Effects of Menu Orientation on Pointing Behavior in Virtual Environments

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Abstract. The present study investigated the effect of menu orientation on user performance in a menu items' selection task in virtual environments. An ISO 9241-9-based multi-tapping task was used to evaluate subjects' performance. We focused on a local interaction task in a mixed reality context where the subject's hand directly interacted with 3D graphical menu items. We evaluated the pointing performance of subjects across three levels of inclination: a vertical menu, a 45°-tilted menu and a horizontal menu. Both quantitative data (movement time, errors) and qualitative data were collected in the evaluation. The results showed that a horizontal orientation of the menu resulted in decreased performance (in terms of movement time and error rate), as compared to the two other conditions. Post-hoc feedback from participants, using a questionnaire confirmed this difference. This research might contribute to guidelines for the design of 3D menus in a virtual environment.

Keywords: floating menu, menu orientation, local interaction, pointing, evaluation, virtual environments.

1 Introduction

Graphical menus are frequently used for system control, one of the basic tasks in Virtual Environments (VEs). Typically, a command is issued to perform a particular function, to change the mode of interaction, or to change the system state [2]. Research on graphical menus in VEs currently focuses on the design of menu characteristics, among them menu appearance and structure, menu placement, menu invocation and availability, etc. [4]. Various menu systems for VEs have been proposed in the literature; however, a standard graphical menu system for VEs is still yet to come.

Among different approaches for menu system design, adopting two-dimensional (2D) graphical menus in VEs presents many advantages. This approach, bringing the commonly used menu concept from 2D user interfaces to VEs, might benefit from well-established practices in 2D menu design. However, whereas traditional 2D menus are always constrained to a fixed vertical plane surface, graphical menus in a 3D spatial context, such as VEs, can be positioned and oriented in many different ways. The menu placement in an immersive environment can be world-referenced,

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object-referenced, body-referenced, device-referenced, etc. [2][4]. In addition, a menu system can also be oriented in different angles with respect to the user's viewpoint. This might also be one of the reasons why the Virtual Reality (VR) and 3D User Interfaces research community agrees on the term "floating menu" to refer to a 3D menu system in VEs. The main issue for menu placement in VEs is to define an optimal combination between menu position and menu orientation, to facilitate interaction with menu items.

The present paper tackles issues of floating menus' placement in VEs, in particular menu orientation. We conducted a study investigating the effect of menu orientation on user performance in a menu items' selection task in VEs. We focused on a local interaction task (pointing to menu items). More specifically, we hypothesized that the inclination of a floating menu would affect users' perception of menu items' distance and consequently the pointing action. We thus hypothesized that differences in menu orientation would lead to differences in terms of pointing time and errors. Determining whether menu orientation has any effect on users' performance, might be helpful for developers in choosing the placement of menus in VEs; especially in the context of human scale virtual environments where virtual objects (in our case menu systems) are usually within reach of users' hand. We did not address here "at-a-distance" interaction or distant pointing, in which a ray-casting technique is usually used to point to a distant menu system. In the present study, the subject's hand directly interacted with menu items.

2 Related Work

The benefit of graphical menus for interaction in a virtual environment was first showed in a study conducted by Jacoby and Ellis [10]. Since then, various studies on the design and evaluation of graphical menus in VEs have been proposed, leading to a collection of more than thirty existing menu systems at present [4]. A comprehensive review of those menu systems can be found in a survey conducted by Dachselt and Hübner [4]. However, most of the previous studies focused on the menu's appearance and structure, rather than on the issues of menu placement. We can find in the literature numerous studies about the arrangement of menu items which varies from a planar layout (for example, Kim et al. [11]; Bowman and Wingrave [3]; Ni et al. [12], to name a few), to a ring layout (for e.g. the Spin menu proposed by Gerber and Bechmann [7]), or to a 3D layout as the Control and Command Cube (Grosjean et al. [8]), etc. Only a few studies focused on the issues of menu placement in a virtual environment. However, those studies mostly worked on the spatial reference frame of the menu system, rather than on menu orientation. Since the menu orientation is also dependent to the reference frame in certain cases (handheld menu for example), it is worth introducing shortly here some typical studies regarding the reference frame of menu systems in VEs.

