

## A Study on Distance Estimation in Virtual Space According to Change of Resolution of Static and Dynamic Image

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### 가상현실공간에서 정적 및 동적 이미지의 해상도 변화에 따른 거리추정에 관한 연구

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#### Abstract

The virtual reality (VR) technology has been used as the application of architectural presentation or simulation tool in the field of industry. The high immersion and intuitive visual information are the great merits of design evaluation or environmental simulation when we are using the virtual environments. But the distortion of distance perception in VR is still a big problem when the accuracy of distance presentation is strictly required. For example, distance estimation is especially important when the virtual environments are applied to the presentational tool for evaluation the space design or planning in the field of architecture. If there are some perception error between the built space in real and represented space in virtual, the accurate design evaluation or modification of design is hard to be carried out during the design development stage. In this paper, we have carried out some experiments about distance estimation in the immersive virtual environments to verify the factors and their influence. We made a hypothesis that the lack of the information for the user in VR causes the different distance estimation from the real world because users are usually comfortable with moving fast and long distance in VR environments compared with moving slow and short distance in real space. So, we carried out basic experiment to prove our hypothesis that the lack of information makes subjects estimate the distance of walking in VR shorter compared with the same distance in real. Also, among the factors that probably affect the distance estimation in VR, we have verified the influence of the image resolution. The influence of resolution degradation of image on the distance estimation was verified with the condition of static and dynamic images. The results showed that the resolution has deep relation with the distance estimation. For example, the subject underestimated the

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• 제1저자 : 류재호

• 투고일 : 2010. 10. 21, 심사일 : 2010. 11. 03, 게재확정일 : 2010. 12. 04.

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※ This paper is an expanded version of paper presented at the international conference on Cyberworlds2005: "Influence of Resolution Degradation on Distance Estimation in Virtual Space Displaying Static and Dynamic Image".

distance at the lower resolution condition. We also found the methods of the making the lower resolution image could affect on the visual perception of subjects.

▶ Keyword : Virtual Space, Estimation of Distance, Resolution of Image

## 요 약

가상현실 시스템에서 높은 현실감과 직관적인 시각정보의 제공이 커다란 장점임에도 불구하고, 가상공간에서의 공간제시에 있어서 거리감각이 정확하게 전달되지 않는 문제점이 있다. 특히나 건축분야와 같은 공간을 취급하는 분야에서의 공간제시에 있어서의 왜곡문제는 시급히 해결해야할 필요성이 있다. 본 논문에서는 가상현실공간에서 거리감각을 고찰함에 있어서 거리감각을 조사하는 하나의 요소로서, 피실험자에 의한 이동거리추정판단에 관한 실험을 행하였다. 가상현실공간에서의 제시정보의 부족이 거리감각의 차이를 가져온다는 가정하에 몰입형 가상현실시스템에서 다양한 영상의 투영조건하에서 이동거리추정판단을 실험적으로 조사함으로써, 가상공간을 형성하는 시스템이 제공하는 정적, 동적 영상이미지의 특성에 의한 거리감각의 변화를 규명하고자 한다. 구체적인 실험방법으로는 실제 건축물의 복도를 모델링하여, 복도의 실제공간과 모델링된 가상공간을 피실험자에게 영상으로 제시하면서 이동거리추정판단의 심리실험을 수행하였다. 실험에 이용한 모델과 같은 실제의 복도에서도 이동거리추정판단의 실험을 동시에 수행함으로써, 실제환경과 가상현실환경과의 거리감각의 차이를 비교분석하고, 그 결과 실제환경과 비교하여 몰입형 가상현실시스템에서의 거리감각이 단축이 되는 경향이 나타남을 설명한다. 나아가, 몰입형 가상현실시스템에 있어서 거리감각이 과소평가되는 경향이 나타나는 요인을 고찰하여, 영상의 해상도를 거리감각을 형성하는 중요한 요소로 판단하고 정적, 동적 이미지의 해상도의 변화에 따른 거리감각을 규명한다.

