TESTING THE USABILITY OF INFORMATION VISUALIZATION TECHNIQUES IN INTERACTIVE 3D VIRTUAL ENVIRONMENTS: A TOOLKIT

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ABSTRACT

Augmenting 3D virtual environments (3DVEs) with additional abstract information, with different data types (such as numbers, texts, images and videos) amplifies and enhances the user's spatial cognition and understanding of geometrical objects in order to perform specific tasks which require both abstract information and a 3D scene. Many interactive information visualization techniques have been created to incorporate abstract information into 3DVEs. The designers of 3DVEs are faced with the challenge of selecting a specific information visualization technique or creating a novel technique according to their specific design needs and contexts. Therefore, a toolkit for the usability evaluation is needed to help them compare the usability of different information visualization techniques according to specific design needs and contexts. Our main objective is to create such toolkit for performing usability tests in order to complete a reusable evaluation grid for comparing the usability of visualization techniques in different evaluation contexts. In this article, we present an evaluation framework and toolkit that we have developed in order to perform usability tests.

KEYWORDS

3D user interface, usability evaluation, user experience, information visualization, 3D virtual environment

1. INTRODUCTION

Augmenting 3D virtual environments (3DVEs) with additional abstract information such as numbers, texts and images amplifies and enhances the user's spatial cognition and understanding of geometrical objects in order to perform specific tasks which require both abstract information and a 3D scene. Many interactive information visualization techniques have been created to incorporate abstract information into 3DVEs. The designers of 3DVEs are faced with the challenge of selecting a specific information visualization technique or creating a novel technique according to their specific design needs and contexts. Such design needs and contexts can be characterized by evaluation contexts. An evaluation context is composed of the task, the type of abstract information to display, the target object context and the user context within the 3DVE (Bazargan et al., 2009). There is no unique technique which can be appropriate for every evaluation context. If a selected technique is not appropriate for a given evaluation context, it will result in low usability and user frustration. For instance, a common usability problem in the design of 3D video games interfaces is related to bad visualization of information which can have a negative effect on the overall quality and success of games (Pinelle et al., 2008). Moreover, designers of 3DVEs find it difficult to decide where to place additional information within 3D environments so that they are understood intuitively and seem related to the object or location they are really related to (Bleisch and Nebiker, 2007). However, most 3DVEs designers don't have any tools to evaluate information visualization techniques according to their specific needs. Therefore, a usability evaluation toolkit is needed to help them compare the usability of different techniques according to specific evaluation contexts. Our main objective is to create such toolkit for performing usability tests in order to complete a reusable evaluation grid for comparing the usability of visualization techniques in different evaluation contexts. This paper is composed of two sections: a state of the art which highlights information visualization techniques, usability evaluation and navigation problems in 3DVEs followed by the description of our toolkit based on a 3D interactive prototype. We also provide 3DVEs specific guidelines for the selection of performance and satisfaction metrics for the usability tests to be performed with the toolkit.

2. STATE OF THE ART

2.1 Information Visualization Techniques in 3DVEs

Many abstract information visualization techniques have been designed (Bazargan and Falquet, 2009). Based on the work of Feiner et al. (1993) on augmented reality design paradigms, Polys (2006) has divided abstract information display locations into five categories according to a user's perspective and what coordinate space the information resides in. Abstract information may be located in *object space*, *world space*, *user space*, *viewport space*, or *display space*. Information that stays attached to an object in the environment (even if that object is moved) is termed *object space*. *World space* information is attached to a specific 3D (world-coordinate) area, region, or location in the environment. *User space* is relative to information fixed to the user's view, so that it's always available as the user navigates the environment. *Display space* information remains at the same location on the display (screen) surface located outside the rendered view of the virtual environment in some additional screen area. Finally, information that is presented at the image plane that overlays the 3DVE where is it always visible regardless of the user's position and viewing orientation is termed *viewport space*.

