Guiding Techniques for Collaborative Exploration in Multi-scale Shared Virtual Environments

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Keywords: Virtual Reality, 3D Navigation, Collaborative Virtual Environments.

Abstract: Exploration of large-scale 3D Virtual Environments (VEs) is often difficult because of lack of familiarity with complex virtual worlds, lack of spatial information that can be offered to users and lack of sensory (visual, auditory, locomotive) details compared to the exploration of real environments. To address this problem, we present a set of metaphors for assisting users in collaborative navigation to perform common exploration tasks in shared collaborative virtual environments. Our propositions consist in three guiding techniques in the form of navigation aids to enable one or several users (called *helping user(s)*) to help one main user (called *exploring user*) to explore the VE efficiently. These three techniques consist in drawing directional arrows, lighting up path to follow, and orienting a compass to show a direction to the exploring user. All the three techniques are generic so they can be used for any kind of 3D VE, and they do not affect the main structure of the VE so its integrity is guaranteed. To compare the efficiency of these three guiding techniques, we have conducted an experimental study of a collaborative task whose aim was to find hidden target objects in a complex and multi-scale shared 3D VE. Our results show that although the directional arrows and compass surpassed the light source for the navigation task, these three techniques are completely appropriate for guiding a user in 3D complex VEs.

1 INTRODUCTION

Navigation is a fundamental and important task for all VE applications as it is in the real world, even if it is not the main objective of a user in a VE (Burigat and Chittaro, 2007). Navigation includes two main tasks: *travel* and *wayfinding*. Travel tasks enable the user to control the position and orientation of his viewpoint (Darken and Peterson, 2001; Bowman et al., 2004). Wayfinding tasks enable the user to build a cognitive map in which he can determine where he is, where everything else is and how to get to particular objects or places (Jul and Furnas, 1997; Darken and Peterson, 2001).

In the literature, many different techniques have been proposed for travel in VEs (Zanbaka et al., 2004; Suma et al., 2010). By evaluating their effect on cognition, they suggest that for applications where problem solving is important, or where opportunity to train is minimal, then having a large tracked space, in which the user can physically walk around the virtual environment, provides benefits over common virtual travel techniques (Zanbaka et al., 2004). Indeed, physical walking is the most natural technique that supports intuitive travel and it can help the user to have more spare cognitive capacity to process and encode stimuli (Suma et al., 2010). However, the size of a virtual environment is usually larger than the amount of available walking space, even with big CAVE-like systems. As a result, alternative travel techniques have been developed to overcome this limitation such as walking-in-place, devices simulating walking, gaze-directed steering, pointing, or torso-directed steering. In the context of this paper, to get an efficient and simple way of traveling and to improve sense of presence in VE, we combine the physical walking technique to give exploring user (as much as possible) an intuitive travel by using a big CAVE-like system with head tracking for position and orientation, and a virtual travel to control the exploring user's position in the VE by using a flystick device.

Wayfinding tasks rely on the exploring user's cognitive map because he must find his way to move using this map. So if he lacks an accurate spatial knowl-

Nguyen T., Duval T. and Fleury C..
Guiding Techniques for Collaborative Exploration in Multi-scale Shared Virtual Environments.
DOI: 10.5220/0004290403270336
In *Proceedings of the International Conference on Computer Graphics Theory and Applications and International Conference on Information Visualization Theory and Applications* (GRAPP-2013), pages 327-336
ISBN: 978-989-8565-46-4

edge about the environment, the performance of navigation will be reduced (Elmqvist et al., 2007). In such large-scale VEs, this problem becomes more serious. In addition, as with navigation in real environment, the exploring user has to navigate the VE many times before he can build a complete cognitive map about this environment, and he may not always want to spend so much effort and time on this task (Burigat and Chittaro, 2007). To deal with these problems, many solutions have been proposed such as navigation aids, guidelines that support the user to explore and gain spatial knowledge about VE, e.g., (Vinson, 1999; Chittaro and Burigat, 2004). Nevertheless, in 3D immersive environments, it is also difficult to give additional navigation aids without interfering with the immersion of the exploring user.

