To Relive a Valuable Experience of the World at the Digital Museum

Yasushi Ikei¹, Yujiro Okuya¹, Seiya Shimabukuro¹, Koji Abe¹,
Tomohiro Amemiya², and Koichi Hirota³

¹ Tokyo Metropolitan University, Tokyo 191-0065, Japan

ikei@computer.org

² NTT Communication Science Laboratories, Kanagawa 243-0198, Japan

amemiya.tomohiro@lab.ntt.co.jp

³ The University of Tokyo, Tokyo 113-8656, Japan

uhirota@mail.ecc.u-tokyo.ac.jp

Abstract. This paper describes a new concept of bodily experience that may be used in the future museum exhibit. An ordinary museum exhibits objects to make themselves talk with their authenticity to visitors, however it does not provide an interaction and vivid context in which they existed. A virtual experience system which creates multisensory stimuli potentially presents the realistic state of valuable artificial objects in the original environments. We think the *experience* of objects in a particular space is another theme that a future museum needs to seek. A novel rendering technique of a virtual body of a visitor is introduced where multisensory displays impart the sensation of presence of an environment and objects of interest through a pseudo walking experience. This digital museum device will add a new experience to relive a trip walking around objects based on recorded data from a real tourist.

Keywords: bodily experience, virtual body, pseudo walking, experience projection, ultra reality.

1 Introduction

A museum is the place where objects of certain value are presented and preserved to hand the knowledge relating to and represented by the objects on to the next generation. The knowledge coexists with the objects is transferred through the instrumentation of museum exhibit by presenting at hand the real object worked in the past. This method is an effective and only way to bring the real authentic things over time to the present.

Although people can see and read about the exhibit of objects, usually they can not *experience* actual use of them in real life. The real relation between humans and artificial objects in a context is another crucial aspect that should be passed to people in the future. Moreover, a very large object that spans over an exhibit-room height or a historical architecture need to be presented by other means than the current museum way of exhibit, that enable visitors to walk

around and feel the environment that holds the objects. Our relation to a large artificial object is only grasped after we move around and see it from various angles and distances.

Thus, the experience to cognitively capture large objects distributed in a field requires a spatial motion of the visitor, specifically the walking through the field watching architectural structures as interested objects. This kind of experience has not been involved in an ordinary museum, and it is the experience usually possible at a real tourist spot where valuable structures stand. If a digital museum could present such tourist spots in the world, it can cover large objects distributed on the whole globe for guided experiences. These sight-seeing experiences of the world may be involved in a future digital (virtual) museum by accumulating the record of real experiences that tourists gained.

One of the key technologies of this virtual museum is an experience *projection* that the past experience of some tourist is shared by a visitor of the museum as if the visitor him-/herself has really walked and looked at the spot by own body. This *experience projection* is performed to a physical body of a visitor. In other words, it is a new presentation of a self-body to a visitor by an external stimulation that causes multisensory sensation of self motion. We investigate a novel methodology that creates first-person reliving sensation of a trip by a virtual self body representation based on a multisensory display.

As the first stage, we focused on representing a walking motion of a person, a kind of playback of prerecorded body motion. This opens a possibility to obtain experiences of other people who visited various sites with their own will at a future digital museum. It would provide the user with the opportunity of learning through the experience of other people, or in a sense, it might be considered as a kind of 'Total Recall [4]' movie where one could buy any experiences. This would provide a new style of exhibit for a digital museum using the virtual reality technology.

2 Representation of a Self Body

Experience has its base on a self body. The rendering of a self body is a long topic of the virtual reality technology. The three factors of the virtual reality were described by Tachi [14] as: a real-time interaction, a 3D space, and a self projection. The last factor, a self projection, is not very obvious issue, and it has not been sufficiently implemented and elucidated since it involves complicated cognitive and sensory aspect that is currently investigated in the light of neuropsychology.