2.2 Usability Evaluation and Navigation Problems in 3DVEs

2.2.1 Usability Evaluation of 3DVEs

The designer of a 3DVE should perform usability tests in order to select a relevant information visualization technique in a given context. A number of research works conducted by Gabbard and his colleagues (1997; 1999), Bowman (2002) and Stanney's et al. (2003) have produced a taxonomy of usability characteristics in virtual environments and a survey of usability evaluation methods in virtual environments. The Multicriteria Assessment of Usability for Virtual Environments (MAUVE) system, provides a structured approach for achieving usability in VE system design and evaluation (Stanney et al., 2003). In a reference book on 3D user interfaces (3DUIs), Bowman et al. (2004) discuss distinctive characteristics of 3DUIs evaluation methods, metrics that help to indicate the usability of 3D UIs and guidelines for choosing specific evaluation methods. The Nottingham Tool for Assessment for Interaction in Virtual Environments (NAIVE) comprises a set of 3DVE tasks and related tests, with appropriate performance criteria levels, covering the main aspects of viewpoint control and object manipulation and operation (Griffiths, 2001). A comprehensive literature survey of user evaluation techniques in selected augmented reality research publications between 1993 and 2007 has been conducted to promote and increase the quality of user evaluation in augmented reality research (Dünser et al., 2008). Billinghurst (2008) provides a comparative analysis of the outcomes of six experiments that measured user performance in specific 3DVEs. The need for the systematic development of 3DVE prototypes interfaces to be used for usability studies is highlighted in the conclusion of his analysis. The Empirical Evaluation Assistant (EEA) is a system designed to rapidly gather feedbacks about the usability of 3D interaction technique during its development lifecycle (Domingues et al., 2007). EEA is based on a knowledge database where experiments results and evaluation task scenario are used to permit to give assistance to the experimenter during the creation of the evaluation. However, the major problem of this approach is to populate the knowledge database (Domingues et al., 2008). Vanderdonckt (1998) has defined ergonomic rules for the interactive object selection in 2D UIs. The obstacles to extend such results to 3DVEs are mainly related to the variability of contexts and navigation problems. Nevertheless, Bach and Scapin (2003; 2005) have studied the ergonomic quality of 3DVEs, developed and validated a set of 20 ergonomic criteria (EC) for human virtual-environments interactions. Based on these EC, usability experts can evaluate the conformity of 3DVEs to selected ergonomic dimensions in order to detect already known problems according to established knowledge. Their experiments results show that the evaluation performance with the EC expert inspections and users tests enable equivalent evaluation performances.

We can observe that although all these studies provide valuable results for the evaluation of 3DVEs, they have their own constraints and limitations. According to our knowledge, there is no data on the usability of specific abstract information visualization techniques such as *dynamic sliding virtual panel* or *dynamic moving virtual panel* which respectively belong to *object space* and *world space* categories (see section 3.4).

2.2.2 Navigation Problems in 3DVEs

Navigation in 3DVEs consists of *orientation* (determining one's present location and viewpoint), *wayfinding* (determining where one wants to go and planning how to get there) and *travelling* (actually moving through the environment to reach the destination) (Bowman et al., 2004). Griffiths et al. (2006) have identified three types of navigation based on their complexity: (1) *simple navigation* (cornering, 180° rotation, forward and backward motion), (2) *complex navigation* (navigation through doorways and navigation onto a specific destination) and (3) *free flying navigation* (simple and complex pathways, vertical movements and flying through doorways). Whatever the navigation mode, the main problems associated with navigation in 3DVEs is the problem of becoming *lost* or *disoriented* in the virtual world. Sayers (2004) has attributed this problem to a number of factors, including: moving too close to virtual world objects and cognitive load placed on the user if the movement is not confined to a level plane. Several tools and techniques to support navigation in 3DVEs have been designed. Baker and Wickens (1995) have found out that effective support for navigation enables the users of 3DVEs to answer three questions: "(1) Where am I now?, (2) Where do I want to go?, (3) How do I get there?". These factors act as common sources for low usability and user frustration (Kaur et al., 1999). Providing the users of 3DVEs with easy to learn navigation tools and techniques which would not require much practice is therefore of particular importance.

