Navigation preferences and task performance in a web-based virtual environment

D. Gude

Institut für Arbeitsphysiologie an der Universität Dortmund, Ardeystrasse 67, 44139 Dortmund, Germany

Abstract

Web-based virtual reality applications allow to present content in a vivid and interactive way, but their users are confined to conventional input and output devices. This is especially problematic with regard to navigation, as the mouse and the arrow-keys of the keyboard are two-dimensional controllers, while navigation in virtual environments requires manipulating the viewpoint in six axes. In a field study it was investigated how users navigate under such conditions, and what consequences these preferences have on the speed and accuracy in an associated task. The majority of subjects favoured the mouse over the keyboard, but this preference did not affect task performance. Additionally, most subjects focused on the walk mode of navigation, allowing to move in only two of the six axis, which was accompanied by a shorter task completion time but also a lower response accuracy. That is, the walk mode has the advantage of being analogous to moving in a real-world environment, but is limited regarding the set of viewpoints from which the virtual environment can be examined. Consequently, web-based virtual environments should be designed in such a way that all task relevant information can be accessed via the walk mode of navigation, as long as special 3D-navigation devices are not generally available.

Keywords: field study, human computer interaction, virtual reality, world wide web, computer input devices, usability

1. Introduction

1.1. Laboratory-based vs. web-based virtual reality

The term ‘Virtual Reality’ (VR) summarizes a suite of projection and interaction technologies, presenting computer-generated models in real-time in a lifelike and interactive way. In a laboratory context, this includes stereoscopic projection systems, presenting the virtual environment to each eye from a slightly different viewpoint, thereby providing a direct perception of depth (3D). Examples of such projection systems are head-mounted displays or large projection screens viewed via shutter glasses. The most common element of real-time interaction is navigation, allowing to perceive the virtual environment from arbitrary viewpoints. Such navigation requires controlling six degrees of freedom (DOF), the three translation axes and the three rotation axes. As classical navigation devices are two-dimensional, e.g., the mouse and the arrow-keys of the keyboard, special 3D-controllers are used for this purpose. Meanwhile, numerous fields of applications have evolved, ranging from education and training to virtual prototyping of new products and workplaces [1].

Due to the success of laboratory-based VR, there are attempts to include corresponding elements in web-based applications, to make the benefits of such interfaces available to a much wider audience. The general concept of such applications is to display a virtual analogue of a real-world setting, which can be used, e.g., as learning or shopping environment. First evidence for the utility of this approach comes from laboratory experiments on e-commerce [2]. In these experiments, it was demonstrated that virtual shops allow better navigation and memory performance, compared to interfaces in which the content is presented as hypertext only or as a combination of hypertext and digital photos. In the field of e-learning, it was found that task performance in a web-based virtual learning environment is comparable to that in a real-world setting [3].

However, in web-based VR the users do not have the special projection and interaction equipment commonly applied in laboratory-based VR. Thus, the virtual environment is not presented stereoscopically, but rather in a two-dimensional way with perspective information (2½D). In addition, navigation is carried out by using the mouse or the arrow-keys of the keyboard. Both restrictions to a 2½D display and a 2D navigation device diminish the degree to which the users can be immersed in the virtual environment. The focus of the present paper is on the navigation problem, for which different solutions have been proposed, but which are still lacking a systematic evaluation.

1.2. The navigation problem in web-based VR

Navigation in web-based virtual environments is related to two questions: (a) what input device to support, mouse vs. arrow-keys, and (b) how to match the six DOF of navigation to the two DOF of the controller. Regarding the choice of the device, one has to take into account that virtual environments generally include additional interactive functionalities, like animations, which are activated by clicking on so-called hot spots. The mouse has the advantage that both navigation and other forms of interaction are controlled by a single device, thereby avoiding a permanent switching between controllers.

To address the problem of matching the DOF of navigation to those of the controller, there are two main approaches. One is to allow movements in only two dimensions, moving forward/backward and rotating to the left/right around the vertical (body) axis. This form of navigation is commonly labelled the walk mode. The other approach is to provide additional modes of navigation, like flying or examining. This is commonly realized in viewers or browsers for applications based on the standard of the Virtual Reality Modeling Language (VRML), e.g., Cortona, Blaxxun Contact, or the Cosmo Player. By pushing a key or button, the user switches between these modes of navigation, each time controlling a different set of two of the six DOF.