Although collaborative exploration of complex and large-scale VEs is not usually considered the main task to achieve in a collaborative VE, the wayfinding time of the exploring user can be considerably reduced by having the assistance from helping users who can have a global and complete view of the VE such as a bird's eye view. By proposing and evaluating new metaphors dedicated to 3D collaborative interactions, including collaborative exploration, the collaboration between distant users who are sharing a virtual environment can be improved.

In order to facilitate the collaboration between the exploring user and the helping users, even when they are on distant sites, we propose a set of three guiding techniques in the form of navigation aids (drawing directional arrows, lighting up the path to follow, and orienting a compass to show the direction) used by the helping users to guide the exploring user to target places. We want to provide some guiding techniques that should be simple, intuitive, efficient and easy to use. In addition, we do not use verbal or textual communication between users because the difference of languages often happens when users work together remotely, and it may cause misunderstanding or delay in collaboration. We also want to build general guiding techniques that do not require developers to create specific maps for each new 3D VE, to modify system or interface for the new VE model, or to add many objects such as guidelines into it. By satisfying these conditions, these techniques can be integrated in many kinds of 3D complex, large-scale VEs while the integrity of these environments is ensured.

Therefore, collaborative exploration can be used in different applications: in exploring visualization of scientific data to find points of interest; in exploring complex large-scale environments that it takes too much time to build a map or to define landmarks; or in exploring unstable environments with so many dynamic elements that it is difficult to build a representative map at every moment such as training simulators for firefighters or soldiers (Backlund et al., 2009).

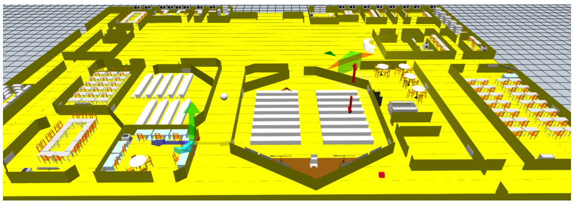

Figure 1: The 3D virtual building from the bird's eye view of the helping user.

To evaluate our propositions, we conducted a study to compare the three guiding techniques in a collaborative application that aimed at finding hidden target objects in a large and complex virtual building (see Figure 1). Without help from another user, the exploring user could not easily find these target objects in a short time.

This paper is structured as follows: section 2 presents a state of the art about navigation aids and collaborative navigation for VEs. Section 3 presents the three considered guiding techniques used to help users to explore VEs. Section 4 describes the context of our experimental study and its results while section 5 discusses these results. Finally, section 6 concludes and section 7 discusses possible future work.

2 RELATED WORK

2.1 Navigation Aids in Virtual Environments

The development of different forms of navigation aids aims to enable the exploring user of a virtual environment to find his way to target objects or places without previous training. In order to overcome wayfinding difficulties in VEs, two principal approaches have been considered: designing VEs to facilitate wayfinding behavior, and proposing wayfinding aids.

Designing VEs is often extracted from environmental design principles of urban architects in real-world. Darken et al. (Darken and Sibert, 1996) suggest three organizational principles to provide a structure by which an observer can organize a VE into a spatial hierarchy capable of supporting wayfinding tasks: dividing a large world into distinct small parts, organizing the small parts under logical spatial ordering, and providing frequent directional cues for orientation. When these principles are applied to structured and architectural environments (e.g., urban landscape, buildings), they make it easier for users to construct cognitive maps efficiently (Vinson, 1999; Darken and Peterson, 2001). However, in other applications, such as scientific visualization applications (Yang and Olson, 2002), or in other kinds of environment, such as open ocean environments or forests, it is difficult but still necessary to organize objects in the environment in an understandable way and to build semantic connections between them.

Many kinds of wayfinding aids have been proposed. Map is the most useful and "classic" wayfinding aid. By using two kinds of map (i.e. egocentric map with "forward-up" orientation and geocentric map with "north-up" orientation (Darken and Peterson, 2001)), users can access a large amount of information about the environment. However, the map scaling problem of a very large VE and the alignment with this environment can cause high cognitive load for users (Bowman et al., 2004). Environment maps can be found as 2D or 3D maps (Chittaro and Venkataraman, 2001). The Worlds-In-Miniature (WIM) metaphor is a technique that augments an immersive display with a hand-held miniature copy of the virtual environment just like a 3D map (Stoakley et al., 1995). It is possible to navigate directly on this WIM map by using it to determine where to go in the VR. Nevertheless, because the environment cannot be seen during this interaction, it limits the spatial knowledge that users can gain for navigation.

