Minimal Virtual Reality System for Virtual Walking in a Real Scene

Michiteru Kitazaki[1](✉), Koichi Hirota[2], and Yasushi Ikei[3]

[1] Department of Computer Science and Engineering, Toyohashi University of Technology, Toyohashi, Aichi, Japan
mich@cs.tut.ac.jp
[2] Graduate School of Information Systems, The University of Electro-Communications, Tokyo, Japan
hirota@vogue.is.uec.ac.jp
[3] Graduate School of System Design, Tokyo Metropolitan University, Tokyo, Japan
ikei@tmu.ac.jp

Abstract. Various sensory stimuli are required to accomplish a fully virtual walking system because walking is related to multimodal sensations. We developed a minimal virtual walking system and evaluated it using psychological factors. The system consisted of a real-scene optic flow and rhythmic foot vibrations. We tested the effects of vibrations synchronized with optic flow and the size of the visual field on the sensations of virtual walking and found that synchronized, two-channel foot vibrations with a 3-D optic flow elicited the virtual walking sensation. A larger visual field enhanced the footstep sensation during walking.

Keywords: Walking · Virtual reality · Optic flow · Vection · Tactile sensation · Vibration

1 Introduction

Walking consists of multisensory sensations and a sensory-motor integrated action. When we walk, we see optic flow, hear sounds, feel airflows, and place feet on the ground while we move our legs and arms in a complex and well-designed manner. We are consciously aware of some of them, but unconsciously aware of others. Therefore, it is difficult to develop a comprehensive virtual reality system to provide virtual walking sensations. Instead, we are focusing on a minimal system for experiencing virtual walking in a real scene.

Optic flow is one of the strongest stimuli that makes us perceive self-motion. A coherent motion presented in a large visual field induces a sensation of self-motion (vection; Fig. 1) [1, 2]. Because walking is a kind of self-motion, vection is effective in producing a virtual walking sensation.

Leg movements are required to walk around in the real world. Omni-directional treadmills and leg support actuator systems enable users to walk in place [3, 4]. These systems utilize the brain's motor commands and user's proprioceptive information

S. Yamamoto (Ed.): HIMI 2016, Part I, LNCS 9734, pp. 501–510, 2016.
DOI: 10.1007/978-3-319-40349-6_48

Fig. 1. Schematic example of real-scene optic flow

from body movements. Thus, users have to actually move their legs in these systems. We would like to provide a virtual experience of leg movement during walking without actually moving the legs. Leg movement during waking is a rhythmic action, and walker's feet strike the ground rhythmically. Thus, rhythmic, tactile stimulation to the soles of the feet may induce a sensation of walking.

We combined visual motion display (vection) and vibration stimuli on both feet. Rhythmic stimulation to the feet may induce spinal central pattern generators to produce an active walking sensation [5, 6]. The system consists of a walking recording system and a walking experience system.

2 Walking Recording System

The recording system captured stereo motion images from two cameras (GoPro HERO 3,1280 × 720 pixels, sampling at 30 Hz) attached to a participant's forehead (Fig. 2) to obtain optic flow. The interocular distance was 6.5 cm, which is similar to an average person's interocular distance [7]. Acceleration sensors (ATR-promotion TSND121, sampling at 1 kHz) were placed on the person's left and right ankles to obtain the timing of foot strikes on the ground synchronized with optic flow (Fig. 3). We recorded walking scenes of two persons (heights: 175 cm and 178 cm) in two different locations (Fig. 4).

Fig. 2. Two cameras mounted on a walker's forehead to capture stereo motion images or 3-D optic flow.

Fig. 3. Two acceleration sensors placed on left and right ankles to extract the timing of footsteps on the ground.