Usually the self projection means that a projected self avatar is observable by both the current user of a VR space and other persons in the same VR space. It is an *objective projection* as it is apparently examined by anyone in the space—this is the first level of self projection. On the other hand in the light of a subjective view point—the second level of self projection, the self projection is considered that the user feels as if his/her body resides in the avatar, or in a weaker sense, his/her body coexist both at the avatar and the actual (real) self body (virtual coexistence).

In this *subjective projection*, the cognitive (conceptual) self body is virtualized and placed at the avatar [1] although the real body still exists in the real world and holds the control of the avatar. In this situation, it would be very interesting to think whether the avatar could control the cognitive self body. That is, the avatar that has a scenario of an experience drives the cognitive self body to provide a copy of the experience to the user. In reality, the scenario of the avatar is of special interest if it is of someone else who had a variety of valuable experience, e.g. world travels, physical presentations of top athletes, artistic skills of a living national treasure artist, or even a ride in a theme park and learning experience at the university.

The projection is from the avatar to the cognitive self body, which is a *back projection* (Figure 1) to usual self projection of the virtual reality. The external experience (of one person) is projected to the user through the self body. In this case, the self body itself is a medium to present the other person's body. It may also be written that the user dives into the other person's body. We call this *the virtual body technology by back projection* in which the user relives the experience of the other person. The *virtual body* is a rendered cognitive self body by the *back projection interface*.

Fig. 1. Back projection in which a virtual body is rendered

3 Virtual Body

Cognition of a self-body and its rendering have been investigated in the context of a virtual body in a VR space [12,13]. A multisensory presentation is a crucial part of implementation by which a virtual body might be really considered as a self body as subjective projection. A high quality sense of presence is expected to be realized if we can properly integrate multisensory stimuli that produce the sensation of virtual self body as if it resided in the VR space, not in the actual state of the physical body. There are many evidences that a passive multisensory perception can easily create virtual body illusion [2] even if it was a whole body [1].

We consider here the method to create a dynamic virtual body illusion that is recognized in a different state from the real state of an actual body. For example, a virtual body of yourself is walking while the actual your body is sitting. This could also be said that your actual body is the medium that renders a virtual body in a different state in conjunction with the VR apparatus. As a part of VR rendering system the actual body displays a virtual body to the user's brain. In the course of this design, the actual body is physically moved appropriately by some haptic devices to evoke a virtual body sensation that creates a virtual experience. This is the ultimate goal, a kind of the ultra reality, of our multisensory display system introduced in the present paper.

To utilize the actual body to represent virtual body motion in a virtual world, multisensory input should be generated and integrated ingeniously. Among them, vestibular sensation is specifically crucial for the experience of spatial body motion and presence located in a relatively large space. A vestibular device such as a vehicle simulator is usually used to represent the movement of a transportation machine (e.g. automobile). It is not applicable to present the motion of the self body. For our purpose, a vestibular device needs to create a first-person sensation of own virtual body movement.

4 A Display System for Virtual Body Motion

4.1 Multisensory VR System Prototype

A multisensory display system, FiveStar (Five Senses Theater [7]) produces multiple modality stimuli to the five senses of the user, except for the gustatory sensation. Figure 2 shows a schematic of the FiveStar. The system consists of a stereoscopic visual display with shutter glasses, a 7.1 channel surround audio system, a tactile and force feedback (haptic) display system, a wind and scent delivery system, and a vestibular body motion system. These subsystems are integrated to provide an interaction to the participant along with a particular scenario of experience. Each device is controlled by a controller PC that is connected with each other by the 100 Mbps Ethernet on which an UDP message is broadcasted to synchronize each function.

Fig. 2. Multisensory display (FiveStar)

Fig. 3. Motion seat (3-dof)

4.2 Vestibular and Haptic Display

Four types of display devices to create walking sensation were developed: a 3-dof motion seat and a lower limb stimulator consisting of a 2-dof horizontal motion plate, two vertical motion pedals, and tactile stimulators at soles and shinbones. These devices, in addition to a wind generator, are integrated to form a new type motion base system that evokes the sensation of walking.

