Development of an Interactive Simulation System for Environment-Behavior Study

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ABSTRACT

An important recent development in the simulation techniques was the changes in the mode of presentation: from passive mode to active one. It is now possible to present an image according to the observer's voluntary movement of body and head by means of a head-mounted display. Such interactive simulation system, which allows people to observe what they like to see, is suitable to study environmental perception, because active attention is essential to manipulate enormous information in the environment. The present paper reports two case studies in which an interactive simulation system was developed to test psychological impact of interior and exterior spaces: the case study 1 intended to clarify the effect of the disposition of transparent and opaque surfaces of a room on the occupants' „sense of enclosure", the case study 2 intended to make clear some physical features along a street which are influential for changing atmosphere. In addition to the empirical research, an attempt to develop a new simulation system which uses both analogue and digital images is briefly reported, and a preliminary experiment was conducted to test the performance of the simulation system in which such movable elements as pedestrians and cars generated by real-time CG were overlaid on the video image of a scale model street.

INTRODUCTION

Considering the psychological impact of environmental changes caused by building construction and urban development, we have to simulate the proposed environment in advance to examine our ideas and concepts whether or not they work as expected. We have seen rapid developments in simulation techniques from the classic representation method like perspective drawings to montage of still photographs, and motion pictures like movie and CG animation. Moreover, an important recent development was the changes in the mode of presentation: from passive mode to active one. It is now possible to present an image according to the observer's voluntary movement of body and head by means of a head-mounted display (HMD). Such interactive simulation system allows people to observe what they like to see. This active mode of visual perception is essential in environmental perception, because active attention is necessary to manipulate from the enormous information in the environment.

The computer generated image presented by HMD, so called "virtual reality", has become popular technique, but it has still limitation in generating a real-time CG animation with high quality. Siitonen (1993,1995) compared two different methods of generating visual image for architectural and urban spaces: one method created an analogue image model by endoscopy, and the other created a digital image model by computer graphics (CG). He evaluated the advantage and disadvantage of the two methods for architectural design and planning in various aspects. He concluded that endoscopy still kept advantage in many aspects such as modeling easiness, light qualities and material realities, although CG had been catching up rapidly.

The present paper reports two case studies in which an interactive simulation system using analogue image by an endoscope was developed, and the psychological impacts of interior and exterior spaces were tested. In addition to the empirical research, an attempt to develop a new simulation system which uses both analogue and digital images is briefly reported, and a preliminary experiment was conducted to test the performance of the simulation system in which such movable elements as pedestrians and cars generated by real-time CG were overlaid on the video image of a scale model street.

CASE STUDY 1: SIMULATION OF AN INTERIOR SPACE FOR ASSESSING THE OCCUPANT'S „SENSE OF ENCLOSURE"

Objectives

A sense of enclosure is one of the most fundamental concepts in environmental design. Architectural design in particular concerns the issue of the perception of a sense of enclosure, and it has been received considerable research interest, since one of the primary functions of architecture is to enclose space (Ashihara, 1970; Inui and Miyata, 1973; Takei and Ohara, 1977). Based on these attempts for the objective analysis of the sense of spatial enclosure, Thiel (1997) has proposed a scale of „degree of enclosure." He conducted an experimental study to

