Investigating the Possibility of Design Simulation Based on Mixed Reality

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We investigated the possibility of using the MR (Mixed Realty) technology in 3D design simulation for overcoming the limitation of human perception on the virtuality in traditional 3D CAD systems. This paper presents an experiment on how accurately and precisely CAD users can adjust the size of virtual objects with the reference of the real objects in an MR environment.

INTRODUCTION

Most of product designers use 3D CAD system as a powerful design tool and many new products are now developed through the concurrent engineering process. Consequently, various traditional design tools have been replaced by CAD systems and designers are now facing the new problems of the lack of tangibility. It is very difficult for designers to get the sense of reality from interim design outputs shown in the computer screens, as they do from physical mock-ups. Various rapid prototyping techniques are used as a solution but there are still limitations in term of the effectiveness and the cost.

In this paper, we propose and evaluate a MR-based solution for the above problem. MR allows the user to see the real world with virtual objects superimposed upon the real world (Figure1). MR-based CAD systems allow users to smoothly perceive physical relationships between virtual objects and the real world. The users can compare the attributes of virtual objects in relation with real objects and adjust them more intuitively.

Figure 2 shows the concept of the proposed 3D design simulation based on MR. Designers use the traditional 3D CAD system for design modeling. The MR environment merges the virtual model and the real world by calculating the logical and the physical relationship. CAD users then observe a realistic 3-dimesional design output and evaluate predicted problems of tentative design solutions. Designers can also simulate various properties, such as size, color, proposition and feature permutation, and the results of simulation are fed back to the 3D CAD system in real time.

From the concept of new way of design simulation, we attempted to investigate how accurately and precisely CAD users can adjust the size of virtual objects with the reference of the real objects in an MR environment.

Figure 1 A virtual kettle in the real world

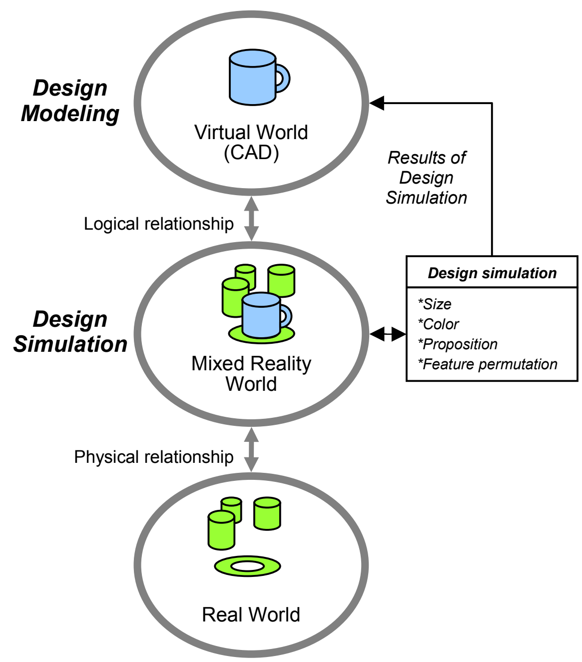

Figure 2 Design simulation based on mixed reality

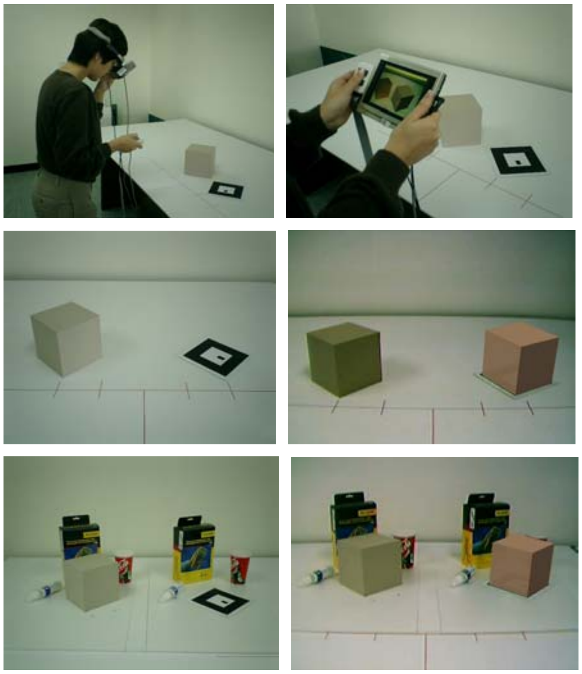

Figure3. Scaling a virtual cube with the HMD (upper left) and the LCD panel ((upper right), Context-poor condition middle left) and context-rich condition middle right), The MR view presented to the subjects lower left and right)

EXPERIMENT

Among many functional attributes of the 3D design simulation system, we focused on scaling in our initial study. We carried out an experiment to examine how accurately and precisely CAD users can adjust the size of virtual objects with the reference of the real objects in the MR environments. MR provides abundant tangible scaling clues for CAD users, so we investigate whether real objects in the background have an effect on the human perception of the size of virtual objects.

