A Physiological Evaluation of Immersive Experience of a View Control Method using Eyelid EMG

Masaki Omata[1], Satoshi Kagoshima[2] and Yasunari Suzuki[2]
[1]*Interdisciplinary Graduate School of Medicine and Engineering, University of Yamanashi, Takeda, Kofu, Japan*
[2]*Department of Computer Science and Media Engineering, University of Yamanashi, Takeda, Kofu, Japan*

Keywords: physiological Evaluation, Immersive Impression, Eyelid-Movement, Electromyogram, Virtual Environment.

Abstract: This paper describes that the number of blood-volume pulses (BVP) and the level of skin conductance (SC) increased more with increasing immersive impression with a view control method using eyelid electromyography in virtual environment (VE) than those with a mouse control method. We have developed the view control method and the visual feedback associated with electromyography (EMG) signals of movements of user's eyelids. The method provides a user with more immersive experiences in a virtual environment because of strong relationship between eyelid movement and visual feedback. This paper reports a physiological evaluation experiment to compare it with a common mouse input method by measuring subjects' physiological data of their fear of an open high place in a virtual environment. Based on the results, we find the eyelid-movement input method improves the user's immersive impression more significantly than the mouse input method.

1 INTRODUCTION

In recent years, some devices have been developed on how to provide a user with more immersive impression in a virtual environment (VE)(Nagahara et al., 2005), (Meehan et al., 2002). In the research field, some visual displays have been developed as visually-immersive devices such as a head-mounted display that covers the user's view and peripheral vision, a wall-sized screen that covers the user's whole body and 3D display that give a user a sense of depth. On the other hand, some interaction techniques in a virtual environment have been designed (Touyama et al., 2006), (Ries et al., 2008), (Asai et al., 2002), (Manders et al., 2008), (Steinicke et al., 2009), (Miyashita et al., 2008), (Haffegee et al., 2007), (Kikuya et al., 2011). Particularly, it is important to provide a user with embodiment interaction techniques in a virtual environment, just like the same as natural embodiment motion in the real world. Therefore, several gestural interaction techniques and several walk-through environments have been developed. By using the interaction techniques and the displays, users can more naturally interact with a virtual environment in where visual feedback to the users corresponds with motor skills of the users.

However, these existing embodied interaction techniques have some shortcomings of the correspondence between motor skills and visual feedback. For instance, people usually scrunch up their eyes to look carefully at an important point. Conversely, people usually open their eyes widely with to get a wide view of surrounding area. Existing virtual reality systems do not incorporate the basic movement like looking. They usually provide users with control devices such as a mouse, a joystick and a location sensor to control user's view. Because there is no real-world-like relationship (eye movement and view) between the device operations and the visual feedback, the device operations may make the user aware of the gap between the real world in where the user controls the device and the virtual world in where the user sees and may reduce the user's immersive impression.

We, therefore, have developed a view control method and the visual feedback associated with electromyographic (EMG) signals of movements of user's eyelids (TheAuthors, 2011). The method provides users with more immersive experiences in a virtual environment because of the strong relationships between the eyelid movements and the visual feedback. Moreover, the visual feedback enhances a user's visual functions in a virtual world, such as zoom-in/out and see-through, by following the relationship between motor skills of seeing and views in the real world. We think that the method will be used for a natural and direct view control system in a three-

Omata M., Kagoshima S. and Suzuki Y..
A Physiological Evaluation of Immersive Experience of a View Control Method using Eyelid EMG.
DOI: 10.5220/0004719102240231
In *Proceedings of the International Conference on Physiological Computing Systems* (PhyCS-2014), pages 224-231
ISBN: 978-989-758-006-2

dimensional virtual environment.

Another research issue of VE interaction is how to evaluate user's immersive experience. A questionnaire, such as Likert scale or semantic differential method, is one of conventional evaluation techniques, but it is not continuous and not objective. Additionally, it is difficult to measure and evaluate sensation by conducting a performance evaluation such as task completion time and error ratio. We therefore conducted a physiological evaluation test to compare the immersive impression with the eyelid-movement input method with that with a mouse input method.