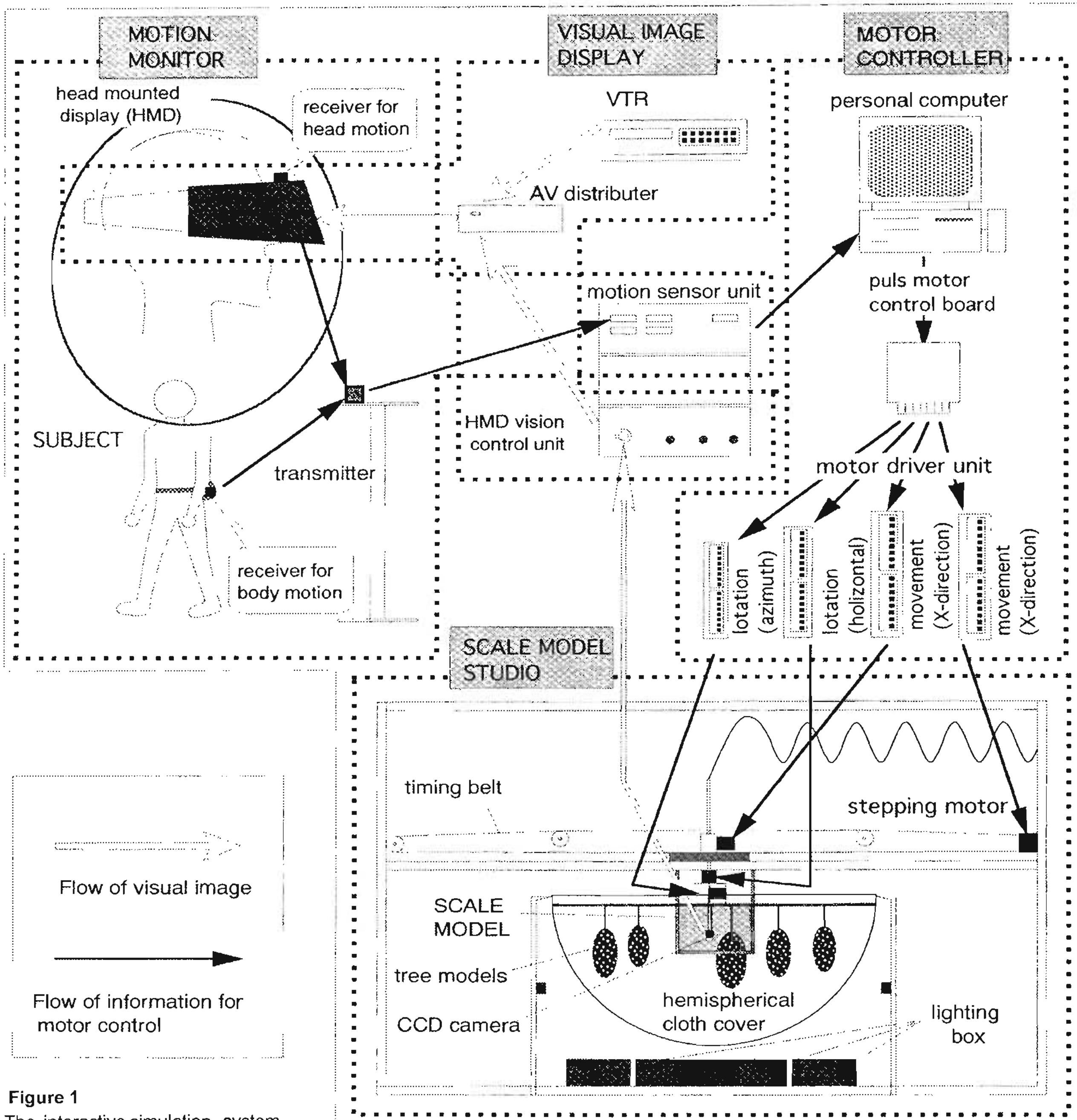

Figure 1
The interactive simulation system

Figure 2, A subjekt wearing the HMD is looking around the interior space of the scale model (The TV monitor shows the same visual image as the HMD)

Figure 3 The simulation apparatus: a CCD color TV camera is inserted into the model space (The hemispherical cloth sheet is partially removed to show the inside)

test the hypothesis concerning the weights of three types of „space establishing elements", objects, screens, and surfaces, in determining the degree of explicitness as a factor in the degree of enclosure (Thiel et al. 1986).

Following Thiel's experimental study, the present study was made to reexamine his hypothesis and to clarify the effect of the disposition of transparent and opaque surfaces on the occupants' „sense of enclosure". While Thiel's experiment used such a conventional technique as showing one-point perspective drawings, our experiment used the interactive simulation apparatus, which allowed subjects to "visit" a model space and look in any direction.

Method

An interactive simulation system *(Figure 1)* was designed to allow subjects, wearing a HMD, to virtually „visit" a scale model space. The CCD color TV camera inserted into the scale model space moves according to subjects head motion of „look around", „look down and up", and horizontal body motion. Subjects can look in any direction *(Figure 2)*. A scale model (1/10) of a living room of typical dimension in Japan (width x depth x ceiling height =4.5m x 4.5m x 2.4m) was made of an aluminum frame, and the finishes of four walls and one ceiling could be systematically varied with either transparent or opaque surfaces. The scale model was fixed to the apparatus upside down in order to insert the CCD camera through a hole made in the model floor: however, the display in the HMD was right side up.