Landmarks are also a very powerful cue to recognize a position in the environment and to acquire spatial knowledge. Landmarks are usually statically implemented *a priori* in the environment but they can also be used as tools. For example, Kim et *al.* (Kim et al., 2005) propose a topic map that contains a semantic link map between landmarks, which are famous regional points in the VE. This topic map can be applied to the navigation of the VE as an ontology of subject knowledge, which represents subjects of the environment (e.g., buildings, its metadata, landmarks), and spatial knowledge, which represents the environment structure. However, it is also limited by the subject and spatial knowledge that designers can describe about the environment in the ontology. The more complex and abstract the environment is, the more difficult the description of the ontology is.

Additionally, there is another way for users to discover the environment progressively by retracing their steps (Ruddle, 2005). It is called *trail* technique and it describes the path that users had previously followed. Ruddle notes that trails are useful for first time navigation in a VE, but that trail pollution impedes their utility during subsequent navigation. Accordingly, this approach is only appropriate for a repeated exploration and search task for a given set of locations.

Furthermore, a set of direction indications as wayfinding aids has also been developed in the literature for VEs: compass (Darken and Peterson, 2001), directional arrows (Bacim et al., 2012; Nguyen et al., 2012), virtual sun (Darken and Peterson, 2001). They are familiar tools for orientation-pointing in VE because of their intuitiveness and efficiency.

2.2 Collaborative Navigation

As mentioned above, collaboration can provide a powerful technique to support the exploring user to deal with lack of spatial knowledge in complex and large-scale VEs. Although Collaborative Virtual Environments (CVEs) have been developed to provide a framework of information sharing and communication (Macedonia et al., 1994; Dumas et al., 1999; Churchill et al., 2001), collaborative navigation task in such environments has not been largely explored and only limited attention has been devoted to evaluate its efficiency in navigation in VEs.

It is essential for navigation in a CVE to support the way of communication between users because it is vital to understand what the others are referring to. Many developers used verbal conversation as means of communication to accomplish a given common task (Hindmarsh et al., 1998; Yang and Olson, 2002). However, if the users are located in distinct physical domains, even in different countries, language difficulty becomes an obstacle for collaboration to a common goal. So the communication technique for collaboration, especially for navigation in CVEs, should be simple, intuitive, efficient and non-verbal. Based upon these points, our primary motive is to develop and to evaluate guiding techniques enabling helping users to guide an exploring user toward target places in complex large-scale CVEs.

We share this objective with the organizers of the 3DUI Contest 2012[1] and its participants. As navigation aids, some techniques have been proposed such as "anchors" and a string of blue arrows that connects them or directional arrows (Bacim et al., 2012; Nguyen et al., 2012), point light sources (Cabral et al., 2012) or beacons (Notelaers et al., 2012; Nguyen et al., 2012; Wang et al., 2012). Although they are powerful navigation aids, it is usually difficult to apply them for navigation in many kinds of environment. The environment of (Bacim et al., 2012) is not flexible. It is difficult to modify the helping user's interface because his view and navigation aids are definitively specified. If the VE changes, the interface of the helping user can not be used any more and we

[1] http://conferences.computer.org/3dui/3dui2012/

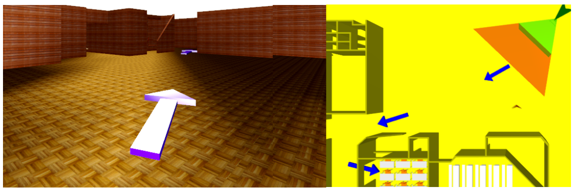

Figure 2: Directional arrows in the exploring user's and the helping user's views.