This paper describes related work, the development summary of the system, the physiological evaluation test about the users' immersive impression and improvement of the recognition algorithm of EMG of user's eyelid movements.

2 RELATED WORK

Asai et al. developed a vision-based interface based on body position for viewpoint control in an immersive projection display by tracking 3D positions of the arms and head of the user by using image processing without attached devices (Asai et al., 2002). They evaluated the utility of the interface by comparing the interface with a joystick. The results indicate that the performance of the interface is comparable to that of the joystick in terms of viewpoint control, but enhances the sensation of speed. Manders et al. presented a method for interacting with 3D objects in an immersed 3D virtual environment with a head-mounted display (HMD) by tracking user's hand gestures with a stereo camera (Manders et al., 2008). The system allows the user to manipulate a 3D object with five degrees of freedom using a series of intuitive hand gestures. Steinicke et al. developed a VR-based user interface for presence-enhancing gameplay with which players can explore the game environment in the most natural way, i. e., by real walking (Steinicke et al., 2009). While the player walked through the virtual game environment by wearing a HMD, they analyzed the usage of transitional environments via which the player could enter a virtual world. The results of the psychophysical experiments have shown that players can be guided on circular arc with a radius of 22.03m whereas they believe themselves to be walking straight. Oshita proposed a motion-capture-based control framework for third-person view virtual environments with a large screen (Oshita, 2006). The framework can generate seamless transitions between user controlled motion and system generated reactive motions.

Because these systems use user's body motions to control view in virtual environment, there are a few fundamental problems. A problem is that the view control is rough by using body motions. Another problem is that the device input makes the user feel the seam between the real and virtual worlds. Therefore, some systems to adopt eye movement for view control have been developed.

Miyashita et al. proposed an electrooculography (EOG)-based gaze interface that was implemented by mounting EOG sensors on a HMD with a head-tracker and proposed a gaze estimation method on the HMD screen(Miyashita et al., 2008). The accuracy of gaze estimation was experimentally determined to be 68.9 %. The system solves the problems of eye-tracker devices' block to a HMD. Haffegee et al. focusses on methods and algorithms for using an eye-tracker to takes the eye-tracker output and converts it into a virtual world gaze vector in an immersive VE by using an eye camera and a head tracker (Haffegee et al., 2007).

These systems mainly adopt the user's line of sight. However, people usually use their eye movements to not only control line of sight but also several controls for sight such as focus, gaze, interest and affect. For instance, people usually tighten their eyelids to look carefully. People also widen their eyes to look at someone with interest or in surprise. Additionally, because a person with x-ray vision in a science fiction movie tightens his/her eyelids to look through objects, we proposed that it is possible to enhance user's visual functions in a virtual environment by tracking eye movements in detail.

3 A VIEW CONTROL METHOD USING EMG OF EYELIDS

We proposed a view control method associated to movements of use's eyelids to enhance user's visual functions in a virtual environment (TheAuthors, 2011). The basic method deals with three types of eyelid movements: staring, neutral and widely-opening. The neutral is a state of looking at something naturally without straining or widely-opening (see figure 1a). The staring is a state of looking carefully with gathering eyebrows (see figure 1b). The widely-opening is a state of looking at whole with raising eyebrows (see figure 1c). Figure 2 shows the state transition diagram of the three states.

By using the states, we designed two types of view control techniques in a virtual environment: the zoom in/out control technique and the see through/annotation control technique. By using the

(a) (b) (c)

Figure 1: Three states of eyelid movements: (a) neutral, (b) staring, and (c) widely-opening.

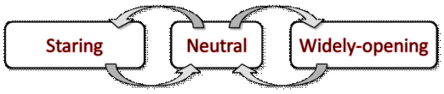

Figure 2: State-transition diagram of the three eyelid states.

zoom in/out technique, a user can look at a distant object as the zoomed-in view by looking at it with gathering eyebrows. Moreover, the user can look at objects, which are outside of the user's neutral view, as the zoomed-out view by looking at the center of the view with raising eyebrows. The view of zoom in/out becomes the normal view when the user repositions the eyebrows and relaxes the palpebral muscles.

