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QUANTIFICATION OF VISUAL ENVIRONMENT RECALL RATIO OF OMNIDIRECTIONAL VIRTUAL REALITY (VR)

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Abstract

Impression evaluation and comparison experiment of real space and VR space were performed aiming at quantification of the recall rate of VR space.

From experimental results, we think that people get an impression close to real space even in VR space. It is considered that not only a low brightness space but also a space with a large brightness contrast such as an indoor space with window or a space with high brightness such as an outdoor space receives an equivalent impression.

In this experiment, as a basic experiment to quantify the recall rate of omnidirectional VR using HMD, we were able to discover some tendencies about the relationship between real space and omnidirectional VR.

Keywords: VR, HMD, visual environment, recall ratio, quantification.

1 Research background

Since the launch of HMDs such as HTC VIVE and PSVR in 2016, omnidirectional VR using HMD has developed rapidly. Many software companies have updated their software to incorporate with this new technology. Thanks to that, now, the omnidirectional VR becomes widespread. With little instruction, anyone who has a fundamental knowledge of personal computers can use omnidirectional VR easily.

The greatest merit of VR is that it is easy to reproduce what is difficult to reproduce in real space. The omnidirectional VR using HMD is more immersive than those projected on conventional large screens, etc. Furthermore, due to the development of graphic technology, the image became clearer and more realistic.

Conventionally, VR is highly anticipated. Various studies[1) 2) 3) 4)] have been conducted on the reproducibility of the real space and on the reproduction of the feeling of brightness. However, these studies are carried out by VRs with screens. It is considerable that the perception given by an omnidirectional VR using HMD is different.

Research on omnidirectional VR using HMD [5) 6) 7)] is also increasing. However, most of the past researches on omnidirectional VR using HMD are carried out on sense of distance and recognition. In my research [8)], I compared impression evaluations in real space and VR space as basic experiments and showed that impression evaluation in VR space was effective. However, this experiment is basic, and it is not clear yet how omnidirectional VR using HMD can reproduce the real space. From this point onwards, experiments which has been difficult to perform in the real space conventionally but could be reproduced with an omnidirectional VR will be increased. In order to conduct those experiments, it is considered necessary to conduct research aimed at quantifying the visual environment recall radio of omnidirectional VR.

2 Purpose of research

In this research, we aimed to quantify the visual environment recall ratio of omnidirectional VR by comparing and analysing the feeling that real space and VR space gives to people.

3 Research method

Figure 1 – Selected outdoor space

Figure 2 – Selected indoor space with window

Figure 3 – Selected indoor space without window

First, it is assumed that the real space can be divided into three types, large outdoor space, indoor space with window and indoor space without window. Generally, the outdoor space is a spacious space which has high luminance due to daylight. The indoor space with window is a space where the luminance contrast is very large. The part which the daylight enters has high luminance. Meanwhile, the part where the daylight does not reach directly have a lower luminance. The indoor space without window is a dark space with no daylight if lighting equipment is not used. Even when lighting equipment is used, it is a low-luminance space compared to a space with daylight.

This time, we conducted comparative experiments of real space and VR space in these 3 types of spaces. Since there is no daylight at night, we compared each space during day time.

Figure 4 – HMD set

We need to conduct experiments in the space where daylight enters, but when we do experiments, the luminance contrast becomes remarkably high on the surface which receiving direct sunlight. Furthermore, as weather and time change, there are also changes in the surface that receives direct sunlight. We thought that this could greatly affect the unification of the conditions when conducting comparative experiments. Therefore, the space to receive direct sunlight is not selected as the comparison target this time. We selected shaded spaces as the outdoor space with daylight and the indoor space with window (Figure 1,2,3).

The experiment was divided into two parts. In Experiment 1, the comparison between the real space and the VR space was performed for each space using the SD method and the ME method. In Experiment 2, comparison of three types of VR space was performed using ME method.

In the experiment, a total of 20 university students and graduate students (9 males and 11 females) were subjects.

