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ORIGINAL ARTICLE

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Evaluating design guidelines for reducing user disorientation in a desktop virtual environment

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Abstract Navigation in virtual environments can be difficult. One contributing factor is user disorientation. Two major causes of this are the lack of navigation cues in the environment and problems with navigating too close to or through virtual world objects. Previous work has developed guidelines, informed by cinematography conventions, for the construction of virtual environments to aid user comprehension of virtual space to reduce user disorientation. To validate these guidelines, two user studies have been performed where users of a desktop virtual environment are to complete a navigation task in a virtual maze. In an initial study [12], collision detection with the maze walls was not enabled and the results indicated that the guidelines were effective for reducing disorientation but not for developing the user's awareness of the environment space. A second study has been performed where collision detection was enabled. Results suggest that the use of the guidelines can help reduce the incidences of user disorientation and aid navigation tasks. However, the guidelines have little impact on users' ability to construct cognitive maps of the desktop virtual environment.

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1 Introduction

Usability problems associated with navigation and exploration of virtual environments are attributable to many causes. These include: the lack of navigation or wayfinding cues to guide users around the environment [5, 23], problems when the whole display screen is reduced to one colour or texture whilst navigating too close to or through virtual objects [10, 13], the cognitive load that is placed on the user [21], the choice of motion control technique [4] and the restricted field of view seen through the display screen [17]. Any one or a combination of these may result in user disorientation. This is problematic as navigation is a basic requirement in navigable virtual environments [6] and a fundamental cornerstone in a growing number of human-computer interfaces [19].

As a usability problem, user disorientation can be present in both immersive and desktop virtual environments. For immersive systems it is typical to find reports of disorientation due to motion sickness [18] and the encapsulation of the visual, and audio, senses within the virtual environment. In contrast, a common criticism of desktop systems is the lack of peripheral vision afforded by the desktop display, reducing users' awareness of their surroundings or of their location in the virtual space [20]. Awareness of a user's surroundings and the implications for successful navigation in a virtual environment are central to the work described here.

This paper presents an exploratory study to evaluate design guidelines to aid user navigation. The focus of the design guidelines [14] is to promote user-centred navigation. This work was carried out as part of the INQUISITIVE project [8], a 3-year research project funded by the UK EPSRC between groups at the

University of York and the CLRC Rutherford Appleton Laboratory (RAL). The aim of the project was to develop methods and principles that could be used to improve the design of interfaces for virtual environments. The work described in this paper focuses on one common usability problem in the navigation and exploration of virtual environments—user disorientation.

The remainder of this paper is organised as follows. In Sect. 2 background material on the design guidelines that are to be evaluated in the study are described. Next, Sect. 3 presents an overview of the study itself, followed in Sect. 4 by a brief review of the subjects and the method used. In Sect. 5 the raw results are presented. Finally, Sects. 6 and 7 present the discussion and a summary of conclusions.

2 Background

Navigation in virtual environments can be difficult. One contributing factor is disorientation associated with the restricted field of view that users are provided with via display technologies, e.g. head-mounted displays (HMDs) and desktop monitors. Such displays only provide a viewport into the 3D space that makes up a virtual environment. Virtual environments do not in general provide the same rich set of cues for distance, motion and direction found in physical environments [2]. However, it is possible to increase the user's awareness about the surrounding space that is outside the current viewport. This space is called *virtual off-screen space*. Visualising off-screen locations and the associated space is a problem for interfaces that provide a limited view of the entire environment [1].

Marsh and Wright [14] propose the use of design guidelines, informed by cinematography conventions, for the construction of virtual environments. A user's comprehension of virtual off-screen space can be increased in order to reduce user disorientation. It is anticipated that the application of the design guidelines will provide users with visual cues to unconsciously predict the contents and/or shape of the immediate surrounding space in addition to that seen within the display screen's restricted field of view. That is, the space that is seen on-screen, within the display screen, implies additional space that is not seen through the current viewport and is in off-screen space. Hence, users are provided with a greater knowledge of their immediately surrounding virtual space, and it is proposed that this will aid the navigation of virtual environments.