On the other hand, by using see-through/annotation technique, a user can look inside an object such as an engine of a car by looking at it with gathering eyebrows. Moreover, the user can read annotation text, such as spec of a car around it by looking at it with raising eyebrows. The views become the initial view when the user repositions the eyebrows and relaxes the palpebral muscles.

We think that the system improves the user's immersive experience because of the relationship between the actual eye movements and the visual feedback. This advantage solves the problem of reducing a user's immersive impression because of the tenuous relationship between visual feedback and the movement of conventional input devices, such as a mouse, a joystick, or a location sensor.

Additionally, the system has a possibility to provide a user with controlling the view in multiple steps by adjusting the strength of his/her eyelid muscle. In other words, the stronger the user gathers his/her eyebrows, the larger the zoom is, and the higher the transparency is.

3.1 Implementation

We use a Z800 3D Visor (eMagin Co.) as a head-mounted display (HMD), a ProComp Infiniti (Thought Technology Ltd.) as a biofeedback device, two MyoScan sensors (Thought Technology Ltd.) as pre-amplified surface electromyography (EMG) sensors, and a PC to implement an eyelid-movement recognizer and a 3 D virtual environment . The specifications of the HMD are as follows: a 105-inch virtual screen at a distance of 3.6 m, 40-degree angle of view, horizontal 360-degree angle and vertical 60-degree angle head tracking, 800 600 pixels. The biofeedback device and the EMG sensors are used to record the EMG signals on a user's facial surface and to send the data to the PC via USB. The recording frequency is 20 Hz, and the recorded signals are raw voltage values. The PC is used to process the EMG data and to render the scene of a virtual environment with Microsoft Visual C++ and OpenGL. The three dimensional view of the scene is controlled with the 6 degrees of freedom data of the head-tracking HMD.

Figures 3 shows the HMD and the electrodes of the EMG sensors attached to a user's face. An EMG sensor consists of three electrodes: positive, negative, and reference. We use an EMG sensor to detect eyelid movements because it is difficult to detect it by image data processing with a camera, such as a study of Valstar et.al(Valstar et al., 2006), because of the narrow space between user's face and the HMD (Figure 3c).

(a) (b) (c)

Figure 3: State of wearing the HMD and attaching the EMG sensors in our proposed system.

3.2 Measuring EMG and Detecting Eyelid Movements

EMG is a technique for detecting and amplifying tiny electrical impulses that are generated by muscle fibers when they contract. An EMG sensor can record the signals from all the muscle fibers within the recording area of the sensor contact. Some research studies use EMG to develop human interfaces. Manabe et al. proposed the use of an EMG of facial muscles to control an electric-powered wheelchair(Manabe et al., 2009). Agustin et al. presented a low-cost gaze-pointing and EMG-clicking device, which a user employs with an EMG headband on his/her forehead (Agustin et al., 2009). Clark et al. used the EMG on a user's arm movement to control a robotic arm (Jr. et al., 2010). Also, Costanza st al. presented a formal evaluation of subtle motionless gestures based on EMG signals from the upper arm for interaction in a mobile context(Costanza et al., 2007) , and Gibert et al. developed describe a light expression recognition system based on 8 facial EMG sensors placed on specific muscles able to discriminate 6 expressions to enhance human computer interaction (Gibert et al., 2009). It is practical to use EMG data in order to enable a computer to intuitively interact with body movements.

Our system measures the EMG data between the eyebrows of a user and between the upper and lower right side of a user's right eye to detect three types of eyelid movements: staring, neutral, and wide opening (Figure 1). This means that the system measures the EMG signals of the frontalis muscle to recognize a wide opening state, and the EMG signals of the corrugator muscle to recognize a staring state. This is based on our preliminary experiment (TheAuthors, 2011).

3.3 Calibration and Recognition

Typically, the values of the electric potential of the EMG signals are positive and negative. Therefore, our system converts all values into absolute values for simple statistical processing for calibration and recognition.