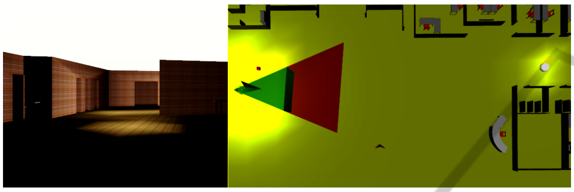

Figure 3: Light source in the exploring user's and the helping user's views.

have to design a new one. The proposition of point-to-point guide by remotely controlling the position of the exploring user in (Nguyen et al., 2012) is not very appropriate for the purpose of navigation aids because it can cause him to become disoriented and to learn nothing for his spatial knowledge about the environment. In addition, there is little feedback from the exploring user to allow the helping user to know about the current situation of the exploring user.

So according to our best knowledge, there is no complete and evaluated solution to improve the performance, the flexibility, and the ease of use of collaborative navigation in such complex, large-scale CVEs.

3 GUIDING TECHNIQUES

In this paper, we propose to evaluate and compare three guiding techniques in the form of navigation aids (arrows, light source and compass) that would enable one or several helping user(s) to guide an exploring user who is traveling in an unfamiliar 3D VE efficiently. The task of the exploring user would be to find targets objects or places without the spatial knowledge of this 3D VE.

3.1 Arrows

The first guiding technique is based on directional arrows (see Figure 2) that are drawn by the helping users to indicate the direction or the path that the exploring user has to follow. The helping users can draw as many directional arrows of different sizes as they want. However, so many directional arrows added within the environment or too big arrows may affect the immersion of the exploring user. As a result, the helping users have to determine when, how and where to put directional arrows to guide efficiently the exploring user. These arrows will disappear after a while. So the helping users are recommended to draw directional arrows within easy reach of the exploring user's visibility zone. By using a dedicated 3D cursor to draw in the view of the helping users, it improves the ease of use for the helping users and it makes possible to draw arrows at any height and in any 3D direction, so it can facilitate the exploration of multi-floor virtual buildings.

To draw these arrows, a helping user simply has to make a kind of 3D drag'n drop gesture. First he must place the 3D cursor at a position that will be the origin of the arrow, then he has to activate the cursor to create the arrow, and the next moves of the 3D cursor will change the length of the arrow, stretching the arrow between the origin of the arrow and the current position of the 3D cursor. When he estimates that the arrow has a good shape, he can signify to the 3D cursor that the stretching of the arrow is finished. This kind of gesture can be driven by any device that can provide a 3D position and can send events to the 3D cursor, for example an ART Flystick or simply a 2D mouse (with the wheel providing depth values).

From a technical point of view, this 3D cursor able to draw arrows can be brought to a CVE by a helping user when he joins the CVE, so there is nothing to change in the main structure of this CVE and its integrity is guaranteed.

3.2 Light Source

The second guiding technique is based on a light source used to light up a path to each target object (see Figure 3). The exploring user cannot see the light source itself but only its effect on objects within the environment. This technique thus depends a lot on the rendering and illumination quality of the exploring user's immersive view. The light source is attached to a support object that can only be seen by a helping user. This helping user controls the light source by moving its support with a 3D cursor and shows up to the exploring user the path he must follow.

It is important to note that when the helping user is using the light source to guide, the available light sources of the building are turned off, the exploring user has himself a virtual lamp attached to his head to light up the environment around him. Then there are just two light sources, one associated to the exploring user's head and one used to guide him.

Here again, from a technical point of view, this

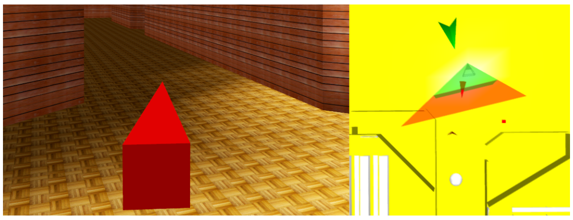

Figure 4: Compass in the exploring user's and the helping user's views.

3D cursor, the light source attached to the head of the exploring user, the light source used to guide him can be brought to the CVE by a helping user when he joins the CVE, so there are very few things to change in the main structure of the CVE: we just need to be able to put the lights of the CVE off.

3.3 Compass

The third guiding technique is based on a compass attached to the position of the exploring user (with an offset), a typical tool to navigate in VEs (see Figure 4). The compass does not point directly to the target object location, but points to the location of another virtual object that plays the role of the "north" of this compass, and this object cannot be seen by the exploring user. A helping user can control this "north" by moving it with a 3D cursor, to show up to the exploring user the path he must follow. So by moving the "north" of the compass, a helping user can guide the exploring user to pass across hallways, rooms, doors, etc. before reaching the target position. It is thus a simple and powerful tool to guide the exploring user in any VE.