▶ Keyword : 가상공간, 거리추정, 이미지 해상도

## 1. Introduction

Recently, according to the development of the virtual reality technology resulted from rapid progress of computer graphic, there is an increasing opportunity to experience the virtual environments system (VEs)[1]. To give the high immersion to the user, many VE systems have been invented including CAVE[2], developed by Illinois University, which is the most famous one and composed of four screens to cover user's whole eye view. Also, there are other systems that have different shape of screen like spherical display system[3, 4, 5].

One of the big purposes of these systems is to give the high sense of presence to the user with multi-modal sensation. When using this kind of virtual reality system, researchers try to train people in pre-defined environments because VR has the advantage of providing a certain situation. The advantage of using the VR technology during the

space training process was proved through the some experiments about the firefighters with comparing the speed and accuracy of rescue performance and the effectiveness of acquiring the spatial knowledge in VR[6].

Also, there are the other researches related with the space cognition or mental map using VR. The interfaces that use the whole body may enhance certain components of navigation performance in virtual environments. Especially the users were able to create a more accurate mental map rather than joystick (hand controlled)[7]. The other study suggested that VEs that adequately represent real world complexity can be effective training media for learning complex routes in buildings, and should be considered whenever the real world site is unavailable for training [8, 9, 10]. It was also reported that the characteristics of perceived distance in computer graphics system are similar with that of real space[11]. Because the computer generated graphics provide the important visual cue

for the user to build up the distance perception, the user can estimate the distance similar in real. However in this study, the results showed only the similar features in VR and real space, not the cause of different space recognition. Considering the experiment condition that uses the 21 inches monitor and no other sensory information except for visual, the situation of experiment was quite different from the real space.

Also several researches show the better distance estimation in real space rather than the restricted field of view condition, and familiar world rather than unfamiliar virtual world[12, 13]. The other research shows the more accurate distance estimation if the subject experienced the increasing interaction in virtual space such as walking to target[14]. Even though the stereo viewing is one of the interesting research topics considered to affect the distance estimation of viewer, some research report that the distance judgement is not unaffected by the stereo viewing[15].

## II. Distance estimation in VR

However, there is one doubt that the user feels and navigates similarly in virtual environments like she/he does in real. It is usually said that the user feels different from the real world for some reasons when he behaves in the VEs. There are some studies that investigate how human recognize space in VEs. The fundamental experiment is comparing the real and virtual environments with measuring the perception of distance because the distance estimation is the most necessary basic knowledge when human behave in space. In this paper, we tried to find the reasons that cause the difference between real and virtual space.

We have carried out some experiments about distance estimation, which is important when the VEs are applied to the presentational tool to evaluate the space design or planning in the field of architecture or building simulation. At this kind of

application, the short distance is more important than the long one because the human behavior scope is relatively small for the realistic reason. Not only at the architectural application but also at many fields of industry, the accurate and proper distance representation is one of the most required functions when the user walks around the virtual space.

To define and clarify the factors that are related with the spatial cognition will help VEs constructor to compensate the difference of the real and virtual world to represent the environment on screen of system that has similar characteristics of real space. Also, the investigation into the human recognition about the distance is a fundamental research area in order to achieve the accurate VEs for the architectural or urban design evaluation.

Before entering the experiment, we made a hypothesis that the lack of the information for the user in VR causes the different distance estimation from the real world because we noticed that users are usually comfortable with moving fast and long distance in VR environments different from real space. We thought that the different behavior came from the shortage of information of sensor in many aspects. In other words, we assume that there is a lack of sensory perception causes different effect on the space cognition of user in VR unlike in reality space. So, at first we carried out basic experiment to prove our assumption that the lack of information make subjects estimate the distance shorter compared with the same distance in real.

## III. Experimental system

### 3.1. Display system

We used the D-vision, multi-projection display system developed by Tokyo Institute of Technology, to provide the virtual experience to subjects[3]. As shown in Figure 1, the D-vision has 6.3 meters wide, 4.0 meters high, and 1.5 meters deep screen.

The central flat part of screen is for rear projection with eight projectors with SXGA, 1280x1024 pixels resolution.

