Usability Evaluation of the EPOCH Multimodal User Interface: Designing 3D Tangible Interactions

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ABSTRACT

This paper expands on the presentation of a methodology that provides a technology-enhanced exhibition of a cultural artefact through the use of a safe hybrid 2D/3D multimodal interface. Such tangible interactions are based on the integration of a 3DOF orientation tracker and information sensors with a 'Kromstaf' rapid prototype replica to provide tactile feedback. The multimodal interface allows the user to manipulate the object via physical gestures which, during evaluation, establish a profound level of virtual object presence and user satisfaction. If a user cannot manipulate the virtual object effectively many application specific tasks cannot be performed. This paper assesses the usability of the multimodal interface by comparing it with two input devices—the Magellan SpaceMouse, and a 'black box', which contains the same electronics as the multimodal interface but without the tactile feedback offered by the 'Kromstaf' replica. A complete human-centred usability evaluation was conducted utilizing task based measures in the form of memory recall investigations after exposure to the interface in conjunction with perceived presence and user satisfaction assessments. Fifty-four participants across three conditions (Kromstaf, space mouse and black box) took part in the evaluation.

Categories and Subject Descriptors

H.5.1 [Information Interfaces and Presentation]: Artificial, augmented, and virtual realities, H.5.1 [Information Systems]: Evaluation/methodology, H.5.2 [Information Systems]: Evaluation, Methodology I.3.1 [Computer Graphics]: Input Devices, I.3.6 [Computer Graphics]: Interaction Techniques**.**

General Terms

Human Factors, Reliability, Experimentation, Measurement,

Keywords

Virtual Environments, Presence, Perception, Multimodal User Interfaces, Evaluation.

1. Introduction

3D interface design is a critical component of any virtual environment application [8]. Virtual Reality interfaces, interaction techniques and devices are also developing at a rapid pace [3], [9] and offer enhanced visualization metaphors over traditional windows style interfaces [13]. However, it has been shown that 3D navigation and orientation tasks are performed less efficiently using simulation systems compared to the real-world equivalent task situation [8]. In order to establish specific user interface requirements the simulation system designer must first identify the occurring tasks relevant to each application scenario [10]. Tasks according to Wuthrich [17] can be broken down into three elementary actions: selection/grabbing, positioning with N degrees of freedom and deforming [19]. Research carried out by Subramanian [18] has shown that an increase in the number of available DOF (Degrees of Freedom) in an interaction device can improve performance. By exploiting the interface requirements of specific tasks, the complexity of the 3D interface could be ultimately reduced, however, diverse application needs could also be identified [20]. Adding modalities such as sound, text or tactile feedback could enhance relevant visualization metaphors. In this paper, users interact with virtual content through a 3D multimodal 'tangible' interface in the form of a replica of a museum artefact [1], [2], [3], [4]. A user uses their hands to manipulate the cultural object replica via physical gestures; a computer system detects this, alters its state, and gives feedback accordingly. The results of a formal usability evaluation which compares this interface with the Magellan SpaceMouse as well as with a plain black box are presented.

Devices such as a Magellan SpaceMouse® can be configured to eliminate the keyboard and standard mouse and be intuitively coupled to the visualization screen. Thus, touching and moving the SpaceMouse puck causes the user to navigate the virtual environment. Further, orientation and touch sensors can be integrated within the replica of the cultural object to allow control of a story through a virtual environment.

Multimodal input systems process two or more combined user input modes in a coordinated manner with the multimedia system [14]. Our method matches the shape and appearance of the virtual object with the shape and appearance of the physical object so that the user can both "see" and "feel" the virtual object. By physically touching a virtual object (mixing the real objects and VR) the quality of virtual experience can be improved [11]. [12]. Converging evidence from both visual and tactical senses improves the illusion of "presence" when experiencing the virtual environment, which is the essence of immersive VR [26].

Presence in VEs can be explained as the participant's sense of 'being there' in a VE; the degree to which the users feel that they are somewhere other than they physically are while experiencing a computer generated simulation [15]. Presence forms an important subjective measure of a user's virtual experience, although both positive and negative correlations between presence and task performance and presence and exposure aftereffects have been reported in literature [16], [22].

