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Usability Testing of Virtual Reality Aided Design: Framework for Prototype Development and a Test Scenario

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Abstract

We have built a framework for using 3D modelling applications in an immersive virtual environment. In this paper we compare our immersive user interface made for an existing application to its original 2D desktop counterpart. The immersive 3D user interface was built on top of a generic distributed rendering framework on a cave–like virtual reality system. A test scenario was designed for comparing basic polygonal 3D modelling with these two user interfaces. Preliminary results of the user test are presented. Results indicate that the test scenario is viable and point out the need for further development.

Keywords: Virtual Reality, CAD, 3D Modelling, 3D User Interface, Usability Testing

1. Introduction

In the past years a wide range of computer-aided design, modelling and animation application prototypes for virtual environments (VE) have been introduced and related technology and methods widely investigated. Along the introduction of these prototypes, the possible benefits to be gained by the virtual reality aided design (VRAD) technology have been proposed. Most common motivation for the development of these VRAD prototypes appears to be the indication that virtual reality (VR) allows more intuitive and natural user interface (UI) compared to the traditional desktop 2D UI of the contemporary CAD and 3D modelling software. Furthermore, VRAD has also been expected to reduce the required training period and increase the labour productivity (Bruno et al, 2002; Li et al 2003; Ye et al, 2006). Despite these expectations and effort used in this research area, little formal evaluation based on usability metrics has been carried out to validate these expected benefits of the VRAD.

In this paper we describe the work we have done for comparing a 2D UI of an existing 3D modelling application with an immersive 3D UI that we have built for the same application. Immersive 3D UI has been built using a distributed rendering framework that allows us to render a range of existing 3D applications in an immersive cave–like VE. In this paper we present an overview of the framework. We have also developed a test scenario, which allows us to test and collect usability metrics from basic polygonal modelling tasks performed using the 3D modelling application with the original 2D UI and with our immersive 3D UI. In this paper, we describe the test scenario and present the preliminary results from a pilot test, carried out using our test scenario.

2. Related Work

VRAD as such is not a novel research area. Prototypes with various 3D modelling approaches have emerged repeatedly since the pioneering days of VR. In general, the research related with VRAD has been dominated by applied research, in which the technology and solutions concerning the development of prototypes has been the main interest. Within the VRAD research field, usability testing, especially in task context, has so far had a minor role (Deisinger et al, 2000; Fiorentino et al, 2004).

Applied research has produced prototypes focusing on a range of specific modelling tasks, such as free-form surface modelling, solid modelling and virtual clay sculpting. Examples of more recent applied research are (Grossman et al, 2001; Schkolne et al, 2001; Wesche and Seidel, 2001; Perles and Vance, 2002; Fiorentino et al, 2002; Akgunduz and Yu, 2004; Fleisch et al, 2004).

The fore mentioned research has mainly focused on describing the development of the various VRAD prototype systems with mainly cursory consideration on empirical validation of their usability. From human computer interaction (HCI) point of view, the research introduced in this paper builds on concept and ideas of direct manipulation as described by (Shneiderman, 1983). Similar formal HCI evaluations, in the context of 3D manipulation, include work by (Mine et al, 1997; Balakrishnan and Kurtenbach, 1999; Kalawsky et al, 1999). Some of the most similar evaluation, in the task context of immersive 3D modelling, includes work by (Deisinger et al, 2000; Fiorentino et al, 2004).

3. Framework

For the testing in VE we use a two-wall cave–like display system called Upponurkka. Details of Upponurkka system have been previously reported by (Lokki et al, 2006). The display system has two front-projected display walls and optical tracking for detecting user's head and pointing device location. To be able to use a range of existing applications with our VR system, we have built a new distributed rendering framework for it.