The remaining part of screen is for front projection with sixteen projectors with XGA, 1024x768 pixels resolution. The projectors were set up at the positions indicated in Figure 1, shows the projectors for front projection mounted on posts. The screen is composed of partial surfaces of planes, spheres, cylinders, and tori. Such a uniquely shaped screen is made of fiberglass-reinforced plastic (FRP) that has not only capability to reproduce complex shape but also enough rigidity to support itself. This special shape of screens reduces the geometric distortion at the joint area of screens compared with the hard edge joint screen system.

Eight pairs of projectors are used to project stereoscopic images, the left-eye image and the right-eye image, onto the rear projection screen and the upper and lower cylindrical parts of the front projection screen. We used orthogonal linear polarized lights to project each image for the left and the right eye. To maintain the light polarization after it is diffused onto the front projection screen, the front screen was painted with gray paint mixed with aluminum powder. The rear projection screen is suitable for conserving polarization of light and has a rather high gain.



Fig. 1. D-vision System

### 3.2. Navigation interface

At the virtual space, the subject used the simple joystick to go forward by her/his hands, as shown in Figure 2. The joystick has different moving speeds depend on the tilt of bar, so the subject can control the moving speed as he like. This also prevents sudden start and stop that make a sense of incompatibility with real walking experience. We used a simple navigation interface in order to get rid of the effect of other sensory perception except visual.



Fig. 2. Joystick for Navigation

## IV. Experimental methods

### 4.1. Distance estimation

At the experiment of distance estimation, there are two kinds of measuring distance methods. One is the magnitude estimation method and the other is a verbal report method. We chose the verbal-report method in order to survey the several distance units rather than single distance unit. The subjects were instructed to walk a certain distance from the start point with using the only visual information. At that time, he used his internal distance concept to judge the walked distance for pointing the instructed distance.

Naturally, there is a gap between the physical and estimation distance. The gap was calculated to

analyze the difference of distance estimation between real and virtual space, because the purpose of this experiment is to investigate the difference perception between the real and virtual space using the personal distance concept not the accurate distance estimation with the physical distance. During the experiment of distance estimation, we also instructed subjects not to use the counting of time consuming and visual landmarks on the scene to prevent the other influences except the visual.

#### 4.2. Experimental environments

Comparing the distance estimation in real and virtual space is not so easy because making experimental environment in real world has some limitations for several reasons, for example the limitation of space, time and cost. So, many researches have used the existing real space to compare with the virtual space. To make experiment possible in real space, we also chose the hallway near by the D-vision system room as the experimental environments. The hallway is about 30 meters length that is enough for the 2, 5, 10, 15 and 20 meters distance estimation. The close location from the system room of immersive virtual environments is another reason why we chose this hallway that can make the subject move to virtual space quickly.

### V. Distance estimation in real & virtual - Experiment 1

At this experiment, we have tried to find the difference of the real world and virtual space cognition when the user estimates the walked distance like they do in the architectural design evaluation process.

First, we checked their walked distance in real space to find the subject's sense of distance when they were instructed to walk 2, 5, 10, 15, and 20 meters. The relatively short distances were verified

at this experiment, compared with other researches, because these distances are critical length to evaluate the space design like architectural planning. The width and length of corridor or room space are usually included in this extent of units. To give the same environmental condition to real world and virtual space, the experiment was carried out in the real corridor space close to the virtual environment system room, as shown in Figure 3 and 4.

After checking the subject's sense of distance at the real space, he/she was instructed to move the specific distance in virtual space. The start point of distance evaluation was changed to the opposite side at the virtual space. The subjects were instructed to use the visual information only at the distance estimation without counting the walking-steps and time consuming in order to investigate the effect of different visual perception between real world and virtual space.

As shown in Figure 5, the result shows the distance in virtual space was underestimated compared with the real space. Subjects have walked longer distance at all instructed distance units in virtual space. The main reason of this underestimated walked distance in virtual reality was considered that it is caused from the lack of the sensory information like the detail of the projected image on screen and the proprioceptive feedback. That means the result corresponds with the assumption of the experiment that much information from visual input make user overestimate the distance compared the standard distance because the real space has the much information without a doubt.

Let's talk about the result more in detail. Here is a table for the mean data of subjects about the distance estimation at the each unit (Table 1). The walked distance is converted to the percent of physical distance. There are about 20 -40% of gap between real world and virtual space. At the percentage of the estimation by physical distance, we can notice the bigger gap at the shorter distance of walking like 2 meters and 5 meters than longer

distance. These mean that the distance estimation at the short distance has much difference from the several sensory gaps including proprioceptive perception when subjects judge the walked distance.