In 2000, Kim et al. [11] conducted a study involving three factors: menu presentation (the way menu elements are disposed on menus), input device and menu reference frame in a Head-Mounted Display (HMD). The two menu's reference frames were: world-reference (where the menu is fixed in a position of the scene, independent to the user's viewpoint) and viewer-reference (where menu position and orientation was updated and so kept unchanged in relation to the user's viewpoint). The menu was placed at a distance and the selection of menu items could be done using a ray-casting technique. However, the study focused more on comparing interaction modalities (gesture versus tracked device) than on the issue of reference frame itself. Besides, the analysis on menu presentation and reference frame was not provided. It is thus difficult to draw any conclusion regarding the effect of different reference frames from this study.

Another study conducted by Bernatchez and Robert [1] compared 5 spatial frames of reference, among them world-reference and 4 types of body-reference in a HMD. The four configurations of body-reference were (1) the menu follows the user in position only (2) the menu follows the user's position and turns to remain facing the user (3) the menu is attached to the user's non dominant hand and (4) the menu is following the user's gaze direction. The menu was placed in the subject's arm range (i.e. local interaction) and subjects controlled their hand's avatar to interact with menu elements. This study showed that the user performed the experimental task (a slider control) the best with the body-reference frame (2).

It is important to note that most previous studies about the placement of floating menus (including the previous two studies) have been conducted using a HMD, which is different from a mixed-reality context, like a rear-projected VR system such as CAVE or a workbench. In those VR systems, subjects can see their own body and use their body to interact with different elements of the virtual scene. Recently, a study conducted by Das and Borst [5] investigated menu manipulation performance in a rear-projected VR system, in different layouts, with different menu placements and in a distant pointing context. The study showed that contextual pop-up menus increased performance, as compared to fixed location menus.

An interesting point is that, in previous studies, the effects of the orientation of the floating menu relative to the user were not taken into consideration. In some studies [5][11], the menu was placed vertically. In other studies [1][13], the floating menu was tilted at a certain degree without any details about the choice of menu orientation. From the literature, we were not able to find the answers for our research problem, which involves both orientation of the floating menu and local interaction in a mixed reality context in an immersive environment. The experiment we conducted in this study was designed to help us understand the effect of orientation of the floating menu in a mixed reality context where the user's hand directly touches virtual menu items.

3 Evaluation

3.1 Methodology

We adopted the methodology presented in Part 9 of the ISO 9241 standard for non-keyboard input devices [9]. Specifically, we undertook a user study involving two-dimensional serial target selection. Performance was quantified by the throughput index (in bits per second (bps)) whose calculation is based on Fitts' law [6] and requires the measurement of effective index of difficulty (ID_e) (cf. Formula (2)) and the average movement time (MT) (cf. Formula (1)).

$$Throughput(TP) = \frac{ID_e}{MT} \tag{1}$$

Movement time is the mean trial duration over a series of target selection tasks. The effective index of difficulty is calculated based on the effective target width (W_e) and distance (D) of the target selected. SD_x is the standard deviation of the over/ under-shoot projected onto the task axis for a given condition.

$$ID_e = \log_2\left(\frac{D}{W_e} + 1\right)\left(where\ W_e = 4.133 \times SD_x\right) \tag{2}$$

3.2 Participants

Seven subjects (age range from 22 to 39 years old, all right-handed) participated in the evaluation, after being tested for normal vision and correct stereoscopic perception. Six have little to no experience with 3D stereo vision in a VR system.

3.3 Procedure

The interpupillary distance of each subject was first measured at the beginning of the experiment. A paper with written instructions was then provided to the subject. Subjects were allowed to ask questions and for additional explanation only before the beginning of the test. After that, a calibration of a device tracking user fingers' 3D position was carried out for each subject. Then, every subject was invited to stand in the centre of the CAVE system. Training trials were prepared in order to let subjects become acquainted with the 3D scenes and task in each condition. Afterwards, the real task began.

After the experiment, each subject was requested to answer to some questions on a seven-point Likert scale. The questionnaire aimed at gathering subjective information regarding: ease of the experimental task, enjoyment, effectiveness, and frustration in relation to each experimental condition. Overall, each experimental session (including calibration phase) lasted for approximately 1 hour.

3.4 Apparatus and Task

Subjects were presented with 9 circular targets, arranged in a circle on a virtual planar surface, projected in a 4-sided CAVE-like setup at the Mediterranean Virtual Reality Center (CRVM)[1]. The floating menu was positioned at the centre of the CAVE. The height of the virtual surface was adjusted according to the subject's height to avoid fatigue of the subject's arm. Subjects were free to choose their position so that they felt comfortable with the pointing task.