Fig. 4. Two visual scenes captured for experiments

3 Walking Experience System

For the walking experience system, 3-D (stereo) motion images with binocular disparity were presented on a head-mounted display (HMD; SONY HMZ-T1, 1280×720 pixels, 45×25.3 degrees of visual angle, 60 Hz, and Oculus Rift DK2, 960×1080 pixels, 90×110 degrees of visual angle, 60 Hz) and rhythmic vibration stimuli were presented to the left and right heels in sync with the walker's sight (Fig. 5). The sound of footsteps were recorded and processed through a low-pass filter at 120 Hz (duration 150 ms; Fig. 6 left). The recording was used to produce tactile vibrations on the observer's feet using vibro-transducers (Acouve Lab Vp408; Fig. 6 right).

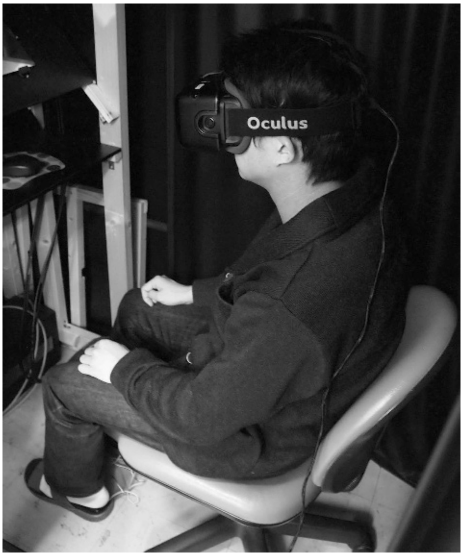

Fig. 5. Two visual scenes captured for experiments

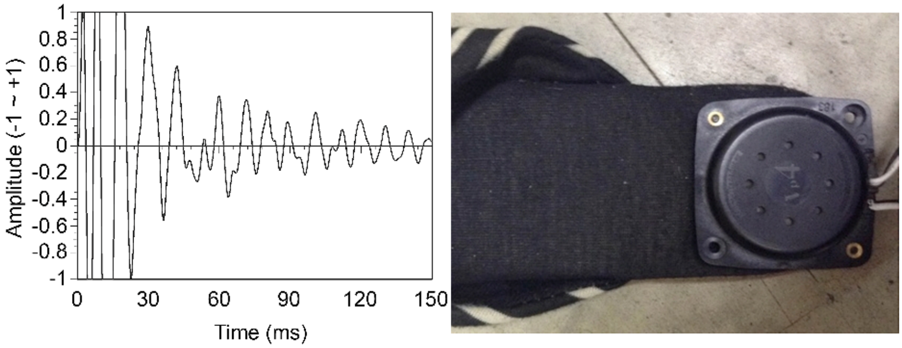

Fig. 6. (Left) Vibration profile. (Right) A vibro-transducer attached to a shoe

4 Experiment 1

Ten naïve participants (undergraduate and graduate students) participated in the experiment after providing a written informed consent. This study was pre-approved by the Committee for Human-subject Studies of Toyohashi University of Technology.

We presented visual motion images to participants using the HMD (SONY HMZ-T1) with and without vibrations on their heels. In half of the trials, participants observed the walker's leg and foot movements at the beginning of walking experiences to enhance syncing foot vibrations with visual walking. Then, they observed a scene of others walking forward. Participants were asked to rate the quality of their experience for vection, walking, footsteps, and telepresence after observing each scene for 25 s. Participants' responses were measured by using a visual analogue scale (VAS; Fig. 7). They moved a mouse cursor to indicate how they perceived each sensation. Moving the mouse left was for the least sensation and right was for the most sensation. We digitized the analogue responses to integral scales of 0–100.

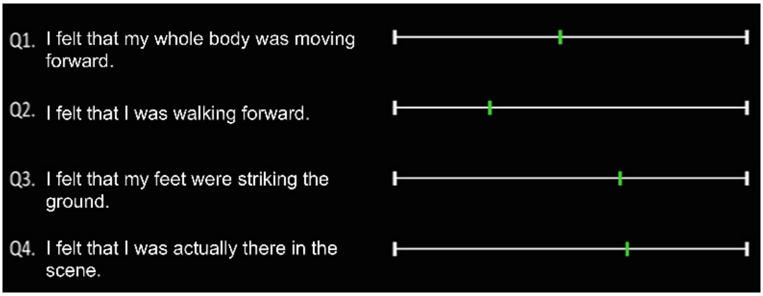

Fig. 7. Visual analogue scale for participants' responses

Participants rated two vibration conditions (with or without vibrations), two visual conditions (with or without visual walking at the beginning), two scene heights, and two locations.