Our system calibrates the thresholds of the EMG data to recognize the three types of eyelid movements for an individual user, before the user uses the view control method. After a user puts the EMG sensors on his/her face, the system records the EMG data five times among 20 frames at the two places while the user maintains each of the eyelid movements. Next, the system calculates the average and the standard deviation (SD) of the recorded EMG data of each eyelid movement state of the user. Based on the calculations, the threshold of the neutral state is the sum of the average and the SD of the state. The threshold of the staring state is the difference between the average and the SD of the state, and the threshold of the wide opening state is the difference between the average and the SD of the state.

While a user uses the eyelid-view-control method, the system continuously records the EMG data among four frames at the two places, calculates two averages and two SDs from the data and compares the averages and the SDs with the thresholds of the calibration data in order to recognize the eyelid movements.

4 PHYSIOLOGICAL EVALUATION

We conducted a physiological evaluation experiment to compare the visually immersive experience of the eyelid-movement input method with that of a mouse input method as a conventional common input method. We measured skin conductance (SC) of a subject's hand and blood-volume pulse (BVP) on a subject's finger and analyzing them. The reason is that physiological data continuously and objectively reflect emotions of users (subjects) who are experiencing an immersive virtual environment.

4.1 Experimental Task

The experimental task is to read a word and say it in the air in front of the subject and on the road under the subject's foot from the edge of the top of a tall building in a 3D virtual environment. The subjects perform the task by using our system or a mouse while wearing the HMD for a first person's view with head tracking. Figure 4 illustrates the task. A subject stands at the edge of the top of a tall building in a virtual environment. First, the subject reads a word and says it on the road after looking down at the road by bending his/her neck down and zooming in on the word (for example, Figure 4 shows gHelloh). We set the font size of the word to small so that it is impossible for the subjects to read it without zooming it in. Next, the subject reads a word and says it in the air in front of him/her by raising his/her head (for example, Figure 4 shows gvirtualh). After that, the subject reads another word and says it on the road again by zooming it in. The subject repeats the task for five words.

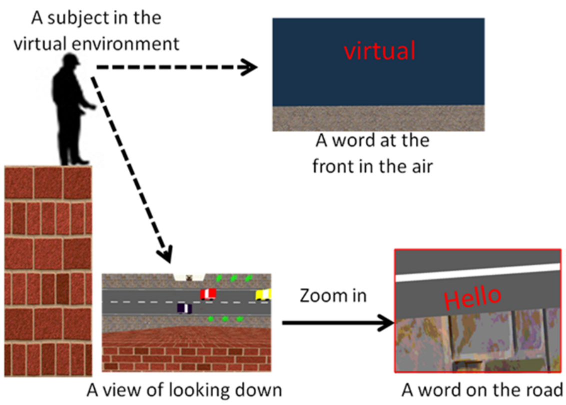

Figure 4: Schematic representation of the experimental task.

We set the task of reading a word from a high altitude because we could provide the subjects with a fear of the open high place in the 3D virtual environment, and hypothesize that the more immersive feelings a subject had, the more he/she would experience a fear of the place. For the purpose of the more immersive experience, we asked the subjects to stand at the edge of the board that was approximately 4 cm thick (Figure 5).

Figure 5: State of standing on a board to provide the subject with the feeling of standing on the edge of a building.

4.2 Procedure

We covered the HMD with a black thick cloth to block natural light from entering between the HMD and the subject's face, because the light in the real world decreases the subject's immersive feelings in a virtual world.

All subjects performed the task once using each method (within subjects); the eyelid-movement input method and a mouse input method. For the mouse input method, a subject held a mouse on his/her thigh while standing on the board. The left click button was used to zoom in and the right click button was used to zoom out. To avoid an ordering effect between the two methods, half of the subjects performed the task of eyelid movements first and the other half performed the task of mouse clicking first.

