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Virtual Reality Environment Design of Managing Both Presence and Virtual Reality Sickness

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Abstract It is difficult to design the Virtual Reality (VR) Environment which controls VR sickness and promotes presence. This is because the relationship between the user's susceptibility to VR sickness and a sense of presence, determined by velocity and visual angle of the visual information, involves a trade-off between the two. Then we propose the optimal value search system which computes efficiently the velocity and visual angle which control VR sickness and do not impair presence by taking account of a subject's characteristic. Under certain experimental conditions, some subjects showed serious VR sickness whose simulator sickness questionnaire total score was more than 60 and needed more than 30 minutes to recover from VR sickness. However, on the condition of angular velocity and visual angle computed by our proposed method, all subjects felt their vection, which was our index for the sense of presence, over 70 percent of their experiment time; no subject needed more than 5 minutes to recover from VR sickness. *J Physiol Anthropol Appl Human Sci 23(6): 313–317, 2004* http://www.jstage.jst.go.jp/browse/jpa

Keywords: virtual reality environment, vection, virtual reality sickness, presence, neural network

Introduction

Recently, virtual reality (VR) environments have become ubiquitous in many fields. Entertainment, manufacture, education, welfare and others are examples of such fields. VR environments have come to be used by various people, for various purposes, in various settings. When VR environments are not used appropriately, however, it has been pointed out that they can damage the health of the user (VRART, 1999).

VR sickness is a typical example of one such damage to health. The symptoms of VR sickness are headache, vertigo, nausea, etc. In the future, some countermeasure to limit VR sickness will be demanded for VR environment design. Because it has been pointed out that VR sickness is closely related to people's spatial cognitive capability, this will be particularly critical as VR environment use expands to children and senior citizens, who have weak spatial cognitive capability. (Yanagida, 1986; Nakagawa et al., 1998)

It is widely considered that the primary factor causing VR sickness is a physical law inconsistency between the visual, vestibular and peculiar information provided by the VR environment to imply movement. We think that the velocity and visual angle of the visual information parameters influence the awareness of this inconsistency. Moreover, we think that these parameters also influence a sense of presence and that the development of VR sickness and the production of sense of presence represent a trade-off for these parameters. Namely, there is a possibility that if priority is given to the promotion of a sense of presence in visual information design, VR sickness will develop, and if priority is given to the control of VR sickness in visual information design, sense of presence will be impaired.

In this research, we choose the yaw axial rotation, designating the zenith axis as the axis of rotation, to express movement. Then we propose an optimal value search system which computes efficiently the angular velocity and visual angle which limit VR sickness without impairing sense of presence as much as possible, taking into account the subject's characteristics.

Proposed System

System design involves the following three problems:

Problem I: The relationship between the VR sickness characteristic and the sense of presence characteristic for angular velocity and visual angle is a trade-off.

Problem II: There is an individual difference in the VR sickness characteristic and the sense of presence characteristic for angular velocity and visual angle.

Problem III: There is the risk adjusting a VR environment to find a satisfactory compromise between the VR sickness and sense of presence may constitute a heavy load for the user.

In particular, since a user's VR sickness characteristic is not known at the time, there is the risk of making a user develop serious VR sickness. Moreover if the number of subjective evaluations for investigating the characteristics increases, the possibility that VR sickness will develop becomes even higher due to the accumulation of fatigue.

In other words, for the proposed system, a mechanism for overcoming these problems is required.

The outline of this optimum value search system is shown in Fig. 1. This system computes optimum values by competing Neural Network I (NN-I), in which the user's VR sickness characteristic is reflected, with Neural Network II (NN-II), in which the user's sense of presence characteristic is reflected. In this system, the Simulator Sickness Questionnaire Total Score (SSQ TS) is used as a standard of the VR sickness characteristic. SSQ is a type of subjective evaluation method which evaluates simulator sickness (Kennedy et al., 1994). Vection occurrence rate (VOR) is used as a standard for the sense of presence characteristic. VOR is the ratio of the time during which the user experienced vection to the total exposure time. Vection is the illusion of the movement which is induced purely through visual stimulation.

