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Depth Perception Assessment for 3D Display Using Real Time Controllable Random Dot Stereogram

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Abstract

This paper proposes a method that can subjectively evaluate the actual depth range of 3D display. It presents the positive and negative depth of 3D display using visual stimulation images such as random dot stereogram (RDS). Develop a system that allows subjects to control the depth range of RDS images in real time to increase evaluation accuracy. Through this, the subject evaluates the clarity of the image form and the permissible level of recognition of the stereoscopic image in the depth range. We can finally determine the depth range of the 3D display using the acquired cognitive evaluation result. Finally, the depth enhancement according to the light field display (LFD) experimental conditions is quantified using a statistical analysis method called T-test. This experimental method can be a successful approach to developing a 3D stereoscopic evaluation system and producing 3D content that affects perceptual factors.

1. Introduction

3D Display shows a three-dimensional image that allows users to feel visual depth. The long history of stereoscopic images can be seen as reflecting human desire for more natural and realistic image expression than 2D image expression expressed in 2D display. Due to the recent development of virtual reality service devices such as VR, AR, and LFD in a non-contact. One of the important factors in determining high-quality stereoscopic images is the depth expression of stereoscopic images. In a device that implements an image, the depth range of the part where the shape of the three-dimensional model exists so close to the human eye and the part where it exists so far from the eye is also related to the human depth perception ability. The ability to perceive depth information is an essential function of the human vision. Correctly perceived and processed binocular information allows us to perceive the stereoscopic world [1]. Factors that people feel three-dimensionality by binocular information include physical factors such as binocular parallax, binocular convergence, motion parallax, and focus control, as well as psychological factors such as perspective, shadow effect, overlap, shielding, prior knowledge, and texture change. The 3D display is a display that stimulates a person's visual senses in the same way as real objects and provides physical factors to recognize them in three dimensions. A person has both left and right eyes at an average interval of 65mm, and each eye can be seen as a variable focus camera that rotates. Binocular convergence occurs when both eyes converge and observe according to the object being observed, and images of different images observed in the direction of each eye are formed on the retinas of both eyes, and when this difference information is interpreted as depth in the brain, binocular parallax is felt. At this time, each eye adjusts its focus according to the distance it is looking at, which is called the focus control of the single eye. In addition, four stereoscopic visual stimuli are performed according to the user's movement, including the motion parallax in which the other side of the object is observed. When looking at a real object, these four stimulating factors provide the same depth information to give a natural three-dimensional effect. Therefore, the ultimate goal of the 3D display can be seen as providing these four depth stimuli in the same way as real objects.

Various attempts have been made by ophthalmologists, optometrists and vision researchers for the assessment of stereo vision. Some of the most widely used tests are Frisby, TNO, Randot and Titmus [2]. However, most of the tests are based on two images with disparity between left eye and right eye to create the depth perception, this is not similar to the viewing condition in our daily life, where the view number is infinite. It is difficult to access stereopsis with real objects, due to the requirement of the precision, facilitation etc [3].

It is necessary to evaluate the depth of 3D stereoscopic images that reflect various stereoscopic perceptual factors of multi-view glasses-free 3D display similar to the viewing conditions of our daily lives with infinite views.

In this paper, a depth perception experiment was conducted to evaluate the expressive depth range of 3D display. For stereo depth perception evaluation, the size of dot and the position arrangement of dot were randomly produced for RDS images widely used in vision evaluation. In addition, a system was developed in which the subject can directly control the location of the depth in real time without producing the RDS image for each specific depth. While the subject controls the RDS image in real time, the area that comes close to the eyes based on zero depth on the display plane is set to positive depth, and the area away from the eyes is set to negative depth. In this depth environment, the subject was allowed to select a range in which the RDS image was clearly felt and a range acceptable as a stereoscopic image. The data of the last derived subjects were classified and the depth range of the 3D display was determined. The subjects set the ratio of experts and non-experts at 5:5, and the experiment was conducted by dividing them into men and women in their 20s and 50s.