A hemispherical cloth sheet was illuminated by fluorescent light to provide the exterior space of the model room, representing the sky *(Figure 3)*. Some trees were placed outside the room to give a sense of exterior space. The luminance of illumination was varied according to day and night conditions. Such furniture as a tea table and chairs were installed to provide realistic cues as to the absolute size of the space, and some lighting fixtures were installed to make reflected images on the glass surfaces for the night conditions.

Ten male and ten female university students, without an architectural education, were employed as subjects for this experiment. The experiment consisted of a series of twelve sessions in which test stimuli (spaces) were systematically varied with either transparent or opaque surfaces *(Figure 4)*. Before the experiment, the following instructions concerning the definition of „sense of enclosure" was given to the subject: „For the least enclosed condition, which we may experience in a large clear space with flat terrain, like a desert or a plain, we give the number „0"." Next, all test spaces were shown by pre-recorded videotape through the HMD. Then the standard stimulus (Space-H, see Figure 4), whose number (magnitude) of enclosure was defined as „100", was visually presented to a subject.

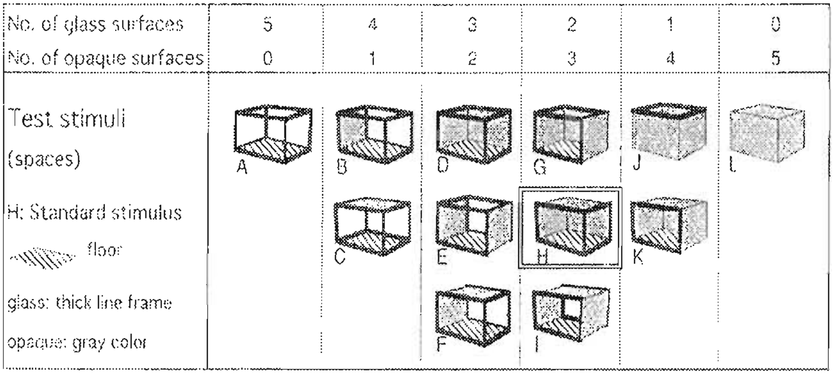

Figure 4 The twelve test stimuli

The task of the subjects was to compare each presented space with the standard stimuli and to render numerical estimates that were proportional to the magnitude of „sense of enclosure". The Subjects were allowed to view the space at will, with voluntary motions, and given as much time as they wished to complete the task. Every subject participated in both experiments of daytime and nighttime conditions.

Results and discussion

Although the range of numbers rendered by the individual subject was different, the rank order of the stimuli was fairly consistent. The Kendall's coefficient of concordance was 0.90 in daytime condition and 0.87 in nighttime condition. This consistency of subjects' responses implied that the simulation system was usable for evaluation of interior spaces. After the raw data of each subject was converted into z-scores (the standard deviation = 1, the mean = 0), the average score of the „sense of enclosure" (En) for each space was calculated.

Table 1 The average score and rank order of „sense of enclosure" for day and night conditions

Number of surfaces (glass / opaque)		5/0	4/1		3/2			2/3			1/4		0/5
space		A	B	C	D	E	F	G	H	I	J	K	L
Daytime	En (average score)	-1.66	-1.27	-0.94	-0.67	-0.57	-0.43	-0.13	0.12	0.45	0.67	0.92	1.79
	rank order	1	2	3	4	5	6	7	8	9	10	11	12
Nighttime	En (average score)	-1.34	-0.77	-0.99	-0.15	-0.12	-0.25	0.48	0.33	0.54	1.17	1.03	1.79
	rank order	1	*3*	*2*	*5*	*6*	*4*	*8*	*7*	9	*11*	*10*	12

As shown in Table 1 and Figure 5, the daytime average score increases as the number of transparent glass surfaces decreases. However, the rank order of the spaces with the same number of the glass surfaces was partially reversed for the nighttime. A careful examination of each case revealed that the ceiling surface in the daytime has a greater impact on the „sense of enclosure" than a wall surface, while the opposite was true in the nighttime.

In both day and night conditions, it was noted that Space-H had lower score, i.e. was perceived as less enclosed, than Space-I, even though both of them had same number of glass walls. Comparing these spaces, we noticed that the glass walls in Space-H are adjacent, while in Space-I two glass-walls are opposite each other. The difference of the scores between Space-D and Space-E can be also explained by the same reason.