There are many factors that affect the degree of presence experienced in a VE. It has been shown that factors that are hypothesized to contribute to a sense of presence are divided in four categories according to [15] as shown in Table 1.

Table 1: Factors that contribute to Sense of Presence according to [15]

CONTROL FACTORS	SENSORY FACTORS	DISTRACTION FACTORS	REALISM FACTORS
Degree of control	Sensory modality	Isolation	Scene realism
Immediacy of control	Environmental richness	Selective attention	Information with objective world
Anticipation of events	Multimodal presentation	Interface awareness	Meaningfulness of experience
Mode of control	Consistency of multimodal information		Separation anxiety/ disorientation
Physical environment modifiality	Degree of movement perception		

This paper is organized as follows. A technological overview of the EPOCH Multimodal User Interface in the form of a cultural artifact replica is presented, followed by the results of a formal usability evaluation which compares it with the SpaceMouse and a plain black box. Finally, we conclude the paper and indicate future work.

2. System Overview

We have developed several example applications in which the multimodal interface is demonstrated. The multimodal interface developed has been integrated with a standard web browser including information content delivered as part of an Internet based virtual museum exhibition. Such a tangible interface could eventually be incorporated into a specific application for use in a museum kiosk environment [2].

2.1 Replica Construction

The replica artefact is based on an 11th century ivory abbot's crook and is displayed at the ENAME museum in Belgium. The replica serves as a physical 3D input interface between the cultural object and its VRML presentation [2], [4], [7], [21].

In order to build the replica the cultural object was initially digitized using a laser scanner at a point spacing of 0.2mm and exported in stereo lithography format. This format was used for creating its replica using rapid prototyping methods, in this case FDM, e.g. fused deposition modeling [5]) (Figure 1).

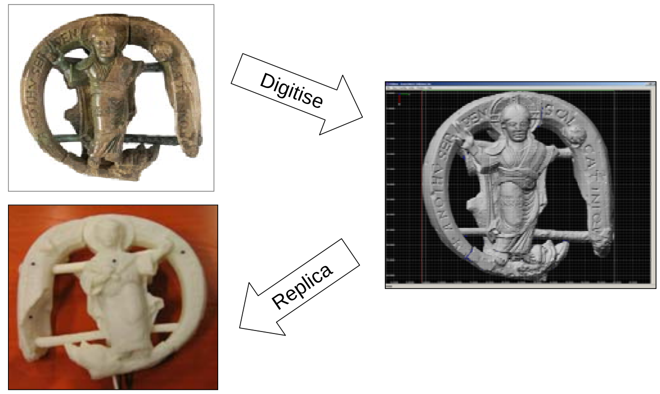

Figure 1: Replica construction steps

The replica was constructed as two hollow shells with a thickness of 3 mm. The orientation tracking device was carefully embedded in the hollow space inside the replica. The tracking device allows the user to sense the orientation of the replica and slave the rotation of the digital artefact or virtual reconstruction to the replica. The device is connected to a Windows PC via a serial or USB port. Simple sensors (buttons) are mounted on the replica in order to offer additional information by selecting appropriate web-based content. When the buttons are pushed they generate I/0 signals, which are fed to a USB Micro U401 microcontroller [6], which is also embedded in the replica's hollow space (Figure 2) [2].

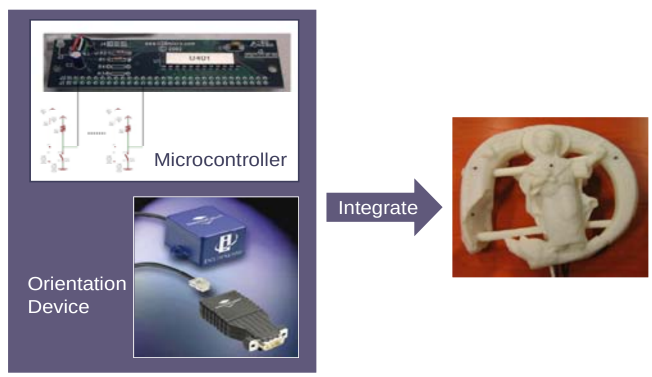

Figure 2: Electronics embedded into the replica

The U401 provides a simple digital I/O interface for the PC [6]. Each sensor is connected to the I/O lines of the microcontroller. When a sensor is activated the U401 microcontroller detects 'grounded' I/O and triggers an event in an ActiveX interface control written to capture this event and trigger an 'information action'. An information action for example could be a hyperlink embedded in the VRML scene containing the virtual model of the object, directing to a web page displaying additional information [2].