Motion Seat. The motion seat, shown in Figure 3, is driven by three linear actuators that were implemented at the base of a FRP seat of an automobile. 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 stroke of each actuator is 100 mm with a 0.01-mm resolution and the maximum velocity of 200 mm/s. The actuators are controlled by a pulse drive board in a control PC.

The motion of the seat has three degrees of freedom: a lift (vertical translation) with roll and pitch rotations. These are used to stimulate vestibular sensation while rendering of virtual walking motion. In addition, the seat is equipped with eight vibro-transducers at the back and bottom cushions. The vibration of transducers is used for small motion component that should be involved in the virtual motion rendering.

Lower Limb Stimulator. The lower limb stimulator (Figure 4) consists of a 2-dof horizontal motion plate, vertical motion pedals, and sole stimulators. These devices contribute to create sensation of a spatial bodily motion by making user's feet move in a two-dimensional plane, and by lifting lower extremities at the heel simultaneously. Synchronous motion of them evokes the sensation of a voluntary walking motion of the body in addition to the movement of the ground if needed.

Fig. 4. Lower limb stimulator. A 2-dof horizontal motion plate (base), two vertical motion pedals, and toe/heel tactile stimulators at the soles.

Fig. 5. Tactile stimulators (voice coils). Six vibrator units in a pair of leg guards (top left), four vibrators in step boxes (bottom left), and four vibrators attached to the pedals.

Figure 5 shows tactile displays for lower limbs: shin stimulators in leg guards (top left), sole stimulators for toes and heels (bottom left and right). These present the tactile sensation that originated from the impact against the floor and consequent vibration during walking [15] in addition to a wind. These tactile displays were not used in the experiments written in the later section to investigate single stimulus independently, although the effects of them were especially crucial in displaying a virtual walking motion.

5 Rendering of Walking Motion

Walking is a full-body motion controlled dexterously by the spinal cord and the brain based on multisensory information that comes from the vestibular sensation, the kinesthesia and tactile sensation and the vision with an intention to walk that originated at the cortex [9,16]. It is clearly a voluntary motion in a sense, however not all of the motion is under conscious control. The cyclic rhythm of leg motion is mainly controlled by the CPG (central pattern generator [5]) in the spinal cord and the brain stem without direct intervention of subjective volition from the cortex. This allows that a passive body movement generated by an external device may be perceived as a part of voluntary walking motion. With this view, we investigated a passive stimulation method for a body that evoked the sensation of a voluntary walking. To determine the amount of stimulus to add to impart a walking sensation, a real walking motion was measured and referred to search an appropriate stimulus created by the display.

5.1 Spatial Trajectory of a Body during a Real Walk

The body trajectory during a real walk was measured by an optical spatial sensor (OptiTrak V100, NaturalPoint, Inc.) as a reference data for rendition of the motion seat and the pedals. A participant walked on a treadmill attaching markers at the head, the coxal bone, the toe and heels placing the sensor on the side and the back of the treadmill. The walking speed was 60 m/min.

The amplitude of a vertical motion at the head and the coxal bone was about 30 mm. The trajectory of the heel is shown in Figure 6. The horizontal displacement in the forward/back direction was about 600 mm, while the vertical lift was about 200 mm. Although the magnitude of a body motion depends on the body height (length of a leg) and a walking velocity, we will refer this amplitude as an approximate value of a real walk since a strict value is not crucial as shown in the later section.

5.2 Rendering of Walking Motion by Motion Seat

As a preliminary experiment, first we produced the same amplitude of a vertical motion as the real walking by the display system. The result was that the actual amplitude motion evoked an extremely larger sensation than the real sensation the subject received during the real walking. This might be ascribed to

Fig. 6. Vertical motion of the heel

the difference in sensory processing in which sensory input could be attenuated when a voluntary motion was executed [3,8]. In the current condition without a voluntary actuation of a body, the added stimulus was felt as if the body was simply moved irrelevantly to a walking. In addition, the posture of sitting on a chair was different from walking of course, which would make the same amount of motion inappropriate for the equivalent perception of body motion.

