Usability Studies In Virtual And Traditional Computer Aided Design Environments For Fault Identification

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ABSTRACT

A usability study was used to measure user performance and user preferences for a CAVE^TM immersive stereoscopic virtual environment with wand interfaces compared directly with a workstation non-stereoscopic traditional CAD interface with keyboard and mouse. In both the CAVE^TM and the adaptable technology environments, crystal eye glasses are used to produce a stereoscopic view. An ascension flock of birds tracking system is used for tracking the user's head and wand pointing device positions in 3D space.

It is argued that with these immersive technologies, including the use of gestures and hand movements, a more natural interface in immersive virtual environments is possible. Such an interface allows a more rapid and efficient set of actions to recognize geometry, interaction within a spatial environment, the ability to find errors, and navigate through a virtual environment. The wand interface provides a significantly improved means of interaction. This study quantitatively measures the differences in interaction when compared with traditional human computer interfaces.

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This paper provides analysis via usability study methods for Fault Identification termed as Benchmark 4. During testing, testers are given some time to "play around" with the CAVE™ environment for familiarity before undertaking a specific exercise. The testers are then instructed regarding tasks to be completed, and are asked to work quickly without sacrificing accuracy. The research team timed each task, and recorded activity on evaluation sheets for Fault Identification Test. At the completion of the testing scenario involving Fault Identification, the subject/testers were given a survey document and asked to respond by checking boxes to communicate their subjective opinions.

Keywords: **Usability Analysis; CAVE™ (Cave Automatic Virtual Environments); Human Computer Interface (HCI); Benchmark; Virtual Reality; Virtual Environments; Competitive Comparison**

INTRODUCTION

This paper is an extension of the work done by Satter (2005) on Competitive Usability Studies of Virtual Environments for Shipbuilding. The key difference is the use of a new immersive environment called CAVE™. The significance and the detail description of this study is very well explained by Satter (2012) in his recent paper. Here we only present the details of this usability study. The CAVE™ was developed at the University of Illinois at Chicago and provides the illusion of immersion by projecting stereo images on the walls and floor of a room-sized cube. Several users wearing lightweight stereo glasses can enter and walk freely inside the CAVE™. A head tracking system continuously adjusts the stereo projection to the current position of the leading viewer. A CAVE™ and wand system schematic is shown in Figures 1 & 2.

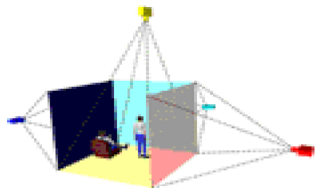

Figure 1: Schematic of the CAVE™ System

Figure 2: The Wand Interface

BENCHMARK 4 (FAULT IDENTIFICATION)

1. Description

In a typical design review process, a design space is presented to the reviewer(s) who examine the space for design flaws (faults). The purpose of this study is to help determine the applicability/usability of various user interfaces (both stereoscopic and non-stereoscopic) in improving this process. Based on the preliminary results of the previous Benchmark testing, a fourth Benchmark scenario was prepared to use the stereoscopic CAVE™ environment for the location and identification of faults within a design space. The scenario implemented and reported here is built upon the operations and scenarios developed for Benchmarks 1, 2, and 3.

Using the same virtual factory space as used for Benchmark 1, ten distinct design faults were injected into this space similar to those prepared for Benchmark 2 (find/repair). However, the Benchmark 4 testing requires only that the users utilize the interface to locate and identify as many of these faults as possible in four minutes. As with the previous testing, each user searches the faults utilizing the traditional CAD workstation (non-stereoscopic interface) and the stereoscopic wand interface in the CAVE^{TM} environment. The two scenario sequences were randomized (non-stereoscopic vs. CAVE^{TM}) and users were randomly assigned to start with either the non-stereoscopic interface or in the CAVE^{TM} environment.

As each user progressed through the active scenario/environment locating and identifying faults, the specific fault and the elapsed time was recorded for the analysis. Although this method provides a significant quantity of data, for Benchmark 4, the key metric for comparison was the total number of faults found in each environment.

This exercise (Benchmark 4) was repeated in each of the two environments under test and the User Survey administered to each user after each pass in each environment. As with the other Benchmark testing, sequencing of the testers through the two environments was randomized so that not all of the users were testing the same interface in the same order. This randomization was used to eliminate bias in the testing.