NN-I is a back-propagation type neural network which consists of 2-inputs, 2-hidden layers and 1-output (2-2-1 BP type NN) (Hirano, 1991). NN-I reflects the user's VR sickness characteristic by learning to use the training data I. NN-I outputs an estimated SSQ TS for each input angular velocity and visual angle across the search range. Training data I consists of data for specific angular velocities, visual angles and the SSQ TSs which are estimated by NN-III for those angular velocities and visual angles. NN-III is an aggregate for the units produced by 2-2-1 BP type NNs. The number of NN-III units is decided by the number of Training data I conditions. After learning from training data III, each NN-III unit output SSQ TS estimated for each input average Excitation Velocity (A-EV) and the standard deviation Excitation Velocity (SD-EV) under assigned condition in Training data I. Excitation velocity (EV) is the minimum angular velocity which causes symptoms of VR Sickness to appear in an SSQ score. EV is measured by exposing the user to an image which begins at rest and then increases in an angular velocity with a fixed acceleration (User Test I). Training data III exists for each unit, so Training data III also is assigned each Training data I condition. Each Training data III is the data list which is enumerated A-EV, SD-EV and SSQ TSs of the subject showing this A-EV and this SD-EV in the past experiments, in order only for number of Training data I conditions.

NN-II is a 2-2-1 BP-type NN. NN-II reflects the user's sense of presence characteristic by learning from training data II. NN-II outputs the estimated VOR for each input angular velocity and visual angle across the search range. Training data II is the data list comprised of angular velocity, visual angle and VOR. The data in the list includes: the measurements from user test II; the maximum angular velocity and visual angle for which the VOR was 100%; linear interpolated angular velocity and visual angle values for a VOR of 50%; and angular velocities and viewing angles for which the VOR was clearly 0%. Vection disappearance angle (VDA) is the visual angle at which vection is no longer perceived, and it is measured by exposing the user to an image which rotates at a constant angular velocity, gradually decreasing the visual angle (User Test II).