As the above discussion indicates, the combination of the exterior conditions (day or night) and the position of transparent glass surfaces (ceiling or wall) influenced the judgment of a "sense of enclosure". Therefore, a functional relationship between the „sense of enclosure" and the total area of opaque surfaces was examined separately for each of four different conditions. As shown Figure 6, a linear regression line for each condition fits well (the correlation coefficient was more than 0.99). This means that we need to treat these phenomena separately according to four conditions; and if we treat them separately, it is explained by a fairly simple relationship.

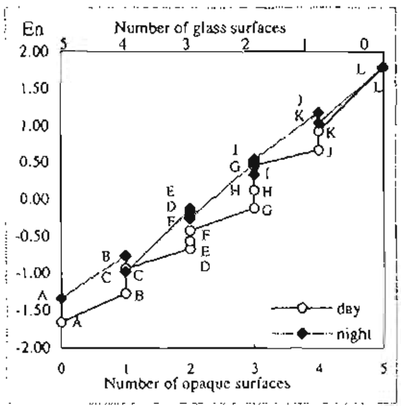

Figure 5 Relation between number of opaque surfaces and „sense of enclosure"

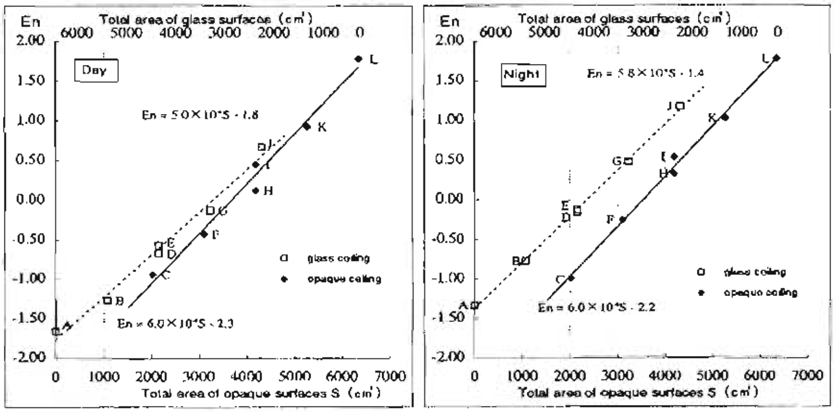

Figure 6 Relation between total area of opaque surfaces and „sence of enclosure"

Conclusion and implications

The result of experiment using the interactive simulation system generally supported Thiel's hypothesis in the daytime condition, although the following findings indicated that some modifications would be required.

(1) Judgements of „degree of enclosure“ depend on the disposition of transparent surfaces: subjects feel less enclosed in a space with two adjacent transparent walls than with other arrangements of the same number of transparent and opaque walls.

(2) Judgements of „degree of enclosure“ vary according to daytime and nighttime conditions: (a) the variance of „degree of enclosure“ between transparent and opaque surfaces was larger in the daytime than in the nighttime; (b) in the daytime, „degree of enclosure“ increases more in case that a transparent ceiling turns to an opaque ceiling than a transparent wall turns to an opaque wall, but the opposite was true in the nighttime.

(3) Judgments of „degree of enclosure“ clearly differentiated between spaces with transparent ceiling and those with an opaque ceiling.

Since the stimuli used in the experiment were limited number of scale models of identical size and proportion, further research is needed to determine the validity of the numerical relations obtained in this study.

CASE STUDY 2: SIMULATION OF AN EXTERIOR SPACE FOR ASSESSING THE ARTICULATION OF STREET SPACES

Objectives

When we walk along a street and enjoy a sequence of scenes, we may perceive a physically continuous street as a series of separated spaces of different atmosphere (Ohno and Kondo, 1994; Ohno, Hata and Kondo, 1996). The present study attempts to make clear some physical features which are influential for changing atmosphere based on the experiments conducted in existing and simulated spaces.

Experiment 1: on the site, Procedure

A popular shopping street in Tokyo, Omote Sando, 700m in length, was chosen as an experimental site *(Figure 7)*, and an experiment was conducted to clarify how people separate the street space into some local spaces of different atmosphere. Each of ten subjects was asked to stroll along the street, and to point out the places where one noticed the change of atmosphere. They were also asked the reasons why they felt the change of atmosphere.