We performed repeated measures ANOVA (two vibration conditions × two visual conditions) for each rating. Vection was perceived more with foot vibrations than without vibrations (main effect of vibration conditions: $F(1,9) = 20.739$, $p = .0014$; Fig. 8), and enhanced with visual walking at the beginning (main effect of visual walking conditions: $F(1,9) = 5.172$, $p = .0490$).

A walking sensation was perceived more with foot vibrations than without vibrations (main effect of vibration conditions: $F(1,9) = 23.876$, $p = .0009$; Fig. 9). There was no significant effect of visual walking or interaction.

Footstep sensations were perceived more with foot vibrations than without vibrations (main effect of vibration conditions: $F(1,9) = 13.345$, $p = .0053$; Fig. 10). There was no significant effect of visual walking or interaction.

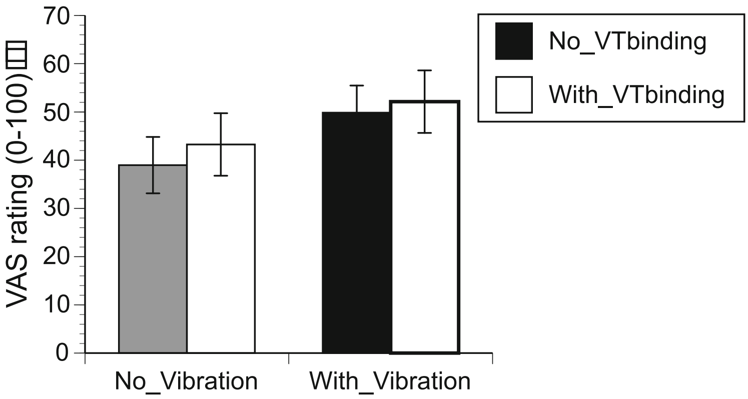

Fig. 8. Results of vection sensation

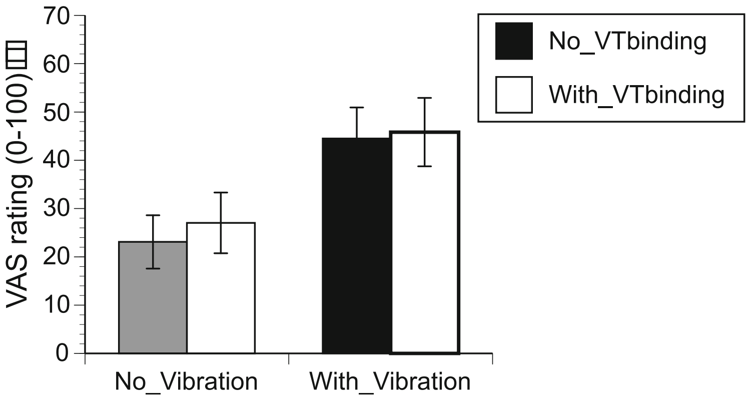

Fig. 9. Results of walking sensation

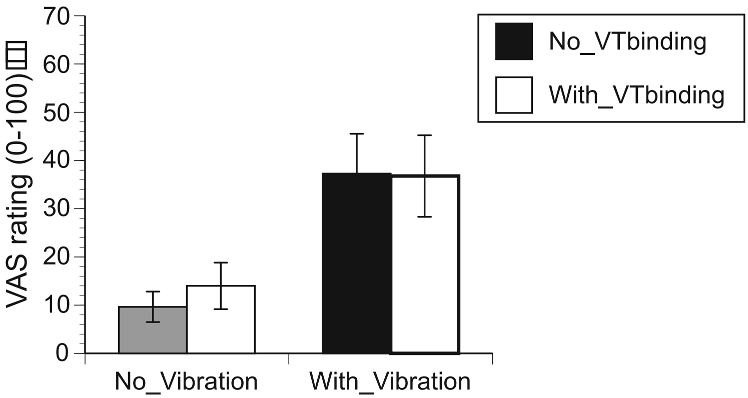

Fig. 10. Results of footstep sensation

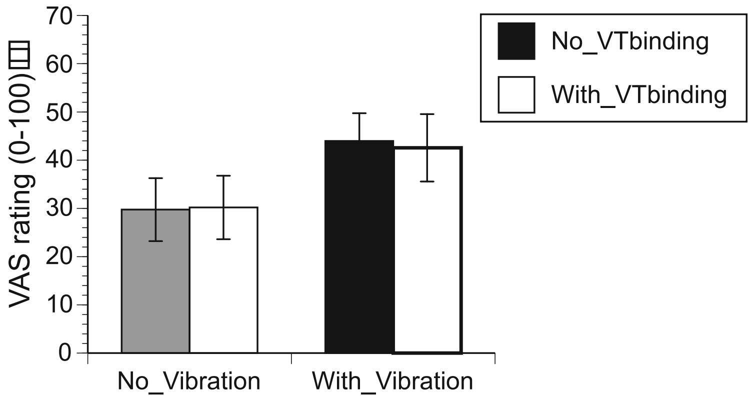

Fig. 11. Results of telepresence sensation

Telepresence was perceived more with foot vibrations than without vibrations (main effect of vibration conditions: $F(1,9) = 21.360$, $p = .0013$; Fig. 11). There was no significant effect of visual walking or interaction.

5 Experiment 2

Fifteen naïve participants (undergraduate and graduate students) performed the experiment after providing a written informed consent. This study was pre-approved by the Committee for Human-subject Studies of Toyohashi University of Technology.