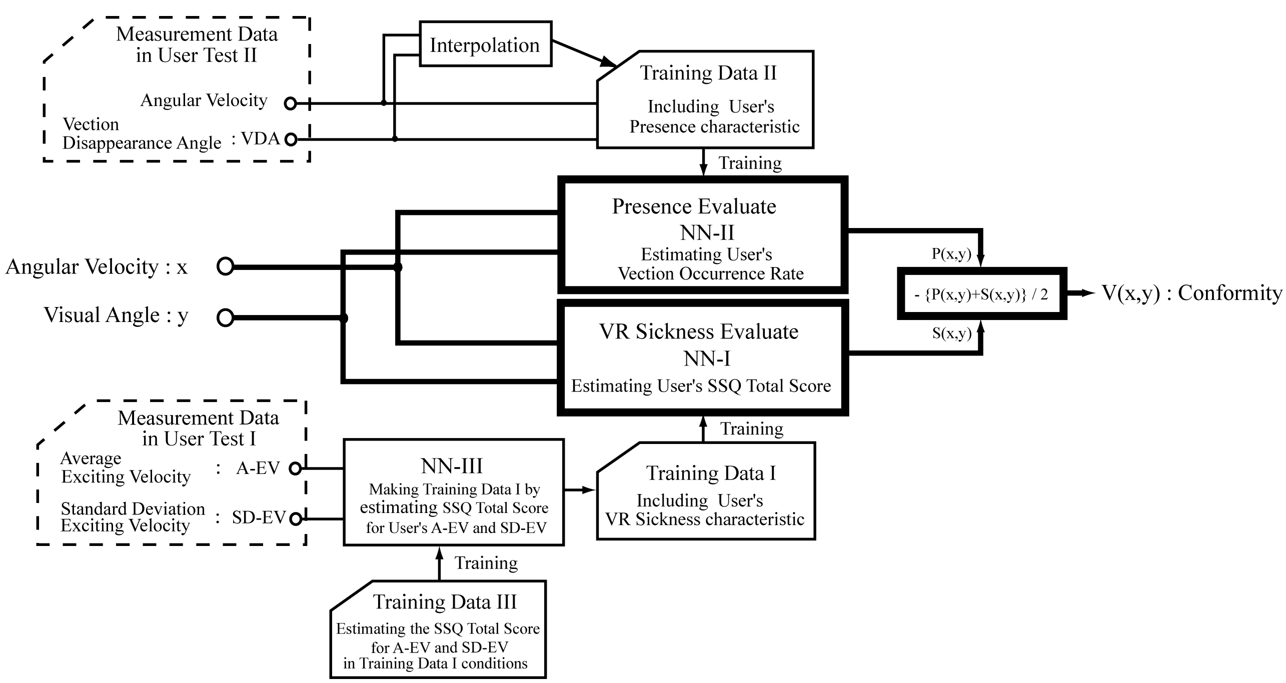

Fig. 1 Optimum value search system.

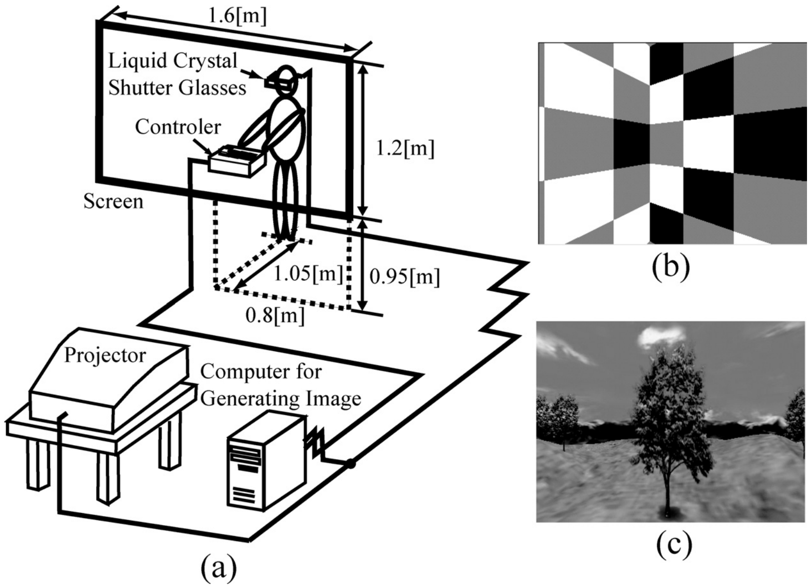

Fig. 2 Experimental setup and content. (a) Experimental setup. (b) Content A. (c) Content B.

Methods

Figure 1(a) shows the experimental setup. The subject wore liquid crystal shutter glasses (switch frequency: 110 [Hz]), had a two-handed controller for reporting during the experiment and stood in the Romberg standing position. A time division-type stereoscopic image was made by a computer for displaying the experimental image.

The scenes used for the experiment were of a virtual cube space (Fig. 2(b) Content A) which consisted of a wall that is covered with a checked pattern using white, black and gray color, and scenery (Fig. 2(c) Content B). Movement expression of the image was achieved along the yaw axis of rotation and the direction of rotation was counterclockwise.

The training data I and II used in this experiment are shown in Tables 2 and 3. Training data I was made for six conditions. For this reason, NN-III consisted of 6 units of 2-2-1 BP type NN. Training data III is measured data in the past experiments for the 12 subjects, excluding the subject of the current experiment, on six conditions of training data I.

14 subjects (9 males and 5 females, aged from 21 to 47 years) participated in this experiment. All subjects have normal eyesight and normal sense of equilibrium.

First, a subject was exposed to rotation around the yaw axis as specified by condition No. 1 in Table 1, once each for both Content A and B. The subject was instructed to push the controller's cross key forward if the subject experienced vection, backward if no vection was experienced, and to do nothing if he or she was unable to judge whether or not vection was occurring. A red sphere (visual angle size of 3 [°]) which appeared for 0.2 [s] and disappeared for 5 [s] or 10 [s], at random, in the center of the image was set. The subject was given the task of pushing a button on the controller if the sphere was recognized. Immediately following exposure, a subjective evaluation of VR sickness was conducted by collecting SSQ and free comments of subjects. Next, selecting between the two results the conditions which provoked the highest SSQ TS, the same experiment was executed under the remaining conditions listed in Table 1.