2. Experimental setup

Real-time cognitive depth experiments using RDS images are conducted in the order of RDS image production, image control tool development, depth numerical calibration of displays and tools, cognitive depth experiments, data classification, and result derivation. In Fig. 1, the depth range that a person can experience in a 3D environment is set to positive and negative depth, respectively, and within that range, the clear level of dot shape and the acceptable level of stereoscopic image are found. This experiment allows the subject to directly select the depth range performance of the product by installing a tool that can control the depth in real time on a PC including a 3D display. The accuracy of the experiment may increase because it is a method in which the subject directly controls the depth image compared to the experimental method of producing each image for each specific depth distance and showing it to the subject.

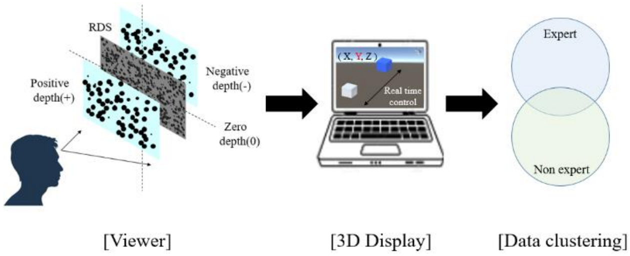


Figure 1. *Evaluation system concept*

2.1 RDS image production

The RDS image was produced in consideration of the background gradation, the gradation of the circle, and the size of the dot. In the 3D LFD, the moiré phenomenon occurs due to the overlap between the display panel and the lens. Since the level of clarity of dot was selected as the factor that determines the depth perception experiment, it is necessary to remove external factors such as moiré. In order to avoid the moiré phenomenon to the maximum, the gradation of the image background and circle was selected. The background was reflected in 128bit gray and the circle in 0bit black gradation. Compared to the 255bit white grayscale environment, the moiré phenomenon is less recognized. In addition, it was reflected in two ways to see the influence of dot size. The RDS image produced in Fig. 2(a) is produced in four configurations and randomly shown to the subject. Fig. 2(b), Fig. 2(c), and Fig. 2(d) show image differences according to dot sharpness per depth. Fig. 2(b) is the image of the most perceptually clear dot. Only the lens shape is found in the background, but noise such as blur does not occur around the dot. Fig. 2(c) is a perceptually acceptable dot form, although the sharpness decreases compared to Fig. 2(b). Some blur forms occur around dot, but they are not perceptually annoying to the eyes. Fig. 2(d) is the form of dot with the most reduced clarity. The black area of the dot is also blurred, and the surrounding blur is also generated significantly. Perceptually, it is difficult to recognize the form of dot. The clarity and acceptable level of depth are evaluated by distinguishing the form of dot that feels perceptual to the subjects.

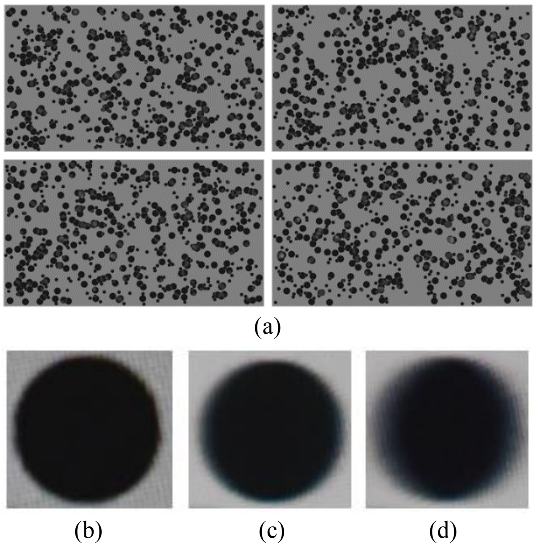


Figure 2. *RDS Image; (a) Random dot image configuration, (b) Perceptually clear dot, (c) Perceptually permissible dot, (d) Perceptually impermissible dot*

2.2 Depth control tool setup

The unity program was used to reflect the produced RDS image in the depth control tool. In the unity program, 3D mapping images synthesized through virtual camera placement at each point in time are operated in real time. The Y-axis, which means the depth distance of this 3D RDS image, can be controlled up to the four-digit position of the decimal point. To determine the Y-axis value of the unity program, calibration is required to match the actual depth distance value of the LFD.

