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AN IMPROVEMENT METHOD OF DEPTH PERCEPTION IN STEREOSCOPIC DISPLAY

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ABSTRACT

In development of virtual object designing systems for professional use, reality of the virtual object is strongly required from various aspects; its shape, color, size and position. Especially, for users, such as car interior designers, who want to examine and evaluate habitability in a narrow space surrounded by objects near at hand, accuracy in depth perception is the most important issue. However, it is difficult to perceive the true position of each virtual object only from binocular disparity in stereoscopic images, because of errors in the display system and no account of the other factors in human's depth perception.
This paper proposes a dynamic calibration technique to reduce the deviation between the computational depth and the perceived one of the virtual object. The calibration is performed by modifying dynamically the pupil distance (PD) parameter in stereoscopic display, according to changes of the object position and the distance to the screen. In the paper, first, the deviation between depths perceived for an actual object and the corresponding virtual one is investigated. Then, a model for calibration by modifying the PD is proposed based on the above results. Finally, this calibration model is implemented from the experimental results on many persons, and its performance is also evaluated.

1. INTRODUCTION

The technology of Virtual Reality (VR) is expected to reduce the design cost, which is comparatively expensive in the development of industry products. Still more, VR extends the possibility of the design work because it effectively examines products by computer graphics and enables sufficient number of trial and error of design processes in contrast to ordinal way with clay models or wood models which are expensive in costs and time. It also enables evaluation of habitability with virtual measures, which are difficult to realize in the real space. The design of the car interior is a suitable example for designing in the virtual space.

Improvement of precision of depth perception in stereoscopic display is a troublesome problem to solve in the development of such a design system, which demands precise representation in position and size of virtual objects. The perceived position in the stereoscopic display is caused the deviation from the just position calculated from coordinates of the model by multiple kinds of errors, that occur in the system of sensing and display and in processes of perception by human sight (Hatada, 1995a, Ishigure, 1996a, Kanatugu, 1996b, Morimoto, 1996c, Kurokawa, 1996d, Shibasaki, 1992, Simizu, 1995b, Yoshida, 1997). The latter of them makes the property of the deviation more complex because it may vary with the person.

In this paper, the deviation in depth perception that depends on each person is researched in detail under a standard experimental system including liquid crystal shuttered glasses and a large screen. Then a calibration of depth perception is implemented to reduce the deviation to sufficiently small one for design. As a result, the deviation is influenced by distances between eyes and the object, viewing directions to the screen, and distances between eyes and the screen. The pupil distance (PD) which gives binocular disparity is dynamically adjusted in generation of stereo images.

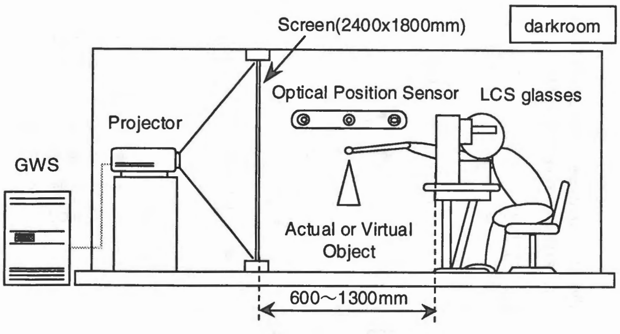

Fig.1 Configuration of Experimental System

Subject	frontal 400mm		frontal 800mm		20deg. 400mm		20deg. 800mm	
A	398.4	(0.787)	796.7	(0.488)	399.6	(0.535)	796.1	(1.676)
B	395.0	(1.528)	796.9	(0.690)	398.9	(0.378)	799.1	(0.900)
C	394.9	(0.900)	797.9	(3.237)	395.4	(1.272)	795.3	(1.976)
D	390.4	(0.787)	789.7	(0.756)	398.6	(1.134)	795.7	(1.113)
E	396.3	(0.951)	795.7	(2.563)	394.4	(0.976)	790.7	(2.928)
F	397.6	(1.512)	801.9	(1.676)	401.7	(0.951)	798.3	(1.496)
G	400.0	(0.577)	800.6	(1.618)	401.1	(1.069)	807.4	(1.718)
H	398.9	(1.069)	799.1	(0.900)	397.1	(0.900)	798.7	(1.254)
I	396.1	(0.690)	796.9	(1.069)	399.9	(1.069)	798.7	(0.756)
J	400.9	(0.690)	798.3	(1.890)	399.1	(1.069)	791.3	(1.604)
mean of above samples	396.8	(0.949)	797.4	(1.489)	398.6	(0.935)	797.1	(1.542)
standard deviation of above samples	3.027	(0.332)	3.281	(0.890)	2.325	(0.275)	4.692	(0.620)