Table 1 Experimental conditions

No.	Angle velocity	Visual Angle
1	90 [°/s]	75 [°]
2	90 [°/s]	52.5 [°]
3	90 [°/s]	30 [°]
4	90 [°/s]	75 [°]
5	90 [°/s]	75 [°]

In the next stage, the subject was exposed to an image where the angular velocity increased 1 [°/s] from 0 [°/s], and excitation velocity was measured. The trial was repeated 5 times and the A-EV (average excitation velocity) and SD-EV (standard deviation of excitation velocity) were computed as the results of User Test I. Subjects were then exposed to an image where the visual angle decreased at 1 [°] per second from 75 [°] and the vection disappearance angle was measured. The trial was repeated 3 times for each angular velocity condition (90, 50, 10 [°/s]) to yield the results of User Test II. The results of both user tests were input into the system and the optimal value was computed for the search range (angular velocity: 0–120 [°/s], visual angle: 0–75 [°]). The same experiment as performed for Table 1 was executed again using these optimal values for the angular velocity and visual angle.

Table 2 Training data I

No.	x−I*1	y−I*2	SSQ Total Score
1	90 [°/s]	75 [°]	NN-III Unit-1 Output
2	90 [°/s]	52.5 [°]	NN-III Unit-2 Output
3	90 [°/s]	30 [°]	NN-III Unit-3 Output
4	90 [°/s]	75 [°]	NN-III Unit-4 Output
5	90 [°/s]	52.5 [°]	NN-III Unit-5 Output
6	90 [°/s]	75 [°]	NN-III Unit-6 Output

*1 Angular velocity *2 Visual angle

Table 3 Training data II

No.	x−II*1	y−II*2	VOR
1	90 [°/s]	DVA-1	0 [%]
2	50 [°/s]	DVA-2	0 [%]
3	10 [°/s]	DVA-3	0 [%]
4	120 [°/s]	75 [°]	100 [%]
5	120 [°/s]	0 [°]	0 [%]
6	60 [°/s]	0 [°]	0 [%]
7	0 [°/s]	0 [°]	0 [%]
8	0 [°/s]	75 [°]	0 [%]
9	0 [°/s]	37.5 [°]	0 [%]
10	interpolate by No. 1 and 4		50 [%]
11	interpolate by No. 2 and 4		50 [%]
12	interpolate by No. 3 and 4		50 [%]

*1 Angular velocity *2 Visual angle

Results and Discussion

Figure 3 shows the average of vection occurrence rate results for each condition, Fig. 4 shows the average of SSQ TS results for each condition, and Fig. 5 shows average time lag of reaction results for each condition. The reaction time lag is calculated by subtracting the average reaction time recorded during the first 60 seconds of the experiment from the average reaction time recorded during the final 60 seconds of the experiment. In each figure, (a) compares the results under constant visual angle conditions (75 [°]), (b) compares the results under constant angular velocity conditions (90 [°/s]) and (c) shows the results for the angular velocity and visual angle which were computed by the system.

Figure 3 and 4 show that as angular velocity and visual angle become large, SSQ TS and the Vection occurrence rate becomes high. From this result, it was confirmed that changing angular velocity and visual angle reveals the trade off between increased sense of presence and VR sickness. Under the No. 1 condition of Table 1, four subjects developed serious VR sickness whose SSQ TS was more than 60 and needed more than 30 minutes to recover from VR sickness. Moreover, in the case where the angular velocities and visual angles computed by this system were used, vection occurred in for about 80% (max: 89.6%, min: 70.2%) of the experiment time and the SSQ TS was limited to 25 or less—comparatively slight VR sickness. All subjects recovered from the VR sickness symptoms within 5 minutes. It was also discovered that the average reaction time lag becomes larger as angular velocity and visual angle become larger. Compared with the other results from the No. 1 condition of Table 1, the average reaction time lag was shortened by 1/3 or less by using the values output by our system. Subjects who complained that the reaction time lag task was difficult to complete after the exposure stopped complaining when system output values were used. It was therefore thought that the system was able to compute angular velocity and visual angle values such that users did not develop serious VR sickness while preserving the sense of presence as much as possible.