The subjects practiced how to use each of the methods for approximately 1 min before they started to perform the task by using the assigned method. During practice, the subjects confirmed the head-tracking function of the HMD and how to zoom in and out by standing on the ground in the virtual environment, not by standing on the top of a building. The subjects performed the experimental task at the rate of approximately 2 min per method. We recorded the subject's physiological data of the time in order to validate the differences in the physiological data of a heightened sense of fear of the high place between the eyelid-movement input method and the mouse input method. We assumed these differences to reflect the differences in immersive feelings between the input methods.

After completing the tasks, the subjects answered a questionnaire consisting of five-point scale pair comparisons about the differences they perceived between the input methods. Table 1 shows the questionnaire.

4.3 Measurement of Physiological Data

We analyzed how the subjects immersed in the virtual environment when using each of the methods by measuring the skin conductance (SC) of a subject's hand and the blood-volume pulse (BVP) on a subject's finger (Figure 6) with a ProComp infiniti encoder. We measured the physiological data because they are known to increase according to the degree of tension of the fear of high place (Meehan et al., 2002) and to estimating arousal and valence levels of emotions (Soleymani et al., 2008), (Lin et al., 2005). We recorded the SC and the BVP of a subject during practice and the experimental tasks, and calculated the differences of the average of the data between practice and the tasks. We hypothesized that the differences of the average between the practice and the experimental task with the eyelid-movement input method is more than that between the practice and the mouse input method, because the subjects experienced the fear of high place by the eyelid-movement method to a larger extent than that by the mouse method. We think the high embodiment of the eyelid movements makes feel more immersive to the user.

Table 1: Questionnaire for user's experience.

Questions and indexes
Q1DFor which did you feel more immersive impression? 1:mouse ——— 5: eyelid movement
Q2DFor which did you become more aware? 1:mouse ——— 5: eyelid movement
Q3DWhich was more intuitive? 1:mouse ——— 5: eyelid movement
Q4DWhich was easier to control as intended? 1:mouse ——— 5: eyelid movement
Q5DFor which did you feel more tired? 1:mouse ——— 5: eyelid movement
Q6DWhich do you like to use? 1:mouse ——— 5: eyelid movement

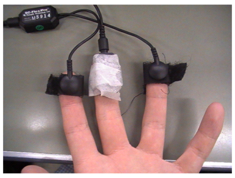

Figure 6: State of attaching an SC sensor and a BVP sensor.

4.4 Results

Ten subjects (men aged between 21 and 25 years old) participated in the experiment. Figure 7 shows a box plot of the average differences of SC between the practice (on the ground) and the experiment (at the top of the building) in each of the input methods (mouse input and eyelid movement), and Figure 8 shows a box plot of the average differences of the number of BVP pulses between the practice and the experiment in each of the input methods. On the basis of the results, we observe a significant difference in SC between the input methods (ANOVA, $F = 5.130, df = 1/9, p < 0.1$). Therefore, we find that the SC of the eyelid-movement input method is significantly higher than that of the mouse input method. In addition, there is a significant difference in the BVP between the input methods (ANOVA, $F = 3.943, df = 1/9, p < 0.05$). Therefore, we also find that the number of BVP pulses of the eyelid-movement input method is significantly higher than that of the mouse input method.

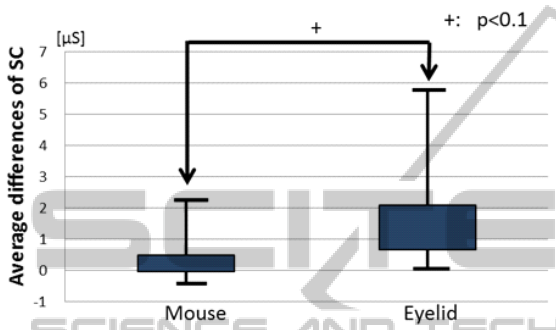

Figure 7: Average differences of SC of the input methods.