Results

Figure 8 shows the results of experiment in which the vertical lines indicate the points where each subject noticed changes in atmosphere. It was noted that many subjects commonly pointed out same places as changing points *(Figure 9)*. From these results, the common articulation point was defined as the place where more than 25% of the subjects judged as changing point.

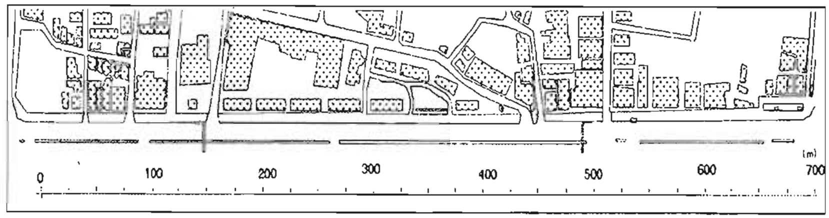

Figure 7 Plan of Omote Sando (north side)

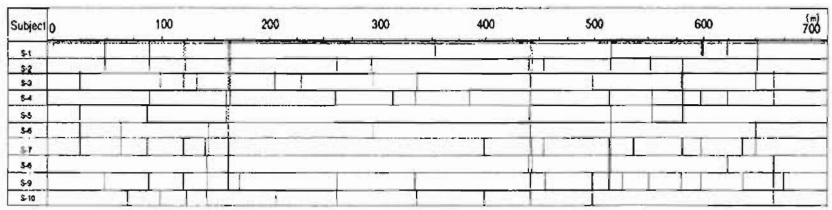

Figure 8 Judgement of each subjekt on a change of atmosphere

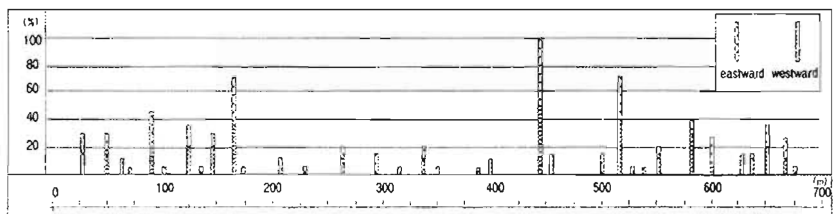

Figure 9 The pecentage of subjekts who feel a change of atmosphere

Relevant physical features

As compared the common articulation point obtained by the experiment with the changes in physical state, some physical features of the place where subjects noticed changes in atmosphere were extracted. The physical features which seemed to be influential for articulation of the street space were: 1) building's height, shape and spatial relation to the street, 2) colors and materials of the building façade, 3) existence/ absence of trees, 4) striking signboards and 5) temporary fences of construction sites.

Experiment 2: using an interactive simulation system, Procedure

An interactive simulation system was applied to examine the relevance of the obtained physical features to changes in atmosphere. The scale models (1/160) of buildings along the street were created by pasting the façade's photographs on the surface. The endoscope which was attached to the CCD camera was inserted into the street model, and the image of the space was presented to the subject through the HMD *(Figure 10)*. Within the model space, the subject could look around freely and move forward by operating the "mouse". An experiment using a series of modified model streets was conducted to verify the relevance of the physical features.

Prior to the experiment, availability of the simulation for judging articulation of the space was tested. A model of the existing Omote Sando Street was made and subjects were asked to point out the changing points in the simulated street. As the result *(Figure 11)*, the changing points were mostly extracted from the same places, but some difference in subjects' response were noted: 1) in the simulated street, subjects were more sensitive to the change of building height and spaces in front of the building, 2) changes in some places were noticed only in the real street probably due to the crowd of pedestrians.