The walk mode of navigation can be viewed as an intuitive equivalent of moving in real-world environments [4]. On the other hand, it does not allow accessing four of the six DOF and, consequently, the virtual environment cannot be surveyed from all possible viewpoints. This is addressed by defining additional navigation modes, at the expense of introducing extra complexity to the navigation task. To keep the complexity to a minimum, the definition of two additional navigation modes would be sufficient, to map the six DOF. Despite this, in Blaxxun Contact, for example, five additional modes are realized. Such a redundancy makes it difficult for the users to develop a mental model of these options, as a precondition to select a mode in a targeted way [5].

Despite its significance for the usability of web-based virtual environments, up to now there are no systematic evaluations of these possible navigation device and navigation mode configurations. Towards this end, a field study was conducted, investigating the device and mode preferences together with their associated effects on task performance, in the context of the web-based e-learning application ErgoScenes.

2. Method

2.1. Task

ErgoScenes is a web-based e-learning service on the ergonomic design of work systems, available via http://www.ergonetz.de/integral2/index_e.html. It allows practicing the evaluation of work systems, by analyzing different scenarios, which are presented as interactive virtual environments. Currently, there are five scenarios, addressing the design of computer workstations and drivers' workplaces of utility vehicles. An example of a computer workstation scenario is presented in Fig. 1.

The concept of ErgoScenes is to simulate the common procedure of evaluating a real-world workplace (computer-mediated learning by doing). In identifying the ergonomic design deficiencies of the virtual workplaces, the user is assisted by a set of multiple-choice questions, which guide him or her through the evaluation procedure. These questions are presented successively in the lower part of the screen, together with an explanation, which is displayed in a separate inline frame. With each item the response alternatives ‘yes’ and ‘no’ are presented as radio buttons. A yes-response implies that the corresponding aspect of the scenario complies with the design criterion under consideration, a no-response signals an ergonomic deficiency. After responding to each item, the user receives feedback whether his or her response was correct, together with an explanation why this is the case. At the end of the evaluation the overall accuracy is fed back quantitatively, by presenting values that correspond to the percentages of hits (a negative response to an actual deficiency) and correct rejections (a positive response to an adequately designed aspect).

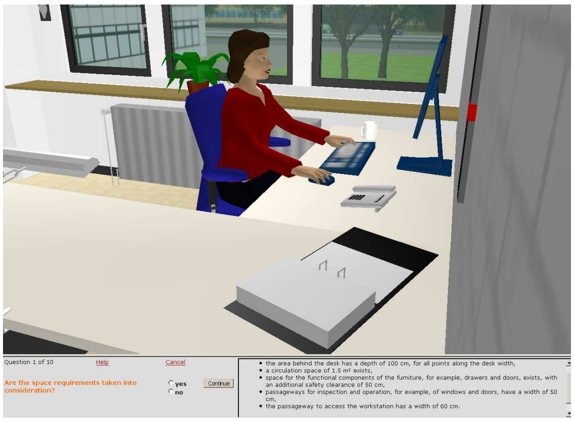
The scenarios allow navigating the virtual environment by using the mouse and/or the arrow keys of the keyboard. There are three navigation modes, which in sum cover all six DOF. In addition to the walk mode outlined above, there are a slide and a rotate mode. The slide mode, initiated by pushing the s-key on the keyboard, allows moving the viewpoint up/down and to the left/right, respectively, similar to viewing a two-dimensional picture. The rotate mode, initiated by pushing the r-key, resembles the steering of an aircraft, rotating around the longitudinal axis (roll) and lateral axis (pitch), respectively.

The scenarios also include interactive elements mimicking those of real-world workplaces, examples for the computer workstations are to open filing cabinets and drawers, moving the louvers up and down, or switching the luminaries on and off. These interactive elements are controlled by the mouse, by pointing at corresponding hot spots and pushing the left mouse button.

2.2. Subjects

To access ErgoScenes, the users need to register. First-time users fill a form that records general personal data, e.g., age, gender, and occupation. Finally, they select a user name and password, for future logins.