3.1 Preparation for experiment

In order to unify the conditions of the real space and the conditions of the VR space as much as possible, the 360 ° images presented to the HMD were taken before the comparison experiment (Figure 4). The human eye can distinguish from high brightness to low brightness for adaptation. On the other hand, when photographing is performed, if we unified the settings of the camera while shooting the high brightness space and the low brightness space respectively, either one of them turns white or black. The space may not be identified well. Therefore, when shooting 360 ° images, the ISO speed was fixed at 100 and the shutter speed was set to auto (Figure 5, 6, 7).

Figure 5 – 360 ° image of outdoor space

Figure 6 – 360 ° image of indoor space with window

Figure 7 – 360 ° image of indoor space without window

3.2 Experiment 1

In Experiment 1, subjects were asked for space evaluation and comparison of space.

For spatial evaluation, subjects were asked to evaluate the evaluation items about the space at each evaluation point by the 7-step SD method. The ME method was used to compare the real space and the VR space.

As for the ME method, the subjects were asked to answer numerically how they felt them in the VR space, the brightness, glare, spaciousness and oppression of the real space are assumed to be 100.

When the subject arrived in the waiting room, the instruction was given. Then, the HMD apparatus was installed at the evaluation point. After that, each subject was sequentially called to the evaluation point for evaluation.

The subject first observed the real space and evaluated the impression of the real space. After wearing the HMD and observing the VR space, the evaluation value of the ME method was answered. Finally, the same impression evaluation as which was conducted in real space was carried out. Such evaluations were conducted at three places.

In addition, considering the adaptation of the eyes, the subject closed their eyes for 1 minute while wearing the HMD before the evaluation.

3.3 Experiment 2

After the comparative evaluation at all evaluation points, Experiment 2 was performed. In Experiment 2, the subjects were asked to compare three VR spaces. ME method was applied to the comparison.

The subjects were asked to answer how they feel in outdoor space / indoor space without window numerically When the VR space at each evaluation point was presented with HMD, and the brightness, glare, spaciousness, and oppressive feeling of the indoor space with window are 100.

The VR space of an indoor space with window was presented first. After confirming the standard state (the state where each value was 100), the VR space of an outdoor space or an indoor space without window was presented. Half of the subjects evaluated outdoor space, and the other half evaluated indoor space without window to prevent bias in the evaluation results.

When changing the presentation space, the eye adaptation was considered. The subjects were asked to close their eyes for 1 minute while wearing the HMD, and then presented the VR space for the next evaluation.

4 Experimental results

4.1 Evaluation results

The results of the spatial evaluation are summarized in the table 1, 2, 3. Evaluation of the real space and the VR space had a similar tendency in all spaces.

In the outdoor space, there is a difference in the evaluation of 14. no discomfort -discomfort. It is evaluated that there is a sense of incongruity somewhat in the VR space while it is evaluated that there is no incongruity in the real space.

Table 1 – Evaluation result (outdoor)

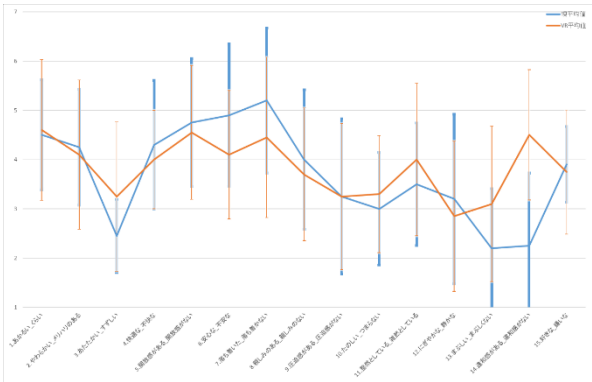


Table 2 – Evaluation result (indoor with window)