The new framework is built on the top of Chromium (Humphreys, 2002). Chromium is a system for manipulating streams of graphics API commands on clusters of workstations. For our purpose we have added two features to Chromium. First, we have developed a module for modifying the view and projection settings of the application. The head location of the user is tracked in the VE, and view and projection settings of each rendering process are modified accordingly. Since these view and projection modifications are done outside the application and applied to the captured OpenGL stream, the application does not need any modifications to be rendered with our VR system. Second modification is for keystone correcting the images of the display projectors. Projectors are positioned to a high angle above display walls to avoid shadows to be cast from the users to the walls, and therefore additional keystone correction is required.

So far, we have successfully tested two open source 3D modelling and animation applications, Blender and Wings 3D, and a 3D game, Quake III, on our framework. For our test scenario we have chosen to use Blender. Blender is a well-known and widely used open source 3D modelling application, and access to its C language source code allowed us to implement the modifications that we needed for the testing.

4. Usability Testing

Using our framework and by modifying Blender 3D modelling application we have enabled basic modelling tasks to be performed with Blender in our VE. Based on this work we have developed a test scenario that allows us to compare the usage of Blender with its original 2D UI to its usage in VE with our immersive 3D UI. This test setup enables benchmarking of the immersive 3D UI with a 2D UI of the existing 3D modelling application, which is to our knowledge unique within the field of VRAD.

In our current research project, we are developing bimanual 3D UIs for modelling and animation tasks. To help our work in designing these UIs, we need a clear understanding of effects and benefits that 3D UIs provide in this specific application area. With this motivation we have formulated the following research hypotheses:

1. Direct manipulation is more efficient with 3D UI in terms of speed.
2. Users will find direct manipulation tools less distracting in 3D than in 2D, as the task flow will contain fewer explicit mode and tool changes.
3. Users will find 3D UI more natural, since all three dimensional direct manipulation operations can be performed intuitively in three dimensions. With 2D UI users need to compile all such operations from series of 2D manipulation operations.
4. Users will prefer 3D to 2D in direct manipulation tasks of imprecise polygonal geometry manipulation.

The presented usability test focused on an elementary 3D modelling task of selection and translation of polygonal object mesh vertices. In the test, users were instructed to perform geometry modifications and their actions were recorded and measured. The same tasks were performed using the modelling application with its original 2D UI on a desktop PC, and using the same application with the developed 3D UI on our VR system. Except for the 3D manipulation methods, 3D UI was kept as similar as possible with the 2D UI in order to keep the comparison viable.

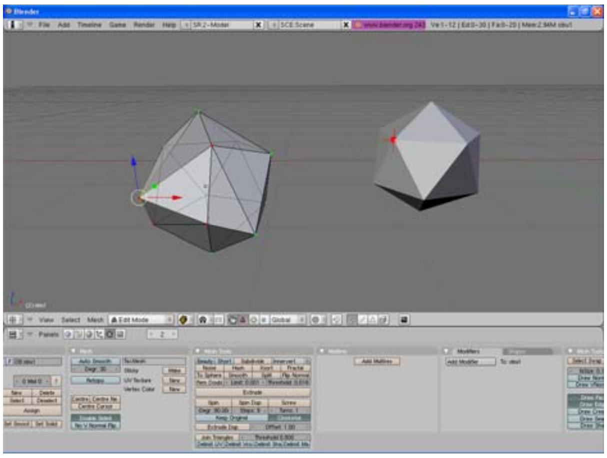

Figure 1. Test scene setup.

4.1. Test Scenario

In our test scenario, there were two polygonal objects placed in the 3D work space of the modelling application. One of the objects was a reference that defined what kind of shape the user was expected to form from the second object. Users could manipulate the second object by selecting and moving vertices, one vertex at a time. In the second object, a number of vertex locations deviated from the vertex locations of the reference object. Users were asked to move the deviating vertices so that they would follow the locations of the reference object vertices. Each vertex of the modified object was colour-coded to indicate whether the vertex location corresponded to the location in reference object or not. Vertices that had an identical location were rendered green and vertices that were misplaced were colour-coded red. Furthermore, when user selected a vertex from the object to be modified, the corresponding vertex in the reference object was highlighted. Purpose of the highlighting was to inform the user which vertex in the reference object corresponded with the selected vertex, and where the selected

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vertex should have been located. The highlighting used same colour coding as selected vertex. See Figure 1 for an example of a test scene with vertex colour coding and highlighting. Object to be modified is on the left side and reference object is on the right side. The modified object has one vertex selected.