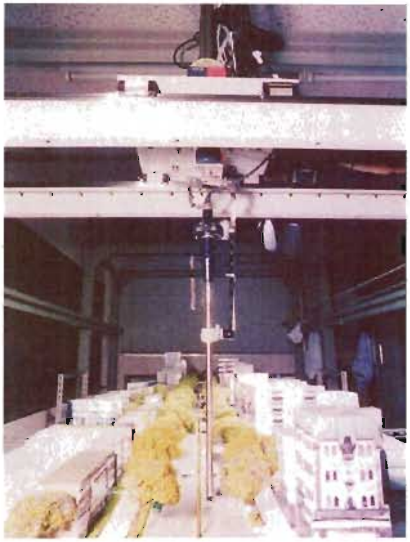

Figure 10 Endoscope and the street model

Results

Figure 12 shows, as an example, the result of experiment using pattern 2, one of the four modified models. It clearly shows the places where trees were removed and buildings were lowered were pointed out by many subjects as changing points, on the contrary, those places where trees were placed to make continuous row of trees, most subjects did not point out the change. Consequently, it was verified that the articulation of space was ascribable to such physical features as existence of trees and the height of building along the street. Table 2 shows the results of all patterns in this study. The cases that were failed to be verified may be due to the multiple factors were involved rather than single reason, or due to the non fixed features as people's activities on the street. This result suggests it necessary for us to carry out such simulations as have a combination of various physical features including the non fixed features.

Physical Features	Pattern 1	Pattern 2	Pattern 3	Pattern 4
Building Height (Raised)	●			
Building Height (Lowered)	×	●		
Building Shape (Changed)			×	
Wall Finish (Material)			●	×
Wall Finish (Color)			●	
Building (Setback)	●			
Building (Setforward)		×	×	
Building (Added)	●	×		×
Trees (Added)		●		●
Trees (Removed)		●		●
Fences (Added)	●			
Fences (Removed)		●		
Direction of Movement	Eastward	Westward	Eastward	Westward
	North		South	

● Verified × Not Verified

Table 2 Result of the examination changend physical fature

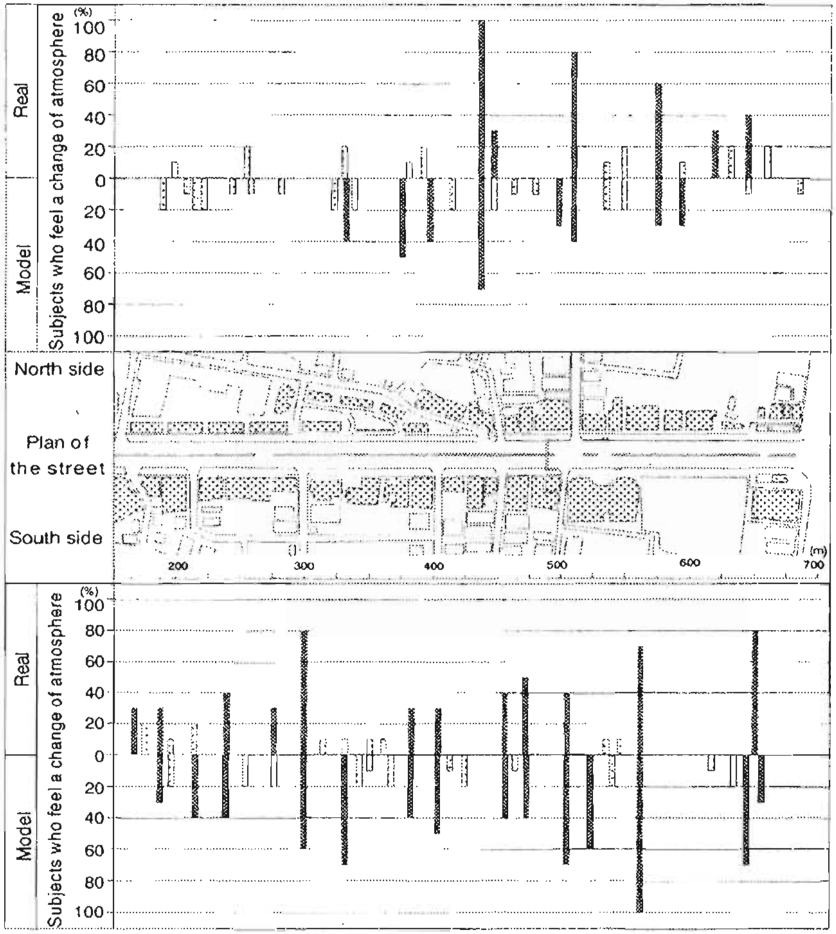

Figure 11 The comparison of changing points in the real street with that in the model street