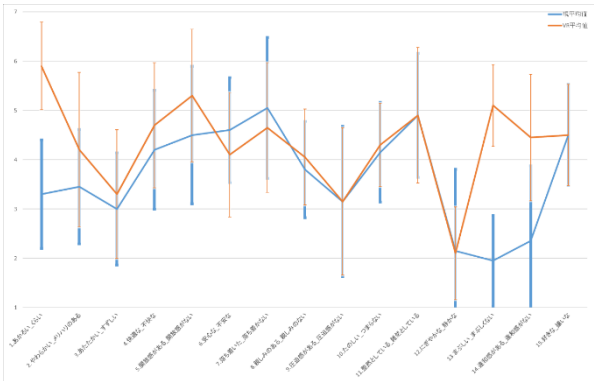
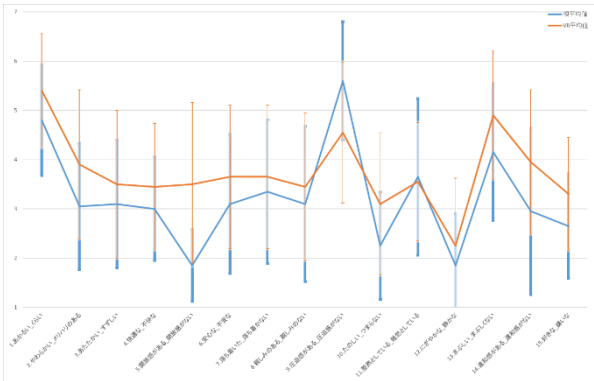


Table 3 – Evaluation result (indoor without window)



In the indoor space with window, there were differences in the evaluation of 1. Bright - dark,13. Dazzling - not dazzling, 14 Discomfort - no Discomfort. In the real space, it was evaluated that

it was a little dark, not bright, and no sense of incongruity, but in the VR space it was evaluated that it was bright, a little dazzling, and some incongruent.

In the indoor space without window, there was a difference in the evaluation of 5. spacious - no spacious. It was evaluated that there is no spaciousness in the real space, but it is estimated that there is a little but no so much sense of spaciousness in the VR space.

4.2 Analysis of variance

Analysis of variance was performed on the mean value of the seven-level impression evaluation of the space, which the subjects answered. The results are as shown in the table 4.

Mostly, the P value is 0.05 or more, so it is considerable that the evaluation of the real space and the evaluation in the VR space do not have a significant difference.

From these, it is determined that, in the VR space, whether it is an outdoor space or an indoor space with & without window, the same feeling as the real space can be received, and an evaluation close to the real space can be made.

Table 4 – Analysis of variance

	Evaluation item	Outr	Win	In
1	Bright - Dark	0.8114	<0.0001	0.113
2	Soft - Hard	0.735	0.1021	0.0696
3	Warm - Cool	0.0452	0.4557	0.3853
4	Comfortable - uncomfortable	0.4319	0.2212	0.244
5	Spacious – Not Spacious	0.6455	0.0801	0.0003
6	Worry free - Uneasy	0.0808	0.195	0.2448
7	Calm – Not Calm	0.1442	0.3752	0.5299
8	Friendly - Unfriendly	0.5069	0.435	0.4876
9	Feel oppression – Feel no oppression	1	1	0.019
10	Fun - Boring	0.4319	0.6227	0.0477
11	Tidy - Cluttered	0.2797	1	0.8281
12	Bustling - Quiet	0.511	0.9094	0.3217
13	Dazzling – Not dazzling	0.0557	<0.0001	0.0938
14	Discomfort – No discomfort	<0.0001	<0.0001	0.0585
15	Like – dislike	0.6602	1	0.0775

4.3 Consideration of ME Method (Real Space: 100)

The table 5 summarizes the results of the ME method in which the VR space is evaluated with the real space as the standard state (100).

The outdoor space of VR is considered to bring a sense that is very similar to real space in terms of brightness, glare, spaciousness and oppression. As for the sense of oppression of the VR space, it is considered that the evaluation value in each space is close to 100, which brings a feeling close to the real space.

On the other hand, since the evaluation value about the brightness, the glare, and the spaciousness of indoor space is over 100, it may be over-estimated. Especially for indoor space with window, the evaluation of brightness and glare was high. Regarding the sense of spaciousness, since both indoor and non-windowed spaces are about 130, it is thought that in the indoor space on the VR there is a tendency to feel the spaciousness about 1.3 times. It is necessary to further study and clarify specific numerical values.