2.2 Graphical User Interface

The graphical user interface of our system is divided into three parts as shown in figure 3.

- The Visualization interface which is based on the Cortona VRML Client [23].
- The Interaction interface which controls the input devices
- The Configuration and Presentation interfaces which are used in order to display information relevant to the virtual artefact

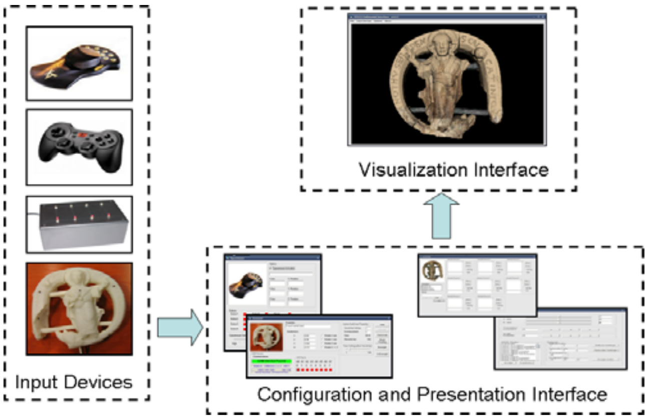

Figure 3: Conceptual diagram of EPOCH multimodal I/F

Interaction with a digital exhibit displayed in the EPOCH Multimodal User interface includes the use of standard I/O devices such as the keyboard mouse and joysticks; VR interaction devices including the SpaceMouse and tangible input devices such as the Kromstaf and the black box.

The Magellan SpaceMouse plus XT is a USB device providing a six degree-of-freedom (6DOF) mouse and a nine button menu interface. Using the Windows API, all nine menu buttons have been programmed to perform simple graphics operations including basic transformations such as rotations, translations and scaling. (Figure 4). In addition, more complex graphics operations can be programmed and linked to specific buttons such as LOD, lights and texture manipulation.

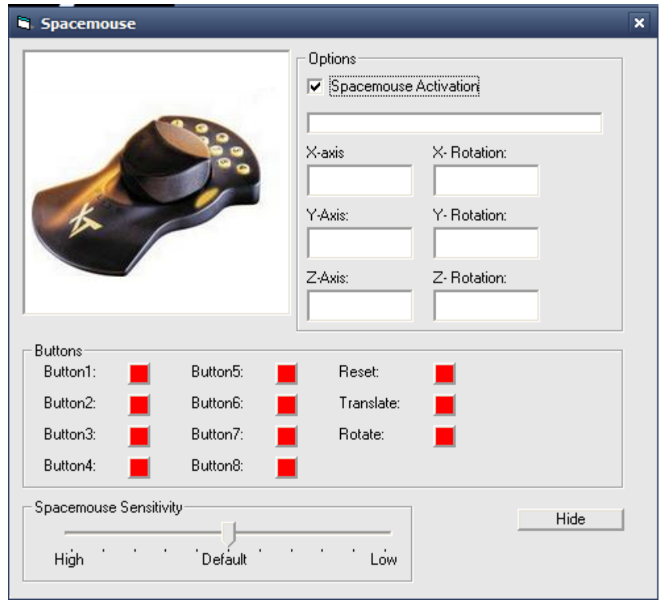

Figure 4: SpaceMouse customization interface

In our case three buttons are used to enable basic transformations and eight buttons are used to provide information about the cultural object such as historical info and a multimedia presentation of the artefact, etc.

The Kromstaf and blackbox interfaces are composed of:

- An orientation tracking device (Intersense Inertia Cube 2)
- USB Microcontroller
- Eight sensors (buttons)

The user can initialize and set the sensitivity and the enhancement of the orientation device [1], [2], [3], restrict the rotation of the artefact to one axis or three axes, and can program each of the eight buttons on the device (Figure 5).