[1] www.realite-virtuelle.univmed.fr

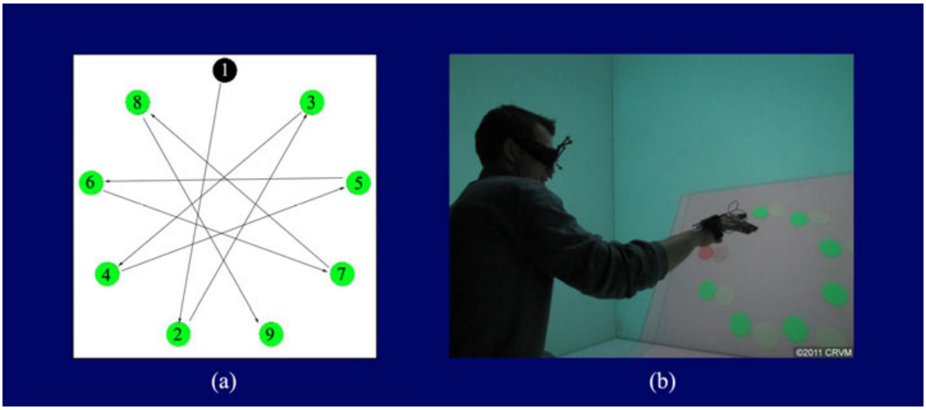

Fig. 1. Experimental task

Figure 1 illustrates the experimental target selection task. Subjects wore the A.R.T. Fingertracking device and used their index fingertip to touch the target (cf. Figure 1(b)). The order of presentation of the 9 targets was predefined as in Figure 1(a). Targets were highlighted in red (except target 1, which was highlighted in black, allowing the subject to rest) one at a time; subjects were asked to point to the highlighted target as quickly and accurately as possible using their index fingertip. Making a selection (whether a hit or a miss) ended the current trial.

Stereoscopic viewing was obtained using Infitec® technology. Real-time tracking of the subject's viewpoint and fingers was obtained using an ART® system. Virtools ® software was used to build and control virtual scenarios, for experimental control and data recording.

3.5 Experimental Design

Fours factors were taken into account in the study

- Target width (W): 0,024 m, 0,036 m
- Target distance (D): 0,12 m, 0,24 m, 0,4 m
- Inclination of the floating menu : vertical (0°), 45°, horizontal (90°) (cf. Fig. 2)
- Block: 1, 2, 3, 4, 5, 6

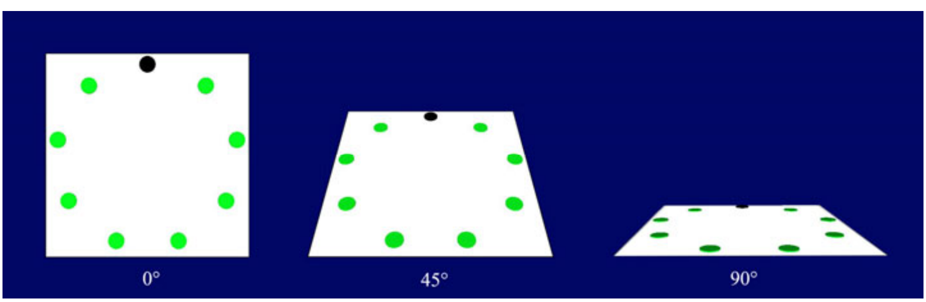

Fig. 2. Three levels of inclination of the floating menu

The combination of two values of target width and three values of target distance defined six IDs (Index of Difficulty) as follows: 2,12 (D=0,12, W=0,036), 2,58 (D=0,12, W=0,024), 2,94 (D=0,24, W=0,036), 3,46 (D=0,24, W=0,024), 3,60 (D=0,4, W=0,036), 4,14 (D=0,4, W=0,024). In total, there were 6048 recorded trials (7 subjects × 6 IDs × 3 inclinations × 6 blocks × 8 trials by ID). The dependent variables were movement time (s), error rate (percent), and throughput (bps). Results were analyzed with repeated measures ANOVAs.

4 Results and Discussion

4.1 Blocks

Movement time with regards to the six trial blocks were respectively 653 ms (Standard Error (SE) = 71), 620 ms (SE=71), 627 ms (SE=68), 627 ms (SE=73), 620 ms (SE=65) and 604 ms (SE=62). The differences were not significant across the six blocks [F (5, 642) = 1,090, p = 0,6364]. Error rates corresponding to the six blocks were respectively 9,93% (SE=5.12%), 7.6% (SE=4,32%), 8,4% (SE=4,32%), 7,31% (SE=4,21%), 7,6% (SE=4,45%) and 7,6% (SE=4,32%). The differences in error rate were also not significant [F(5,642) = 0,992, p = 0,422]. As a matter of fact, there was no learning effect across blocks, indicating that subjects easily adapted to the experimental task and the input device.