4.4 Consideration of the ME method (VR indoor space with window: 100)

The table 6 summarizes the results of the ME method in which the VR outdoor space and indoor space without window were evaluated with the VR indoor space with window as the standard state (100).

Table 5 – ME method (real space: 100) result

	Brightness	Glare	Spaciousness	Oppression
Out	109	107.65	109.25	97
Win	176.1	153.75	136.5	93
In	142.75	139	130	107.75

Table 6 – ME method (VR indoor with window: 100) result

	Brightness	Glare	Spaciousness	Oppression
Out	90.75	88.25	138	82.5
Win	100	100	100	100
In	80.25	83	52.5	146

The evaluation values of brightness and glare were lower in outdoor space and indoor space without window than in indoor space with window. For the spaciousness, the larger the real space, the higher the evaluation value tends to be. As for the feeling of oppression also, the evaluation value tends to be lower as the real space is larger. This is like the feeling you receive in real space. Therefore, in VR, it can be considered that the size of the space is also reproduced. I think that it is necessary to further study about how much it has been reproduced.

4.5 Measuring luminance

The luminance values measured in each space are summarized in the table 7.

The average brightness of the outdoor space was about 670 cd / m^2. In the indoor space with window, the difference between the brightness on the surface with the window (front) and the brightness on the back was large, and there was a difference of nearly 10 times. Also, in the indoor space without window, the difference in brightness between the front and back was large, and there was a difference of nearly seven times.

The luminance values of the images displayed by the HMD were measured and summarized in the table 8 (Figure 8).

Figure 8 – Measuring the brightness of the HMD

In the outdoor space, the left side was nearly twice as bright as the other side. The difference in brightness between the front and the back of the indoor space with window is about 4 times, which is smaller than the difference in brightness in the real space. The difference in brightness between the front and back of the indoor space without window is about 3 times, which is also smaller than the difference in brightness in the real space.

Table 7 – Luminance value of real space

	Avg	Overall Avg
Out F	617.40	
Out L	716.96	
Out B	789.26	
Out R	563.45	671.77
Win F	154.71	
Win L	71.81	
Win B	15.04	
Win R	94.75	84.08
In F	31.82	
In L	189.02	
In B	224.00	
In R	105.85	137.67

Table 8 – Brightness value of VR space

	Avg	Overall Avg
Out F	31.59	
Out L	60.20	
Out B	36.67	
Out R	21.90	37.59
Win F	95.12	
Win L	61.64	
Win B	24.07	
Win R	56.85	59.42
In F	16.14	
In L	65.94	
In B	45.15	
In R	49.04	44.07

4.6 Comparison of brightness

The luminance value of the real space is the highest in the outdoor space, followed by the indoor space without window, and the lowest is the indoor space with window. Furthermore, the brightness of the outdoor space was several times greater than the indoor space with & without window. On the other hand, in the VR space, the brightness of the indoor space with window is the largest, followed by the indoor space without window, and the lowest is the outdoor space. Furthermore, the difference in luminance between the outdoor space and the indoor space with & without window was smaller than that in the real space.

In order to compare the luminance of the real space and the luminance of the VR space, values obtained by dividing the luminance of the real space from the luminance of the VR space are summarized in the table 9.

In the outdoor space, the left side was brighter than the other side, but it was about 0.056 on average. The indoor space with window was 0.711 in the front (high brightness surface) and 1.994 in the back (low brightness surface). The luminance was compressed at the front (high luminance surface) and the luminance was expanded at the back (low luminance surface). The indoor space without window was about 0.380 on average, although there was a slight difference between the front and back.

4.6.1 Comparison of the result of ME method (real space: 100) with the luminance

In order to compare the measured luminance with the result of the ME method in which the VR space is evaluated with the real space as the standard state (100), the table10 is summarized.