Here again, from a technical point of view, this 3D cursor, the compass attached to the position of the exploring user, and the virtual object serving as the "north" of the compass can be brought to the CVE by a helping user when he joins the CVE, so, as for the arrow-based guiding technique, there is nothing to change in the main structure of the CVE.

To place the compass at the best possible position relative to the exploring user, it is possible to allow the exploring user to adjust its offset, simply by moving the compass through a 3D interaction. However, this possibility was not offered to our exploring users during the experiment that is presented in this paper.

3.4 The Guiding Viewpoints

To be able to use these three guiding techniques in an efficient way, we built two principal kinds of views for our helping user: a bird's eye view (see Figure 1) and a first-person perspective by "looking over the exploring user's shoulder" (just like a camera attached to the shoulder of the exploring user) (see Figure 5). The bird's eye view could be considered as a 3D map or a World-In-Miniature (Stoakley et al., 1995). These views were obtained by choosing some particular points of view: the "looking over the exploring user's shoulder" view was attached to the point of view of the exploring user and the bird's eye view was obtained by increasing the helping user's scale. Both views were built without any changes to the main structure of the VE, with the same concerns: to guarantee the integrity of the VE, and to offer the possibility to be used for any kind of VE.

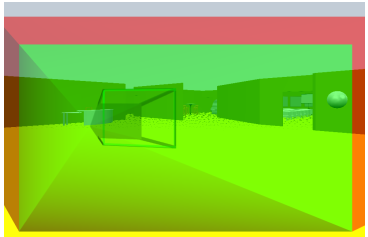

Figure 5: A "looking over the exploring user's shoulder" view of the helping user.

4 EVALUATION

4.1 Context

The Virtual Environment

In order to test these three different navigation aids, we have built a complex, large virtual building (about 2500 m^2) with hallways and many rooms of different sizes filled with furniture objects (e.g., tables, chairs, shelves). These objects were repeatedly used to fill these rooms. It means that each object itself could not be taken as a landmark, and only the way that each room was arranged made it distinct from the others in the building. Besides, the position of objects did not change during the experiment. We used this environment to conduct all the studies described in this paper, with different views from several positions in the VE for a helping user to observe all activities of an exploring user in the immersive system.

The Exploring User

The exploring user was immersed in the VE with a first-person perspective (see Figure 6). He was controlling a flystick to travel in the virtual world and as his head was tracked in a CAVE-like system, he was

Figure 6: First-person perspective of the exploring user in a CAVE-like system.

able to move physically to observe objects more carefully in the environment. He was also able to move forward or backward, and to turn right or left by using the joystick of the flystick. The direction of movement by the joystick was where he was looking at. He used some specific buttons of the flystick to pick up target objects or to return to a starting position.

The Helping User

Our system would have made it possible for several helping users to collaborate at the same time with the exploring user. However, in order to simplify the evaluation, there was only one helping user during this experiment. Moreover, this helping user was the same for all the exploring users of the experiment: he had a good knowledge of the apparition order and positions of targets, and he was in charge of providing the navigation aids always in the same way for each exploring user. He was the designer of the guiding techniques and was strongly involved in their implementation, their deployment and their testing. So his performance was stable when guiding each exploring user, as he had already improved his skills during the tuning of the experimental setup.

For interaction, the helping user had a 3D cursor to manipulate objects within the VE, to add navigation aids such as directional arrows, or to control the light source or the "north" of the compass. The helping user was also able to control the position and orientation of his own viewpoint as well as to change his own scale in the view. It means that he was able to become bigger to have an overall view of the building, or smaller to take a look inside each room to locate the target (but he was not allowed to pick up the target by himself). He was also able to see where was the exploring user at every moment. The interface of the helping users was pure in 3D, although in our experiment he was using a desktop environment. Nevertheless, it would be possible and perfectly adequate for the helping user to use an immersive display system.