We presented the same stimuli to participants using another HMD (Oculus Rift DK2) with and without vibrations on their heels. The Oculus Rift DK2 has a much larger visual field of view (90(width) × 110(height) degrees of visual angle) than the HMD of Experiment 1 (45 × 25.3 degrees of visual angle). However, we presented the visual stimuli in 66.4 × 37.2 degrees (604 × 254 pixels) at the center of the display because of a limitation of the captured image size (Fig. 12).

Participants observed leg and feet movement of walkers at the beginning of walking experiences in all trials. They rated the quality of their experience for vection, walking, footsteps, and telepresence after observing each scene for 20 s. They performed three repetitions of all combinations of two vibration conditions (with or without vibrations), two scene heights, and two locations in random order.

We conducted two-railed, single sample t-tests for the vibration conditions. All of the vection ($t(14) = 2.527$, $p = .0121$), walking ($t(14) = 3.454$, $p = .0019$), footstep ($t(14) = 3.500$, $p = .0018$), and telepresence ($t(14) = 2.399$, $p = .0155$) sensations were stronger with the foot vibrations than without the vibrations (Fig. 13).

To investigate effects of the visual field size of the HMDs, we compared the data of Experiment 1 and Experiment 2 for the common conditions (with or without foot vibrations, and with the visual walking scene at the beginning; Fig. 14). We conducted two-way ANOVA (two visual sizes × two vibration conditions) for each rating. All of the vection ($F(1,23) = 9.703$, $p = .0049$), walking ($F(1,23) = 22.865$, $p = .0001$),