Fig. 3 shows the depth calibration of LFD. After driving the RDS image in a specific depth area with the LFD, place the arrow at the position of the dot that feels perceptual. At this time, the position of the arrow is measured from the panel position to the actual distance. Real distance is calculated for the Y value as shown in Equation 1.

$$\text{Real distance (mm)} = 1000 \times Y \quad (1)$$

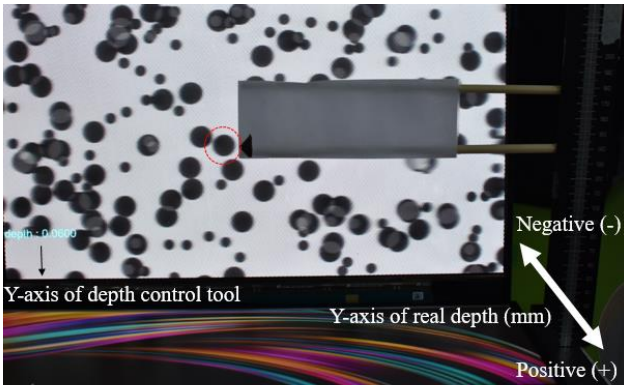


Figure 3. *LFD Calibration*

2.3 Perceptual experiment progress

Two LFDs were used for depth perception experiments. Table1 shows sample specifications with different 3D crosstalk performance for LFD products under the same conditions. Through the depth perception experiment, it is possible to confirm the depth expression effect according to the 3D crosstalk level.

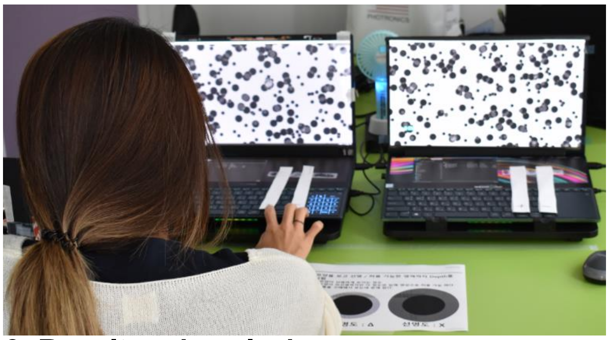
Table 1. Specification of LFD Samples

Specification	Sample1	Sample2
3D Type	Light field display	
Size (Inch)	15.6	
Resolution	3840 × 2160	
View numbers	34	
3D Crosstalk (%)	10	3

Fig. 4 shows the subject actually conducting a depth perception experiment of LFD. The subject can directly control the RDS image at the positive and negative depth positions. When the subject places the RDS image in the clear or allowable area, the Y value in the unity program is converted into the actual distance value and dataized.

The subjects were divided into two clusters. It was composed of a 5:5 ratio of expert clusters and general public clusters that participated in LFD development. In addition, the subject's age group was divided into each gender between 20s and 50s and the experiment was conducted.

Figure 4. *Depth perception experiment*



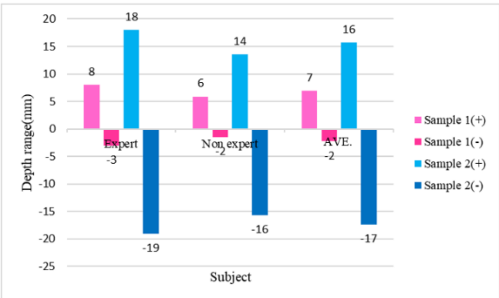
3. Result and analysis

The 3D depth perception experiment derived results based on the depth range judged by the actual subject's eyes.

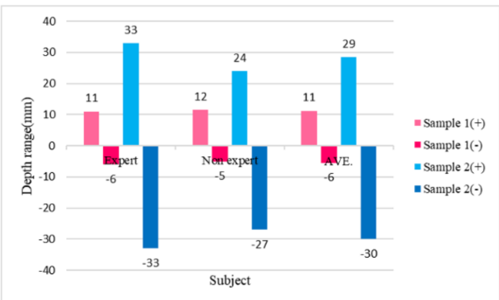
We quantitatively prove the 3D evaluation method through depth analysis for each sample by analyzing the data statistical results of the T-test using the actual depth perception experiment results, deriving the correlation between 3D depth and crosstalk, and checking the clarity through 3D depth images

3.1 Measurement result

The results of the depth perception experiment were divided into a clear range and an acceptable range. Fig. 5 (a) shows the perceptually clear depth range for each sample. For experts, the depth range was selected from +8mm to -3mm in sample1. Depth range was selected from +18mm to -19mm in sample2. For non-experts, the depth range was selected from +6mm to -2mm in sample1. Sample 2 was selected from +14mm to -16mm. For the average of the two groups, the depth range was selected from +7mm to -2mm in sample1. Sample 2 was selected from +16mm to -17mm.



