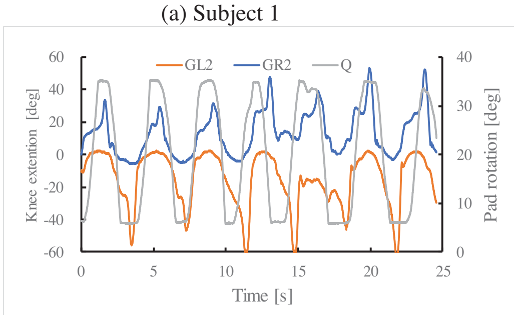


(c) Results with the fixed pad

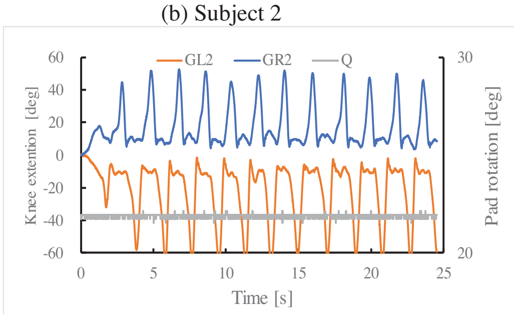
Figure 4. Results of the pad rotation and pressing force



(a) Subject 1



(b) Subject 2



(c) Results with the fixed pad

Figure 5. Results of the pad rotation and knee extensions

$$S(k) = |X(k)|^2 . \qquad (2)$$

The computed results of the power spectrum with respect to the pad rotation, pressing force and the knee extensions are demonstrated in Fig. 6. The results of the pad rotation and the knee extensions demonstrate similar patterns, especially with respect to the results of subject A and subject B, for whom a large rotation of the chest pad was generated.

C. Correlational Analysis

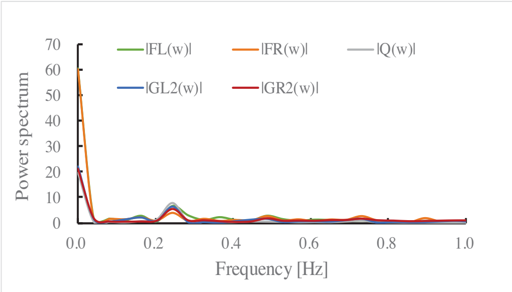
Correlational analysis is an effective tool to clarify the relationship between two time-series data. In this paper, we use this method to investigate the relationship between pad rotation and walking motion. Generally, correlational function R_τ of the two time-series data of $\{x(k)$ and $y(k)$, k=1, 2, 2$M\}$ can be calculated by the following equation:

$$R(\tau) = \frac{1}{M}\sum_{k=1}^{M} x(k)\, y(k+\tau) \quad (\tau = 0,1,2,\ldots,M) . \qquad (3)$$

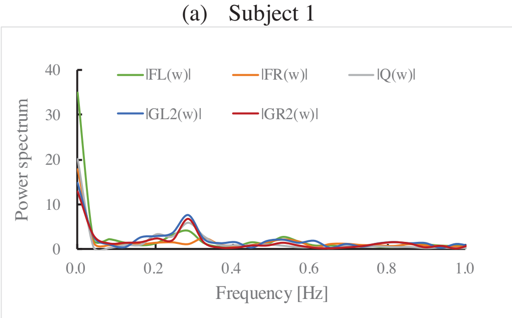
The computed correlational functions between the pad rotation and the pressing force as well as the pad rotation and the knee extensions are demonstrated in Fig. 7. In this figure, a strong relationship between the pad rotation and the knee extensions is observed especially with respect to the results of subjects A and B. This indicates that the knee extensions were considerably influenced by the pad rotation during the walk tests.

IV. Conclusions

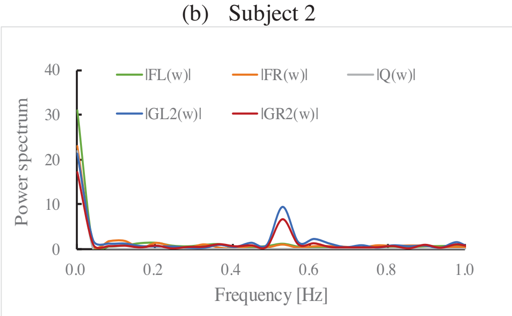
In this study, a compact data acquisition system was developed to perform the measurements easily without the constraints of the strict requirement of environment that were imposed in our previous study. Unlike the previous study in which the motion capturing system was employed, this study used two goniometers to measure the knee extensions. The obtained results demonstrated that the pressing force of the upper body of the user changed rhythmically in proportional to the pad rotation during the walk tests, which resulted in rhythmical changes in the knee extensions. The results of the frequency analysis indicated a strong relationship between the pad rotation and knee extensions. Therefore, the obtained