An appropriate amplitude of a vertical motion (with roll and pitch motion) was experimentally searched by a participant based on the method of adjustment in a general psychophysical procedure. The adjustment involved three linear actuators so that the resultant motion had three degrees of freedom. In addition, to avoid the trajectory with the completely constant shape during steps of a walking motion, a 10 to 20 percent random fluctuation in amplitude was automatically introduced.

Figures 7 and 8 show the vertical motion that the participant adjusted, of the headrest and the left-hand support of the seat, respectively. Other parts, the right-hand support and the seating face, were also measured as well as some sites of the participant's body, although not discussed here. The amplitude of the headrest was about 1 to 2 mm, far smaller than the real walking motion, with some fluctuation included in the process of adjustment. The amplitude of the left-hand support was also about the same range (around 1 to 2 mm) that changed cyclically along with a walking phase. The amplitude of seat motion was about one fifteenth of the amplitude observed in the real walking.

5.3 Rendering of Walking Motion by the Pedals

Reciprocal lift motions were added to the participant's legs by two motion pedals shown in Figure 4 to evoke a sensation of walking while the participant sat on the seat with his shinbone set approximately vertical and the angle of the knee joint held to approximately 90 degrees. Based on the real trajectory of a heel (Figure 6), a similar trajectory was designed in the form as shown in Figure 9, and the trajectories around this form were displayed and rated by participants. The period ratio of the swing phase and the stance phase was 2:3 as observed in the real walking motion. Ascend/descend period ratio was also set after the real

Fig. 7. Vertical motion at the headrest of the seat. Fluctuation of the amplitude is a part of the designated trajectory.

Fig. 8. Vertical motion at the left-hand support of the seat. Alternating amplitude indicates the roll motion involved in the motion rendering.

motion. This lifting motion was provided to two lower legs with a 180-degree phase difference. Ten stimuli of vertical lifting of {0.1, 1.0, 2.0, 5.0, 10, 20, 30, 40, 50, 60} mm at the heel were randomly presented to the participant for 10 times each. Seven male participants (the mean age of 22.4 years) rated the lifting stimulus in terms of the similarity to the sensation of a real walking, or the extent to which the walking sensation was evoked. A 5-scale rating (5 is most similar or evoking) was used. Before the session, participants walked on a level floor for 10 m at 1400 ms walking period paced by the sound of a metronome to memorize the sensation of walking. The participant wore headphones that provided a noise, and closed eyes during the rating session. During this evaluation session, the motion seat was fixed providing no motion cue.

The result is shown in Figure 10. The rating score of similarity to the sensation of the real walking was analyzed using a one-way analysis of variance (ANOVA) regarding the amplitude values of vertical lifting. The analysis revealed the significant effects of the vertical amplitude ($F(9, 54)=10.6, p<0.001$). In post-hoc comparisons (Fisher LSD test), amplitude values of 10 to 30 mm yielded a larger rating than others. This indicates that the optimal amount of lift was about 10 to 30 mm to evoke the sensation of walking in the case of the foot lifting motion. The value is around one tenth of the real lift motion. Regarding the motion shape, some participants commented that the motion direction change at the

Fig. 9. Vertical motion pedal lift trajectory (heel motion)

Fig. 10. Pedal lift rating (heel motion rating, error bar denotes SE)

top position was too fast and it lessened the amount of similarity to the real walking.

6 Conclusion

We introduced a novel display system that will project the sensation of walking around a large object as an exhibit to a visitor of a future digital museum. The experience of a large object should involve multiple view points that are best provided by walking. Our working hypothesis is that a walking experience can be introduced through an externally actuated body motion that is perceived as if the participant walked by own feet voluntarily.

The display method was investigated after a body trajectory during a real walk was measured for a reference. Produced stimuli by display devices that projected a virtual walking was compared with the real walk. The equivalent amplitude of vertical motion on the display was as small as about one tenth to twentieth of the real motion. This small value is good for the implementation of the display since its mechanical structure can be much reduced to allow more places for use.