The results presented here are based on records from 81 first-time users working with the scenario depicted in Fig. 1, 35 women and 46 men, with a mean age of 32.8 years (S.D. = 12.4 years). The occupation spectrum included pupils (14%), students (22%), health professionals (19%), other service professionals (35%), and other occupations (11%). The majority of the subjects came from Germany (78%), followed by other European countries (19%), and North and South America (4%). 58% of the subjects reported previous experience in the field of ergonomics, 22% indicated previous experience with virtual reality applications.



Are the space requirements taken into consideration?

○ yes
○ no

- the area behind the desk has a depth of 100 cm, for all points along the desk width,
- a circulation space of 1.5 m² exists,
- space for the functional components of the furniture, for example, drawers and doors, exists, with an additional safety clearance of 50 cm,
- passageways for inspection and operation, for example, of windows and doors, have a width of 50 cm,
- the passageway to access the workstation has a width of 60 cm.

Fig. 1: Example of a computer workstation scenario

2.3. Variables

During the evaluation of the scenario, the users’ navigation and interaction was recorded, as well as their responses to the items. Based on these data, the subjects were grouped according to two navigation preference aspects. The first aspect was the navigation device preference, differentiating between mouse users (i.e., those using the mouse for more than 90% of the time), keyboard users (i.e., those using the arrow-keys for more than 90% of the time), and users navigating both by mouse and keyboard (i.e., those not falling in one of the previous two categories). The second grouping variable was the navigation mode preference, differentiating between subjects navigating by walk mode only and those using the slide and/or rotate mode, in addition.

Dependent variables were the frequencies of the six differentiated navigation preference categories and the associated speed and accuracy values for task performance. Speed refers to the time to complete the evaluation; accuracy was defined as the percentages of hits and correct rejections.

2.4. Hypotheses

Regarding the navigation device preference it was expected that the majority of the analysed subjects chose to navigate by using the mouse, rather than the arrow-keys, thereby avoiding a permanent switching between devices while accessing the interactive elements and answering the questions. Moreover, it was hypothesized that the navigation device is used in a consistent way, that is, subjects using both mouse and keyboard were expected to form the smallest group. Concerning the navigation mode preference, it was expected that the majority of the subjects concentrates on the walk mode, as a natural and easy to handle way of moving in the virtual environment, not employing the other two modes for controlling the remaining four DOF. In sum, navigation was expected to be performed predominantly via a mouse-based walk mode.

A second question was concerned with the relation of these preferences to performance, namely speed and accuracy in the evaluation task. It was expected that the preference of the mouse as the navigation device would speed up task performance by avoiding a permanent switching between controllers. On the other hand, no effect of the device preference on accuracy was hypothesized, neither on the percentage of hits or correct rejections. Focusing on the walk mode was also expected to result in a speed advantage, in comparison to subjects using additional modes of navigation. However, the latter group should show a higher accuracy, compared to those using the walk mode only, because of being able to examine the virtual environment from a larger set of viewpoints.

3. Results

3.1. Navigation preferences

The results regarding the frequency distribution of navigation device and navigation mode preferences are presented in Fig. 2. As expected, the majority of the subjects preferred a mouse-based walk mode of navigation. Of those favouring the walk mode, the other two categories featured comparable frequencies. Of those using additional modes of navigation, most frequently both the mouse and the keyboard were used as navigation devices, while there were no pronounced differences between these three categories.

This pattern of results was analysed in a two-factorial log-linear model, with the independent variables device (mouse, keyboard, mouse and keyboard) and mode (walk mode only vs. additional modes). In this analysis, there were no main effects of device ($\chi^2 = 3.25$, $df = 2$, $p > .10$) and mode ($\chi^2 = 1.49$, $df = 1$, $p > .20$), but a significant interaction between these variables ($\chi^2 = 16.64$, $df = 2$, $p < .001$), suggesting that only the group of a mouse-based walk mode of navigation differed from the other five groups.