In order to locate the next target that the exploring user had to find, the helping user was allowed to move a 3D clipping plane to make a 3D scan of the VE. This scanning tool was also brought into the VE by the helping user. It was generic and as the three guiding techniques that are evaluated in this paper, it guaranteed the integrity of the VE.

Explicit Communications between Users

The helping user was able to send signals (in our experiment, they were color signals) to the exploring user to inform him about his situation. When the helping user was searching the target object on the map and the exploring user had to wait until the helping user found it, the helping user could send an orange signal. When the exploring user was entering the right room or was following the right way, the helping user could send a green signal. Last, when the exploring user was taking the wrong way, the helping user could send a red signal. These signals could become a communication channel between the users performing a collaborative task.

4.2 Task

Task to Achieve

As mentioned above, each exploring user of this experiment had to find 12 different positions of target objects represented by small glowing cubes. When the exploring user was picking up the target object, this target was disappearing and a color signal was appearing to tell both users that the target had been reached and that the system had stopped measuring time. Then the exploring user was invited to go back to the starting position for the search of the next target. By pressing a dedicated button of his flystick, he was teleported back to this starting position. And when both the exploring and the helping user were ready, the target object was reappearing at another position in the environment. During the experiment, each guiding technique was used successively 4 times to find 4 target positions. There was a total of 12 different positions for the three guiding techniques. The 12 targets were always appearing in the same order, and the order of the techniques used for the guiding (A: Arrows, L: Light, C: Compass) was changing after each user, to be one of these 6 configurations: A-L-C, A-C-L, L-A-C, L-C-A, C-A-L, C-L-A. So we were needing a number of participants that would be multiple of 6 in order to encounter the same number of these 6 configurations.

Measures

In order to evaluate how the three guiding techniques have influenced the efficiency of navigation, we did not count the time it took the helping user to find where was the target position on the map. We just considered the time it took the exploring user to complete the target search task. It included two separate but continuous tasks: a navigation task and a search task. The navigation task was based on the navigation aids added in the environment to find a path from the starting position to the target position. The starting position was always the same for all the target objects and for all the participants of the experiment. So, for each target, the exploring user moved always from the same starting point and the system measured the time taken to reach the target object. This time was thus measured into the navigation time and the search time. The navigation time was the time taken to navigate from the starting position to the area of 2.5 meters around the target and the search time was the time to search and pick up the target in this area. We used this approach to calculate the time because sometimes the target object was well hidden in the environment, so the exploring user was not able to find it at first glance, and we wanted to make a clear difference between the time taken for the navigation (coming not farther than 2.5 meters from the target) and the time taken for the precise searching and finding of the target. Once the exploring user had entered this zone, the search time was recorded. However, the navigation time was specifically taken into consideration because it was directly representing the performance of navigation aids. The search time was also recorded in order to obtain preliminary data for further studies about efficient and appropriate metaphors for the searching task.

4.3 Experimental Setup

The hardware setup of the experiment consisted of a big CAVE-like system in the shape of an "L" whose size was 9.60 meters long, 3.10 meters high and 2.88 meters deep. This visual system immersed exploring users in a high-quality visual world and they were using a pair of active shutter glasses. We also used a tracking system to locate the position and the orientation of the exploring user's head. To enable exploring users to manipulate objects in such an environment, we used a tracked flystick as an input device. The helping user worked with a desktop workstation and used a mouse to drive a 3D cursor.

The software setup used for the experiment included Java to write the CVE, Java3D to develop the helping user's views on desktop, jReality to develop the immersive view of the exploring user, and Blender to model the virtual environment.

4.4 Participants

In this study, the designer of the virtual environment played the role of the guiding user. Additionally, there were 18 male and 6 female subjects who served as exploring users. Their age ranged from 21 to 61, averaging at 30.5. Thirteen of them (8 males and 5 females) had no experience at all in immersive navigation in 3D virtual environments.

4.5 Procedure

Before beginning the training phase of the experiment, each participant was verbally instructed about the experiment procedure, the virtual environment and the control devices. He was explained the goal of the experiment to search a target object at different positions by following the navigation aids added in the environment. He was also instructed to pay attention to find the target carefully when he reached the narrow zone around the target because it was not always easy to find it at first glance.

