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Augmenting 3D Interactions with Haptic Guide in Large Scale Virtual Environments

Sehat Ullah^{*†}, Nassima Ouramdane^{*}, Samir Otmane^{*}, Paul Richard[†]
Frédéric Davesne^{*}, Malik Mallem^{*}

Abstract—3D interaction techniques play a vital role in virtual environments (VEs) enrichment and have profound effects on the user's performance and sense of presence. In this context haptic feedback may be useful to assist the user in complex tasks particularly in the absence of efficient depth cues. In this paper we propose and evaluate two haptic guides (spherical and conical) for object selection. These guides are meant to improve the Follow-Me 3D interaction technique. Twenty volunteers were instructed to reach for and select four spherical targets in a large scale VE. Three different interaction zones (free manipulation, visual and haptic zones) are defined. Each one is characterized by a specific interaction granularity which defines different assistance levels (visual and haptic). We observed for both types of haptic guides a reduction in task completion time. All participants reported that it was easier to select objects using spherical guide with visual feedback only. However they reported that both haptic guides provided them significant guidance in object selection.

Index Terms—Virtual reality, large-scale VEs, 3D interaction techniques, haptic guide, human performance.

I. INTRODUCTION

The successful advancement in the field of high quality computer graphics and the capability of inexpensive personal computers to render high-end 3D graphics in a more realistic manner has made the virtual reality feasible to be used in areas like industrial design, data visualization, training etc. Similarly there are other domains of VR application such as medical [22], [16], assembling, repairing [2] and education [8], [4] etc. In order to effectively utilize virtual reality in various domains (some cited above and many others), we need to develop more simple and realistic interaction techniques, giving increased user performance, presence and immersion in VE. From the very first day of virtual reality researchers have investigated, proposed and evaluated various interaction techniques including those trying to solve the problem of grabbing and manipulating of object [5], [15], [25]. Selection/grabbing is the fundamental step which is taken before manipulating an object or usually command control in VE. On the other hand, user is also required to reach or approach the object he/she intends to select, therefore need free movement in the VE. This we model and implement in the form of a "free zone" in the VE, also discussed in [14]. The second zone we propose contains a visual guide [12] which is dynamically activated to guide the user for object's selection.

In order to fully understand VEs, to make them more realistic and to increase human performance, the inclusion

of haptic modalities becomes more important [28]. The third zone that we propose in this article contains haptic guide which actively assist the user towards the object and makes the selection easier. Furthermore we implement two different versions of the haptic guide; one is supposed to act from all directions around the object and can be effectively used in applications that do not necessitate a specific point or direction in selection. The second acts in a single direction which is pre-specified as object's selection direction, obviously it can be used in application where objects are selected or grabbed from a specific point, for example objects selection or grabbing by robots. This section is followed by the related work, section 3 presents the proposed haptic guide, hardware platform and software architecture used for its implementation. Section 4 describes experimentation and evaluation. Conclusion is given in section 5.

II. RELATED WORK

To increase the user's immersion in VEs and to impart them with realistic experience, several sensory modalities like 3D vision sound and haptic need to be added. The realism of VEs is normally measured in term of believability for which Magnenat-Thalmann defines immersion, presentation and interaction as essential elements [10]. A lot of work related has already been done in VR systems, but the formalization of the interaction itself has not really been studied intensively yet. Bowman [5] has carried out a detail taxonomy of object selection and manipulation based on task decomposition.

Similarly [19], [18] have partitioned the interaction into two broad categories: exocentric interactions and egocentric interactions. In exocentric interactions users interact with VEs from the outside (also known as the God's eye viewpoint). The World-In-Miniature is an example of this technique where users hold a small representation of the VE in their hand, and manipulate virtual objects by manipulating the iconic versions of those objects in the miniature world [25]. Automatic scaling [11] also falls in exocentric type interaction, where object being manipulated are instantly brought into users' reach. In egocentric interaction, which is the most common case for immersive VEs, the user interacts from inside the environment. The egocentric interactions are further divided into two metaphors: virtual pointer and virtual hand. In the first case, the user selects and manipulates objects by pointing at them. When the vector originating from the virtual pointer intersects with an object, it may be picked and manipulated [15]. The direction of the virtual pointer can be specified by using two