(mm)

Tabel 1 Mean and standard deviation of perceived depth for each subject (actual objects)

Subject	frontal 400mm		frontal 800mm		20deg 400mm		20deg 800mm	
A	386.2	(1.915)	801.0	(1.113)	370.1	(2.289)	789.5	(3.024)
B	391.0	(3.934)	810.4	(7.712)	375.4	(1.272)	773.3	(3.266)
C	391.0	(0.900)	791.5	(2.268)	373.6	(0.756)	780.2	(1.345)
D	388.3	(0.900)	801.4	(3.132)	385.9	(1.826)	795.3	(3.606)
E	385.7	(7.743)	795.5	(1.864)	371.6	(0.756)	783.6	(4.152)
F	402.5	(2.628)	817.1	(4.220)	401.0	(1.676)	808.2	(1.952)
G	392.9	(1.676)	805.0	(2.690)	392.0	(3.338)	784.3	(5.228)
H	389.6	(2.440)	798.5	(3.934)	385.0	(7.010)	786.7	(2.637)
I	405.6	(1.215)	809.5	(4.112)	397.3	(2.878)	800.9	(5.062)
J	385.8	(2.440)	789.7	(2.360)	372.4	(1.134)	780.6	(2.360)
mean of above samples	391.9	(2.579)	802.0	(3.341)	382.4	(2.294)	788.3	(3.263)
standard deviation of above samples	6.896	(2.036)	8.696	(1.842)	11.411	(1.868)	10.510	(1.277)

(mm)

Tabel 2 Mean and standard deviation of perceived depth for each subject (virtual objects)

2. TENDENCY OF THE DEVIATION IN DEPTH PERCEPTION

2.1 Experimental system

Figure 1 shows the principle of the experimental system. A pair of stereoscopic images (resolution of 1024x768 pixel) is projected on the screen (size of 2400x1800mm) from the opposition to the viewer. We use a large and plane screen which fully covers the field of view and which is suitable for the general way of rendering. Liquid crystal shuttered glasses are synchronized for the alternate projection to each eye. The viewing volume, which is surrounded by each eye point and four corners of the screen, is projected on the screen to render objects accurately in a position and size (Cruz-Neira, 1993). In other words, stereo images have theoretically correct binocular disparity according to depth. An optical position sensor is used for sensing positions pointed by subjects for experiments without distortion occurred with magnetic one.

A cone (height 100mm, radius 25mm) is presented as the object and it is pointed at the top by the stick whose top is sharp. The deviation is measured as the difference between the pointed position and theoretical one calculated from coordinates of the object model. The virtual object is colored and shaded the same as actual one as much as possible. The whole of the display system is installed in a darkroom, and images mapped check pattern without binocular disparity is drawn on the screen as background.

2.2 Tendency different from actual object perception

Depth perception of virtual objects based on the action of pointing should be discussed in comparison with that of actual ones. At first, precision of actual ones is examined in four cases. A cone-shaped object is put on directly in front of the subject and in the 20 degrees deviated direction from frontal with two kinds of distance of 400mm and 800mm between eyes and the top of the cone. The head of the subject is fixed with the distance of 1300mm from the screen and the value of depth is given as an average of the trial of seven times in every case. A short rest time is taken between each trial to keep the independence of trials. Then it is examined for virtual ones in the same way as for actual ones.