In the training phase, the participant was suggested to navigate freely in the virtual building. When he was feeling at ease with the environment and the control devices, we were beginning the training phase. The participant was given a simple task to complete: he was asked to find his way from a starting point (the entrance of the building) to some target positions with our three different guiding techniques.

In the evaluation phase, the participant was asked to search 12 target positions in the environment by basing on three different guiding techniques.

In the final phase, the participant filled out a short subjective questionnaire concerning his experience of navigating in immersive virtual environments and his opinion about the guiding in general, his preferences for the perturbation, stress, fatigue, intuitiveness, and efficiency of each guiding technique.

4.6 Results

Navigation Performance

We focused on the efficiency of the three different guiding techniques when we applied them in the navigation task. So the navigation time was considered as an important measure in this statistical analysis. P values of average navigation time of the three techniques were calculated using repeated measures

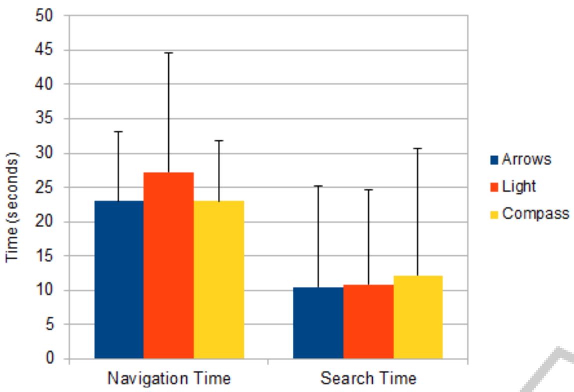

Figure 7: Means and standard deviations of navigation and search time (in seconds) for three guiding techniques.

ANOVA and post hoc multiple pairwise comparison (Tukey-Kramer post hoc analysis).

The average navigation time, the average search time and their standard deviations are presented in Figure 7. For the recorded navigation time, the result revealed a statistically significant difference for the three navigation aids ($F(2,285) = 3.67$, $p = 0.026$). In addition, the Tukey-Kramer post hoc analysis indicated that navigation time in the Light condition (mean = 27.26) was significantly higher than navigation time in the Arrows condition (mean = 22.99) ($p = 0.05$) and Compass condition (mean = 22.97) ($p = 0.05$), while there was no significant difference between Arrows and Compass conditions ($p = 0.99$).

However, based on the preliminary results of search time, we did not find out about any significant effect of guiding techniques on the recorded search time: for the three guiding techniques ($F(2,285) = 0.29$, $p = 0.74$) as well as for each condition. These results indicated that the effect of the guiding techniques for search time was not statistically significant but this must be confirmed by further studies.

Subjective Estimation

Each user was asked to fill a questionnaire with subjective ratings (using a 7-point Likert scale) for the three techniques according to the following criteria: perturbation, stress, fatigue, intuitiveness, and efficiency. A Friedman test has been performed on the questionnaire and the p-values were showed in table 1. Dunn post-hoc analysis showed that the light was rated to be significantly more perturbing, more tiring, and less intuitive and less efficient than the arrows and the compass guiding techniques. Moreover, no significant differences were found between the arrows and the compass guiding techniques on these five subjective ratings. Regarding the subjects' general preference, we found most exploring users preferred to be guided by arrows or by the compass.

Table 1: Average scores and p-values for five qualitative measures with significant differences shown in bold.

Question	Navigation Aids		
	Arrows	Light	Compass
Perturbation	6.17	4.58	5.67
	p = 0.00054		
Stress	6.29	5.46	6.54
	p = 0.01063		
Fatigue	6.08	4.87	6.41
	p = 0.00011		
Intuitiveness	6.17	4.54	6.20
	p = 0.00010		
Efficiency	5.87	4.46	6.16
	p = 0.00002		

5 DISCUSSION

The results of the navigation performance study showed that the directional arrows and the compass outperformed the light source in navigation task. The low performance of the light source came from the lack of accuracy of light effect on the environment. It might come from the confusion between the guiding light source and the light source that the exploring user had with him when he was approaching the guiding light source. The light source was also too sensitive to the elements of the environment such as the quality of 3D model of the environment or the rendering and illumination quality of the immersive view as mentioned above. However, we found out that the confusion between the light source to guide and the light source of the exploring user rather affected the search task than the exploration task because this confusion usually happened in a small space such as in a room when the exploring user was surrounded by many different objects.