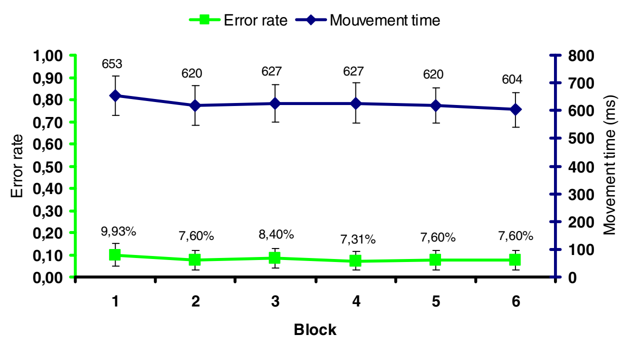

Fig. 3. Movement time and Error rate across six blocks of trial; vertical bars show standard errors

4.2 Movement Time and Error Rate

Average movement time was 632 ms (SE=75), 599 ms (SE=52) and 644 ms (SE=75) in the 0°, 45° and 90° inclination of the floating menu respectively. The difference was significant (F(2,642) = 4,673, p=0,01)**.** Post-hoc comparisons using Tukey test revealed significant differences in movement time between the 45° and 90° conditions (p<0,01). There was no difference between the 45° and 0° conditions.

Average error rates corresponding to the three levels of inclination (0°, 45° and 90°) were respectively 6,2% (SE=3.56%), 6,12% (SE=3,57%) and 11,86% (SE=5,59%). The difference was significant [F(2,642) = 22,039, p < 0,001]. Post-hoc comparisons (Tukey test) revealed a significant difference in error rate between the 45° and 90° conditions ($p < 0{,}001$) and between the 0° and 90° conditions ($p < 0{,}001$). There was no difference between the 45° and 0° conditions (p=0,997).

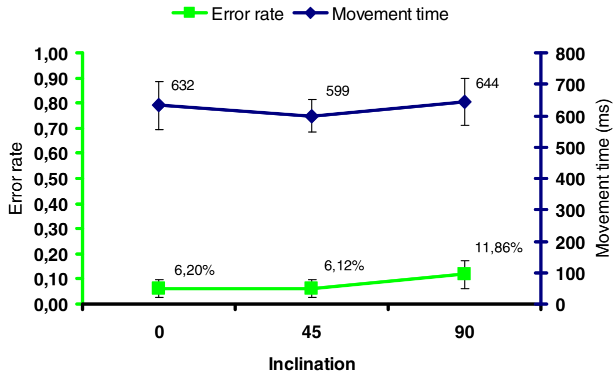

Fig. 4. Movement time and Error rate (vertical bars show standard errors) corresponding to the three levels of inclination of the floating menu

4.3 Throughput

The difference in throughput, which incorporates both speed and accuracy, was also significant ($F(2,642)=6{,}807$, p=0,001). The average throughput was 5.46 bps (SE=0,62), 5,48 bps (SE=0,52) and 5,01 bps (SE=0,64) respectively for the 0°, 45° and 90° conditions. Post-hoc comparisons using Tukey test revealed significant differences in throughput between the 45° and 90° conditions (p=0,003), and between the 0° and 90° conditions (p=0,005). There was no difference between the 45° and 0° conditions (p=0,991).

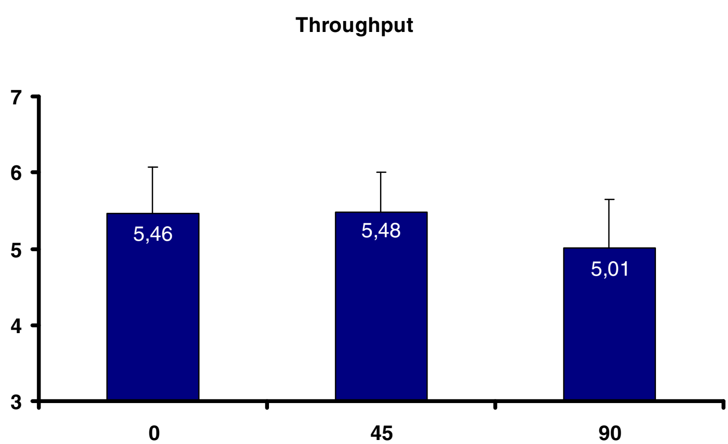

Fig. 5. Average throughput value (vertical bars show standard errors) as a function of the three levels of inclination of the floating menu