2. *Benchmark 4, Pass 3, faults count Analysis:*

The following is a presentation of the Benchmark 4, pass 3; faults count analysis for all the users. Pass 3 results are presented here as representative of user best-final case results. All other results are presented in Appendix D [3]

Figure 3 presents the user's ability to find faults in a span of four minutes in each of the two environments. The results clearly indicate a higher fault count using the stereoscopic CAVE^{TM} environment. In CAVE^{TM}, users on an average located 9.17 or 9 out of 10 faults in a span of 4 minutes. On the other hand, in workstation, users on an average located 7.1 or 7 out of 10 faults in a span of 4 minutes.

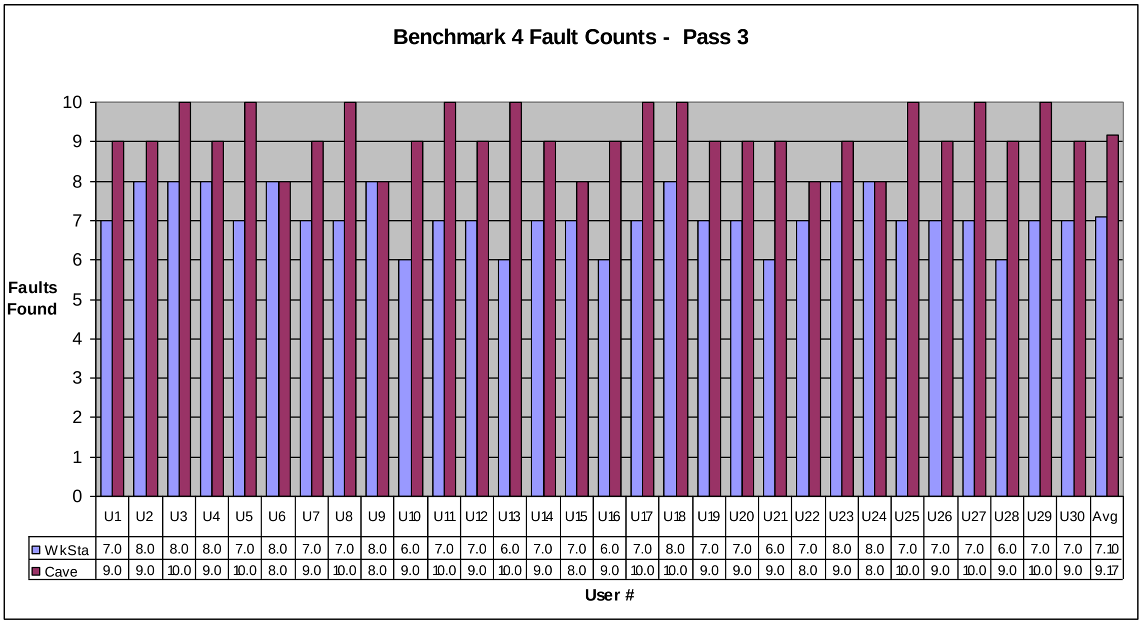

Figure 3: B4p3 Faults Count

B4P3	# Users	Mean	St. Dev.	Low	High	P Value	Normal?	CV
Cave	30	9.17	0.7	8	10	<0.10	No	1%
W/S	30	7.1	0.66	6	8	<0.10	No	1%
		Homogeneity of Variance			Test for Differences			
		Levene's Test		Equal Var?	Mann-Whitney Test		Equal?	Significant?
		F-Value	Pr > F		Value	Pr > T		
Cave vs W/S		0.26	0.61	Yes	6.53	<0.001	No	Cave

Table 1: B4p3 Faults Count Statistics

3. B4p3- Benchmark 4 Pass 3 Descriptive Statistics

Table 1 (Benchmark 4 pass 3 faults count / B4p3) presents the results of the descriptive statistics analysis of user's pass 3 faults count in the two-test environment. The K.S. test is used to test for normality of data. Since the P value is less than 0.1, the data are not normal. The Levene's test to test for equal variance was then used. Since the P value is greater than 0.1 the data have equal variance. Since the data are not normal, Mann Whitney test is used. With the Mann Whitney test, P value is less than 0.1, which indicates that medians are unequal for CAVE^{TM} and workstation. Examination of these results shows that for the two environments, the differences are statistically significant. The conclusion then is that at the 90% confidence level, there is significant evidence to support the alternative hypothesis (H_a). Thus, since the stereoscopic wand environment demonstrates faster faults count, CAVE^{TM} is statistically "better" than non-stereoscopic workstation environment for Benchmark 4 during pass 3.