(a) Subject 1

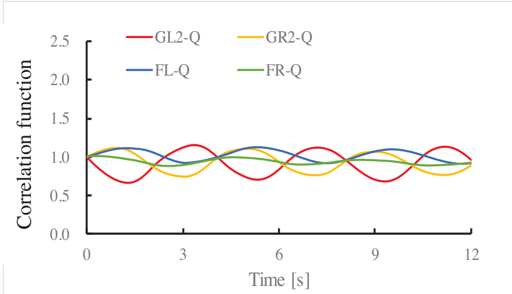


(b) Subject 2

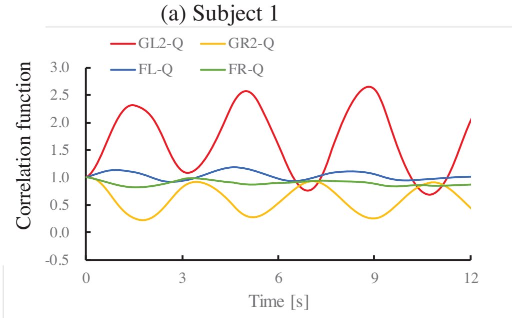


(c) Results with the fixed pad

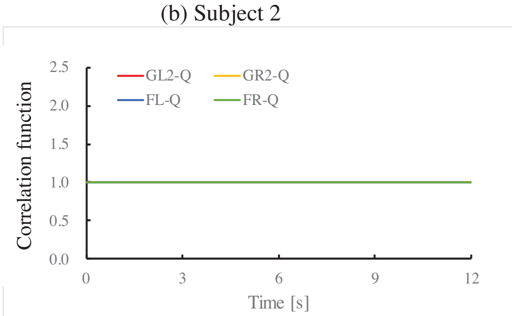
Figure 6. Results of the power spectrum



(a) Subject 1



(b) Subject 2



(c) Results with the fixed pad

Figure 7. Results of the correlation function

results confirmed the effectiveness of employing the developed rollator for walk assistance purposes.

ACKNOWLEDGMENT

This work was supported by JSPS KAKENHI Grant Numbers JP18K12174.

REFERENCES

[1] G White paper of Japan Ministry of Health and Welfare, 2001.

[2] T. Hayashi, H. Kawamoto and Y. Sankai, "Control method of robot suit HAL working as operator's muscle using biological and dynamical information," Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems, pp.3063-3068, 2005.

[3] A. Watanabe, K. Kawai, K. Sato, Y. Miyazaki, H. Ito and T. Mori, Gait changes brought about by continued use of Honda's stride management assist in patients with stoke-related hemiplegia, Journal of Japanese Physical Therapy Association, Vol.43 No.4, pp.337-341, 2016.

[4] S. Hirano, etc, Development of rehabilitation robots, Bulletin of the Japanese Society of Prosthetic and Orthotic Education, Research and Development 29(2), 90-97, 2013

[5] http://www.daiwahouse.co.jp/robot/popo/

[6] Y. Shimizu, et al. "A Preliminary Report about a new Robot WPAL (Wearable Power-Assist Locomotor) for Paraplegic Gait Reconstruction," The Japanese Journal of Rehabilitation Medicine 46(8), 527-533, 2009.

[7] M. Fujie, "Walk Support Robot," J. of RSJ, Vol. 14 No.5, pp.628-631, 1996.

[8] T. Tono, M. Watanabe and M. Fujie, "Development of control algorithm for synchronously pelvic assist during gait," Proc. of Conf. Welfare, Wellbeing, Life Support, pp.532-535, 2010.

[9] Jian Huang, Noriho Koyachi, and Naoki Miyano, "Evaluation of a Walking Assistant Rollator Integrated with a Rotating Chest Support Mechanism," JSME Conference on Robotics and Mechatoronics (ROBOMEC'15), CDROM 2P1-J05, (2015)

[10] Jian Huang, Noriho Koyachi, and Naoki Miyano, "Evaluating the Assistant Effectiveness of a Walking Rollator Equipped with a Free Rotating Chest Support Mechanism," u-Healthcare 2015, S3-2-4, (2015)

[11] Jian Huang and Noriho Koyachi, "Evaluation of the Stimulatory Effectiveness of a Rollator Integrated with an Uncontrolled Rotating Chest Pad," JSME Conference on Robotics and Mechatoronics (ROBOMEC'16), DVD 2A2-02A3, (2016)

[12] J. Huang, N. Koyachi, Evaluating the Assistance Effectiveness of a Newly Developed Rollator Mounted with a Freely Rotating Chest Support Pad, Proc. of The 2016 IEEE International Conference on Robotics and Biomimetics (ROBIO2016), pp.1185-1190, 2016.

[13] Jian Huang and Noriho Koyachi, "Measurements of Walking Using a Newly Developed Rollator Having an Free Rotating Chest Pad

Integrated with Multiple Sensors," JSME Conference on Robotics and Mechatoronics (ROBOMEC'17), DVD 2P1-P10, 2017

[14] Jian Huang and Noriho Koyachi, "Measurements of Walk Using a Rollator Having a Free Rotating Chest Pad" JSME Conference on Robotics and Mechatoronics (ROBOMEC'18), DVD 2A1-E05, 2018