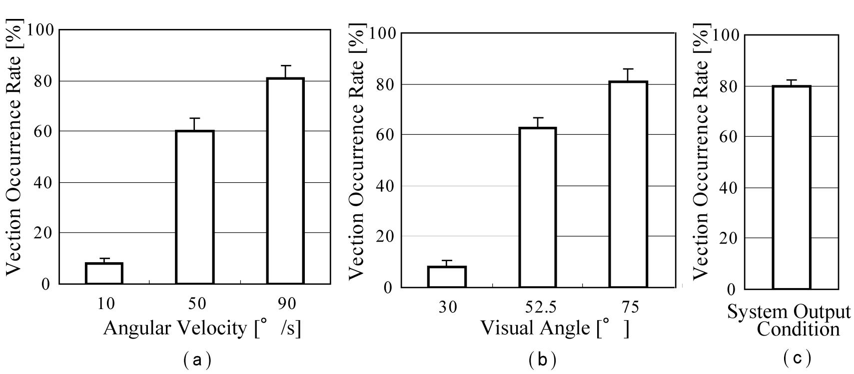

Fig. 3 Comparison of average (SD) of vection occurrence rate for constant angle, for constant angular velocity and for system output condition. (a) Visual angle constant (75 [°]). (b) Angular velocity constant (90 [°/s]). (c) System output condition.

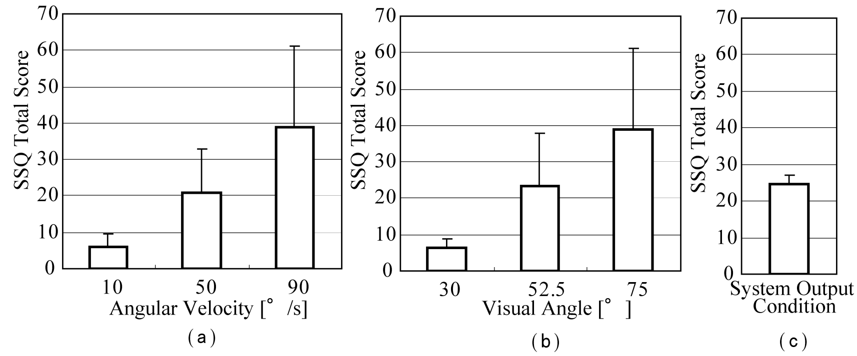

Fig. 4 Comparison of average (SD) of SSQ Total Score for constant angle, for constant angular velocity and for system output condition. (a) Visual angle constant (75[°]). (b) Angular velocity constant (90[°/s]). (c) System output condition.

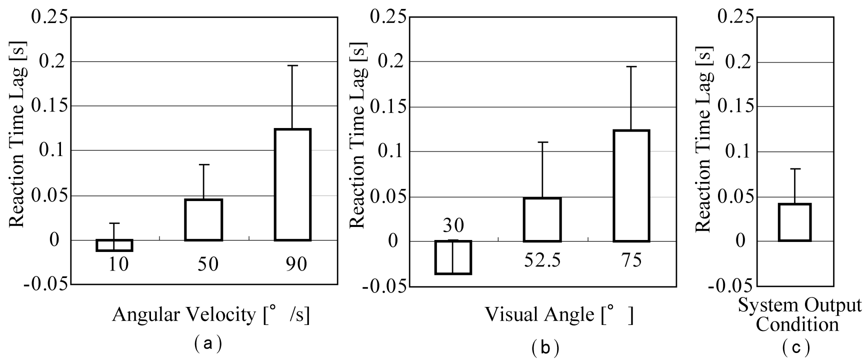

Fig. 5 Comparison of average (SD) of Reaction Time Lag for constant angle, for constant angular velocity and for system output condition. (a) Visual angle constant (75 [°]). (b) Angular velocity constant (90 [°/s]). (c) System output condition.

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