4. Benchmark 4 passes 3 Overall Impressions Ratings Analysis:

Figure 4 (Benchmark 4 pass 3 Overall Impressions Ratings / B4p3Ovr) graphically presents comparisons of the Benchmark 4 (faults count) pass 3 overall ratings of the two environments. Inspection of the average ratings shows that users preferred the stereoscopic environment (CAVE^{TM}) over the non-stereoscopic environment (workstation).

5. Detailed Statistical Analysis

The following sections present a detailed statistical analysis of user overall impressions ratings of the two test environments following their 3rd and final pass of the Benchmark 4 scenario. All other results are presented in Appendix D [3]. The statistical analysis of these ratings provides insight into the final opinions of the users. As discussed before, the NCSS software package was used to perform each analysis. Each set of user overall impressions ratings is first examined to determine if the data are normally distributed (Gaussian distribution) using the KS statistic. The descriptive statistics test results are presented in tabular form followed by the results of Levene's test for equal variance of the data. The null hypothesis (H_0) and alternative hypothesis (H_a) discussed for Benchmark 1 statistical analysis testing applies here (Benchmark 4) as well.

6. Benchmark 4 Pass 3 Overall Impressions Ratings Statistics

Table 2 presents the results of the descriptive statistics analysis of user's Benchmark 4 pass 3 overall impressions of the interface. The K.S. test is used to test for normality of data. Since the P value is less than 0.1 for workstation and the CAVE™, the data are not normal. Levene's test is used to test for equal variance; since the P value is greater than 0.1 the data have equal variance. Since the data are not normal, Mann Whitney test is used. But with Mann Whitney test, P value is less than 0.1, which indicates that medians are unequal for the CAVE™ and workstation. Examination of these results shows that for the two environments, the differences are statistically significant. The conclusion then is that at the 90% confidence level, there is significant evidence to support the alternative hypothesis (H_a). This proves that the CAVE™ environment is preferred over workstation environment in Benchmark 4 pass 3 overall impressions subjective ratings.

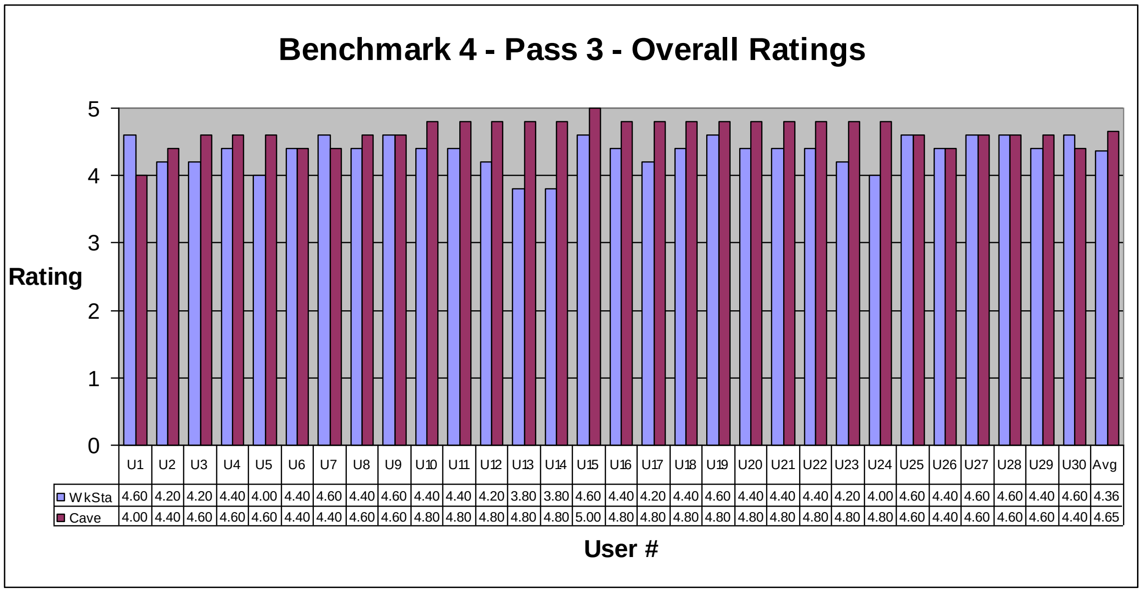

Figure 4: B4p3Ovr Overall Impressions Ratings

B4OP3	# Users	Mean	St. Dev.	Low	High	P Value	Normal?	CV
Cave	30	4.65	0.2	4	5.00	<0.10	No	4.00%
W/S	30	4.36	0.23	3.8	4.60	<0.10	No	5.00%
		Homogeneity of Variance			Test for Differences			
		Levene's Test		Equal Var?	Mann-WhitneyTest		Equal?	Significant?
		F-Value	P Value		Value	P Value		
Cave vs W/S		0.01	0.99	Yes	-4.69	<0.001	No	Cave