In the virtual space, the initial stage of walk is not well recognized by the subjects because of the shortage of the sensory information. So the shortage of initial stage of walking is the one of the factors which cause the bigger gap in the short distance in distance estimation. From the comparison of the distance estimation between the real world and virtual space, we have the result showing that the subject underestimates the distance in virtual space.



Fig. 3. Real Hallway



Fig. 4. Virtual Hallway

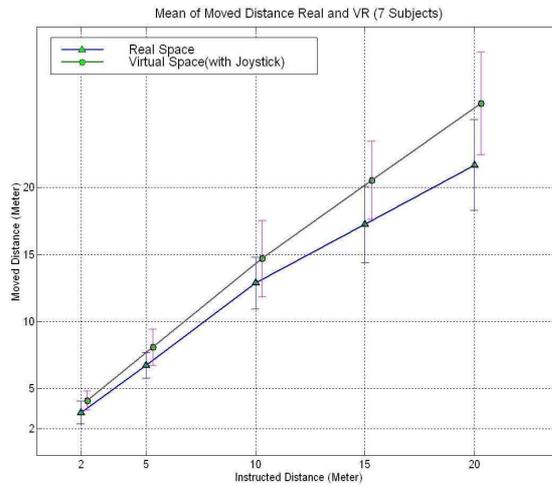


Fig. 5. Comparison of Distance Estimation in Real & Virtual Space

Table 1. Comparison of Estimation by Physical Distance in Real & VR Space

		2M	5M	10M	15M	20M
VR	Estimation	4.1	8.1	14.7	20.5	26.3
	Estimation/ Physical	205 %	161 %	147 %	136 %	131 %
Real Worl d	Estimation	3.2	6.7	12.8	17.2	21.6
	Estimation/ Physical	160 %	134 %	128 %	114 %	108 %

Until now, we have verified the different distance estimation of real and virtual space. Then, what are the factors of this different distance perception in virtual space? Maybe, there are two kinds of factors that are believed to affect on the underestimation of distance in virtual space. Regarding the image, the resolution, the brightness and the stereoscopic are included in this category. Also, regarding the system, the field of view (FOV) and force feedback are included in this category.

Among these factors, we chose the image-resolution to be investigated that is regarded as the very important factors because the resolution has a deep relationship with the amount of information how much it carry.

## VI. Distance estimation with resolution - Experiment 2

### 6.1. Distance Estimation with Still Images - Test 1

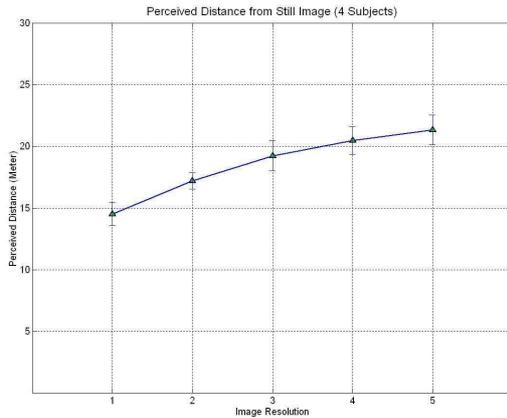


Fig. 6. Distance Perception with Still Image

Table 2. Image Resolution for Comparison

	A	B	C	D	E
Resolution	258 X 224	507 X 448	1015 X 896	2034 X 1792	4068 X 3584
Visual Acuity	0.02	0.05	0.1	0.21	0.42

Table 3. Comparison of Estimation by Physical Distance in Still Image

	A	B	C	D	E
Estimation	14.5M	17.2M	19.4M	20.4M	21.4M
Estimation/ Physical	58%	69%	77%	82%	86%

We have carried out two tests to investigate two kinds of distance perception with the different image resolution. The one is the distance estimation with still image. And the other is the distance estimation during the moving situation. The reason why we have execute the two kind of test like still and

moving situation is that the user in virtual environments have these kinds of experience during the evaluation of design and training. So, the investigation on two situations is meaningful.

