Development of Learning System to Support for Passing Steps of Wheelchair

Kotone Sakiyama[1], Yukie Majima[2] and Seiko Masuda[2]
[1]*Graduate School of Humanities and Sustainable System Sciences, Osaka Prefecture University, Osaka, Japan*
[2]*Graduate School of Informatics, Osaka Metropolitan University, Osaka, Japan*

Keywords: Learning Support, System Development, Wheelchair.

Abstract: Recent aging of the population has led to an increased number of persons requiring assistance and a shortage of caregivers. Wheelchairs are often used for transportation by people who require assistance, but they must use appropriate operating techniques because they can easily impose burdens on caregivers when climbing over steps. Therefore, for this study, an educational system was developed based on issues elucidated by conventional educational methods and earlier research. Assistive technology evaluation in this system is performed from the perspective of a passenger's riding comfort by measuring and analyzing the wheelchair's degree of tilt and vibration level using a sensor. The system provides a learner with feedback for adopting an appropriate operating posture based on the evaluation results. This system can engender efficient learning by quantitatively measuring and presenting the learner's level of proficiency and by providing immediate feedback according to the user's proficiency level.

1 INTRODUCTION

In recent years, the population in Japan has been aging rapidly: as of October 2018, the population aged 65 and over numbered 35.58 million. The ratio of aged persons, as a percentage of the total population, was 28.1% (Cabinet Office, 2018), representing an increase of 6.0% from 22.1% during the prior decade (Cabinet Office, 2008). That increase in the number of persons requiring assistance (Cabinet Office, 2017) and the shortage of caregivers (Ministry of Health, Labour and Welfare, 2021) accompanying the aging population have come to pose major difficulties for Japan.

Wheelchairs are extremely common assistive devices for people who need caregivers. Of course, wheelchair mobility requires appropriate caregiving techniques so that caregivers do not feel burdened even if they are elderly or female. Particularly, climbing over steps in a wheelchair requires lifting of the front and rear wheels, which can impose heavy burdens on a caregiver. Accidents such as falling down and loss of riding comfort can also occur because of inappropriate wheelchair assistance. Therefore, caregiver education for appropriate wheelchair assistance skills must be provided.

In recent years, asynchronous caregiver education including e-learning and video materials has become possible because of the rapid spread of online education. Nevertheless, many caregiving skills involve tacit knowledge such as how to apply force and how to move the body. Therefore, quantitative evaluation of improvement in the skills of unskilled caregivers (unskilled caregivers) in asynchronous education is difficult.

For this study, we developed a system that uses sensors to evaluate wheelchair assistance skills quantitatively, especially when climbing over steep steps. The system educates non-skilled users about the appropriate operation of wheelchairs.

2 WHEELCHAIR ASSISTANCE EDUCATION SYSTEM

What should be done to help non-skilled workers acquire appropriate operation skills through asynchronous education? We can review some challenges of conventional asynchronous education in the course of education.

Sakiyama, K., Majima, Y. and Masuda, S.
Development of Learning System to Support for Passing Steps of Wheelchair.
DOI: 10.5220/0011772500003414
In *Proceedings of the 16th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2023) - Volume 5: HEALTHINF*, pages 497-501
ISBN: 978-989-758-631-6; ISSN: 2184-4305

2.1 Functional Requirements

During current nursing and caregiving education, most teaching materials that particularly address wheelchairs are based on videos and texts. Evaluation of learning is based on the number of times the material is viewed or a test to confirm knowledge retention. Nevertheless, the degree of actual improvement of skills is not evaluated quantitatively. It therefore remains unclear whether students have acquired the appropriate operating techniques, or not. To resolve this difficulty, Huang et al. (2014) proposed a self-study support system that extracts the wheelchair transfer techniques and skills of skilled nurses, teaches them to learners, and evaluates them using a Kinect™ motion sensor (Microsoft Corp.). Later, Nakagawa et al. (2015) proposed a skill teaching system that emphasizes skill teaching and which evaluates skills using a similar sensor. They reported that this system enables learners to understand their proficiency level quantitatively and to learn more efficiently than the conventional teaching by video, voice, or text. Based on those earlier studies, we believe that an effective educational system that is more effective than conventional teaching methods requires a teaching function, a sensor-based measurement function, and an evaluation function that evaluates wheelchair assistance skills quantitatively.

Compared to conventional video-based or text-based teaching methods, the sensor-based technology teaching system provides immediate feedback to the learner, which helps the learner to visualize the skill. However, previously described systems (Huang et al., 2014; Nakagawa et al., 2015) require special equipment and personnel with specialized knowledge to operate the equipment, which makes learning difficult. By contrast, this system will enable unskilled users to learn proper wheelchair operation using a smartphone (iPhone; Apple Corp.), a common device, for skill measurement and using an interface designed to require no complicated operations.

2.2 Technical Evaluation

Preventing a decrease in wheelchair users' comfort and reducing burdens on caregivers when operating wheelchairs are necessary. Factors reported as reducing riding comfort include increased wheelchair movement speed (Tanaka et al., 2006), large gradients when ascending or descending a ramp (Yamada et al., 2004), and strong bumping when passing over a step (Narisawa et al., 2001).