Table 9 – VR/real (luminance)

	GM	Overall Avg
Out F	0.054	
Out L	0.084	
Out B	0.045	
Out R	0.042	0.056
Win F	0.711	
Win L	1.316	
Win B	1.994	
Win R	0.957	1.244
In F	0.507	
In L	0.349	
In B	0.202	
In R	0.463	0.380

Table 10 – Comparison of ME method and luminance

	Brightness	Glare	Spaciousness	Oppression
Out	109	107.65	109.25	97
Win	176.1	153.75	136.5	93
In	142.75	139	130	107.75
	B /100	G/100	S/100	O/100
Out	1.09	1.08	1.09	0.97
Win	1.76	1.54	1.37	0.93
In	1.43	1.39	1.30	1.08
	B/100/Ratio	G/100/Ratio	S/100/Ratio	O/100/Ratio
Out	19.358	19.118	19.403	17.227
Win	1.415	1.236	1.097	0.747
In	3.755	3.656	3.419	2.834
Win F	2.477	2.163	1.920	1.308
Win B	0.883	0.771	0.685	0.466

VR/Real GM
0.056
1.244
0.380

High luminance
0.711
Low luminance
1.994

First, the evaluation value obtained by the ME method was divided by 100 in the standard state, and the ratio of the value to the comparison value of the luminance (VR / actual) was calculated.

It is assumed that there is a direct correlation between the evaluation of brightness and glare and the luminance. Then, in the outdoor space, although there is a difference of about 20 times in luminance, the evaluation by the ME method is very close to 100, and it is evaluated as equivalent to the real space. In the indoor space with & without window, the luminance tends to be overestimated.

The luminance in the real space and the luminance on the VR may have a large difference such as 20 times or may be small. However, since all evaluations are close to real space, VR is considered to have space reproducibility regardless of the magnitude of the luminance difference.

The indoor and non-window spaces selected this time had large differences in brightness. It is considered that the evaluation of the space where the brightness contrast is large tends to overestimate the brightness and the glare.

In the VR space, the high-intensity part was compressed, and the low-intensity part tended to be expanded. This may be because the aperture and shutter speed are set to auto when shooting 360 ° images with THETAs.

4.6.2 ME method (VR indoor space with window: 100)

Next, in order to compare the measured brightness with the result of the ME method in which the VR outdoor space and indoor space without window are evaluated with the VR indoor space with window as the standard state (100), the table 11 is summarized.

The ratio of the value obtained by dividing the ME method (VR) value by 100 in the standard state and the luminance value in the VR space by 59.42 in the standard state was calculated.

It is assumed that there is a direct correlation between the evaluation of brightness and glare and the luminance. Then, the brightness of the outdoor space was recognized as about 1.4 times. Indoor space with & without window was evaluated almost equal to real space.

Table 11 – Comparison of ME method (VR) and luminance

	Brightness	Glare	Spaciousness	Oppression
Out	90.75	88.25	138.00	82.50
Win	100.00	100.00	100.00	100.00
In	80.25	83.00	52.50	146.00
	B/100	G/100	S/100	O/100
Out	0.91	0.88	1.38	0.83
Win	1.00	1.00	1.00	1.00
In	0.80	0.83	0.53	1.46
	B/100/Ratio	G/100/Ratio	S/100/Ratio	O/100/Ratio
Out	1.43	1.39	2.18	1.30
Win	1.00	1.00	1.00	1.00
In	1.08	1.12	0.71	1.97

VR ME
37.59
59.42
44.07
VR/59.42
0.63
1.00
0.74

5 Discussion

Impression evaluation and comparison experiment of real space and VR space were performed aiming at quantification of the recall rate of VR space.

From this experiment, I think that people get an impression close to real space even in VR space. It is considered that not only a low brightness space but also a space with a large brightness contrast such as an indoor space with window or a space with high brightness such as an outdoor space receives an equivalent impression.

In this experiment, as a basic experiment to quantify the recall rate of omnidirectional VR using HMD, we were able to discover some tendencies about the relationship between real space and omnidirectional VR. However, this experiment alone cannot determine the reproduce rate. In order to calculate the reproduce rate, it is necessary to conduct experiments with a larger number of samples and to reconfirm the tendency obtained this time.

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