We also compared the display devices for MR. In general, HMD is widely used as a display device for VR and MR, but HMD is too burdensome to use in the real world. So, we adopted a 5.6" hand-held LCD panel, as TransVision [1], and compared its scaling accuracy and precision with that of the VGA HMD condition.

METHOD

The MR-based 3D design simulation system was built using vision-based SDK "ARToolKit" [2]. The system captures real world video through a small PC camera (FOV=60°), detects a 160*160mm printed marker and

			Display	
			HMD	LCD
Context	Poor	(a) Size of reference real cube	150	150
		(b) Adjusted size of virtual cube	147.2	149.3
		(c) error(a-b)	2.8**	0.7
		(d) STDEV	8.7	8.6
		(e) Relative error	1.9%	0.5%
		(f) Relative STDEV	5.9%	5.8%
	Rich	(a) Size of reference real cube	150	150
		(b) Adjusted size of virtual cube	150.6	150.1
		(c) error(a-b)	-0.6	-0.1
		(d) STDEV	8.8	9.3
		(e) Relative error	-0.4%	-0.1%
		(f) Relative STDEV	5.9%	6.2%

Table1. Results from context-richness and display type experiments (Distance between real and virtual cubes = 500mm, Size of real cube = 150mm)

			Display	
			HMD	LCD
Distance	250mm	(a) Size of reference real cube	150	150
		(b) Adjusted size of virtual cube	147.1	149.7
		(c) error(a-b)	2.9**	0.3
		(d) STDEV	6	5.8
		(e) Relative error	1.9%	0.2%
		(f) Relative STDEV	4.1%	3.8%
	500mm	(a) Size of reference real cube	150	150
		(b) Adjusted size of virtual cube	147.2	149.3
		(c) error (a-b)	2.8**	0.7
		(d) STDEV	8.7	8.6
		(e) Relative error	1.9%	0.5%
		(f) Relative STDEV	5.9%	5.8%

Table2. Results from distances and display type experiments (Context-richness= poor, Size of real cube = 150mm)

			Display	
			HMD	LCD
Cube size	50mm	(a) Size of reference real cube	50	50
		(b) Adjusted size of virtual cube	48.4	49.2
		(c) error(a-b)	1.6**	0.8**
		(d) STDEV	2.7	2.0
		(e) Relative error	3.2%	1.6%
		(f) Relative STDEV	5.6%	4.1%
	150mm	(a) Size of reference real cube	150	150
		(b) Adjusted size of virtual cube	147.1	149.7
		(c) error(a-b)	2.9**	0.3
		(d) STDEV	6.0	5.8
		(e) Relative error	1.9%	0.2%
		(f) Relative STDEV	4.1%	3.8%

Table3. Results from distances and display type experiments (Context-richness= poor, Distance between real and virtual cubes = 250mm)

registers a virtual cube on it, so that the users perceive the depth of the virtual object in 3D. A 150×150×150mm real cube was also presented as a reference object for the scaling experiment. The design of experiment involved three factors, that is, the type of display device (HMD/LCD), context-richness (existence of background reference objects) and the distance between the virtual cube and the real cube (250mm/ 500mm).

A couple of two-factorial experiments were conducted with 30 subjects (average age = 21.9, university students using 3D CAD system) and each treatment had 5 replicates. The initial size of the virtual cube was presented at random and the subjects were asked to adjust the size of virtual cube to be same with the real reference cube. After the experiment, the subjects also were asked to evaluate the ease of use with HMD and LCD panel using a 5-point scale. The size of virtual cube (VC) is set to be calculated from scale factor (SF) and visual marker size (MS) as following equation.

$$VC = SF*MS/80$$

RESULTS

Context-richness and device type

The results of the experiment suggests that there is a significant difference ($p<0.00025$) between the size of the virtual and the real cube only in the context-poor and HMD-use situation. But, in all other situations, the subjects were able to adjust the size of virtual cube to be same with the real reference cube accurately enough within 0.5% relative error (Table1). As the result of ANOVA test, it was found that context-richness ($F(1,149)=11.186$, $p= 0.001$) and display type & context-richness interaction ($F(1, 149) = 7.596$, $p<0.007$) have a significant effect on scaling accuracy (Figure 4).

Distance and device type

The context-richness and the display type do not affect scaling precision significantly, but the decrement of distance between the real reference cube and the virtual cube improves scaling precision significantly (distance =250mm / RSD=3.9%, distance = 500mm / RSD= 5.8%) (Table2). We found that device type has a significant effect ($F(1,149)=27.897$, $p<0.00025$) on scaling accuracy over the distance between real and virtual objects (Figure5).