Burigat and Chittaro (2007) have compared three navigation aids that help experienced and inexperienced users perform wayfinding task in 3DVEs by pointing out the location of objects or places. Their results highlight that navigation aid based on 3D arrows outperformed, in terms of user performance and preference, the others navigation aids. In an in-depth study of navigation in 3DVEs, (Sebok and Nystad, 2004) indicate that the importance of navigation to overall perceived usability on VEs is related to the relevance of navigation to the main tasks that the user is trying to accomplish with the system. Thus, if navigation is difficult to perform, perceived usability will be low. In such situations, the authors recommend that most critical factors for improving navigation in 3D VEs are to include target-selection techniques, visual landmarks (viewpoints), gravity, visual momentum (show the transition between current location and landmark) and integrate navigation capabilities into a single device (i.e. a mouse). The results of their study also suggest that the navigation system should allow for the direction of view to be decoupled from the direction of travel and virtual body orientation. As a consequence, users will be able to look around from various locations in 3DVEs, without losing their orientation on a path. Results from tests performed with the Nottingham tool for assessment of interaction in virtual environments (NAÏVE) covering the main aspects of navigation control and object operation provide similar recommendations (Griffiths et al., 2006). Sweeney and Adams (2009) have conducted task based experiments in Second Life and concluded that such improved navigation can increase the sense of attention and immersion in 3DVEs.

The Google Earth and Maps team have introduced a new mode of navigation which liberates the users from the road arrows in Google Street View called *smart navigation* (Filip, 2009). The usual way to navigate through Street View has been the forward and backward arrows along the roads which move the user to the next immediate panorama. To travel to a new location, by using Google Street View's *smart navigation* technique, the user must double clicking on a destination place or object to see. Taking into account all the above recommendation for the design of navigation system in 3DVEs, and preliminary evaluation with our 3D interactive prototype, we have designed and implemented a constrained navigation technique which is easy to learn and use. This navigation technique is presented in detail in section 3.5.

2.3 Conceptual Approach

Bazargan and Falquet (2009) have presented an analytical model in which the usability of an information visualization technique is evaluated according to specific *evaluation contexts*. The *evaluation context* is composed of the *task*, the *type of abstract information* to display, the geometrical context of the target object (*target object context*) and the geometrical context of the user (*user context*) within the 3DVE (Bazargan et al., 2009). The main *task* is information access which is an activity to be performed by the user to reach some abstract information about a target object in the 3DVE. For instance, the abstract information to visualize can be represented by virtual panels which are composed of images and fragments of texts. The *type of abstract information* to display can be numbers, texts, images and videos. They can formally be characterized by data types as the ones available in XML Schema Datatype. It is important to distinguish between abstract information and it's visual representation. For exemple, the content of a webpage can be considered as a collection of numbers, texts, images and videos. The *target object context* is characterized by main geometrical properties of the object and it's environment: object dimension, object complexity, environment density and object position. The *user context* is the 3D space where the user can navigate to access abstract information related to target objects. The target object context and the user context can be described by a set of formal descriptors. These descriptors are generic and express the configuration of the 3D space in the neighborhood of the target object and the 3D subspace where the user can navigate (Bazargan and Falquet, 2009). It is necessary to take into account the target object context as well as the user context as some techniques are more or less sensitive to them. For instance, the visualization of a virtual panel which contains an image and a short text implies that the user is able to navigate backwards in order to find a position where it would be possible to visualize the whole image and read all the text on the virtual panel. This is obviously difficult to achieve in 3D spaces with geometrical constraints and obstacles such as small closed rooms, high walls and any type of complex scenes where the user is unable to navigate to a relevant position in the 3DVE. Our objective is to create a reusable evaluation grid for comparing the usability of visualization techniques according to specific evaluation contexts.

3. 3D INTERACTIVE PROTOTYPE FOR USABILITY TESTING

In order to evaluate the usability of abstract information visualization techniques, we have developed a toolkit composed of five elements: a 3D scene with constrained simple navigation implemented; a set of abstract information composed of image and text represented by virtual panels; implementations methodology for visualization techniques; a set of user tasks and user scenarios which indicate, step by step, the task to be performed by the user in different evaluation contexts.

3.1 Selection of a 3D Scene

After many preliminary experimental evaluations, we have finally decided to use a simplified version of the Karnak temple 3D model, in Google Sketch Up format, provided on line by the Digital Karnak Project (UCLA, 2008) under "Attribution - Non Commercial - Share Alike 2.5 Generic" license. Karnak is one of the largest temple complexes in the world located in Egypt. The Digital Karnak Project 3D model is quite useful for our usability tests as it has relevant geometrical complexity which offers different evaluation contexts.