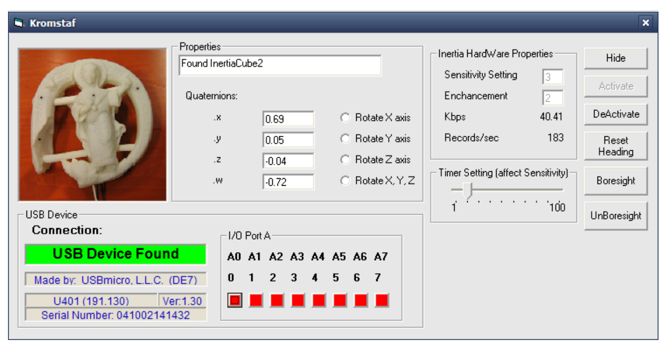

Figure 5: Kromstaf customization interface

3. Methodology and Results

In the following sub-section the methodology and the results of a formal usability evaluation study are presented, which compares a tangible interface in the form of a cultural artifact replica with the Magellan SpaceMouse as well as with a plain black box.

3.1 Apparatus and Visual Content

The EPOCH Multimodal User Interface has been implemented with off-the-self hardware components. An Intersense inertia cube (i.e. 3DOF orientation tracker) and a SpaceMouse were utilised for rotation of the virtual object. A workstation with two 2.0 GHz Opteron processors and 4 GB of memory was used for the experiments. The workstation is equipped with an NVIDIA GeForce 6800 graphics card. Standard display technology, such as PC 19' inch TFT monitor has been used in order to display the 3D content of the application.

3.2 Participants

Fifty-four participants were recruited from the University of Sussex undergraduate and postgraduate population and were paid for their participation. A between subjects design was used. The 54 participants were therefore separated into three groups of 18 corresponding to the three different types of interface tested. Participants in all conditions were naïve as to the purpose of the experiment. All participants had normal or corrected to normal vision and no reported neuromotor impairment.

In order to avoid the differences in confounding variables, i.e. differences between conditions other than the independent variable that could cause differences in the dependent variable participants in each group were balanced according to their age, their gender and their background (Figure 6).

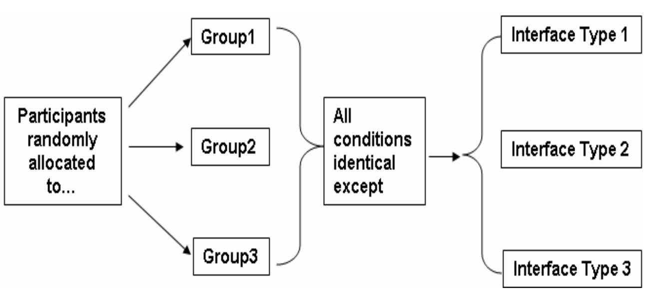

Figure 6: **EPOCH experimental design**

3.3 Procedure

We ensured that each participant was comfortable and at ease prior to the start of the experiment. The participants were told that we would use the participant's data anonymously; along with the data of several others and that the experiment is divided into two main stages. During the first stage of the experiment we tested participants' written memory recall of the cultural artefact by manipulating either the artifact replica, the SpaceMouse or the plain black box for a brief exposure to the system. During the second stage we assessed participants' perceived level of presence and user satisfaction across all conditions. The instructions and the statements that were used during the preliminary briefing were standardized. Initially, the participant's age, gender, and background were recorded. During the first stage of the experiment, participants were instructed to interact with a 3D representation of the cultural artifact displayed on a TFT monitor using one of the physical interfaces and examine the virtual object from all sides, but without pressing any of the buttons on the interface.

At the start of the experiment a popup window was generated in order to acquire the participant's ID and the interface type. Once the ID had been entered the window was removed and a timer started. When the timer indicated that 60 seconds of exposure time had expired, the simulation was stopped, ensuring that each participant was restricted to exactly 60 seconds of exposure time to the interface and virtual environment. Participants were asked then to write down or sketch on a blank paper what they remembered of the virtual object they saw on the screen. After completion of the memory recall task a modified presence questionnaire was administered [16].

During the second stage of the experiment participants were asked to interact with the virtual object and were allowed to press any of the buttons on each of the physical interfaces. At the end of this stage the participants were asked to complete a slightly modified QUIS Questionnaire (Questionnaire for User Interaction Satisfaction) [24], [25].