Cube size and device type

The decrement of the reference cube size made scaling accuracy worse and there were significant scaling errors in the experiments with 50mm reference cube (Table 3). As the result of regression analysis, we drew following equations about the relationship between the size of reference cube (VC) and adjusted virtual cube (RC).

HMD: $VC = -0.990+0.988RC$ ($R^2=0.991$) (Figure6)

LCD: $VC = -1.050+1.005RC$ ($R^2=0.996$) (Figure7)

Subjective evaluation for ease of scaling

The 5-point scale subjective evaluation showed

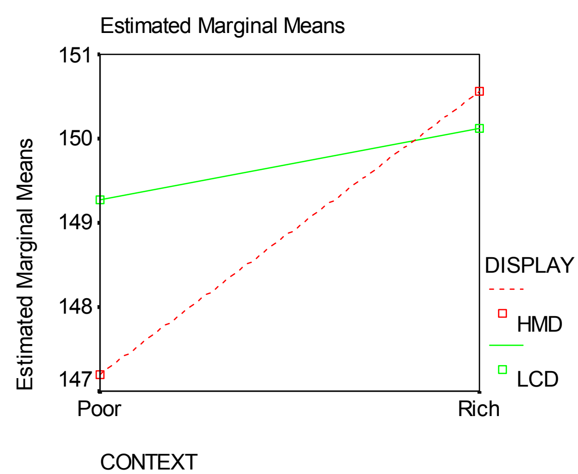

Figure4 .Plot of Context-richness-display type interaction

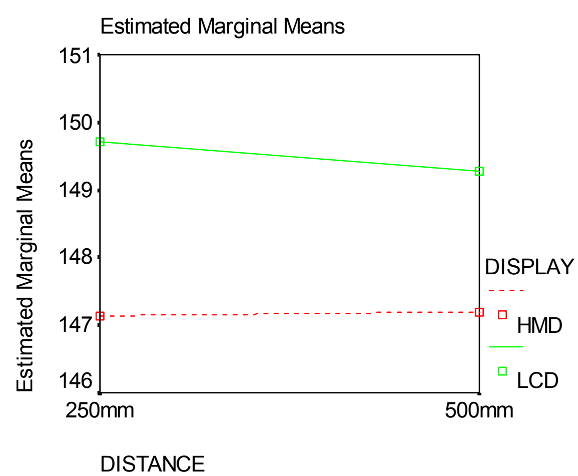

Figure5. Plot of distance-display type interaction

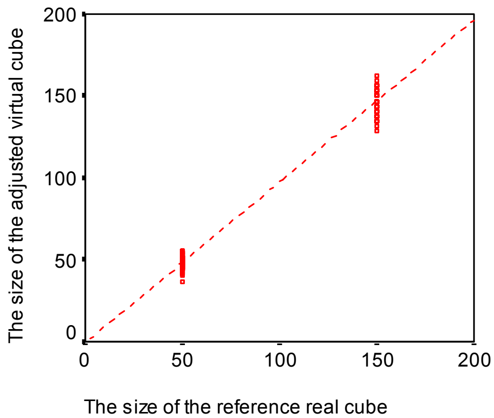

Figure6. Regression analysis of adjusted virtual cube size over reference real cube size in the case of using HMD

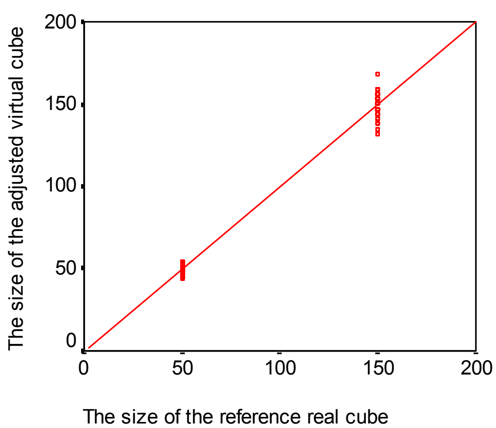

Figure7. Regression analysis of adjusted virtual cube size over reference real cube size in the case of using LCD panel

slightly higher user preference on LCD panel (2.8/5.0) than HMD (2.5/ 5.0).

DISCUSSION AND CONCLUSION

One of interesting findings was that CAD users tend to perceive a virtual object bigger than a real object only in the context-poor and HMD-use situation. It may be inferred that this result is caused by the fish-eye distortion of the PC camera. The subjects had a tendency to put the virtual cube in the center of view port, and the real reference cube looks smaller relatively. However, in all other situations, the camera distortion may be compensated by many scaling clues obtained from background objects and the ambient environment.

On the other hand, the scaling precision needs to be improved for the vision-based MR technology to become a practical 3D design simulation tool. This may be achieved by reducing the camera distortion, improving the visual quality and seamlessly blending them with the view of the real world. In conclusion, the results show that MR technology has the potential to be used efficiently in design simulation and LCD panel is not inferior to HMD as a display device.

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