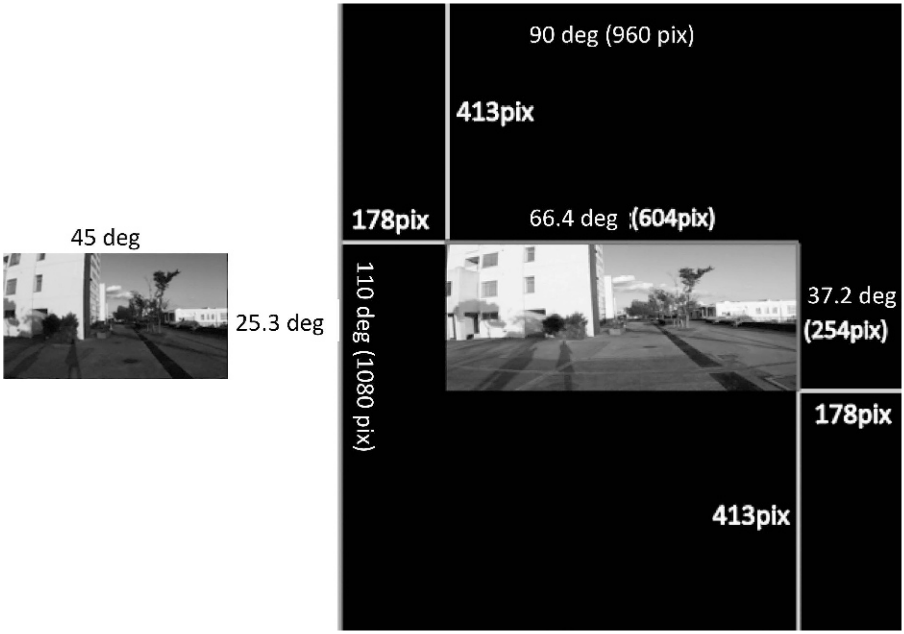

Fig. 12. Comparison of the visual field size of Experiments 1 (Left) and 2 (Right)