Particularly, the lifting angle of the wheelchair and the vibration felt by the user are regarded as affecting the ride quality, especially when the wheelchair is lifted up and down, because the operator stops near a step and starts the operation when climbing over a step. Noto and Muraki (2016) analyzed the relation between the caregiver's posture during the operation, the wheelchair trajectory, and the caregiver's subjective evaluation. Results clarified that increased leaning of the wheelchair when the front wheels are lifted when climbing over a step can decrease the user's riding comfort. Sawada et al. (2007) specifically examined the vibration level, which is an index of vibration felt by the human body, and analyzed the vibration level of a wheelchair when climbing over a step. Results clarified that the vibration at frequencies of 20–30 Hz generated in the vertical direction affect the user's riding comfort.

For this study, based on methods used for earlier studies, we use the tilt of the wheelchair body when the front wheels are lifted and the vibration level during wheelchair operation as technical evaluation indices for surmounting a step.

2.2.1 Tilt of Wheelchair when Lifting Front Wheels

When climbing over a step, the tilt angle of the wheelchair relative to the ground (the shaded area in Figure 1) reaches its maximum when the front wheels are lifted. This angle is measured by a level sensor attached to the side of the wheelchair.

Figure 1: Wheelchair tilt and sensor.

2.2.2 Vibration Level during Wheelchair Operation

The vibration level is an index to evaluate the effects of vibration on the human body. The vibration level is calculated by obtaining the frequency-weighted acceleration run-time value of the measured acceleration with vibration sensory correction (Figure

2), as defined in JIS C 1510 (Japanese Standards Association, 1997).

The frequency-weighted acceleration run-time value (a_w) is obtained using the following equation, where the vibration acceleration run for the frequency i Hz component is $a(i)$ and the relative response at frequency i Hz is $C_n(i)$.

$$a_w = \left[\Sigma_f a(i)^2 10^{C_n(i)/10}\right]^{1/2} \tag{1}$$

The vibration acceleration running value $a(i)$ is obtained using the following equation, where $G(i)$ is the power spectrum $G(i)$ of the components of the fundamental frequency Δf and frequency i Hz of the frequency analysis of the vibration acceleration response.

$$a(i)^2 = \Delta f x G(i) \tag{2}$$

By substituting equation (2) into equation (1), we obtain equation (3).

$$a_w = \left[\Sigma_f \Delta f x G(i) 10^{C_n(i)/10}\right]^{1/2} \tag{3}$$

As a result, vibration level (4) is obtainable using the following equation.

$$\begin{aligned} L_v &= 20\, log(a_w/a_0) \\ &= 10\log\left(\left[\Sigma_f \Delta f x G(i) 10^{C_n(i)/10}\right] / a_0^2\right) \end{aligned} \tag{4}$$

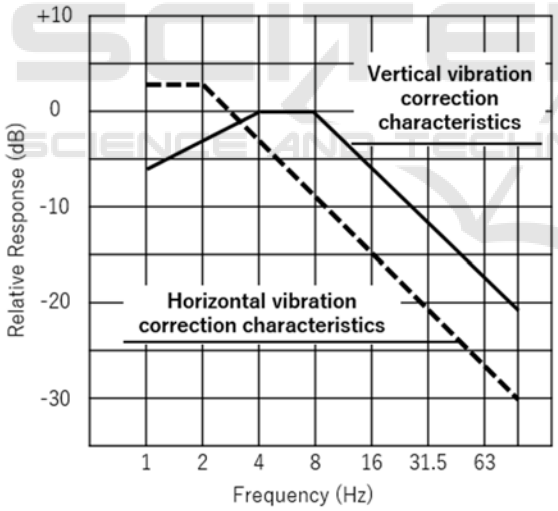


Figure 2: Human body vibration sensory compensation.

2.3 Technical Instruction

Teaching is performed by providing the learner with information (challenging points and advice) inferred from values of the evaluation indices. The teaching information for the wheelchair step climbing operation is based on the appropriate operating posture (Figure 3) as identified by Noto et al. (2016).

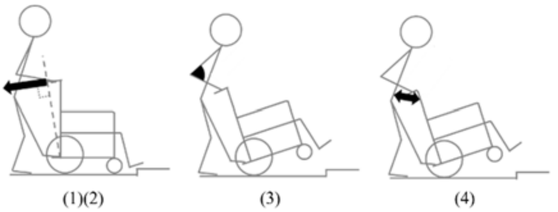


Figure 3: Operating posture when wheelchair climbs over steps.

(1) Apply force to the grip in a perpendicular direction to the line connecting the tipping lever and the grip.
(2) Do not apply force only to the legs, but press down the grip obliquely downward and backward simultaneously.
(3) Maintain a moderate elbow angle.
(4) Maintain an appropriate distance between the caregiver's trunk and the wheelchair.