Users were asked to perform three different test cases where object shapes and the number of misplaced vertices varied. The objects and the number of misplaced vertices can be seen in the Figure 2.

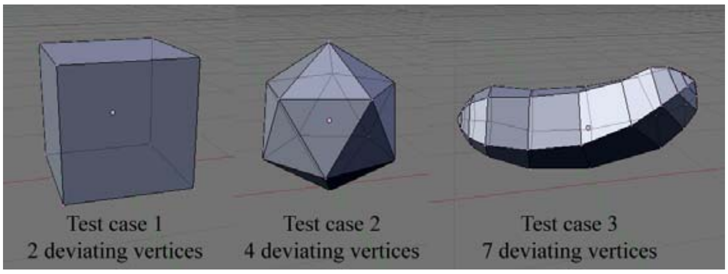

Figure 2. Test case objects and numbers of deviating vertices

4.2. Testing with the 2D UI

For testing with 2D UI, the original UI of the Blender 3D modelling application was kept unmodified, except for the vertex colour coding, highlighting and data recording. With 2D UI, users worked on a standard desktop setup consisting of a monitor, a mouse and a keyboard. User operations were constrained to include only vertex editing with direct manipulation or using a manipulator helper object. Manipulator is a visual tool that allows users to constrain vertex transformations to only one axis. Manipulator was available only in 2D UI. Manipulator helper object is visible in the Figure 1. In addition to vertex manipulation, users were provided with viewpoint controls that were operated by mouse and/or keyboard shortcut keys.

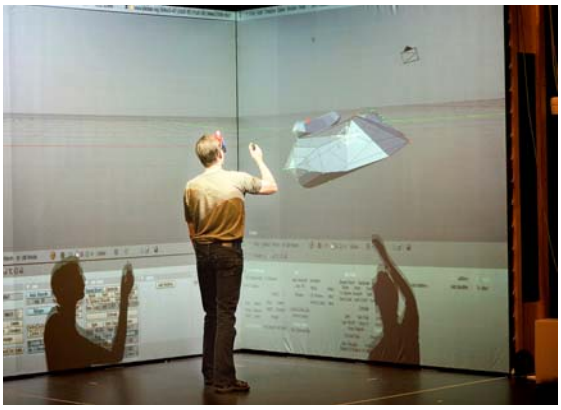

Figure 3. Modelling in VE

4.3. Testing with the 3D UI

We conducted 3D UI testing using our VR system. In VE, users had an optically tracked 3D pointing device they used as an input device. The location of 3D pointer in the VE was visualized with a 3D cursor object. The pointing device had one button that was used for selecting and moving the vertices. To select and move a vertex, user needed to touch it with the cursor object, i.e. to move the cursor over the vertex on all three axes, and click the button of the 3D pointing device. The user could translate the vertex freely in all three axes as long as the pointing device button was kept pressed. The head location of the user was also optically tracked and the rendering viewpoints were modified accordingly. The user was able to move freely around the VE and inspect objects, as if the objects were in the same space with him/her. There were no additional means for manipulating the viewpoint and there was also no manipulator object available in the 3D UI. In Figure 3 a user is performing vertex manipulation in VE.

4.4. Instrumentation and Collected Data

Numerical data of user performance was collected during the test performance with automated instrumentation built into the 3D modelling application. This data was collected by logging all user actions during the task that related with viewpoint and vertex manipulation. Each operation was given a time stamp and written to a log file. In addition to quantitative data, user feedback was collected with a questionnaire and by interviewing the users between the test cases.