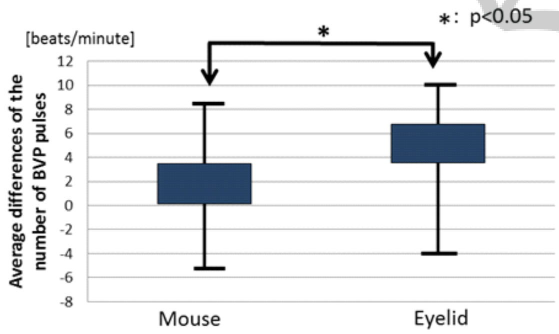

Figure 8: Average differences of the number of BVP pulses of the input methods.

As observed from the typical signals of SC in both methods (Figures 9 and 10), the values of SC of most of the subjects increased soon after the subject saw the high altitude. Then, the values gradually decreased. However, in the eyelid-movement input method, there were typically some waves on the SC signals (Figures 9). The solid perpendicular lines of Figure 9 and Figure 10 show start and finish of the task.

Figure 11 shows the averages and the standard deviations of the answers to the questionnaire (Table 1). In terms of results, we find the subjects considered that the eyelid-movement input method is more immersive than the mouse input method (Q1). Also, they considered the eyelid-movement input method is intuitive (Q3) because of marginal awareness of the boundary between the real and virtual worlds (Q2); they also would like to use it again (Q6). However,

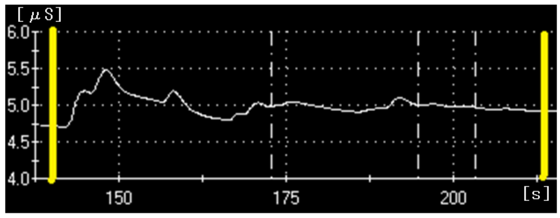

Figure 9: Typical SC signals in eyelid-movement input method.

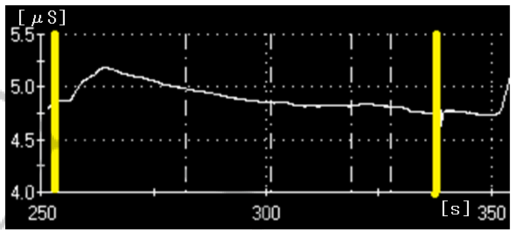

Figure 10: Typical SC signals in mouse input method.

they observed that it was not as controllable as intended (Q4), and they felt tired by using it (Q5).

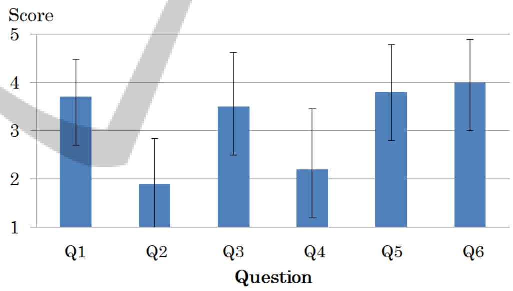

Figure 11: Average and SD scores of the answers.

4.5 Discussion

Based on the results, our proposed eyelid-movement input method improves the users' immersive experiences more effectively than the mouse input method. We find that the eyelid-movement input method has a significant fear effect on the users' immersive experience because of the increase in SC and BVP pulses. Additionally, the differences of the physiological data between the eyelid-movement input method and the mouse input method denote the same tendency of the results of the questionnaire. We think that the physiological data show not only the differences but also the time series variation of subjects' sense of fear. Therefore, we consider that the waves of the SC in eyelid-movement input method (Figure 9) show the noticeable changes in the sense of fear with the physical and intuitive operation. We also consider that this is due to the fact that the eyelid-movement input is associated with the act of looking at something, but the mouse input is not associated with any such act. Therefore, the subjects performed the task intuitively, without being aware of the boundary between the real and virtual worlds, and immersed themselves in the virtual world.