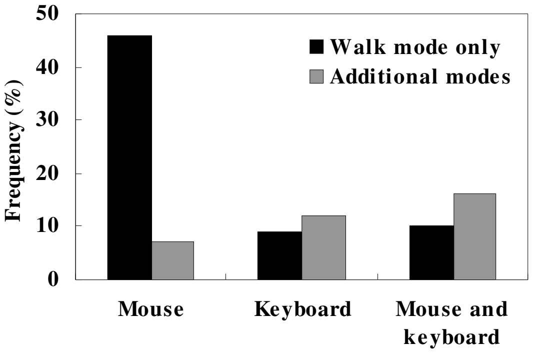


Fig. 2: Navigation device and mode preferences

This interpretation could be confirmed in a subsequent analysis, from which this group was excluded, resulting in no significant differences between the remaining groups ($\chi^2 = 3.40$, $df = 4$, $p > .40$).

3.2. Performance and its relation to preferences

On the average, the subjects spent 14.9 min (S.D. = 11.6 min) to complete the ten questions of the evaluation task. The mean percentage of hits was 36% (S.D. = 24%); the corresponding value for correct rejections was 82% (S.D. = 19%). The difference of these accuracy variables was highly significant, $F(1, 80) = 176.86$, $p < .001$. In terms of signal detection theory, this result implies that the subjects employed a rather conservative decision criterion, resulting in a marked bias towards positive responses.

The consequences of the navigation preferences identified above for these performance variables were investigated. The time to complete the evaluation task was analyzed in a 2-factorial ANOVA with navigation device (mouse, keyboard, mouse and keyboard) and mode (walk mode only vs. additional modes) as independent variables. There was a significant main effect of navigation mode ($F[1, 75] = 4.17$, $p < .05$), but no main effect of navigation device ($F[2, 75] < 1$) nor an interaction between navigation mode and device ($F[2, 75] < 1$). The main effect of navigation mode is depicted in Fig. 3. According to this, the subjects focusing on the walk mode were faster than those using additional navigation modes. This is in line with the initial expectation that the utilization of additional modes adds complexity to the navigation task. On the other hand, the originally hypothesized disadvantages of using the keyboard and using both mouse and keyboard were not confirmed.

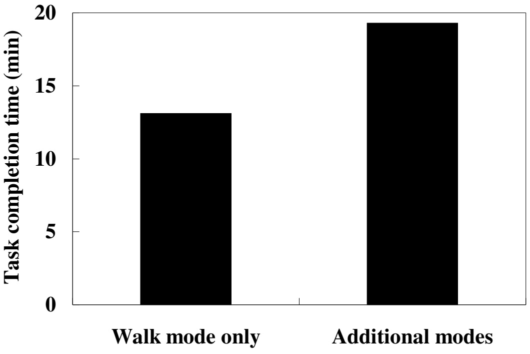


Fig. 3: Effect of navigation mode preference on task completion time

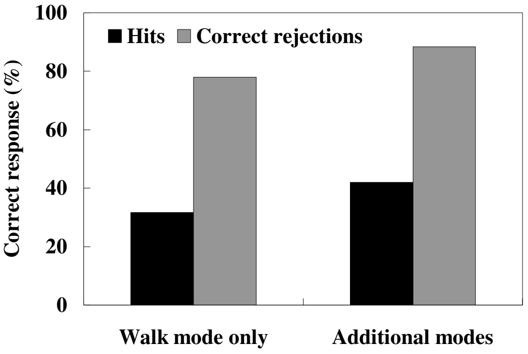


Fig. 4: Effect of navigation mode preference on response accuracy

The response accuracy was analyzed in a 3-factorial ANOVA with navigation device (mouse, keyboard, mouse and keyboard) and navigation mode (walk mode only vs. additional modes) as independent variables and response type (hits vs. correct rejections) as repeated measurement variable. Regarding the independent variables, there was a significant main effect of navigation mode ($F[1, 75] = 7.20$, $p < .01$), but no main effect of navigation device ($F[2, 75] = 1.23$, $p > .20$) or interaction between navigation mode and device ($F[2, 75] = 2.01$, $p > .10$). In addition, there were no significant interactions between the independent variables and response type, of navigation mode ($F[1, 75] < 1$), navigation device ($F[2, 75] = 1.02$, $p > .30$), or the interaction of mode and device ($F[2, 75] < 1$).