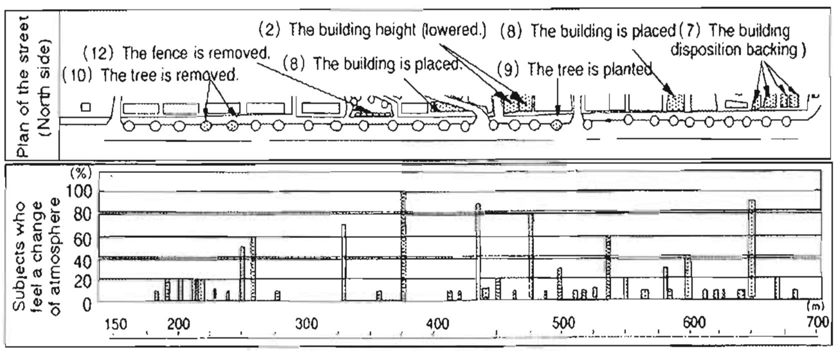

Figure 12 The changing points in the street (change physical fatures - pattern 2)

DEVELOPMENT OF A SIMULATION SYSTEM USING ENDOSCOPY AND COMPUTER GRAPHICS

Introduction

As we discussed previously, there are advantages and disadvantages in both analogue and digital methods. We developed a new interactive simulation system that attempted to take advantages of the two different methods. To test this simulator's performance, we conducted a preliminary experiment concerning the effect of movable elements on the environmental perception.

Description of a new simulation system

A new interactive simulation system *(Table 3)* shows such movable elements as pedestrians and cars against static environmental background. These movable elements generated by real-time CG are overlaid on the video image of a scale model space taken by an endoscope. The simulated picture, presented to a subject by a HMD, appears according to subjects head motion of „look around" and body motion of "walk forward".

In the CG system, pedestrians and cars need to be modeled and their motions are programed in advance. Buildings are also modeled to hide those movable elements which go behind the building. In order to overlay the CG image on the video image by chroma-key technique, the buildings and the background of the CG image are colored in blue. As shown in Figure 13, a personal computer receives the subject's rotation data from a Polhemus sensor on the HMD and the translation data from the mouse which is handled by the subject. The data are transfer to the graphic workstation and to the controllers of the DC servomotors simultaneously. The graphic workstation controls the CG image accordingly by virtual reality software. Finally, the real-time CG is overlaid on the video image of a scale model space by a digital chromakeyer and the simulated picture is presented to the subject by the HMD.

	Manufacuturer	Products
Hardware	SGI	O2 R10000/250MHz (Graphic workstation)
	NEC	PC-9801V16/166MHz (Motor control)
Software	Alias Wavefront	Explorer Professional (Modeling and Animation)
	Media Lab	Clovis VR (Virtual Reality)
Head-Mounted Display	Shimadzu	See-Through Vision STV-ES
Digital Chromakeyer	SONY	DCK-500
Digital Video	SONY	WV-D10000