3.2 Selection of Contexts within the 3D Scene

We have selected specific target objects and subspaces within the 3D scene which respectively offer representative target object contexts and user contexts. For instance, a target object context is a textured obelisk with low level of details, surrounded by other obelisks, standing next to a wall (see Figure 1(a)). In one user context, for example, the abstract information rendered by a virtual panel related to a target object is located at the end of a long corridor with high walls and the user is located at the entrance of the corridor with no way to navigate backwards. In another user context, the abstract information rendered by a virtual panel related to a target object is located just in front of the user which can't go backwards (see Figure 1(b)). Other user contexts include open spaces and closed spaces in which the user can navigate to access abstract information related to target objects rendered by a virtual panels.

3.3 Definition of Tasks and Scenarios

The user receives written instruction which explains, step-by-step, the tasks to perform in order to accomplish the scenario. The first task is to navigate to a specific position indicated by an annotation text labeled "1-START" by using specific simple navigation widgets presented in section 3.5. Each predefined position is located in a specific user context. The second task is to identify a specific obelisk which is indicated with an annotation letter labeled "A" in the 3D scene. Each virtual panel has an annotation letter attached to it. In the third task, in order to identify the obelisk labeled "A", the user must click on the related panel and read aloud the title written between the image and the main description text on the panel. In the fourth task, in order to identify the next obelisk in the 3D scene, the user must read aloud the next position number "2" displayed on the bottom right corner of the virtual panel. The fifth task is to close the virtual panel by clicking on it. The sixth task is to navigate to the next position indicated by an annotation labeled "2" by using specific simple navigation widgets. The seventh task is to identify a specific obelisk which is indicated with an annotation letter labeled "B" in the 3D scene. Then, the user is instructed to keep performing similar tasks while navigating from one user context to another. Some tasks might require simple backward or forward navigation. A specific position labeled "5-END" is located in the fifth and final user context. The user ends interacting with the prototype after identifying the last obelisk labeled "E", located within the last user context, and closing the related virtual panel.

3.4 Implementation of Visualization Techniques

The information visualization techniques we have implemented for the first usability test phase are *dynamic sliding virtual panel* (see Figure 1(a) and 1(b)) and *dynamic moving virtual panel* (see Figure 2(a) and 2(b)) which respectively belong to *object space* and *world space* categories and described in section 2.1. To this end, we have used Google SkectchUp's Pro *Dynamic Components* (DCs) position and size attributes, *onClick* function parameters and together with Ruby scripts edited with help of the built-in Ruby code editor in order to create reusable SkecthUp DCs.