The main effect of navigation mode on the two response accuracy variables is presented in Fig. 4. Compared to the walk mode, using additional navigation modes resulted in a higher percentage of hits as well as correct rejections. This implies that – as expected – examining the virtual environment from a larger set of viewpoints, the subjects were able to get additional information, improving the accuracy with which they performed the evaluation task.

4. Discussion

In sum, all but one of the initial hypotheses could be confirmed, providing evidence for the problems associated with the use of two-dimensional navigation devices in web-based virtual environments. As expected, most subjects preferred a mouse-based walk mode of navigation. This result reflects two usability aspects of navigating virtual environments, ease and naturalness. The mouse was required for other interactions, like answering the questions and clicking on hot spots in the virtual environment, suggesting its use as the navigation device. On the other hand, there were also substantial numbers of subjects preferring the keyboard or using both mouse and keyboard. For these subjects, the integration of their navigation in the other interactions with the application was not decisive. Moreover, and diverging from the initial expectation, their task performance was not significantly different from those subjects in the respective mouse preference groups. This implies that switching between devices was not crucial in the context investigated here. Consequently, navigation both by mouse and by keyboard should be supported by web-based virtual environments, in contrast to the frequent approach to focus on the mouse user only.

The widespread focus on the walk mode is in line with observations reported in [4]. The finding indicates a pronounced tendency to transfer real-world movement schemata to the interaction with virtual environments. This tendency could be attributed to the fact that the present analysis was based on first-time users, and therefore the navigation preferences might change with additional practice. On the other hand, as web-based virtual environments are not yet widespread, the designers of such applications have to assume that most of their users will start out as novices. Thus, they should ensure that their users would not cancel frustrated before having the chance of becoming more familiar with this type of application. Nevertheless, the investigation of the relationship between the walk mode preference and the level of expertise is an interesting question for future research.

A second potentially moderating variable is the form of the virtual environment. It is a rather natural approach to transfer the movement schema of walking to the room-like virtual environment investigated here. In other, non-ground based contexts, like aerial or space environments, other ways of navigation might be preferred, which would set different constraints for the design of corresponding virtual environments. This addresses the question of the flexibility of the cognitive mechanisms underlying movement and orientation in virtual spaces, whether the walk mode is rather universal in nature or just one of a larger set of movement schemata that users have at their disposal, which are applied in a context sensitive way. While not yet investigated in a targeted and systematic approach, a first indication of such context sensitivity comes from a laboratory experiment in which navigation mode preferences and navigation performance were affected by the characteristics of the virtual environment [6].

Unfortunately, favouring the walk mode resulted in a speed-accuracy trade-off, in the virtual environment investigated here: being analogous to moving in a real-world environment, this mode was accompanied by a shorter task completion time, but being limited with regard to the set of viewpoints from which the virtual environment can be perceived, it was complemented by a lower response accuracy. This result can be addressed in two ways: one would be to enable the users to control all six DOF in an intuitive way, to provide a comprehensive access to task relevant information, and thereby promoting accuracy. However, this trail is difficult to follow, as it requires more sophisticated input devices, currently not yet available to most users of the World Wide Web. Therefore, the other alternative seems to be more appropriate, to ensure that all task relevant information can be accessed by using the walk mode only, requesting a suitable design of the virtual environment.

Finally, it should be mentioned that the current implementation of the walk mode gives room for several improvements, to enhance the correspondence to movements in real-world environments. For example, there are indications that the gain of controllers is frequently perceived as too high, eventually resulting in disorientation [5]. The problem could be addressed by restricting the gain to a magnitude that is comparable to walking in real-world environments. This approach could be combined with the implementation of smooth acceleration and deceleration phases, in such a way that the navigation in the virtual environment follows the basic laws of mass inertia. Another example is the differential realization of forward and backward movements, which are currently handled in an equivalent way, while the latter is substantially slower than the former in real-world environments. These two examples are provided to illustrate the potential of implementing physical and biomechanical constraints, to give a more realistic ‘look and feel’ in navigating web-based virtual environments. As outlined in the introduction, this domain is characterized by several restrictions, due to the lack of special projection systems and interaction devices commonly used in laboratory-based VR, resulting in comparatively low levels of immersion. On the other hand, even under these restrictions there are opportunities to refine interaction techniques towards higher degrees of immersion, potentially associated with superior usability and task performance.

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