On the other hand, based on the results of the questionnaire, the eyelid-movement input did not perform as the users intended a few times, as compared with the mouse input, and imposed a physical load on the subjects. We consider that this is due to the fact that the system failed to recognize some eyelid movements a few times, although the system recognized all the mouse clicks correctly. Actually, some subjects experienced cognitive loads because of recognition errors between the zoom-in and zoom-out movements, and some subjects experienced physical loads, because a user of the eyelid-movement input method was required to maintain a state, such as wide opening of the eyelids. In addition, the average time to complete the task by using the mouse input was 83 s, which was shorter than the time of the eyelid-movement input, which was 160 s. For these reasons, we have improved the recognition algorithm to recognize each eyelid movement more accuracy, and we have enhanced the system to recognize not only the three types of eyelid movements but also multi-degrees of eyelid state based on the present three states.

5 IMPROVEMENT

We improved the recognition algorithm by adapting an algorithm to remove outliers of EMG data because there had been a lot of variation in the EMG data. We have used the Smirnov-Grubbs' test that detects outliers ($p < 0.05$) not included a normal distribution of recorded EMG data, removes them and repeats the detection and the remove until an outlier is undetectable. Expression (1) shows the Smirnov-Grubbs' test.

$$T = \frac{|X_{max} - \overline{X}|}{\sqrt{U}} \tag{1}$$

where $\overline{X}$ is mean of data, X_{max} is the farthest value from $\overline{X}$, U is dispersion and T is test statistic. If a value is less than T, the value is an outlier.

We conducted an experiment to verify the recognition rate of the improved system. Ten subjects (eight men and two women, aged between 21 and 22 years old) participated in the experiment. They did three types of eyelid movements ten times each type in a random order (within-subjects design) by using the conventional system and the improved system.

Table 2: Recognition rates of the three states of the conventional system (%).

	Neutral	Staring	Widly-Opening
Average	82.0	78.0	84.0
SD	14.0	24.4	20.0

Table 3: Recognition rates of the three states of the improved system (%).

	Neutral	Staring	Widely-Opening
Average	90.0	90.0	92.0
SD	7.7	8.9	8.7

Table 3 and table 4 show the recognition rates of each movement of each system. The average recognition rate of the conventional system is 80 % and that of the improved system is 90 %. Additionally, the deviation of the improved system is smaller than that of the conventional system. We therefore find that the improved system is more accuracy than the conventional system.

Moreover, we enhanced the number of states to recognize eyelid movements from three types to five types; strongly staring, softly staring, neutral, softly opening, and widely-opening (see figure 12). As the result of verifying the recognition rates of the five movements like the experiment described above, table 4 shows the recognition rates of the five types (within-subjects design) of ten subjects (eight men and two women, aged between 21 and 22 years old). The rate of the softly staring and the rate of the softly-opening are lower than other rates.

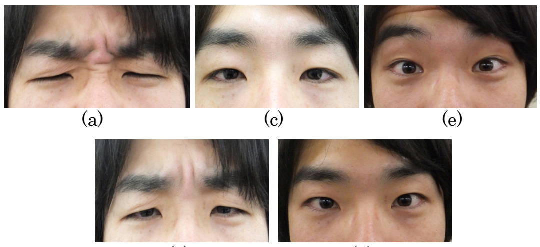

Figure 12: Three states of eyelid movements: (a) strongly staring, (b) softly staring, (c) neutral, (d) softly opening, and (e) widely-opening.

6 CONCLUSIONS

We conducted an experiment to compare our proposed method with the mouse input method by measuring the subjects' physiological data of the fear of the open high place in the virtual environment. On the

Table 4: Recognition rates of the three states of the improved system (%).

	Neutral	Strongly-staring	Softly-staring	Widely-Opening	Softly-opening
Average	93.0	91.0	81.0	94.0	74.0
SD	6.4	7.0	9.4	6.6	6.6

basis of the results, we find that the eyelid-movement input method improves the user's immersive impression more significantly than the mouse input method. Therefore, we conclude that it is important to immerse an input method in an immersive virtual environment because the user can use it intuitively and does not have to be concerned about the seam between the real and the virtual worlds. We also conclude that physiological data are useful in continuously and objectively evaluating usability of an input method.

For future work, we plan to further improve the user's immersive experience by applying real-world embodiment movements and emotions estimated from a user's physiological data, such as EMG, SC, BVP, brain waves and cerebral blood flow.