4.5. Test Procedure

All user tests were carried out using a similar procedure. When test user arrived, first the test purpose and structure was explained to him/her. The whole session was video taped to ensure that all actions of the user got recorded and could be analysed. Before the first test, the background information of the user and his/her expectations were collected with a questionnaire and by interviewing. The previous experiences of 3D modelling, CAD and VR were collected along other computer usage characteristics.

After collecting the background information, the first test scene was introduced to the test user and the whole test scenario with visualization, controls and the UI were explained. Once test had been explained, the user started the test. In the first test case the user was instructed to practice the use of the UI at his/her own pace. Once the user informed feeling ready to start the actual test, the second test scene was loaded. This time the user was asked to complete the test case as fast as possible.

Half of the test users started the test by first performing the test cases with the 3D UI, and the other half started with the 2D UI. In both UIs the objects in the test cases were identical, so that the performance comparison between the UIs would be possible.

Once the users had performed all three test cases on one UI, they were asked to fill a questionnaire form about common usability factors, e.g. efficiency, ease of use and learning. The questions were formulated as positive claims, e.g. “Vertex selection was quick”. The users were asked to answer on Likert scale “Strongly agree”, “Agree”, “Indifferent”, “Disagree” and “Strongly Disagree”. After this users performed the same test cases with the other UI and filled the question form for this part, having the same questions as for the first UI. When the tests had been performed with both UIs, the user answered the last part of the questionnaire asking to compare the two user interfaces on scale “3D Significantly Better”, “3D Better”, “Indifferent”, “2D Better”, “2D Significantly Better”. After filling the questionnaire user was interviewed. The interview permitted the user to describe his/her experiences more freely.

5. Preliminary Results

This experiment was carried out primarily to find out the needs for improvements in our system and research setting, i.e. to serve as a pilot for a comprehensive testing to be carried out subsequently.

The task completion times are depicted in Figure 4. All but one user performed the tasks faster in the 2D than the 3D UI. The speed difference was especially clear, as the average task completion time was five-fold on Task 2 and double on Task 3. Two users (4 and 5) were familiar with the 3D modelling application used for testing, which is also evident in their low task completion times (more than twice as fast compared to the other users).

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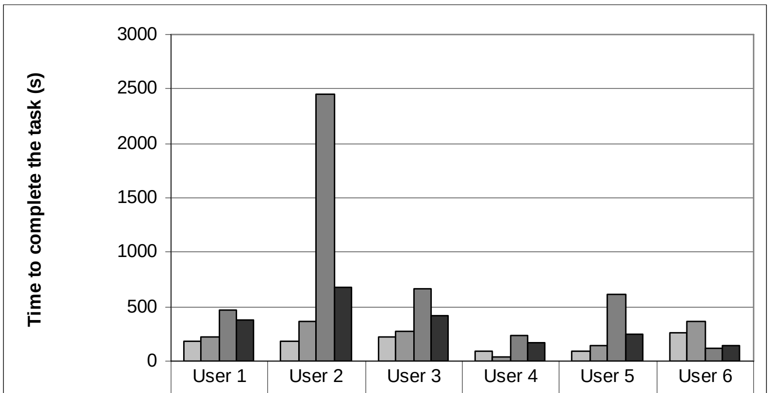

	User 1	User 2	User 3	User 4	User 5	User 6
Task 2 2D	186,656	188,766	222,156	89,969	88,25	264,047
Task 3 2D	220,172	368,406	274,438	38,86	137,125	362,5
Task 2 3D	475,547	2447,828	664,829	228,625	609,782	111,828
Task 3 3D	373,922	677,281	415,016	172,875	248,407	146,719

Figure 4. User task completion times in tasks 2 and 3.

Task completion times of users 2, 4 and 6 are especially interesting. User 2 had severe difficulties on Task 2 in 3D, but this only partially explains the big difference in completion times. User 4 was the most experienced 3D modeller, and could complete the tasks quickly both in 2D and 3D. User 6 was the only one to complete the tasks faster on the 3D than the 2D UI. He was able to complete his tasks twice as fast in 3D, close to the 2D performance of experienced modellers.