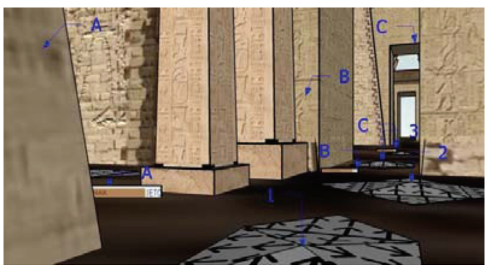

Figure 1(a). state before user interaction

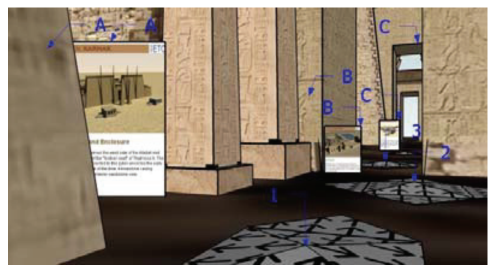

Figure 1(b). state after user interaction

Figure 1. *dynamic sliding virtual panel* visualization technique

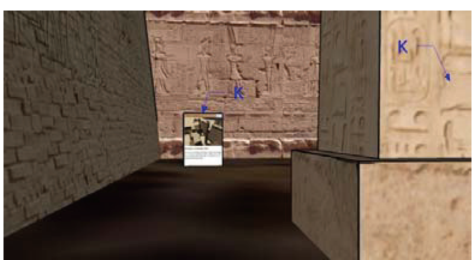

Figure 2(a). state before user interaction

Figure 2(b). state after user interaction

Figure 2. *dynamic moving virtual panel* visualization technique

3.5 Implementation of Constrained Simple Navigation

In order to avoid navigation problems such as disorientation in 3DVEs, as described in section 2.2.2, we have decided to limit the navigation modes to a simple and easy to use mode. This limitation can also be removed as our toolkit also supports free navigation mode which we won't use for our experiments. The constrained simple navigation technique we have designed and implemented are based on reusable SketchUp *dynamic components* based on interactive widgets which are located on the ground level plan. The main part of the widget is composed of four faces of a square based pyramid with additional triangles connected to each face on the ground level plan, if needed, according to specific evaluation contexts. Once the user decides to navigate to a predefined position and look into a specific direction, she or he clicks on a face, gets teleported to the summit of the pyramid and the direction of the view is indicated by the orientation of the arrows faces. The 3D scene is covered with these navigation widgets so that the user is able to navigate in the 3D scene according to predefined positions (see Figure 3(a) and 3(b)). Once positioned on a pyramid's summit, the user can made 360° orations, look down and up. The additional triangles connected to the main pyramids can be used to navigate backwards, if needed, in specific evaluation contexts (see Figure 3(c) and 3(d)).

Figure 3(a). overview of the widgets on the ground | Figure 3(b). detailed view of the widgets | Figure 3(c). before user navigation interaction | Figure 3(d). after user backward navigation

Figure 3. Constrained simple navigation widgets

4. SPECIFIC GUIDELINES

4.1 Planning the Usability Study

Designing and performing a usability test with the toolkit is based on conventional usability evaluation methods. Usability studies which involve 3DVEs require a specific consideration during the participants selection phase. We have created a user pre-selection questionnaire in order to distinguish between experienced and inexperienced users and access the user's familiarization with 3DVEs and specially video games. The inexperienced users are the ones that we plan to consider for the first phase of our usability tests. We intend to use a within-subject design with a sample size of 10 users as recommended by Bach and Scapin (2005). The advantage of this approach is that it does not require a large sample size, and there is no need to worry about differences across groups.

4.2 Usability Metrics

4.2.1 Performance Metric

Time-on-task or task completion time is the way we are going to measure the usability of a given abstract information visualization technique. It is simply the time elapsed between the start of a task and the end of a task expressed in seconds. We plan to use Data Logger, an open source usability testing product, to capture task time manually with the help of the moderator who will record start and end times. According to our knowledge, there is no software to perform this task automatically in 3DVEs. We also plan to all record activity on the screen including mouse movement capture and navigation actions with the Snagit screen video capture software.

4.2.2 Satisfaction Metric

We have created a post-test satisfaction questionnaire based on an adaptation of Kalawsky's (1999) VRUSE questionnaire designed to measure the usability of virtual reality systems according to the attitude and perception of its users. Unlike questionnaires designed for generic interfaces VRUSE is specially designed to provide a means for evaluating 3DVEs by providing detailed information about a user's viewpoint of the interface. Ten usability factors have been considered with specific focus on ease of use and presence factors.

5. CONCLUSION AND PERSPECTIVES

The contribution of this research is a reusable toolkit for the evaluation of the usability of abstract information visualization techniques in 3DVEs. The toolkit we have developed is composed of five elements: a 3D scene with constrained simple navigation implemented; a set of abstract information composed of image and text in form of virtual panels; implementations methodology for visualization techniques; a set of user tasks and user scenarios which indicate, step by step, the task to be performed by the user in different evaluation contexts. This toolkit can be extended to test any abstract visualization technique suggested by other researches in the future. Designers of 3DVEs who are interest in this reusable toolkit are invited to contact the authors to get usage instructions, learn how to build scenarios other than the ones explicitly designed for the current experiment. We are also looking forward to receive constructive feedback by designers of 3DVEs who have the own abstract visualization technique, scenarios and would like us to test them with our toolkit. The next step in this research is to select the participants, conduct usability tests with our toolkit and perform data collection and analysis in order to fill-in a reusable evaluation grid for comparing the usability of abstract information visualization techniques according to evaluation contexts.

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