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points: position of the user's dominant eye and location of the tracker manipulated by the user [15]. For example, we may refer to the Ray-Casting technique [11]. This technique uses a laser pointer where an infinite ray extending from the virtual hand. The first object intersected along the ray is eligible for selection. This technique is very efficient to achieve selection tasks. The flash light technique [9] use the same principle as the Ray-casting technique, but the laser pointer is replaced by an infinite cone. It facilitates the selection of remote or small objects, but not appropriate for the selection of close objects. In the case of virtual hand metaphors, virtual representation of their real hand is used. Here, an object in the VE can be selected and/or manipulated when the virtual hand touches the object. Simple Virtual Hand technique [26], is one representative of the virtual hand metaphors. It uses a one-to-one mapping between the virtual hand and the physical hand. The Go-Go technique [17] also called arm-extension technique is based on the Virtual Hand Metaphors, but it introduces a non one-to one linear mapping between the virtual hand and the physical hand. The selection of remote or small objects is very difficult with the simple virtual hand and the Go-Go techniques. The PRISM [6] technique is used as an addition to other existing techniques to increase precision.

Interaction with objects in VE is not a very easy task in general. In order to make the interaction easier and increase user performance, various devices like stereoscopic display, 3D audio or force feedback devices may be utilized. In the context of assistance for 3D interaction, virtual guides [23] are valuable tools, for example in the context of teleoperation [12], [13].

The visual guides are generally characterized by their place of attachment (position and orientation), manipulation area, condition for activation, associated function and a condition of deactivation [12]. In the other hand, the haptic virtual Fixtures (virtual Fixture), currently being used only in robot-assisted manipulation tasks, are simply software-generated forces and position signals that guide the user along a specified path and/or prevent penetration into forbidden regions [1]. In these type of haptic virtual fixtures users not only have very little freedom but also lack visual guides that may reduce performance. Similarly [20] has proposed haptically augmented surgical system limiting the surgeon movement in certain areas. Oakely et al. have investigated the use of haptic feedback in GUI's and have concluded that carefully designed force feedback may bring best performance [7]. Alex B. et al have used virtual fixtures for targeting tasks in a desktop environment, but these can only be used with static objects with predefined path [3]. similarly they superimpose the visual and haptic fixtures on each other.

III. DESCRIPTION OF THE PROPOSED SYSTEM

A. Introduction

The proposed system gets its inspiration from the Follow-Me 3D interaction technique [14]. This technique has been developed to provide both visual assistance and assistance to the command for selecting or manipulating objects in Mixed Reality. This technique owns two main characteristics: the

VE is divided into three zones (see figure 1) in which the interaction has its own granularity, whether one wants to move freely and realistically in the VE (free manipulation zone), approach more securely to a target but without losing any degree of freedom (scaled manipulation zone) and finally approach to the target and manipulate it easily with high accuracy (precise manipulation zone). In the precise manipulation zone, virtual guides are used to handle both precision and security of manipulation, which induces a loss of freedom for the user. The aim of a virtual guide is firstly to anticipate the most probable action of the user into the VE and then to make him perform his action as simply as possible with high precision. In order to achieve this goal, the virtual guide puts limitations to the user's possible actions in the virtual world so that he has to follow the virtual guide with a specific subspace of VE (with a specific orientation).

In precise manipulation zone the *Follow-Me* technique reduces the degree of freedom of the virtual pointer to 1DoF (i.e. only forward and backward movement is allowed) but physically the user is free and can move his hand held pointer in any direction. This may puzzle the user and may also create problems at cognitive level. To solve this problem we used our haptic guides which not only provide active guidance (attractive force toward the object) to the user to select an object but also physically constraints his/her hand's movement whenever required.

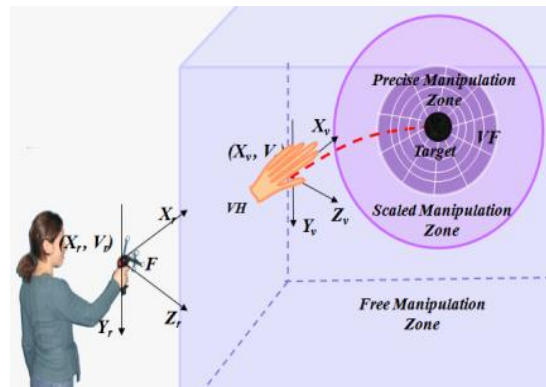


Fig. 1. : Illustration of the Follow-Me 3D interaction technique.