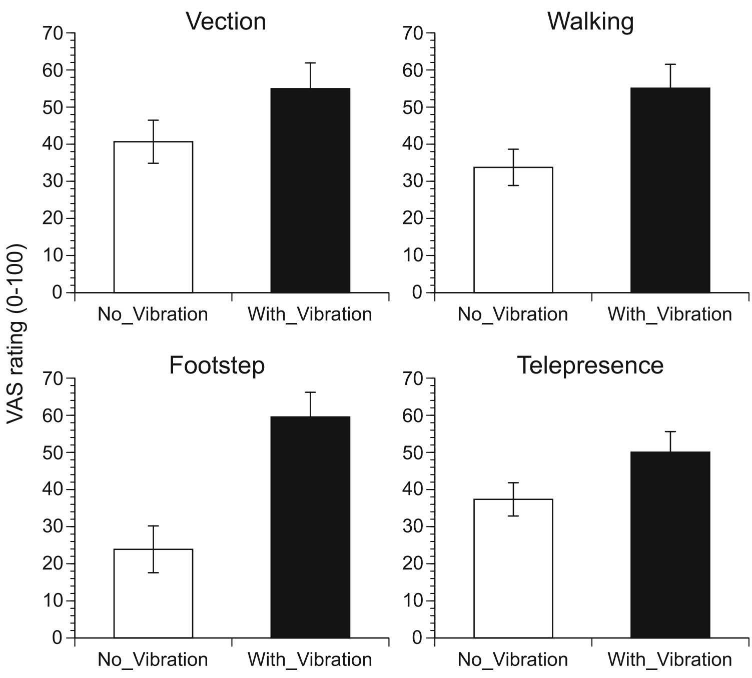

Fig. 13. Results of Experiment 2

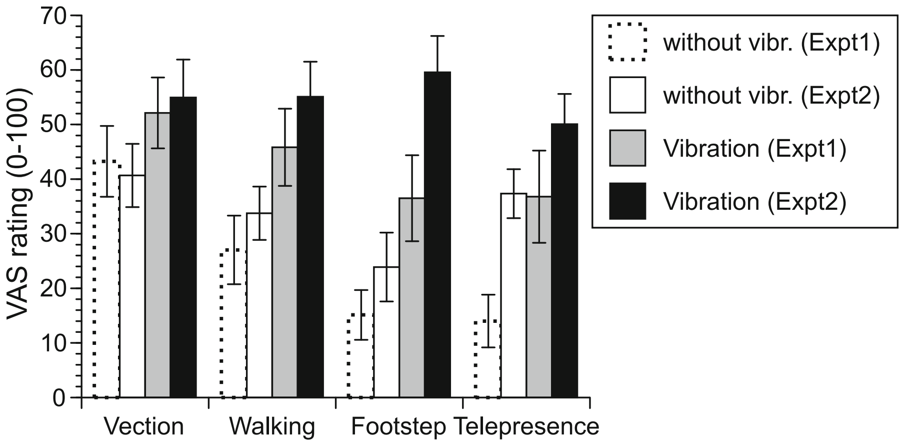

Fig. 14. Comparison of results of Experiment 1 and Experiment 2

footstep ($F(1,23) = 18.370$ $p = .0003$), and telepresence ($F(1,23) = 11.978$, $p = .0021$) sensations were stronger with the foot vibrations than without the vibrations. Only the footstep sensation was improved by a large visual field ($F(1,23) = 4.738$, $p = .0400$), and the others were not significantly improved (vection $p = .9903$, walking $p = 3423$, telepresence $p = .3596$). There was no interaction ($ps > .354$).

6 Conclusion

Subjective ratings of an active walking experience, including vection, footsteps, and telepresence, were improved with rhythmic vibrations on the heels of participants' feet. These results suggest that our minimum walking experience system, which has only 3-D visual motion images and two channel foot vibrations, gave users an active walking sensation to a certain extent.

The walking experiences, except for the footstep sensation, might not be affected by the size of visual stimuli. However we need further investigation because the number of subjects was not very large (N = 10, 15), and also the difference of visual size was not large (about two times in area size).

In the next step, we are going to present walking sensations on different surfaces such as soft sand or hard concrete roads by modulating foot vibrations.

Acknowledgments. This research was supported in part by the SCOPE program (141203019), and a Grant-in-Aid for Scientific Research (A) (#26240029 and #15H01701). We thank Atsuhiro Fujita, Takaaki Hayashizaki, Katsuya Yoshiho, Keisuke Goto, and Shohei Ueda for data collection and analysis.

References

1. Dichgans, J., Brandt, T.: Visual-vestibular interactions: effects on self-motion perception and postural control. In: Held, R., Leibowitz, H.W., Teuber, H.L. (eds.) Handbook of Sensory Physiology, vol. 8, pp. 755–804. Springer, Heidelberg (1978)
2. Kitazaki, M., Sato, T.: Attentional modulation of self-motion perception. Perception **32**, 475–484 (2003)
3. Iwata, H.: Walking about virtual environments on an infinite floor. In: Proceedings of IEEE VR 1999, pp. 286–293 (1999)
4. Iwata, H., Yano, H., Nakaizumi, F.: Gait Master: a versatile locomotion interface for uneven virtual terrain. In: Proceedings of IEEE VR 2001, pp. 131–137 (2001)
5. Gravano, S., Ivanenko, Y.P., Maccioni, G., Macellari, V., Poppele, R.E., Lacquaniti, F.: A novel approach to mechanical foot stimulation during human locomotion under body weight support. Hum. Mov. Sci. **30**, 352–367 (2011)
6. Cheron, G., Duvinage, M., De Saedeleer, C., Castermans, T., Bengoetxea, A., Petieau, M., Seetharaman, K., Hoellinger, T., Dan, B., Dutoit, T., Sylos Labini, F., Lacquaniti, F., Ivanenko, Y.: From spinal central pattern generators to cortical network: integrated BCI for walking rehabilitation. Neural Plast. **2012**, 375148 (2012)
7. Dodgson, N.A.: Variation and extrema of human interpupillary distance. In: Proceedings of SPIE, 5291, Stereoscopic Displays and Virtual Reality Systems XI (2004). doi:10.1117/12.529999