REFERENCES

Agustin, J. S., Hansen, J. P., Hansen, D. W., and Skovsgaard, H. H. T. (2009). Low-cost gaze pointing and emg clicking. chi extended abstracts. *CHI Extended Abstracts 2009*, pages 3247–3252.

Asai, K., Osawa, N., Sugimoto, Y., and Tanaka, Y. (2002). Viewpoint motion control by body position in immersive projection display. *Proc. of SAC2002*, pages 1074–1079.

Costanza, E., Inverso, S. A., Allen, R., and Maes, P. (2007). Intimate interfaces in action: assessing the usability and subtlety of emg-based motionless gestures. *Proc. of CHI 2007*, pages 819–828.

Gibert, G., Pruzinec, M., Schultz, T., and Stevens, C. (2009). Enhancement of human computer interaction with facial electromyographic sensors. *Proc. of OZCHI 2009*, pages 421–424.

Haffegee, A., Alexandrov, V. N., and Barrow, R. (2007). Eye tracking and gaze vector calculation within immersive virtual environments. *Proc. of VRSTACM*, pages 225–226.

Jr., F. C., Nguyen, D., Guerra-Filho, G., and Huber, M. (2010). Identification of static and dynamic muscle activation patterns for intuitive human/computer interfaces. *Proc. of PETRA 2010*.

Kikuya, K., Hara, S., Shinzato, Y., Ijichi, K., Abe, H., Matsuno, T., Shikata, K., and Ohshima, T. (2011). Hyakki men: Development of a mixed reality attraction with gestural user interface. *INTERACTION 2011*, 2011(3):469–472.

Lin, T., Hu, W., Omata, M., and Imamiya, A. (2005). Do physiological data relate to traditional usability indexes? *Proc. of OZCHI '05*.

Manabe, T., Tamura, H., and Tanno, K. (2009). The control experiments of the electric wheelchair using s-emg of facial muscles. *Proc. FIT2009*, pages 541–542.

Manders, C., Farbiz, F., Tang, K. Y., Yuan, M., Chong, B., and Chua, G. G. (2008). Interacting with 3d objects in a virtual environment using an intuitive gesture system. *Proc. of VRCAI08*.

Meehan, M., Insko, B., Whitton, M., and Brooks, F. P. (2002). Physiological measures of presence in stressful virtual environments. *ACM Trans. Graph. In SIGGRAPH '02*, 21(3):645–652.

Miyashita, H., Hayashi, M., and ichi Okada, K. (2008). Implementation of eog-based gaze estimation in hmd with head-tracker. *Proc. of ICAT2008*, pages 20–27.

Nagahara, H., Yagi, Y., and Yachida, M. (2005). A wide-field-of-view catadioptrical head-mounted display. *Electronics and Communications in Japan*, J88-D-II(1):95–104.

Oshita, M. (2006). Motion-capture-based avatar control framework in third-person view virtual environments. *Proc. of ACE '06*.

Ries, B., Interrante, V., Kaeding, M., and Anderson, L. (2008). The effect of self-embodiment on distance perception in immersive virtual environments. *Proc. of VRST 2008*, 15(5):167–170.

Soleymani, M., Chanel, G., Kierkels, J. J. M., and Pun, T. (2008). Affective ranking of movie scenes using physiological signals and content analysis. *Proc. of MSACM*, pages 32–39.

Steinicke, F., Bruder, G., Hinrichs, K. H., and Steed, A. (2009). Presence-enhancing real walking user interface for first-person video games. *Proc. of ACM SIGGRAPH Symposium on Video Games*, pages 111–118.

TheAuthors (2011). *****. *****.

Touyama, H., Hirota, K., and Hirose, M. (2006). Implementation of electromyogram interface in cabin immersive multiscreen display. *Proc. of IEEE Virtual Reality 2006*, pages 273–276.

Valstar, M., Pantic, M., Ambadar, Z., and Cohn, J. F. (2006). Spontaneous vs. posed facial behavior: Automatic analysis of brow actions. *Proc. of ICMI '06*, pages 162–170.