PD of each subject for creation of stereoscopic images is measured by calipers under the condition that he presumes the distance of the infinity. It is kept through experiments that stereo glasses are attached to make a condition the same and that subjects are made to point above the top of cone with the distance of about 10mm to avoid feeling the sense of touch. Ten men and women of 21-36 ages are chosen as subjects after removing persons who are difficult to perceive depth.

Means and standard deviations of seven samples of measured depth are given for each person in Table 1 and Table 2, respectively for actual ones and for virtual ones. Note, values enclosed in parentheses indicate standard deviations. They say that considerable deviations, which are relatively greater than standard deviations, appear only in virtual object perception and they depend on each person.

2.3 Tendency against the change of the presented depth

To investigate the tendency of the deviation in virtual object

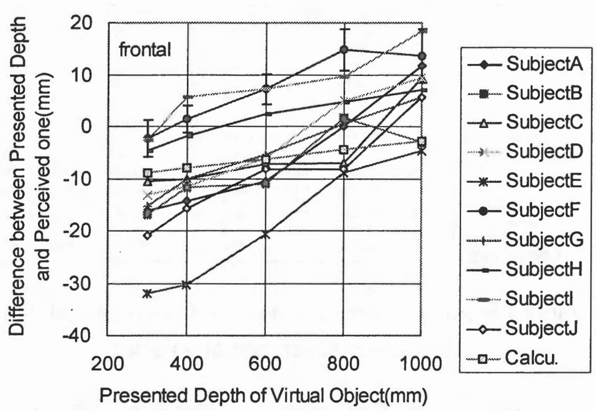

Fig.2 Difference between presented depth and perceived one (frontal)

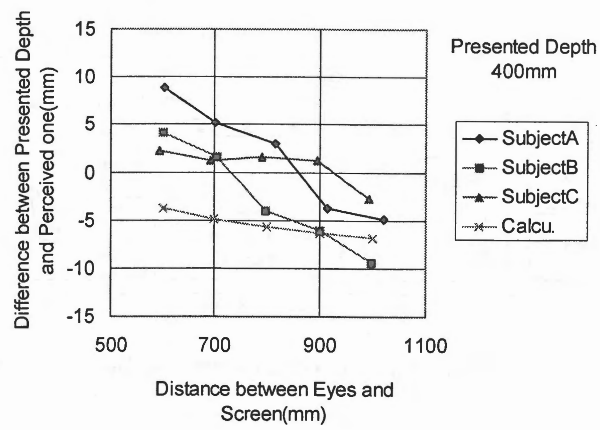

Fig.4 Transition of differences depending on distance between the eye position and the screen

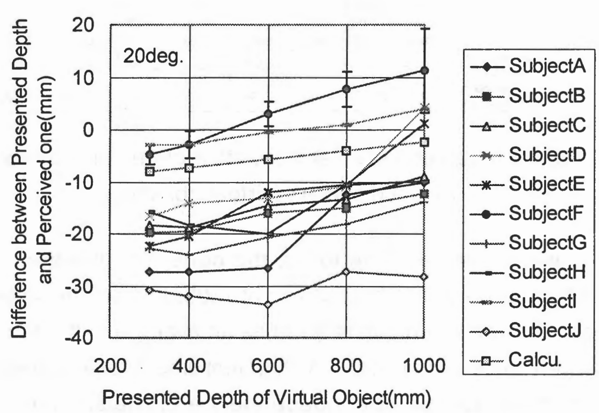

Fig.3 Difference between presented depth and perceived one (20deg. left from frontal)

perception in detail, it is measured at five kinds of depths of 300, 400, 600, 800 and 1000mm in the same way as subsection 2.2. But, seven times of presentation for each depth, which is 35 times in total, are executed at random.

Figure 2 and Figure 3 show the tendency of the deviation, respectively in front and in the 20 degrees deviate direction. Each point on the graph shows the difference between the mean of seven samples and the theoretical value. The standard deviation of each sample set is also indicated as the error bar for subject F. They show that the deviation is proportional to the depth and that a proportion constant and the basis point where the deviation becomes zero are different among subjects. And difference between Figure 2 and Figure 3 make it predict that perceived depths in deviated direction are biased to the front in the whole. In other words, the basis point is biased to the back.