Two guidelines defined by Marsh and Wright [14] involve the cinematography conventions for *exit and entry points* and *partially out of the frame*. In the context of virtual environments, Marsh and Wright identify *exit and entry points* as doors, paths, roads etc. that lead out of the screen and *partially out of the frame* as familiar objects shown partly in the current view frame. The proposed guidelines for these two conventions are:

– *exit and entry points*: wherever possible, it must be clear to the user that there exists the option to exit the area contained within the confines of the display screen;
– *partially out of the frame*: the placement of objects in the virtual environment should be such that there is always more than one object partially in the user's field of view. The partially displayed objects will provide cues to the user that there exists, currently hidden, space outside the field of view.

An exploratory study to investigate these design guidelines was performed [12]. The study focused on the *partially out of the frame* guideline and, to a lesser extent, the *exit and entry points* guideline. That is, the guideline *partially out of the frame* was manipulated. It was anticipated that the guidelines would appear natural and transparent and support user navigation by reducing the number of disorientation-based usability problems (e.g. walking through virtual objects and object collisions [24]).

As the focus of the study was to investigate user disorientation it was important to provide a test environment where an extreme form of user disorientation was possible, for example allowing the user to move through walls, a commonly documented navigation problem for virtual environments without collision detection. Thus users are able to move through walls and even stop the viewpoint within wall structures.

However, it is possible that the absence of collision detection would have a biasing effect on the way users navigated the environment, independent of the implemented representations of the design guidelines. Bowman et al. [3] observe that keeping a user within an environment with simple collision detection can prevent some disorientation. Therefore a follow-on study (the focus of this paper) was conducted within the same test environment but with collision detection enabled.

3 Study outline

Both studies were developed to test the effectiveness of Marsh and Wright's design guidelines [14] to reduce usability problems associated with navigation and exploration within virtual environments, and in particular to reduce user disorientation. Each study consisted of two subject groups. Both subject groups were required to carry out a navigation task in a desktop virtual environment; one with the design guidelines implemented and the other in the same virtual environment without the design guidelines implemented. The test desktop-based virtual environment used was a "virtual corridor" or maze implemented in the Windows version of GNU MAVERIK[1] [16]. The walls of the maze were coloured

[1]MAVERIK is a publicly available virtual reality system developed by the Advanced Interfaces Group at the University of Manchester (see http://aig.cs.man.ac.uk/maverik/; cited 6 May 2004).

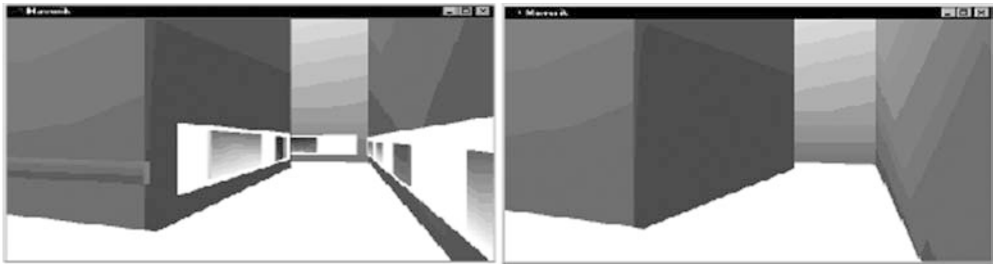

Fig. 1 A portion of the virtual corridor/maze with and without the implemented guidelines

with random alternating colours so that the maze without implemented guidelines[2] would provide necessary perspective cues for subjects. In a pre-study evaluation, a single-colour maze, without implemented guidelines, was noted to be extremely difficult to navigate as corners at a distance blended into the background walls.

In both studies the implemented guidelines were represented by pictures[3], picture frames, wall panels and dado rails, mounted along the walls of the virtual corridors. Their placement was in accordance with the design guideline for *partially out of the frame*. The maze had neither windows nor doors and had one entrance, one exit and a corridor or pathway connecting them; these are the *exit and entry points* according to the design guidelines. As the *exit and entry points* were the same for each maze, any future reference to the design guidelines will therefore apply to those *partially out of the frame*. An example of a typical point of view with and without the implemented guidelines is shown in Fig. 1.