Both questionnaires were presented on paper and then transcribed into SPPS v13.0 for analysis. All results were checked after input. The presence questionnaire is a modified version of Brett Stevens Questionnaire [16] and is based on seven-point Likert scale, while the User Satisfaction Questionnaire is based on a nine-point Likert scale.

3.4 Analysis of Results

First, we analyzed the data we collected during the first stage of the experiment which includes the memory test and the presence questionnaire across the three conditions. The memory recall scores as the dependent variable were derived by coding the elements of the artefact remembered and converting them into numerical data which signified memory performance. All data were analyzed using **AN**alysis of **VA**riance (ANOVA). ANOVA is a powerful set of procedures used for testing significance where two or more conditions are used. Significance decisions involve rejecting or retaining the null hypothesis which claims that groups are identical. The null hypothesis is rejected when the probability that a result occurring under it is less than .05. The memory recall results are shown in Table 2.

Table 2: Means Scores of memory test across three conditions

Interface Type (Conditions)	*N*	*Mean (std deviations)*
Kromstaf	18	5.17 (1.15)
Blackbox	18	4.33 (.97)
Spacemouse	18	3.61 (1.14)

Table 2 shows that memory performance associated with the Kromstaf cultural replica interface are higher than the blackbox and the spacemouse, which tends to indicate that using the replica as a manipulation tangible interface may have an effect on memory performance depending on statistical significance.

Looking at more specific tests, e.g. a contrast test investigating 'ease of use' (See table 1 'degree of control' control factor), all significant values are reported at $p<0.05$. This means that we have a significant difference between all three interfaces for the 'ease of use' test. So for example, there was a significant effect on how the participants described the virtual object during the memory task f (2, 51) = 9.153, □ = 0.55.

Planned contrasts between the 3 interfaces revealed that the Kromstaf interface produces significantly better results for memory performance compared with the black box and the SpaceMouse t (51) = -3.79, r=0.47 and that the blackbox performs slightly better than the SpaceMouse t (51) =-1.985, r=0.28.

Other tests show that object manipulation (i.e. rotation) is significantly affected by interface type, f (2, 51) = 11.992, $p<0.001$). As shown in Table 3, the difference between group 1 (Kromstaf) and group 2 (blackbox) is not significant (p =.0827), but the difference between group 1, group 2 and group 3 (SpaceMouse) is significant (p=.001). The observed similarity of memory performance results between the Kromstaff and blackbox manipulation is most likely due to the fact that they both use the 3DOF orientation tracker.

Table 3: Interface comparison for object

Comparison of Interfaces		***Sig.***
Kromstaf	BlackBox	.827
	Spacemouse	.001
BlackBox	Kromstaf	.827
	Spacemouse	.003
Spacemouse	Kromstaf	.001
	BlackBox	.003

The user satisfaction questionnaire is divided into four sections. The first section is based on overall user reaction. As shown in Figure 5, overall system reaction varied from 6-8 on the Likert scale in all three interfaces across groups and genders. For the first 5 questions (Q1 to Q5) of Figure 5 it appears that differences between interfaces for females are minimal, while for males there is a distinct trend towards preference for the replica as a manipulation interface.

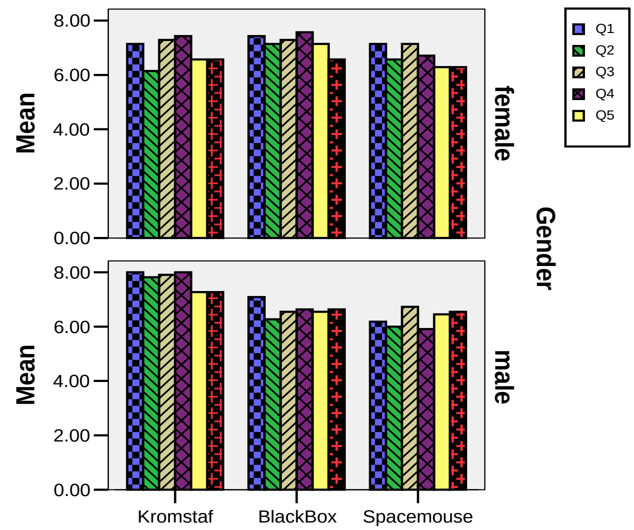

Figure 5: Overall system reaction between groups and between genders

The second section of the QUIS questionnaire is based on preferences related to the window system. This includes characters on the window system and the window layout. The analysis of these results showed as that there isn't any significant difference between the three interfaces, f (2, 51) = .108 and p=.90.