Theoretical values of the deviation occurred by ignoring change of actual PD due to convergence are also indicated in Figure 2 and Figure 3 when PD is 65mm and eyeball radius is 12mm. However, they are too different from experimental results to be the main reason of the deviation though it improves the deviation.

2.4 Tendency against the change of the distance to the screen

Influence by the change in the distance between eyes and the screen is also important because it changes according to the movement of the eye position in the actual application. Five kinds of distances of 600, 700, 800, 900 and 1000mm are examined under the condition that the presented depth of the object is fixed to 400mm. It is measured eight times for each distance, that is 40 samples in total.

Figure 4 shows that the greater the distance to the screen is, the more the deviation biases toward front.

2.5 Possibility of improvement of the deviation

Above three kinds of experiments result is following tendencies.

1) Considerable deviations appear in virtual object perception compared with actual one, but they have possibility to be improved because standard deviations are intensively small to the absolute of them and they have linear relations to changes of the presented depth of the object and the distance to the screen.

2) Change of viewing direction also has some influence though the extent of change is comparatively small.

Here, our purpose is to investigate the structure of the deviation and to improve the deviation. It is also important to trace the occurrence factor of the deviation, but it is considered to be a difficult problem in the presence. Therefore, in the next section, the way of improvement of the deviation is implemented based on three kinds of parameters presented depth, distance to the screen and viewing direction.

3. IMPLEMENTATION OF IMPROVEMENT

3.1 Improvement by adjusting Pupil Distance

The pupil distance for rendering of stereoscopic images (PDR) is adjusted to improve the deviation here because PD has great correlation to binocular disparity. The suitable amount of adjustment of PDR is unified according to the presented depth and the distance to the screen. Actually derived relations between PDR and the deviation about subject A is shown in Figure 5 when the presented depth is fixed to 400mm, the distance to the screen is 800mm, and viewing direction is directly in front. Figure 6 shows adjusted PDR when presented depth is changed from 300mm to 600mm with the interval of 50mm. The mean of correlation coefficient of a linear regression for each presented depth is 0.93.

3.2 Structure of correction function

In Figure 2, 3, and 4, the relation of the deviation to each of three variables the presented depth, viewing direction and the distance to the screen is considered as linear fundamentally. And the error included each sample influences greater than the loss of linear approximation when the number of samples is small. Therefore, the correction function is defined as a simplest linear function here.

The correction function $f(x,s,\theta)$ which decides the amount of adjustment of PDR is given as:

$$f(x,s,\theta) = ax + bs + c\theta + d \qquad \text{......} \ (1)$$

Here, variable x means the presented depth of the object, variable θ is the deviation of the viewing direction from directly in front, and variable s is the distance between eyes and the screen.