The studies attempted to answer the following questions—do the implemented guidelines:

– appear natural and transparent, that is, are not identified as a product of the design guidelines?
– provide visual cues to help guide participants through virtual space?
– imply to users the existence of space other than that which is seen within the confines of the restricted field of view, that is, imply virtual off-screen space?

The focus of both studies was to investigate user disorientation and whether the implemented guidelines had an effect on reducing this disorientation. However, measuring user disorientation is a non-trivial matter as it is a subjective cognitive condition closely associated with virtual environment issues of immersion, presence and the sense of "being in" the illusion created by 3D virtual space [15]. Two methods were used to gauge user disorientation through the studies. Firstly, an explicit question about whether the user felt disoriented during the session was in a post-study questionnaire (see Appendix A). The responses to this question were also augmented with audio/video footage captured during the session. Secondly, possible disorientating situations were isolated from recorded session logs tracking user movement in the virtual environment. In the first study, with no collision detection, the number of times that the user moved/walked through a maze wall was measured. However, it is not assumed that every time a user walks through a wall they *are* disoriented, for example the user may have meant to try walking through the wall to better understand the environment layout [2], but that disorientation is more likely to happen in such a situation. Therefore, it was proposed that the implemented guidelines would reduce this type of behaviour.

A similar but less extreme form of disorientation can happen if a user moves very close to an object in a virtual environment. If the object fills the user's field of view, e.g. "nose against the wall" [9], the viewpoint turns to one colour/texture and the user is without visual cues to allow them to determine their next navigation action. This form of user disorientation is commonly found in environments with collision detection as users get stuck on objects/walls they are close to [25]. This was used as a potential user-disorientation measure for the second study. However, this was not as easy to determine as the walked-through-walls measure, which could be easily determined via the movement logs of each session. Therefore, recorded traces of user movements through the maze, both from first person and plan, or bird's-eye, views, were reviewed manually by the authors. Figure 2 shows two example traces from the second study with the potential disorientating situations marked. Potential disorientating situations were identified from examples in the traces where the whole field of view was present in one colour and the user obviously hesitated before resuming travel in the environment.

4 Subjects and method

The 18 paid volunteers who took part in the collision-detection-on study were recruited through a university web site, notice board advertisements in university colleges and participants at a university open day. They consisted of 4 females and 14 males with ages ranging between 16 and 32. A mix of subject sex and age were evenly spread between the two groups. All had previous experience of computer games, describing themselves as novices (9), experienced users (7) and expert players (2).

[2]Hereafter, the *design guidelines* will refer to the proposed design guidelines developed by Marsh and Wright [14], while the *implemented guidelines* will refer to the physical representation of these guidelines applied to the test virtual environment.

[3]Pictures on the maze walls included works of art by Picasso, Monet and Matisse.

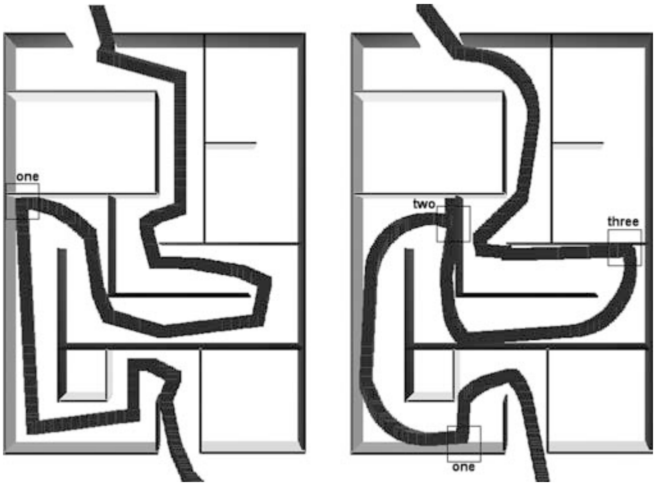

Fig. 2 Example disorientation situations identified in the second study traces

Four subjects had previous virtual reality technology experience, two with desktop virtual environments, one with HMD virtual environments and one with both.