There were no significant differences among the three guiding techniques in the search task. It can be explained because some of the targets were very easy to find (the exploring user was able to see them as soon as he entered the room where the target was hiding) while some others were very difficult to find (hidden within some furniture in a room). So the final physical approach to the target did not really depend on the navigation aids but rather on the ability of the exploring user to move physically in his surrounding workspace. Further experiments will be needed to have a better evaluation of these guiding techniques for precise search of target.

The subjective results supported the results of navigation performance study in evaluating the efficiency of the arrows and compass aids in collaborative navigation. Most of the participants found them more intuitive, easy to follow, and efficient to indicate direction than the light source. However, some exploring users found the light source more natural than the other guiding techniques, especially when they were in a big hall or in a long hallway.

Sometimes, in small rooms, not only the light source made the exploring users confused, but also the compass or the directional arrows because they were occluded by the VE (for example, by walls). And for the search task, an exploring user of our experiment found that the compass was a little annoying and confusing when it was near the target because its "north" was unstable. So some factors such as the quality of the 3D rendering, the structure of the virtual building, and the size of navigation aids could have a deep impact on navigation and search performances. We need to take them into consideration to improve the performance of collaborative exploration.

The activity of the helping user could also explain some differences between the guiding techniques. Indeed, to guide an exploring user using directional arrows, he simply had to use about 4 or 5 arrows to draw the direction toward each target. With the compass, he just had to put the support object that controlled the compass "north" at the entrance of the hallway or the room where he wanted the exploring user to enter to and then put it near the target when the exploring user approached it. It was more complicated with the light source because of the confusion between the two light sources. The helping user had to move the light source or make it flicker to get the intention of the exploring user. He also had to choose where to put the light source to make a clear difference between the effect of this guiding light source and those of its own light source in the environment.

Our VR framework enables a helping user to use these guiding techniques in many different platforms: he can be immersed in a CAVE-like system with a tracking system or simply be in front of a desktop computer with a mouse. This can facilitate the flexibility of collaborative exploration between distant users who have different working conditions.

6 CONCLUSIONS

In this paper we have presented a set of three collaborative guiding techniques (directional arrows, light source and compass) that enable some helping users to guide an exploring user in a complex 3D CVE. These collaborative guiding techniques can be used in many kinds of 3D CVEs because they do not modify the structure of the environment. Indeed, all the guiding aids are dynamically provided by the helping users through the creation or the manipulation of few dedicated 3D objects that the helping users can bring with them when they join the CVE. The helping users can also bring with them a generic 3D clipping plane to make a 3D scan of the VE to locate the targets or the places to reach.

An experimental study was conducted to evaluate these three types of guiding techniques for navigation and search in a complex, large-scale building. The results of our experiment showed that these three guiding techniques could reduce wasted time in the wayfinding task because of their simplicity, intuitiveness and efficiency in navigation. Additionally, although the directional arrows and the compass outperformed the light source for the navigation task, several exploring users found the light source guiding technique very natural, and it can probably be combined with the two other guiding techniques.

7 FUTURE WORK

In the future, these guiding techniques should be improved to overcome some of their limitations such as the occlusions of arrows and compass (by enabling the exploring user to change their size or their position dynamically), the instability of compass, or the confusion of light sources (by enabling the exploring user or the helping users to change properties of these light sources such as color, intensity, attenuation, visibility of their beacon dynamically, ...). It would also be very interesting to study the best way to combine these guiding techniques or to switch dynamically between them in order to optimize the overall guiding for navigation and search of targets.

We will have to make further experiments to evaluate the efficiency of these guiding techniques for precise search of objects or to propose other appropriate metaphors for this kind of task.

Our work will also be extended by evaluating the ease of use, the simplicity and the efficiency of these guiding techniques from the helping user's point of view when he is immersed in the environment with a 3D interface and when he is not with a 2D interface and a 3D cursor. The efficiency of these guiding techniques provided by the helping users could also be compared with these same guiding technique automatically generated by computer.

ACKNOWLEDGEMENTS

We wish to thank Foundation Rennes 1 Progress, Innovation, Entrepreneurship for its support.

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