3.3 Variables for correction function

It is not rational to get the samples in the all of combinations

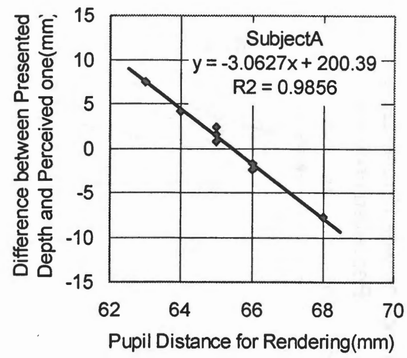

Fig.5 Difference depending on pupil distance

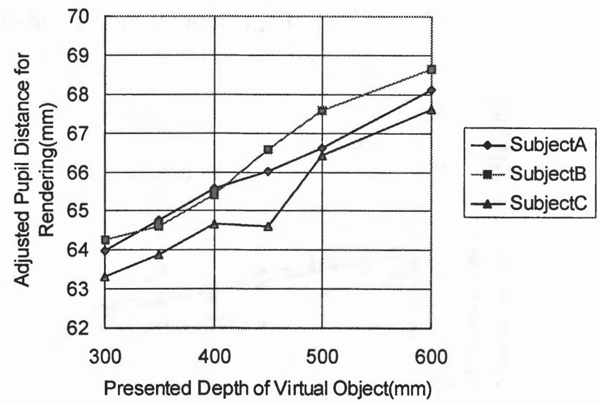

Fig.6Transition of pupil distance depending on presented depth

Subject	Correction Function
A	$f(x,s,\theta) = 0.0381x - 2.77\times10^{-5}\cdot x\cdot s + 1.56\times10^{-4}\cdot s - 0.046\theta + 60.15$
B	$f(x,s,\theta) = 0.0414x - 3.60\times10^{-5}\cdot x\cdot s + 1.13\times10^{-2}\cdot s - 0.329\theta + 51.22$
C	$f(x,s,\theta) = 0.0405x - 3.25\times10^{-5}\cdot x\cdot s + 3.35\times10^{-3}\cdot s - 0.035\theta + 56.33$

Tabel 3 Examples of correction function

of three kinds of variables because influence of variable s is smaller than that of variable x and influence of θ is far smaller than those of other variables. Therefore, the case of the combination of three kinds of variables x,s,θ is limited as follows:

$$\{(x,s,\theta)|x=x_1,x_2,....,n,s=s_1,s_2,\theta=0°\}$$

and

$$\{(x_m,s_1,\theta_1)|x_m \text{ is the central value of } x\}$$

As a result, the number of samples necessary to fix the function becomes 2n+1 if number n is the number of variation of variable x. The correction function is derived by the

