Characteristics of Virtual Walking Sensation Created by a 3-dof Motion Seat

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Abstract

This paper describes rendering characteristics of a virtual walk by a motion seat. The motion seat creates a small body motion in three dof (lift, roll, and pitch directions) to make the user feel as if the user him-/herself is walking despite sitting own body. We consider the actual self body is a medium to render the virtual body to share experiences of others by using the motion seat as part of the multisensory display. After setting the motion to optimally present a walking sensation, basic characteristics of perception levels of the virtual walk by the seat motion were measured and compared with those for a real walk. The result indicated that the perception levels of the virtual walk were around those of a real walk.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—artificial realities; H.5.2 [Information Interfaces and Presentation]: User Interfaces

1 Introduction

A locomotion interface [1] has been developed to enable physical walking motion of the user in the virtual environments. It usually requires a large device if the real voluntary walking motion of the user is allowed and the device cancels the user's motion as in an omni-directional treadmill. Otherwise, the real walking needs to be changed in its velocity and/or direction to hold the user's body within a limited area where the device tracks the motion and present the scene to the user [2]. Walking simulation method without voluntary motion of legs was presented recently [3, 4] where the user sat on the chair and the foot was stimulated passively during a virtual walk. The studies showed that the stimulation to the feet was effective to enhance the reality of walking.

The passive condition is of great use when the user receives the content of a virtual space such as a (guided) tour of the virtual scenes, a kind of a multimodal movie. This may allow the user to share the body motion of the other person who visited any place of interest, for example, the world heritage, the highest mountain, or museums in the world. A significant part of human experiences could be relived by another person if we take advantage of a life-log big data. The creation of walk experience is one of base technology for that experience sharing. A multisensory display was developed for this purpose [5]. The display renders a recorded bodily experience where the self body is virtualized allowing to become other person's body. In the present paper, we focus on the functional contribution of a motion seat (without other sensory input) to the virtual walk rendering comparing it with the real walk.

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2 Virtual body rendering

We investigate the method to create a bodily illusion where the user perceives a different body state from the real state of the actual body. For example, a virtual body of yourself is walking while your actual body is sitting. This could also be said that *the actual body is the medium* that renders the virtual body in a different state in conjunction with the ordinary VR displays. As a part of the VR rendering system, the actual body displays the virtual body to the user's brain. In the course of this design, the actual body is physically moved passively by haptic devices to evoke the virtual body sensation that creates a virtual experience. To utilize the actual body to present the virtual body motion in a virtual world, a multisensory input as perceived in the real world needs to be generated and integrated properly. Among them, the vestibular sensation is specifically crucial for the experience of spatial body motion.

In this paper, we discuss a part of investigation on the method to present bodily sensation of virtual walking while the subject sits on a motion seat. A seated posture is appropriate for this purpose because it releases the muscle tension of the user enabling the precise control of the body motion. In addition, the difference of posture from the standing state (while actual walking) is relatively small so that the presentation is expected easier than other posture (e.g. supine). It is safe for all ages, and for any users who might have physical problems.

We have built a multisensory display system [5] to present stimuli in modalities of vision, audition, olfactory, haptic (proprioceptive, tactile) and vestibular sensations for the virtual body creation.

3 Motion seat for virtual body motion

The motion seat shown in Fig. 1 has three degrees of freedom: a lift (vertical translation) with roll and pitch rotations. These are used to stimulate vestibular and proprioceptive/tactile sensations while rendering of virtual walking motion.

The seat is driven by three linear actuators that are implemented at the base of a FRP bucket seat. Three actuators are attached at the vertices of an isosceles triangle on a support plate. One actuator is placed at the front, and two are at the rear. The positional resolution is 0.01 mm and the maximum velocity 200 mm/s with up to a 100 mm stroke. The rotation range is up to 0.3 rad with the maximum speed of 1.25 rad/s. The total thrust (lift) force is 600 N.

Figure 1: The seat motion directions.

4 Rendering of walking motion

4.1 Real walk

Walking is a full-body complex motion controlled dexterously by the brain and the spinal cord based on the vestibular, kinesthesis, and tactile sensations in addition to vision with an intention to walk originated at the cortex [6]. It is explicitly an voluntary motion, however not all parts of the motion is under the conscious control.

The cyclic rhythm of leg motion is mainly controlled by the CPG (central pattern generator [7]) in the spinal cord and the brain stem without direct intervention of subjective volition from the cortex. A constant and straight walking motion, specifically on a level floor, is almost unconsciously performed, and its sensation is unclear if not attended. This allows a hypothesis that a passive body motion generated by an external device may be perceived as a part of voluntary walking motion.

4.2 Perception levels of a REAL walk

The sensation of a real walk on a level floor was first analyzed to compare it with the sensation generated by the presentation of the motion seat. Seven participants (mean age of 23 years) walked with sneakers on a corridor covered with a carpet for about 40 m. The walking speed was paced by the sound of the metronome through earphones toned at the rate of 0.7 s (each step). The participant wore special glasses that lowered the vision to the extent that the participant could walk without fear of collision or fall. The experimenter attended the participant during the real walk session.

The items to rate were regarding the intensity of sensation (or the level of awareness) of nine aspects of walking perception: a) Power (acceleration of each step), b) Walk speed, c) Periodicity (repetitive motion), d) Lateral alteration (lateral sway), e) Muscle tension (perceived), f) Continuous body motion, g) Regularity of body motion, h) Balance control, and i) Sole taction (tactile sensation at the foot) . The participant reported on a questionnaire for each rating item with a visual analogue scale where the left end meant 'none; not clear at all', and the right end 'clear and strong; definitely exist' assigned 0 and 100, respectively, for a later analysis.