B. Proposed models for Haptic Guides

As described earlier, our system is hybrid of visual as well as haptic guides. Since we have two implementations for our visual and haptic guides, for which the free zone is the same, We start to describe them one after another. In first case each object in VE is surrounded by two concentric spherical zones, having different radii. The outer sphere acts as a visual zone and is activated (becomes visible) when the condition $D_p < R_v$ becomes true and remains active till the object is selected for manipulation. Here D_p represents the distance between the virtual pointer and the object whereas R_v is the radius of the visual sphere. Similarly haptic guide activates itself when the condition $D_p = R_h$ is true, where R_h is the radius of the haptic sphere (not visible). Once haptic guide is active, the user feels an attractive force towards the object. The haptic guide

is deactivated when the above mentioned condition becomes false or the object is selected for manipulation. The magnitude F of the attractive force in haptic guide is calculated according to the following equation:

$$F = \frac{(K * R_h)}{D_p}, D_p \neq 0 \quad (1)$$

Here $K > 0$ is a constant which signify the minimum attractive force felt by the user. Care should be taken in determining R_h , in order to avoid the overlapping of haptic sphere of two objects if they are close to each other. The force calculating mechanism is very interesting in the sense that we keep count of the user's intensions i.e. if he/she approaches towards the object, the attractive force increases as a consequence and vice versa. Referring to [1] virtual fixtures (haptic guides), are used to provide either assistance to the users or prevent them entering into forbidden regions. Furthermore they can be either of impedance or admittance type. Impedance type can be termed as potential fields, actively influencing the movements of manipulator that may create instability during interaction. On the other hand, admittance type is influenced by user's movements, for example if the user does not apply a force, the manipulator will not move. Here the attractive force in our haptic model provides assistance to user in object's selection. Similarly this may be called an amalgamation of both impedance and admittance type guidance because if we keep the value of K not too big, then in the outer volume of the haptic sphere, user will be attracted by a small force towards the object and user's movement will be more powerfull compared to attractive force, but this will be opposite in the inner volume of the haptic sphere and close to the object. The spherical guide is illustrated in figure 2.

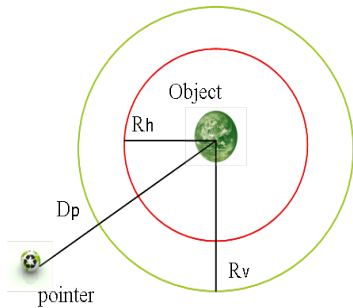


Fig. 2. Illustration of the spherical guide.

In the second implementation we make use of cones both for visual and haptic guides, in order to confine users to select objects from a single and specific direction. The virtual pointer always emanates a laser ray in the direction of the selection. The visual guide is activated over the nearest object in virtual world through which not only the laser ray passes but the condition $D_p = L_v$ also becomes true. Here D_p is distance between the virtual pointer and object, L_v is the length of visual cone. In the active visual guide (cone), if the user further moves towards the object the haptic guide is activated when $D_p = L_h$ occurs, where L_h is the length

of the haptic cone. The attractive force is calculated as follows:

$$F = \frac{(K * L_h)}{D_p}, D_p \neq 0 \quad (2)$$

Here again $K > 0$ is constant signifying the minimum attractive force. Like the first case of our haptic guide, here also the Force increases as the distance D_p decreases and vice versa. An additional function associated with this guide is that it prevents the user to go out of the cone through its walls, once haptics are active. Therefore this haptic guide combines the characteristics of both guidance virtual fixtures and "forbidden region virtual fixtures". Granularity is an important concept associated with interaction in VE, and maps the relationship between the user's movements in the real world with those of the virtual world [14]. For example, mapping large movements (in real the world) of the user into small ones (in the VE) and vice versa, or some loss in the degree of freedom etc. may create some difficulties for the user at cognitive level, for example, when he/she can freely move the real world pointer in all directions but the corresponding virtual pointer is restricted to move in a single direction. In our solution, once the user is inside the haptic cone, his/her movements are not only restricted in the virtual world but also in the physical world, through our force feedback device SPIDAR (Space Interface Device for Artificial Reality) [24], [27], [21], thus providing more realistic interactions. To impart users with more realistic interaction, we also simulate the weight of each object selected for manipulation. The conical guide is illustrated figure 3.