The third part of the QUIS questionnaire is based on generic ease of use of the interface. There was a significant difference on the ease of use of the interface, f (2, 51) =8.193, □=.53. Planned contrasts revealed that the Kromstaf interface is easier to use than the SpaceMouse, t (51)=3.448, r=.44, and that the spacemouse is significantly worse than the blackbox t(27) =3.56, r=.43.

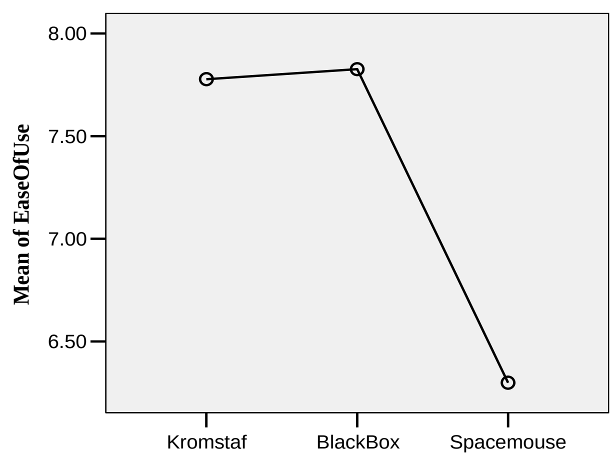

Figure 6: Mean of 'ease of use' across the three conditions

The fourth part of the QUIS questionnaire is exploring the multimedia content of the EPOCH multimodal user interface. The multimedia contents are used to provide a better understanding of the virtual object and contribute to the enhancement of the user's experience. Most responses obtained for this part of the questionnaire range between 5 and 9 indicating a high degree of user satisfaction.

A significant difference was noticed when comparing all three interfaces f (2, 51) = 22.41, □= .73. Table 4 indicates that the

Kromstaf replica scores better than the SpaceMouse in terms of overall performance. Similarly, manipulating the blackbox provokes more user satisfaction than the SpaceMouse. A comparison of significance between the Kromstaf replica and the blackbox does not indicate a significant difference for the overall QUIS. T

Table 4: Comparisons of the 3 interfaces

Comparisons Of Interfaces	***Means (std deviation)***	***df***	***p***	***t***	***r***
Kromstaf vs BlackBox	5.2 (.584)	51	.109	1.63	0.22
Kromstaf vs Spacemouse	4.88 (.46)	51	.0001	6.44	0.66
BlackBox vs Spacemouse	3.9 (.77)	51	.0001	4.80	0.55

4. Conclusions

A formal usability evaluation has been performed in order to evaluate the usability of the EPOCH multimodal user interface in the form of a replica of a cultural artefact and compare it with the SpaceMouse and blackbox for manipulating 3D content. Physical and tactile feedback significantly improves the sense of presence and ease of interaction in virtual environments (immersive, non immersive). By analysing the results of the experimental study we conclude that the participants that use the Kromstaf interface had performed better in the memory task compared to the other devices. This result allows us to conclude that high fidelity interfaces which allow the user to interact with a physical mock-up of an artefact are more efficient in terms of memory recall performance compared to interacting with a lower fidelity interface such as plain box or a SpaceMouse. Augmenting the real physical world by coupling digital information to everyday physical objects and environments through tangible interfaces for 3D interaction, memory recall of elements of such objects provoke enhanced memory performance. Moreover, although there was a clear difference between the replica as well as the blackbox and the SpaceMouse provoking better user satisfaction, an overall statistically significant difference was not observed between the replica and the blackbox. Therefore, system designers should pick a 3D manipulation interface according to system goals: if the goal is better memory retention and learning, the replica was proven more efficient than the black box. If a system's scope is only user satisfaction, simpler manipulation interfaces could suffice. It has to be noted though that both interfaces fall under the category of 'tangible' interfaces therefore, tactile feedback has overall been shown to be significant for 3D interactions.

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