Contrary to our initial expectations, Task 2 took more time than Task 3 with both interfaces (with the exception to User 6 with the 3D UI where the difference in task completion times is negligible). This was surprising, as the Task 3 contained more vertices to edit.

The survey answers indicated that the test users liked point selection and manipulation, as well as speed of use and accuracy, better in the 2D UI. The 3D UI was found easier to learn and use. As far as the overall performance in this task is concerned, the 2D UI was found better by four of six users, User 1 having no preference and User 6 preferring the 3D UI. Users 4 and 6 stand out again as interesting cases, the former giving lowest and latter giving the highest ratings to the 3D UI. In contrast, neither rated the 2D UI low. The other results of our survey are varied and need deeper investigation with bigger population to draw any conclusions.

We also collected information on where the user was viewing the object from. In 3D UI, the users performed most of their editing perpendicular to the edited object surface. The object was viewed from the side when they needed information on the depth of the vertex, relative to the other parts of the surface. The movements were controlled rather than impulsive – the users usually fixed themselves to a certain viewpoint and then started the editing. In 2D UI, the less experienced users rotated around the object and viewed the object from various viewpoints, but the few users that could handle the keyboard shortcuts for viewing the object from top and side managed with very few viewpoint manipulations. Figure 5 demonstrates the difference between user view positions between the 2D and the 3D UI.

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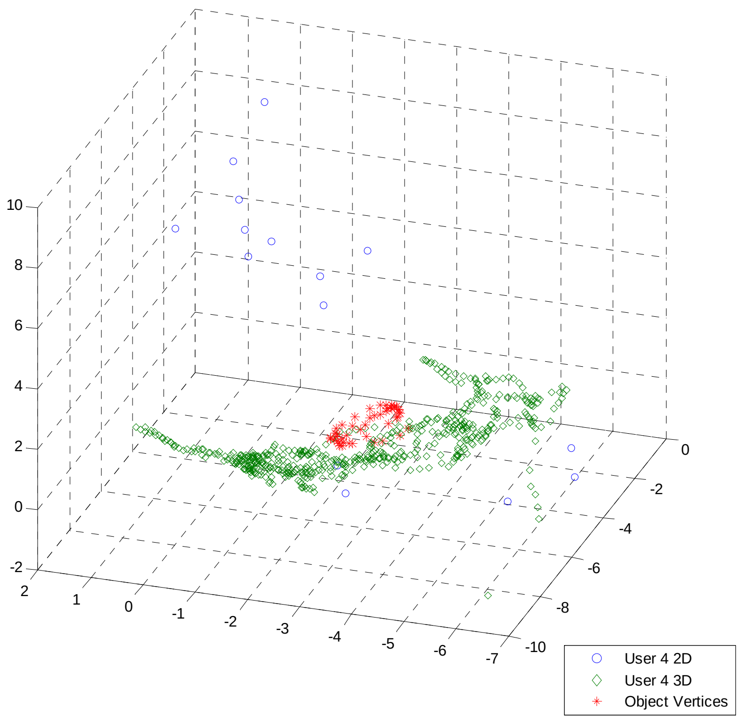

Figure 5. User 4 view positions in Task 3, both in 2D and 3D UIs.

6. Discussion

Since at this stage only a pilot test with the described test scenario has been conducted, no definitive answers to our hypotheses can be given. However, even the limited number of test users gave us some indications. Furthermore, the qualitative data gained by interviewing and questionnaires provide valuable insight into the differences between the two UIs, in the context of basic polygon modelling and direct manipulation.

With the pilot testing we have also discovered several issues that need to be concerned before comprehensive testing can be conducted. One important factor to be improved is the performance of the 3D UI hardware. The impact to usability, caused by somewhat inaccurate and unsteady performance of optical tracking and quality issues with stereoscopic rendering, cannot be accurately estimated. We feel that they do explain part of the speed and accuracy issues in 3D UI and also may affect the user evaluation and usability.