Subjects were allocated study time slots and alternately placed in one of the two groups, with and without implemented guidelines. From a first-person perspective, with the field of view as if one was in the environment, subjects were asked to move through the "corridors" of a virtual building. The experiment was run on a standard desktop personal computer environment consisting of a 433-MHz Pentium processor, Windows 98 operating system, 17-in. colour monitor and a standard keyboard. The test subjects were located in an isolated office, with one instructor/observer and a tripod-mounted video camera to record the session. The subjects' movements were logged, via a background computer process, through the session and collisions with the walls noted. The logged movements were used to re-run the user's travel through the test environment in post-study analysis.

Immediately after completing the navigation task, subjects were asked to identify a 2D plan, or bird's-eye view, of the "virtual maze" from three different maps to determine if they had constructed an accurate mental model of the environment. The concept of an internal (mental) model or "cognitive map" is an important part of the navigation process [22]. The three maps can be seen in Fig. 3; map B is a plan view of the actual environment used in the session. Subjects also completed a questionnaire (Appendix A) after the session.

Fig. 3 2D plan views of corridors (maze) within the virtual building. **a** Simple maze. **b** Actual maze. **c** Complex maze

5 Results

A summary of the results from the study can be seen in Table 1. In this study, every subject collided with at least one wall. In the first navigation study [12], a measure of possible user disorientation was the number of times that a user walked through the walls of the maze. The actual number of wall collisions in a session was not deemed to be an accurate measure as the experiment environment collected collision data on every movement frame. Hence when users were disoriented and moving within walls, multiple collision events were collected that did not necessarily represent the degree of disorientation. However, this is not possible to measure with collision detection enabled. Thus the measure for possible disorientation used in this study was whether users entered into potentially disorienting situations while navigating the maze. The wall collision data in themselves were deemed to be an inaccurate measure of disorientation as some users who were not disoriented used the walls to navigate by sliding down them, thus generating multiple collision events. Disorientation situations were identified by expert judgement after reviewing captured footage of the sessions (for examples see Fig. 2). As shown in Table 1, three subjects with the implemented guidelines and six subjects without the implemented guidelines moved into such situations.

From the questionnaire answers, the majority of subjects had no problems with the arrow key controls, with 15 finding the arrow keys effective and 12 being happy with the speed of movement. Five subjects in each group chose the correct map, while no subjects selected map A. Of those that chose map C, four were without the implemented guidelines and four were with the implemented guidelines.

In total, seven of the subjects felt disoriented during the navigation task—two with the implemented guidelines and five without. Of those without the implemented guidelines four noted their proximity to the walls as the cause of their disorientation. For example, two responses were "If I went too close to a wall and [sic] just hit a blank space of colour" and "Display only one colour and could not tell is [sic] moving or not." Another subject found the changing colours on the different

Table 1 Summary of results

	Guidelines	Without guidelines
Collided with walls	9	9
Disorientation situations	3	6
map: A	0	0
map: B	5	5
map: C	4	4
Disorientated	2	5
Awareness of activities external to study task	3	1
Breaks in attention	5	1

wall partitions disorienting. Of the subjects with the implemented guidelines, one subject thought that the pictures played a part in successfully navigating the maze and another subject was concerned about what their orientation was in the maze. Four subjects, three with implemented guidelines, experienced an awareness of activity external to the navigation task. Activities cited included the noises made by people outside the test room, the hum of the computer, the video camera and the supervision, of being watched and notes being taken. The five subjects with implemented guidelines who noted breaks in their attention all noted the pictures on the walls as the cause, with one also noting the colours of the walls. One subject without implemented guidelines also noted the colours of the walls as a distracting feature.

6 Discussion

The main aim of this study was to determine whether the implemented guidelines, informed by the design guidelines, were effective in reducing user disorientation while navigating in a desktop virtual environment with collision detection enabled. The study considered four discrete measures of user disorientation:

- number of wall collisions,
- disorientation responses in the post-study questionnaire (Appendix A),
- number of identified potential disorientating situations,
- awareness of the space, via the map selection process and involvement in the task.

In this study every user collided with a wall at least once. Also the number of times that each subject hit the walls was approximately the same across those with the implemented guidelines and those without (Fig. 4).

A similar result was found in the first study. One reason for this is that the only penalty for a wall collision was if the user got stuck on the wall and movement was halted. This, however, would not be a problem if the subject were sliding forwards or backwards along a wall, although this would generate a wall collision event in the monitoring software. Also in the first study, as collision detection was disabled, subjects would be unaware that they had collided with a wall in certain circumstances, for example if cutting a corner while navigating. Therefore this is not an accurate measure of user disorientation.