Table 3 Specification of the interactive simulation system

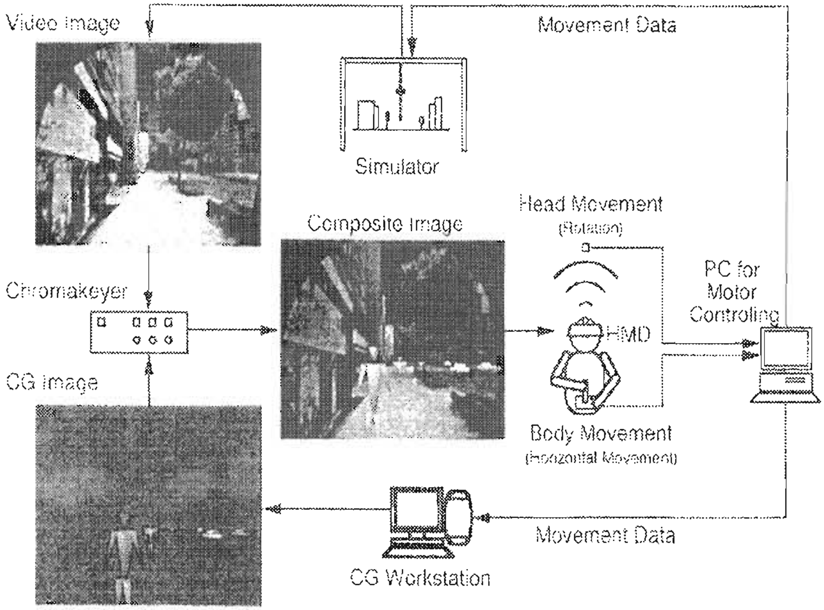

Figure 13 The new interactive simulation system

A preliminary experiment, Procedure

As noted in the previous experiment, there are some differences in subjects' responses in the real and the model spaces. Part of the reasons may be absence of pedestrians and cars in the scale model simulation. The flow of pedestrian may weaken the impact of buildings' characteristics, and a crowd of people may affect the atmosphere. In order to test the influence of such movable elements as pedestrians and cars on the subjects' judgement of articulation, an experiment was conducted in the places where the judgement in the real street differed from that in the model street. Five subjects was asked to point out the place where they noticed the change while walking through the image of scale model space on which pedestrians and cars produced by real-time CG were overlaid. The CG image moves according to subject's motion.

Results

The subway entrance near the east end of the street was marked as changing point in the real situation, but was not noticed in the model street *(Figure 11, top).* However, as shown in Figure 14 (A), after adding pedestrian flow, it became noticeable place. Because of the subway entrance, pedestrians flow pattern was different from other part of the street.

Another place where a building setbacks was noticed in the model space was not noticed in the real situation (*Figure 11, bottom*). It was considered that the pedestrian flow might weaken the impact of building shape and its relation to the street. However, the result of the experiment with movable elements have not support this assumption *(Figure 14 (B))*.

In this preliminary experiment, we found some effects of movable elements on the environmental perception in some situations. Further study is necessary for more reliable results in the various situations with more improved simulation system.

Conclusions

The performance of the interactive simulation system was tested by applying to empirical studies concerning psychological impact of interior and exterior spaces, and the feasibility of the system for testing human perception of their environment was generally proved although some limitations were pointed out. A new interactive simulation system in which movable elements generated by real-time CG are overlaid on the video

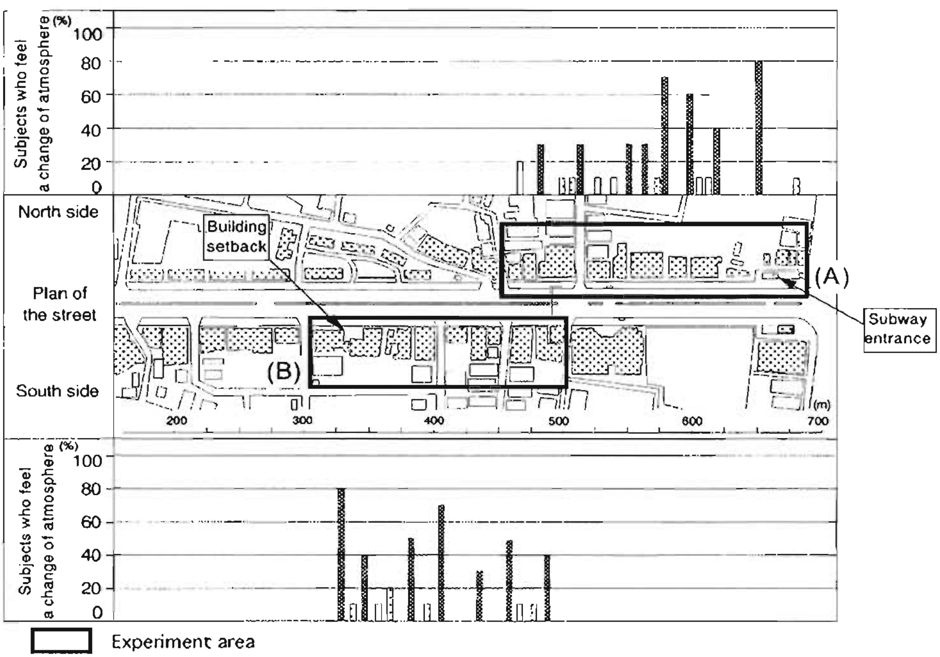

Figure 14 The changing points in the model street with moveable elements by CG

image of a scale model space was introduced. Though the new simulation system which uses both analogue and digital images is still its infancy, if the system is improved, it would be a useful tool to assess human behavior in the environment. In the present paper, we treated the simulation system as a research tool to assess architectural and urban spaces. However, the system is usable for architectural education and practice: it helps architects to communicate with the users, the managers, the contractors, the regulating agencies, and the investing clients of the new proposed environment.

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