Another issue that needs to be considered and its impact controlled, is the existing know-how users have on 2D UIs of existing 3D modelling and CAD systems. The learned UI metaphors and behaviour may give a clear advantage in performance to the 2D UI and also affect how the 3D UI is evaluated by the user. On the other hand, according to the user comments, in some occasions the 3D UI was experienced to be more appealing because of its novelty value, which in turn may affect the feedback received.

In the following sub-chapters our observations concerning our hypotheses are discussed.

6.1. Is Direct Manipulation Faster in 3D UI in Terms of Speed?

None of the users agreed on this statement as such. As known, accuracy and speed are intertwined. Our task required somewhat precise positioning that was found difficult with current VE. Even User 6 that could perform the task faster in 3D than 2D commented *”If we are operating within this tolerance, I say 3D is faster; but if we would really need to place the point*

tightly accurately, I am not so sure about it anymore". Some users liked the possibility to translate the vertices in all three dimensions, but still missed the possibility for constrained manipulation. When asked, they agreed that translation in depth axis was clearly less accurate, even with the current stereo projection.
User 1 and 4 saw the possibility that the 3D UI could be faster for novice users, as in a traditional user interface it would be difficult to get anything done without extensive training. This statement is in accordance with the proposed advantages of direct manipulation (e.g. Schneiderman, 1983), but as all users had at least some experience on CAD systems, we could not verify it.

6.2. Will the Users Find Direct Manipulation Tools Less Distracting in 3D than in 2D?

We did not do explicit measurement on distraction. Instead, we asked the users to comment on the tools and viewport manipulation. A common comment was that the 3D UI tools were easier as there were fewer things to remember – there were only the one-button pointing device and navigating by moving. One could say that this task could be performed more easily with our 3D UI tool, as fewer tools were required to complete the task.
Users generally agreed on this hypothesis, when it comes to the ease in navigating in the space. However, expert users missed the possibility to view from predefined viewpoints (e.g. top, down and other viewpoints perpendicular to each other). Moreover, the users found the freely moving viewpoint in 3D UI problematic when they started translating the vertices; User 4 commented *"When I moved the tiny vertex, I almost needed to hold my breath"*. We assume that fixing to a certain viewpoint might be their strategy to handle the existing latency and jitter issues. These factors could be considered a form of distraction, as well.

6.3. Will the Users Find 3D UI More Natural?

Term 'natural' as such was not used in the interview or questionnaires. However, when the users compared the ease of use (intuitiveness) and ease to learn the UIs, all answered the 3D UI to be "Better", or "Significantly Better". This clearly indicates that users found the 3D UI more natural. Although users answered the 3D UI to be easier to use and easier to learn, they didn't necessarily prefer 3D UI to the 2D UI.

6.4. Will the Users Prefer 3D to 2D in Direct Manipulation Tasks of Imprecise Polygonal Geometry Manipulation?

When users were asked to evaluate which of the UIs suits them better for the task, 2D UI was preferred. When users were asked to give the same evaluation, trying to oversee the technical shortcoming of the 3D UI, the answers were more neutral. However, when users were asked which UI they would prefer to work on, the answer was that on 2D UI. Asking this question often led users to ponder on how the exact nature and duration of the work would affect their preference.

7. Conclusions and Further Work

Based on the pilot test, we feel that the test scenario presented here is a useful tool for evaluating and benchmarking an immersive 3D UI in the context of 3D modelling and direct manipulation. In the future we are going to conduct a comprehensive user test using the described test scenario with the improvements that we have discovered necessary during the pilot testing phase. In addition to improving tracking and display technology currently used in our VR system, we also need to improve few issues in our test scenario. We need to consider if we should minimise the effect of previous 3D modelling experience with longitudinal study that would allow users to have comparative practice with the 3D UI as they have had with the 2D UI.

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