A total of seven subjects self-reported in the post-study questionnaire that they felt disoriented while navigating in the environment. Of those, two had the implemented guidelines and five were without. This result indicates that the implemented guidelines played a part in reducing user disorientation. Next, how the subjects performed in terms of the identified disorientation situations and whether this was also related to subjects' overall feelings of disorientation was examined. From the traces of the subjects' movements (for examples see Fig. 2), nine subjects encountered potential disorientation situations, with three having the implemented guidelines and six not having them. This indicates that the implemented guidelines had a positive effect on reducing the subjects' navigation into disorientating situations. A similar result was found in the first study [12], where the implemented guidelines were shown to reduce the number of times that users walked through the maze walls.

However, from Table 1 it is not obvious that those subjects who were disoriented are the same subjects who entered the disorientating situations. Figure 5 shows a comparison of the subjects' results in terms of the implemented guidelines, disorientation indicated by questionnaire answers and expert-identified disorientation situations. It can be seen that only subjects without implemented guidelines (subjects 10 and 11 in Fig. 5) found themselves in disorienting situations more than once. Also, of the subjects who were both disoriented and placed in disorientation situations, only one (subject 1 in Fig. 5) had implemented guidelines, while the other three subjects (10, 11 and 13 in Fig. 5) were without implemented guidelines. One conclusion from this study

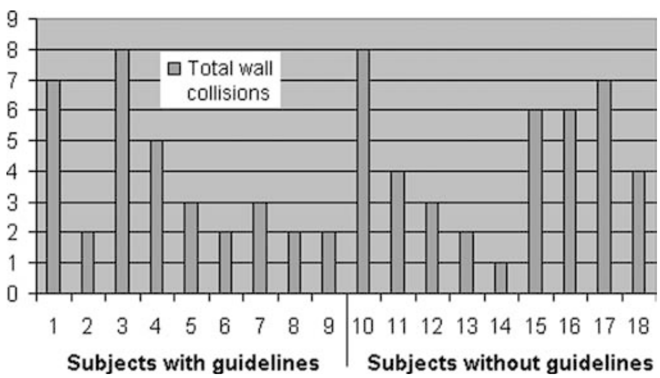

Fig. 4 Comparing number of wall collisions with use of implemented guidelines

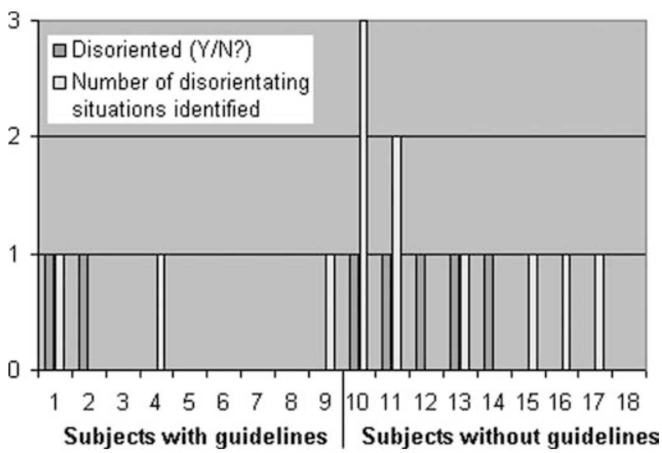

Fig. 5 Comparing implemented guidelines with subject disorientation and disorienting situations

is that the implemented guidelines not only reduced the subjects' perceived disorientation but helped subjects to avoid situations where they would become disoriented.

The final measure of subject disorientation in the study environment was the subjects' awareness of their surroundings. In the two-dimensional (2D) maze recognition test (Fig. 3), an equal number of subjects chose correct and incorrect maps. This was evenly distributed over subjects with or without the implemented guidelines. In the first study, subjects with the implemented guidelines scored lower than those without and, specifically, more subjects with implemented guidelines chose the more complex map (map C). Marsh and Smith [12] suggested that the use of implemented guidelines added a complexity to the environment that the subjects then associated with the more complex map. This was not the case in the current study. However, as collision detection was not enabled in the first study, the subjects could walk through the maze walls, and this may have distorted their view of the environment. In summary, the implemented guidelines did not significantly help or hinder the construction of user awareness of the spatial layout to the environment.