4.4 Qualitative Results

As stated before, after the experimental session, subjects were asked to fill a short questionnaire addressing the following questions: ease of the task, enjoyment, frustration and effectiveness with respect to the three level of inclination of the floating menu. Values reported in the histograms (cf. Fig. 6) are medians. Except frustration where high score referred to a high level of frustration from subjects, high scores in the other parameters corresponded to positive feedback. Median values regarding the ease of the task, for the 0° condition it was 5 (1st quartile = 5; 3rd quartile = 6); for the 45° condition it was 6 (5; 6) and for the 90° condition 3 (3; 5). Median values for the 0°, 45° and 90° conditions in terms of enjoyment were respectively 5 (5; 6), 5 (5; 6), and 3 (2; 3). Regarding the frustration with respect to each condition, median values were 2 (2; 3), 2 (2; 3), and 5 (5; 5) respectively for the 0°, 45° and 90° conditions. Finally, as for the effectiveness of different inclinations in supporting the pointing task, median value for the 0° condition was 5 (3; 5), for the 45° condition 6 (4; 7), and for the 90° condition 3 (2; 4).

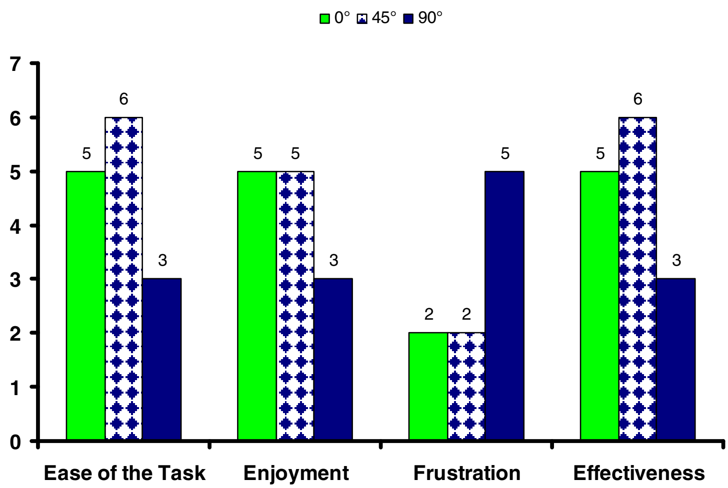

Fig. 6. Results from the questionnaire (on a 0-7 Likert scale)

Additional analyses were performed on the questionnaire data using the Friedman test. There was a statistically significant difference in subjects' feedback regarding the ease of the task [$\chi^2(2) = 6{,}348$, p = 0,042], the enjoyment [$\chi^2(2) = 11{,}385$, p = 0,003], the level of frustration [$\chi^2(2) = 10{,}300$, p = 0,006] and the effectiveness [$\chi^2(2) = 8{,}400$, p = 0,015]. Post-hoc comparisons using Wilcoxon signed ranks test revealed significant differences between the 45° and 90° conditions in subjects' feedback regarding the ease of the task [Z = -2,132, p = 0,033], the enjoyment [Z = -2,414, p = 0,016], the frustration [Z = -2,220, p = 0,026], and the effectiveness [Z = -2,070, p = 0,042] . There were also significant differences between the 0° and 90° conditions in subject's feedback regarding the enjoyment [Z = -2,410, p = 0,016], the frustration [Z = -2,041, p = 0,041], and the effectiveness [Z = -2,032, p = 0,038]. Overall, the 0° and

45° conditions received positive scores while the 90° condition received negative feedback from subjects. This result was in line with the quantitative results regarding the subject's performance above.

5 Conclusion

The focus of this evaluation was on the effect of menu orientation in a local pointing task. The vertical menu plane (inclination of 0°) and 45°-tilted menu plane resulted in better performance (shorter pointing time and lower error rate), as compared to the horizontal floating menu (i.e. the inclination of 90°). Even though menu items in the three conditions of inclination used in the present study were within reach of subjects' hand, inclination seemed to affect users' pointing to menu items. We suggest that a horizontal menu orientation has to be avoided since this configuration potentially lead to difficulties in judging the position of menu items and subsequently in pointing to those targets.

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