At the test 1, we have investigated the distance perception with the various resolution in the still images. First, the subject checked the sense of distance on the real hallway to compare with the virtual hallway. They stand on the spot 25 meters away from the opposite wall. After then, they were seen virtual hallway with five resolution images. And, they were forced to report the perceived distance from the images. For the experiment, we prepared the five kinds of resolution images as shown in Table 2. At Table 2, the resolution number is the whole resolution in the screen of D-vision. At the test 2, the subjects are instructed to walk 2, 5, 10, 15, and 20 meters at the two resolution conditions.

Here are the results of the test 1 of distance estimation with the still images, as shown in Figure 6. And, there is the calculated percentage of distance estimation by physical distance at Table 3. The results show that the subject perceived the deeper depth sense from the high resolution images. Even though at the highest performance of display system in resolution, the subject have the sensation of shorter distance compared with the real space. At the condition of E, the highest-resolution which system can produce, the mean of perceived distance by subjects is 21.4 meter that is 86% of real distance. At the condition of A, the lowest-resolution, the mean of perceived distance by subjects is 14.5 meter that is 58% of real distance. It is apparent that at the lower-resolution image condition the subject underestimates the distance much more than higher-resolution image condition. This result corresponds with the experimental assumption that the lack of visual information in virtual space causes the underestimation of distance. This underestimation of distance in the low-resolution image has been caused from the

lesser clue of perspective and distance. By upgrading the resolution performance in the virtual space, we can expect more accurate distance representation. But, it is not clear that the amount of improvement will reach the 25 meter because there is a possibility that the upward trend in the line of graph can saturate under the distance of real.

This means that we need to make about the 15% longer distance hallway than what we want represent in the virtual space because the distance in virtual space is perceived shortly even though we have made accurate distance hallway model. But, at this point we just verified the length of virtual hallway not the width. In order to express the accurate distance, even if we make the longer virtual hallway, we are not sure of the proper sense of width.

## 6.2. Distance Estimation with Dynamic Images - Test 2

### - Methods of Making Low-Resolution Image

At the making low-resolution image on the screen, we thought about two kinds of methods. First is the simple way of making low-resolution with distinctive pixel boundary. Second is the making low-resolution with indistinctive pixel boundary by adding anti-aliasing. This method will produce the smoothly continued image. The two kinds of methods of making low-resolution image are considered to have unique characteristics even though they carry low information. By investigating the influence of different methods at making low-resolution image, we tried to find the different influence by different methods of making low-resolution.

### - Low-Resolution Image with Distinctive Pixel

Here are the results of test 2 about the low-resolution image with the distinctive pixel, as shown in Figure 8. At the test 1, the subjects reported the further depth perception at the high-resolution image. This corresponds with the experimental

expectation that lack of visual information cause the underestimation of distance. At the still image test, the low-resolution image is underestimated in the depth due to the lesser clue for the perspective, so subjects feel the object come closer.

But, at the test 2, the data showed the different result, as shown in Figure 8. At the high-resolution condition, the subjects underestimated the moved distance. This result does not correspond with the experimental assumption that the subject should underestimate the distance in the lower-resolution image condition.



Fig. 7. Low Resolution Image with Distinctive Pixel

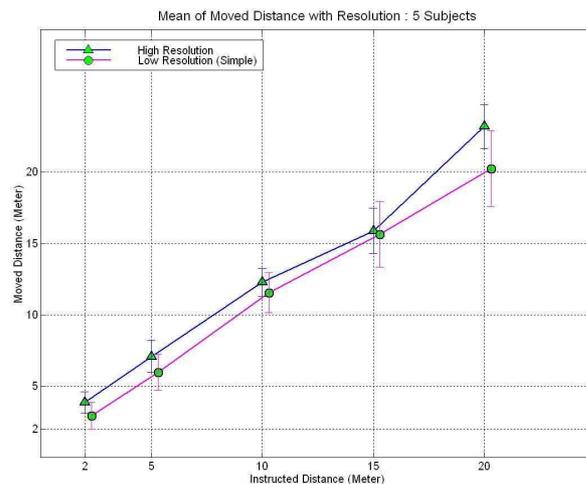


Fig. 8. Distance Perception in Low Resolution Image with Distinctive Pixel

We think that this is caused from the methods of making low-resolution image that produce strong optical flow by the distinctive pixel boundary. When the subject walks through the virtual space, she/he overestimated the moved distance at the low-resolution image because he judge the moved distance longer in low-resolution image compared with the high-resolution from the strong optical flow.