(a)



(b)

Figure 5. *Comparison of evaluation results for 3D Depth perception; (a) Perceptually clear depth range, (b) Perceptually permissible depth range.*

Fig. 5 (b) shows the perceptually permissible depth range for each sample. For experts, the depth range was selected from +11mm to -6mm in Sample1. Depth range was selected from +33mm to -33mm in Sample2. For non-experts, the depth range was selected from +12mm to -5mm in sample1. Sample 2 was selected from +24mm to -27mm. For the average of the two groups, the depth range was selected from +11mm to -6mm in sample1. Sample 2 was selected from +29mm to -30mm.

The standard deviation of the two groups was 0.009 in experts and 0.014 in non-experts. Since there was less standard deviation in the expert group compared to non-experts and the non-expert selection range was included within the expert selection range, the total depth range was selected as the expert selection range.

3.2 T-test analysis

T-test is a typical statistical analysis method, which uses T-distribution theory to infer the probability of difference, so as to compare whether the difference between two groups of data is significant [4].

Specifically, in statistics, if the p-value(i.e. the probability that there is no significant difference between the two groups) calculated by T-test is 0.05, it means that there is 95% confidence that there is a difference between the two groups of results, which is generally used as the boundary between significance and non-significance. Therefore, if the p-value is greater than 0.05, it indicates that the confidence level of the two groups is not enough to draw any specific conclusion, but if the p-value is less than 0.05, it can be considered that there is a significant difference between the two groups of data [5].

In this part, we compare the results of expert group and non-expert group by T-test to evaluate whether the unique variable between the two groups (i.e. subject expertise) has a significant impact on the depth range judgment results of participants. In the same way, we also analyzed whether sample differences have a significant impact on depth range judgment results.

The probability value derived from the T-test result is expressed as "P". If there is no average difference between the two groups by "P", null hypothesis and alternative hypothesis are adopted if there is a difference in the average of the two groups, and the other is rejected. Hypothesis is denoted by "H", null hypothesis is denoted by "0", and alternative hypothesis is denoted by "1".

In Table 2, the Expert group and the non-expert group are compared and analyzed as T-tests to evaluate the zero drag of the subjects' evaluation expertise on the experimental results. The p-value of the two groups is calculated as 0.0883 at positive depth. In the negative depth, the p-value is calculated as 0.298. In both groups, the p-value is 0.05 or higher as a result of the T-test, so the h-value is determined as '0'. In other words, since the average difference between the two groups does not occur, the subjects' evaluation expertise has little influence on the depth experiment results.

Table 2. T-test results of subject expertise to positive depth and negative depth

Indexes	P	H
Positive depth	0.0883	0
Negative depth	0.2980	0
*P<0.05		

In Table 3, the depth range experimental group of sample1 and the depth range experimental group of sample2 are compared and analyzed as T-tests to evaluate the zero term of the difference between samples with different 3D crosstalk. The p-value of the two groups is calculated as 0.0001 at positive depth. In the negative depth, the p-value is calculated as 0.0001. In both groups, the p-value is 0.05 or less as a result of the T-test, so the h-value is determined as “1”. That is, since the average difference between the two groups occurs, the difference between samples with different 3D crosstalk has a great influence on the depth experiment results.

Table 3. T-test results of sample differences to positive depth and negative depth

Indexes	P	H
Positive depth	0.0001*	1
Negative depth	0.0001*	1
*P<0.05		

3.3 Correlation analysis between 3D depth and crosstalk

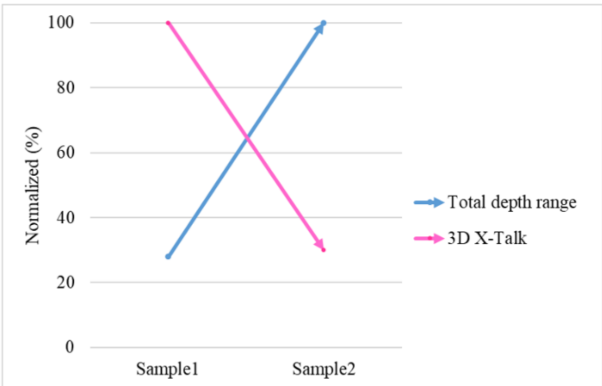


***Figure 6.** Correlation between 3D Depth and crosstalk*

Fig. 6 shows the correlation between total depth range and 3D crosstalk. Total depth range increased by 70% from sample1 to sample2. 3D crosstalk decreased by 70% from Sample1 to Sample2. As the depth range increases, the inverse proportional relationship in which the 3D crosstalk decreases can be confirmed.