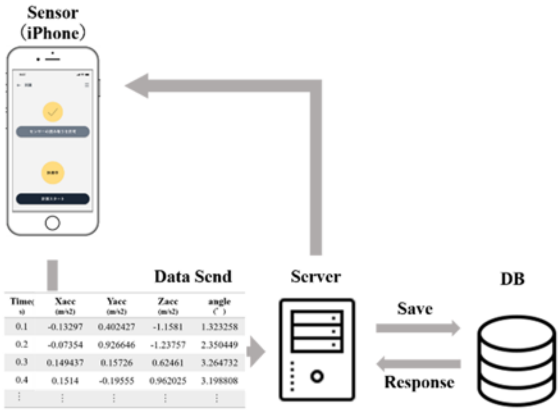
Failure to maintain the operating posture above will impose a physical burden on the caregiver and also affect the comfort level of the wheelchair user.

3 EDUCATION SYSTEM

We configured the system based on the requirements of the functions necessary for teaching wheelchair technology described in the previous section. From the viewpoint of ease of learning, we use the sensor built into the iPhone, which does not require any special equipment. Although the technical specifications of the iPhone sensor are not disclosed, some previous studies (Noto et al., 2016; Sawada et al., 2007) have used the iPhone sensor as a substitute for existing sensors. Table 1 lists technologies used in the development of the proposed system, and Figure 4 provides an overview. The proposed system has three functions.

Table 1: Technologies used for system development.

Item	Technology
Frontend	Vue.js
Backend	Node.js, Python
DB	MySQL
PaaS	Heroku



Time(s)	Xacc (m/s2)	Yacc (m/s2)	Zacc (m/s2)	angle (°)
0.1	-0.13297	0.402427	-1.1581	1.323258
0.2	-0.07354	0.926646	-1.23757	2.350449
0.3	0.149437	0.15726	0.62461	3.264732
0.4	0.1514	-0.19555	0.962025	3.198808
⋮	⋮	⋮	⋮	⋮

Figure 4: System overview.

3.1 Measurement Functions

After placing the device on the wheelchair, the measurement starts by clicking the start button. During the measurement, triaxial acceleration and angle data are recorded every 0.1s. This process continues until the button is clicked again. The data are sent to the server after measurement completion.

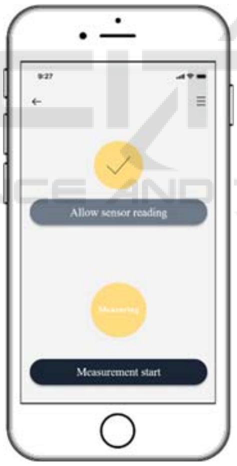


Figure 5: Measurement function interface.

3.2 Evaluation Functions

The vibration level and maximum angle are calculated from the data sent in 3.1.1 according to the technical evaluation method described in 2.2. Results are stored in the database and are displayed on the client side. Difference between data of the learner and data of skilled persons of similar physique are also displayed to assist learners in quantitatively understanding their own techniques.

Vibration level

	Result	Difference from experts
Forward and backward	100	+10
Up and Down	103	+13
Left and Right	98	+4

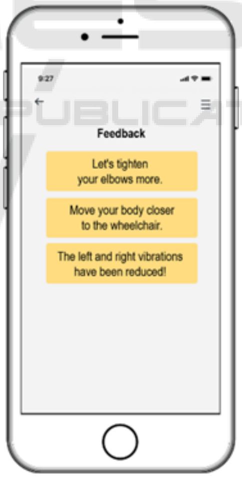
Angle

	Result	Difference from experts
Max	5 °	-1

Figure 6: Evaluation function interface.

3.3 Teaching Functions

Return feedback to the learner based on 3.1.2&2.3. Feedback information is provided to the learner based on the assumed technical tasks according to differences between the learner's data and the expert's data. Table 2 presents examples of the assumed tasks and the feedback information for the learner to take appropriate operating postures.



Let's tighten your elbows more.

Move your body closer to the wheelchair.

The left and right vibrations have been reduced!

Figure 7: Teaching function interface.

4 CONCLUSIONS

When learning how to assist a patient without a nearby instructor, learners were forced to learn by themselves through video and text-based materials. Therefore, learners had to judge their proficiency level subjectively. It was difficult for them to assess

Table 2: Examples of Feedback Information.

Assumed issue	**Feedback for proper operating posture**
Lifting the front wheel too much.	• Gently pull the grip. • Reduce elbow angle.
Insufficient height to lift the front wheels, hitting a step.	• Increase elbow angle. • When lifting the front wheel, pull the grip backward at an angle.
Distance between the body and the wheelchair is too much.	• Approach and operate the wheelchair.

their own skills quantitatively. By contrast, the educational system proposed in this study measures and presents the learner's proficiency level quantitatively. Moreover, it enables immediate feedback according to their level of proficiency, which can be expected to engender more efficient learning. In future studies, we would like to verify the usefulness of our system by comparing the learning effects of the proposed educational system with those of conventional video-based and text-based teaching methods.

ACKNOWLEDGEMENTS

This work was supported by JSPS KAKENHI Grant Number 20H03971.

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