Table 2: B4p3Ovr Overall Impressions Ratings Statistics

B4 Pass to Pass Comparison

	Pass1 to Pass2		Pass2 to Pass 3		Pass1 to Pass3	
	Diff	%	Diff	%	Diff	%
Cave	-0.93	-12%	-0.77	-9%	-1.7	-23%
W/S	-0.93	-16%	-0.37	-5%	-1.3	-22%

Table 3: B4 Pass-to-Pass Comparison of Faults Count

Table 3 presents pass-to-pass comparison of Benchmark 4 (Faults Count). The negative values in table 3 prove that pass 1 faults count was less than pass 2 and pass 2 faults count was less than pass 3. For example a value of -22% for Workstation (pass 1 to pass 3) is calculated as (5.8-7.1)/5.8, where 5.8 and 7.1 represent the means of Benchmark 4 for pass 1 and pass 3 respectively. From table 3 one can conclude that user's showed more improvement from pass-to-pass in the $CAVE^{TM}$ than in workstation. This is due to the fact that users found the faults easily in a four screen $CAVE^{TM}$ than on a single screen traditional CAD workstation.

B4 Overall Ratings Pass to Pass Comparison

	Pass1 to Pass2		Pass2 to Pass 3		Pass1 to Pass3	
	Diff	%	Diff	%	Diff	%
Cave	0.44	-13%	-0.69	-17%	-1.13	-32%
W/S	0.2	6%	-0.83	-24%	1.03	31%

Table 4: B4 Overall Impressions Ratings Pass to Pass Comparison

Table 4 presents pass-to-pass comparison of Benchmark 4 overall impressions subjective ratings. The negative values in table 4 prove that pass 1 ratings were lower than pass 2 and pass 2 ratings were lower than pass 3. For example a value of -32% for $CAVE^{TM}$ (pass 1 to pass 3) is calculated as (3.52-4.65)/3.52, where 3.52 and 4.65 represent the means of Benchmark 4 overall impressions ratings for pass 1 and pass 3 respectively. From table 4 one can conclude that the $CAVE^{TM}$ environment is preferred over workstation.

Usability Survey

User ID: ______

Environment: 19" CAD Stereo

Pass: 1 2 3

		Very Good 5	Good 4	Neutral 3	Poor 2	Very Poor 1
	Navigation					
1	Initial impression of navigational modes					
2	Gross control movement					
3	Speed of cursor/pointer movement					
4	Ability to make fine adjustments to the placement of the cursor/pointer					
5	Ability to recover cursor/pointer movements					
6	Ease of use					
7	After-test impression of the navigational modes					
	Locating					
1	Initial impression of the interface in locating specific parts/equipment					
2	Ease of identification of selected part/equipment					
3	Ability to make fine adjustments in selecting specific parts/equipment					
4	Ease of use					
5	After-test impression of the location/selection mechanism					
	Movement					
1	Initial impression of the interface for relocating parts/equipment					
2	Ease of movement across the three axis					
3	Ability to make fine part/equipment movement adjustments					
4	Ease of use					
5	After-test impression of the movement mechanism					
	General					
1	Initial impression of the overall system					
2	Ability to relate a 2D planform to the space as presented					
3	"Intuitiveness" of the interface - do the controls follow expected use?					
4	Overall ease of use					
5	After-test impression of the overall system.					

Comments

Figure 5: Usability Survey Questionnaire (Satter, 2005)

7. CONCLUSIONS

For Benchmark 4 (shopping list), the statistics shows better results (lower timings and higher subjective ratings) for the CAVE^{TM} in both objective and subjective measures than the workstation.

The results presented below prove the objective of this research that the state of the art Perceptual User Interface or PUI (CAVE^{TM} and wand) are much better, efficient, faster environment than the traditional Graphical User Interface GUI (Workstation and mouse),

- 94% of the results were in favor of CAVE^{TM} in both objective and subjective measures.
- 2/3 of the results for pass-to-pass improvement were better for the CAVE^{TM} for both objective and subjective measures.

AUTHOR INFORMATION

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