3.4 3D depth image analysis

Fig. 7 shows the compare images at the same depth within the perceptually permissible depth range. Fig. 7 (a) is an image of sample1 taken with a camera in the depth range acceptable in sample2. Fig. 7 (b) is an image taken with a camera of an image of sample2 in a depth range acceptable in sample2. As the depth range increases, it can be seen that the sharpness decreases in the image of sample1 compared to sample2. In Zero depth, it can be seen that the sharpness of the two samples is the same level.

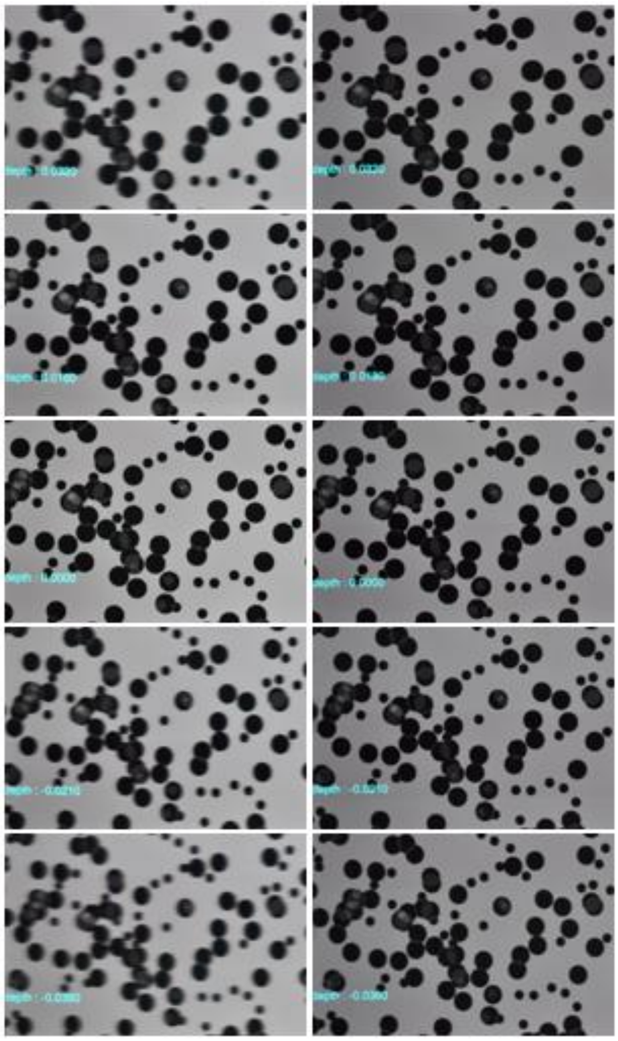


***Figure 7** Compare images at the same depth within the perceptually permissible depth range; (a) Sample1, (b) Sample2.*

4. Conclusions

Selecting a 3D depth range is an important factor in determining the expression performance of a stereoscopic image in a 3D display. In evaluating the range of depth expression of 3D stereoscopic images, 3D performance levels can be identified through 3D perception evaluation and analysis.

We use the visual stimulation of RDS images to make people perceive positive and negative depths. The size and arrangement of dot are randomly adopted to give visual stimulation. Create a system that allows the subject to directly select the depth range using the produced RDS image. The subject directly controls the depth of the RDS image to a clear and acceptable level. The depth performance of the 3D display can be determined through the perceptual depth range derived from the expert and non-expert groups.

It is also possible to derive a correlation between 3D crosstalk values through 3D perceptual depth evaluation. As the depth range increases, the 3D crosstalk decreases. In the future, the depth range performance of each product of the 3D display will be derived through this evaluation method and applied to the appropriate 3D contents depth design accordingly.

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