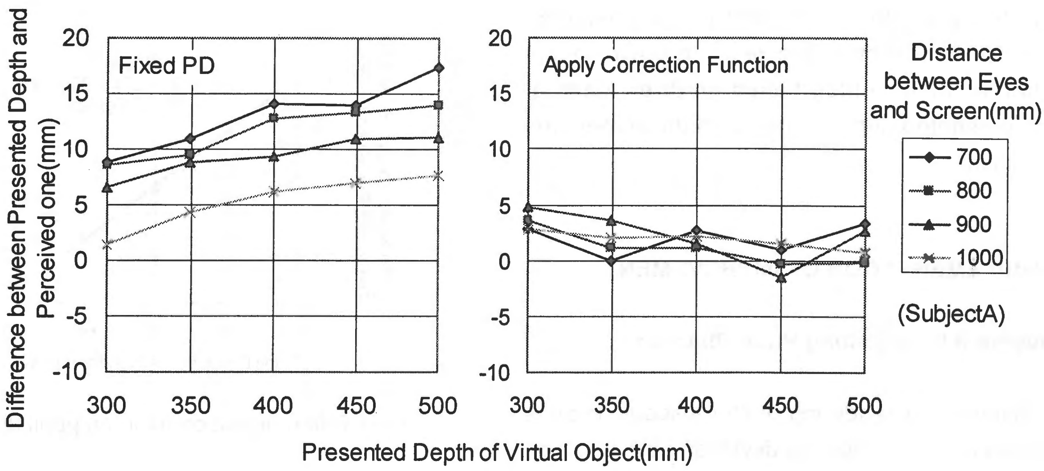

Fig.7 Improvement of difference by applying correction function

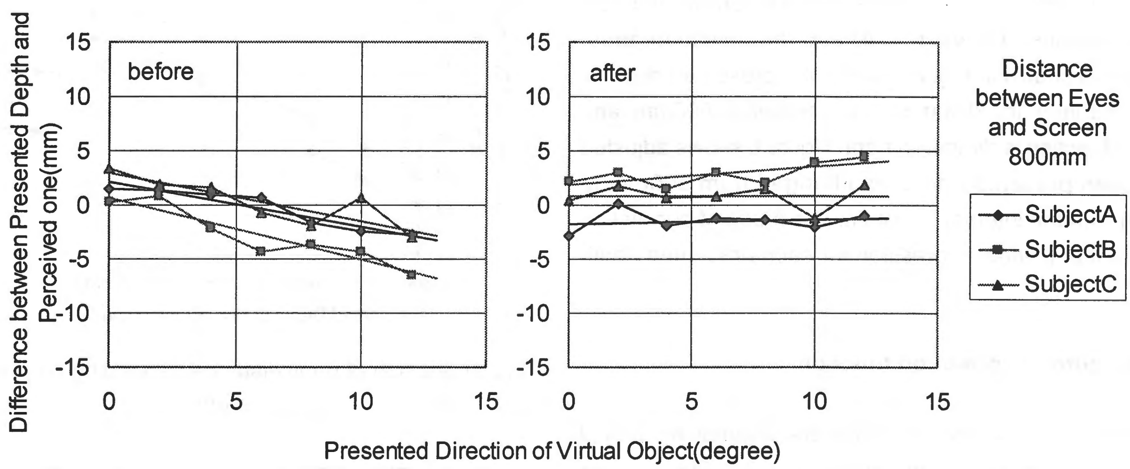

Fig.8 Effect of correction according to viewing direction

		SubjectA	SubjectB	SubjectC	Mean
Fixed PD	Mean absolute value	9.80	2.25	5.75	5.93
	Standard deviation	4.03	1.62	2.62	2.76
Apply correction function	Mean absolute value	2.16	1.84	3.46	2.49
	Standard deviation	1.60	1.27	1.76	1.54

(mm)

Tabel 4 Mean absolute value and standard deviation of a set of samples

	SubjectA	SubjectB	SubjectC
before	-0.449	-0.601	-0.394
after	-0.024	0.127	0.005

(mm)

Tabel 5 Improvement of slope in property of perception

following processes.

1) Find $f(x,s_1,0°)$ by a linear regression from samples at $s=s_1, \theta=0°$

2) Find $f(x,s_2,0°)$ at $s=s_2, \theta=0°$ in the same way.

3) Find $f(x,s,0°)$ by a linear interpolation between previous two equations.

4) Finally, Find $f(x,s,\theta)$ by adding bias, which is equal to the difference between $f(x_m,s_1,0°)$ and $f(x_m,s_1,\theta_1)$ in proportion to θ, to $f(x,s,0°)$

After they are fixed as following equations,

$$f(x,s_1,0°)=a_1x+b_1$$

$$f(x,s_2,0°)=a_2x+b_2$$

the correction function is obtained as equation(2).

$$f(x,s,\theta)=\frac{(a_2x+b_2)(s-s_1)-(a_1x+b_1)(s-s_2)}{(s_2-s_1)}+\frac{f(x_m,s_1,\theta_1)-f(x_m,s_1,0°)}{\theta_1}\theta \quad ...... (2)$$

After all, equation (2) is considered the one the clause of the product of x and s is added to Equation (1). The correction functions obtained about three subjects actually are shown in Table 3.

3.4 Experiments for verification

Two kinds of experiments are examined to verify the improvement.

As a first, effect of improvement against changes of presented depth and the distance to the screen is confirmed. Table 4 shows the whole result before and after improvement when presented depth is changed from 300mm to 500mm with the interval of 50mm, the distance to the screen is done from 700mm to 1000mm with the interval of 100mm and viewing direction is directly in front. The result for subject A is also shown in detail in Figure 7. Five samples are obtained on each case.

As a second, effect of considering θ in Table 3 is confirmed which has smaller influence than other parameters. Table 4 shows the whole result before and after improvement when presented depth is changed from 250mm to 650mm with the interval of 50mm, viewing direction is done to the downward from 4 degrees to 8 degrees and to the left from 0 degrees to 12 degrees with the interval of 2 degrees, and the distance to the screen is fixed to 800mm. The slope of equation obtained by a least squares method is collected as Table 5.

4. CONCLUSIONS

This paper proposed the technique to improve the deviation in depth perception of virtual objects based on adjustment of the pupil distance in rendering of stereoscopic images. Property of the deviation was examined in detail according to the change of the object presented depth and the distance between eyes and the screen. It was used for designing the correction function and the deviation was effectively improved from the small number of samples.

The improvement method will be expanded to be suitable for arbitrary presented depth and will be applied to perception of complex shaped objects in the future.

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