Figure 2's *blue* bar shows the result of ratings of perception level on nine items for a *real* walk. Discussion is given in section 4.4.

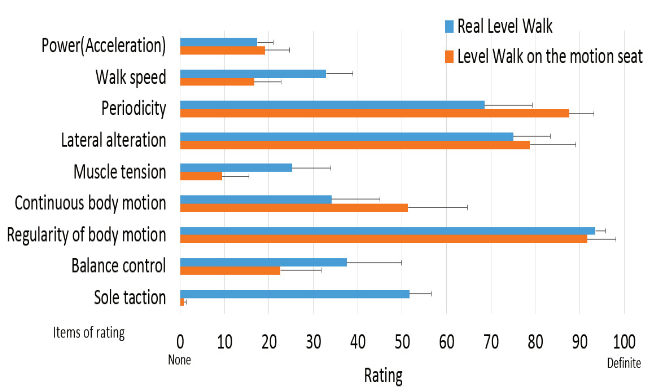

Figure 2: Perception levels of the real and virtual walks.

4.3 Perception levels of a virtual walk (seat motion)

Before the rating, the three-dof motion (lift, roll and pitch) of the seat was adjusted by the participants so that the seat motion presented walking sensation most appropriately. The procedure was as follows. First, the participant walked on the level floor, then sat on the motion seat and adjusted the motion of the seat regarding the amplitude of lift, roll, pitch, and the motion speed (single step time below 0.7 s) by using a game controller device. Seven participants performed this adjustment for optimal motion with closed eyes and noise-masked ears. The common trajectory was a sine-like function ($-0.5\pi \leq \theta \leq 1.5\pi$) wave ([8]) for each virtual step.The resultant mean values were 1.26 mm, 0.13 deg, 0.15 deg, and 6.47 mm/s, respectively. The SEs were 0.12 mm, 0.012 deg, 0.010 deg, 0.626 mm/s. The amplitude was 10 to 20 times smaller than the real movement of the body in a real walk [8]. Then, the participant rated the perception level of the virtual walk presented by the trajectory using the same items as in the real walk. The result is shown by red bars in Fig. 2.

4.4 Discussion

The bodily perception level (awareness) of the real walk differed with items. The value for the virtual walk was around that of the real walk in most cases except for two items, which indicates the appropriateness of the rendering of the motion seat. The sensation of a) power (acceleration of each step) was very low for both (real and virtual) walks, since the level walk did not require much force to maintain the walking state. The sensation of b) walk speed estimation was also very low due to the slow speed of the walk. The speed of the virtual walk was lowered due to the perceived wind was zero in this condition. The periodicity, the lateral alteration and the regularity of body motion were highest in the both walks. These are the most common features of walking, and were easy to perceive for the participant. The virtual walk clearly achieved these aspects. As for the muscle tension and the sole taction, the motion seat itself does not have the presentation on the two items. The sole taction can be provided by pedal devices of the multisensory system. The continuous body motion was more clearly perceived in the virtual walk since the waveform of the seat was regular as compared with the real walk. The balance control was rated relatively lower in the real walk since the level walk was easy, while in the virtual walk it was more weakly perceived due to its passive stimulation condition.

5 Conclusion and Future Work

The seat motion was investigated in terms of presenting walking sensation based on vestibular and proprioceptive stimulations. The result indicated that the perception levels of the virtual walk by the seat motion had almost the same tendency to the real walk. We consider that the motion seat could created the essential part of the walking sensation. Missing sensory component can be presented by other multisensory devices of the whole system [5]. These would establish a base of virtualization of the body. The future work involves the elucidation of a mechanism for presenting a general virtual body which enables to share the experience of others based on a captured spatial motion (action) of any body.

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References

[1] Locomotion Interfaces, in Handbook of Virtual Environments: Design, Implementation, and Applications (Human Factors and Ergonomics), ed. Kay M. Stanney, 2002

[2] Peck, T.C., Fuchs, H., Whitton, M.C. The design and evaluation of a large-scale real-walking locomotion interface. IEEE Transactions on Visualization and Computer Graphics 18, 1053-1067 (2012)

[3] Jayakumar, R.P., Mishra, S.K., Dannenhoffer, J.F., Okamura, A.M. Haptic footstep display, Haptics Symposium 2012, 425-430 (2012)

[4] Turchet, L., Burelli, P., Serafin, S. Haptic Feedback for Enhancing Realism of Walking Simulations. IEEE T. Haptics 6(1): 35-45 (2013)

[5] Ikei, Y., Abe, K. Hirota, K. Amemiya, T., A multisensory VR system exploring the Ultra-Reality. Proc. Virtual System and Multi Media 2012, 71-78 (2012)

[6] Perry, J.: Gait Analysis: Normal and Pathological Function 12 (1992)

[7] Dimitrijevic, M.R., et al.: Evidence for a Spinal Central Pattern Generator in Humans. Annals of The New York Academy of Sciences 860, 360-376 (1998)

[8] Ikei, Y., Shimabukuro, S., Kato, S., Okuya, Y., Abe, K., Hirota, K., Amemiya, T., Rendering of Virtual Walking Sensation by a Passive Body Motion, Proc. EuroHaptics2014, 184 (2014)