**- Low-Resolution Image with Indistinctive Pixel**

Here, we used the different method of making low resolution image using anti-aliasing to investigate the influence of different methods of making low-resolution image, as shown in Figure 9.

In the test 1, the results of distance estimation with still and anti-aliasing in the low-resolution image are same with the former low-resolution image condition. Whatever the methods of making low-resolution, the low-resolution image has lesser perspective clues.

But, at the results of test 2, we found different trend from the former experiment, as shown in Figure 10. The graph of result shows the underestimation of distance at the low-resolution image condition that corresponds with the experimental hypothesis. The reason why the result of distance estimation during moving situation of indistinctive pixel image is different from the former experiment is that the subject feel low moving speed caused from the dull moving sense at the low-resolution condition.



Fig. 9. Low Resolution Image with Indistinctive Pixel

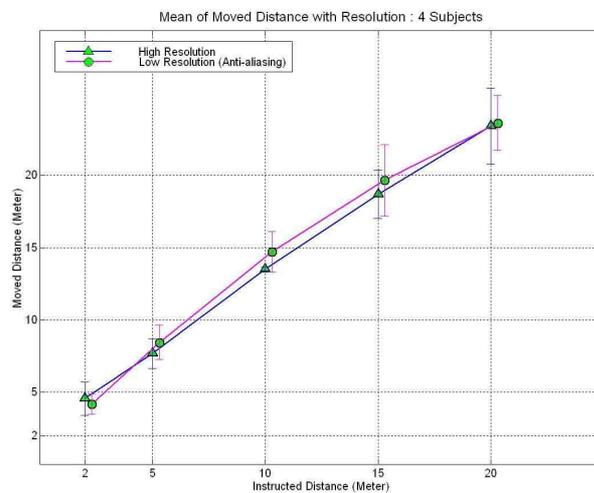


Fig. 10. Distance Perception in Low Resolution Image with Indistinctive Pixel

## VII. Discussion

In order to investigate the factors of underestimation of distance in virtual space, we carried out some experiments about the low-resolution image with the still image and moving situation. From the experiments about the low-resolution image, we have these results.

Firstly, at the experiment 1, we have verified the underestimation of distance in the virtual space. At

the result, we found the bigger gap of distance estimation between real world and virtual space at the initial stage of walking result from the lack of sensory information.

Secondly, at the distance estimation with still image in the test 1 of experiment 2, we have the result that low resolution image makes subjects underestimate the sense of distance in virtual space. This is caused by the lack of perspective clue at the low-resolution image compared with the high-resolution that is used to judge the depth of space. Also, despite of the making low-resolution methods, the high-resolution space has deeper sense of depth rather than low-resolution space. These results correspond with the experimental hypothesis.

Thirdly, at the experimental about the distance estimation during the moving situation in the test 2 of experiment 2, we found interesting results. Depending on the making low-resolution methods, the subjects feel different moving speed, so the data show opposite result. At the indistinctive pixel condition, the low-resolution have affected on the underestimation of walked distance.

From these results, we have reached the conclusion that the importance of image resolution in virtual space to make the accurate sense of distance. By upgrading the resolution of image, we can reduce the certain degree of distance perception gap between real and virtual.

## VIII. Conclusions

Trough the several experiments, we verified the influence of the amount of the information that was acquired from the eye of user. We reached the result that the lack of information in VR environments makes user underestimate the distance compared with real space. The longer walked distance in virtual space was recognized as the same compared with the certain distance in real. Also, we have examined the image-resolution factor in display which affects on the distance estimation in the immersive environment.

The result will be helpful in constructing of immersive virtual environment system for the architectural design application to evaluate the concept design. As the future work, we are planning to search the other factors of different space cognition in virtual space for example highlight, high dynamic range, light simulation and so on.

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