In this research, we set a hypothesis of a dynamic virtual body rendered by *the back projection*. Observed large difference between the real body motion and its equivalence on the display is considered to be related to the particular brain process of modulating sensory information based on the efference copy and the presynaptic inhibition [11] in addition to the conscious intention to walk [6]. The mechanism needs to be elucidated in conjunction with the field of neuropsychology.

Since the reality is perceived by the body interaction with the world, so that the body itself limits the reality. If we can assume the body as a medium of VR space media, then our experience will be augmented and expanded, since the body is the base of an experience. The direct consequence of this is that your experience can be that of the other person. The user can relive other's experience as if it occurred originally on the user. This may be said the user's body is replaced with the other's [10]. In other words, the user dives into the other's body and obtains his experience as depicted in [4]. If this technology is realized, the museum will obtain a new dynamic presentation method of human experience that is not provided by the current exhibit method of the museum. For this method the multisensory information is crucial in imparting the sensation of presence of an environment. In addition, a pseudo walking using recorded data from a real tourist will be the main part of experience of reliving a trip around objects.

Acknowledgements. The authors wish to thank Professor Michitaka Hirose at the University of Tokyo for his valuable advice on the present research. This research was supported by NICT (National Institute of Information and Communications Technologies).

References

1. Blanke, O.: Multisensory brain mechanisms of bodily self-consciousness. *Nature Reviews. Neuroscience* 13(8), 556–571 (2012)
2. Botvinick, M., Cohen, J.: Rubber hands 'feel' touch that eyes see. *Nature* 391, 756 (1998)
3. Cullen, K.E.: Sensory signals during active versus passive movement. *Current Opinion in Neurobiology* 14, 698–706 (2004)
4. Dick, P.K.: *Total Recall*. Gollancz (2012)
5. Dimitrijevic, M.R., Gerasimenko, Y., Pinter, M.M.: Evidence for a spinal central pattern generator in humans. *Annals of The New York Academy Of Sciences* 860(1), 360–376 (1998)
6. Haggard, P.: Conscious intention and motor cognition. *Trends in cognitive sciences* 9(6), 290–295 (2005)
7. Ikei, Y., Abe, K., Hirota, K., Amemiya, T.: A multisensory VR system exploring the ultra-reality. In: *Proc. VSMM 2012*, pp. 71–78 (2012)
8. Lambert, F.M., Combes, D., Simmers, J., Straka, H.: Gaze Stabilization by Efference Copy Signaling without Sensory Feedback during Vertebrate Locomotion. *Current Biology*, 1–10 (2012)
9. Perry, J.: *Gait Analysis: Normal and Pathological Function* 12 (1992)
10. Petkova, V.I., Ehrsson, H.H.: If I Were You: Perceptual Illusion of Body Swapping. *PLoS ONE* 3, 9 (2008)
11. Rossignol, S., Dubuc, R., Gossard, J.-P.: Dynamic sensorimotor interactions in locomotion. *Physiol. Rev.* 86, 89–154 (2006)
12. Slater, M., Marcos, D., Ehrsson, H., Sanchez-Vives, M.V.: Inducing illusory ownership of a virtual body. *Frontiers in Neuroscience* 3(2), 214–220 (2009)
13. Slater, M., McCarthy, J., Maringelli, F.: The influence of body movement on subjective presence in virtual environments. *Human Factors: The Journal of the Human Factors and Ergonomics Society* (1998)
14. Tachi, S., Sato, M., Hirose, M.: *Virtual Reality*. Corona Publishing Co., Ltd. (2010)
15. Terziman, L., Marchal, M., Multon, F., Arnaldi, B., Lecuyer, A.: King-Kong Effects: Improving Sensation of Walking in VR with Visual and Tactile Vibrations at each Step. In: *IEEE International Symposium on 3D User Interfaces (IEEE 3DUI)*, pp. 19–26 (2012)
16. Whittle, M.W.: *An Introduction to Gait Analysis* (2007)