Six subjects acknowledged that the implemented guidelines had momentarily caused them to break their attention from the navigation task to admire the pictures on the walls. That is, the pictures evoked interest and/or curiosity in the subjects. Although it seems reasonable to suggest that the subjects' concentration was momentarily broken from the navigation task, the subjects did remain attached to the illusion created within the virtual environment, the inducement of experience as reflected by "staying there" [11]. Only one subject noted the pictures as a cause of disorientation, and this was a confusion about the navigation task, not the placement or quality of the pictures. This suggests that the implemented guidelines appeared transparent to most subjects and blended naturally with the study virtual environment. A similar result with the implemented guidelines was found in the first study.

Finally, three subjects with implemented guidelines acknowledged being aware of activity external to the navigation task compared to one subject without implemented guidelines. In all four cases, general noises outside the study room and the supervision of the session, the supervisor being present and the video camera were stated as the causes of the external awareness. These four cases seem to be the personal preferences of the subjects, and overall the presence or absence of the guidelines seemed to have little effect on those subjects who could be distracted. A similar result was found in the first study.

7 Conclusions

In general, the subjects in the study performed positively. The implemented guidelines did provide noticeable aid for subjects when navigating the virtual maze. In terms of user disorientation, over both studies the difference between the environments with collision detection enabled or not were not significant. With regard to the benefit afforded by the implemented guidelines, results of the spatial test were less convincing, which may be attributed to the difficulty of transforming a mental model formed in a 3D environment into a 2D plan view. This may be a problem for subjects regardless of guideline implementation.

Unfortunately, the strength of the positive results must be tempered with the obvious limitations of the studies. In both studies, only a limited number of users, 18 in each, were tested and many of the users' backgrounds and experience in virtual environments varied. Also, measurement of actual user disorientation was difficult due to the subjective nature of the condition. However, both studies were preliminary investigations into the potential for design guidelines to aid user navigation and advance our understanding of techniques to reduce user disorientation. The study reported in this paper was conducted in a desktop virtual environment, and, due to the nature of the design guidelines, it is likely that they could also benefit navigation in more immersive virtual environments. This is a topic for future research.

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Appendix A: Post-study questionnaire

[*Delete as appropriate]

1.	age group *: **18–25, 26–32, 33–39, 40–46, 47–52, over 52**			
2.	**female/ male** *			
3.	have you any experience of the following:			
	i.	computer games?	**y/n*** (if no, go to ii.)	
		how would you rate your skill level:	**novice, experienced, expert***	
	ii.	virtual reality?	**y/n*** (if no, go to 4.)	
		using: Head Mounted Displays (HMD)?	**y/n***	
		using: desktop computer	**y/n***	
		which of the following best applies to the virtual reality products for which you have had experience?		
		Educational	**y/n***	
		Entertainment	**y/n***	
		other, please specify ___________________________		
4.	where did you hear about the study? ______________________			
5.	please rate the level of difficulty/effectiveness of using the cursor keys -*arrow keys*- to move around the corridors? **difficult** 1 2 3 4 5 6 7 **effective** *please comment:*			
6.	please rate the speed of movement through the corridors? **too slow** 1 2 3 4 5 6 7**too fast** *please comment:*			
7.	did you feel disorientated at any time? *if yes, please comment on the cause of this disorientation:*		**y/n***	
8.	how attentive/focused did you feel in the task of moving through the corridors? **not focused** 1 2 3 4 5 6 7**totally focused**			
9.	when moving through the corridors, were you aware of activities external to your task? *if yes, what things were you aware of:*		**y/n***	
10.	when moving through the corridors, did anything break your attention from your task to activities external to your task? *if yes, what things were you aware of:*		**y/n***	
11.	how much of the route through the corridors can you remember? **none at all** 1 2 3 4 5 6 7**all the route**			
12.	please describe as much of the route through the corridors as possible:			
13.	if you wish to learn more about the study please write your email below:			

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