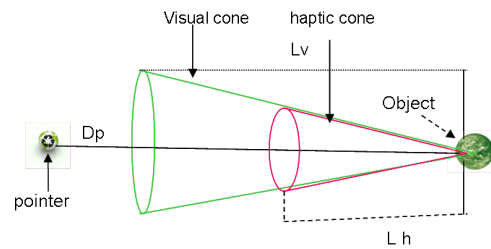


Fig. 3. Illustration of the conical guide.

C. Hardware Setup

For experimentation we use a large scale semi-immersive environment equipped with a retro-projected large screen (3m x 2.5m) for stereoscopic images, viewed with polarized glasses. In addition we have optical tracking system and stereo sound, but the most important thing in the experimental platform is the use of string based force feedback device called SPIDAR. We use human scale (3m x 3m x 3m) SPIDAR, placed in front of large display screen. The motors, encoders and pulleys are mounted on the corners of the iron cubic frame as shown in the figure 4. The High Definition Haptic Controller (HDHC) takes encoders' counts to calculate grip's position and orientation, provides tension to the strings to simulate force

and communicate with computer via USB 2.0. Because it is a string-based system, it has a transparent property so that the user can easily see the virtual world. It also provides a space where the user can freely move around. The string attachments are soft, so there is no risk for the user of hurting himself if he would get entangled in the strings.

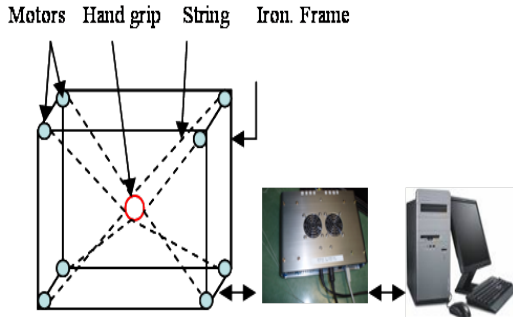


Fig. 4. : Illustrations of SPIDAR (a) Motors and strings (b) HDHC (c) Computer.

D. Software Architecture

Our software that enabled us to use the human scale SPIDAR in the VE and to implement our concept of haptic, has client-server architecture as illustrated in the figure 5

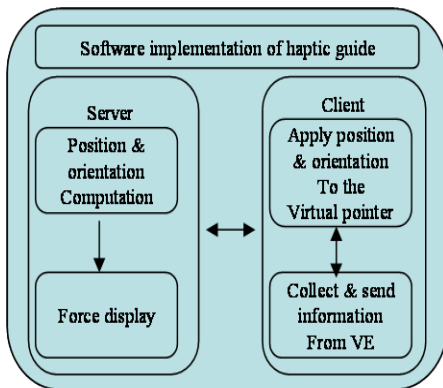


Fig. 5. Illustration of the software architecture.

The two major parts of the software are installed on two separate machines communicating through network. We developed the server part of this software using C++ language. This part of the software performs the following tasks:

1. Establish PC and HDHC controller communication
2. Take the calculated position and orientation from the HDHC controller.
3. Establish connection with Virtools client.
4. Calculate and display forces or weight based on the information received from the client

The client part of this software was developed using Virtools Dev4.0 environment. This part is responsible for the presentation of VE and supports the interactivity between the virtual objects and the user. The position and orientation sent by the SPIDAR server are applied to the virtual pointer. The information collected and sent by the client to the server includes current zone of the virtual pointer, activation and

deactivation events for haptic zone, radius or length of the haptic zone, distance between the virtual pointer and the object, information on collision detection and force direction etc.

IV. EXPERIMENTS

A. Experimental protocol

In order to investigate the effect of the proposed haptic guides on human performance, 20 volunteers subjects including 16 males and 4 females participated in the experiments. They were master, PhD or post doc students having age from 23 to 35 years. All of them were right handed and had prior knowledge of interactions in VE. We divided the participants into two groups of 10 persons. The first group, including 8 males and two females, performed the experiment to evaluate the spherical guide, while the second group (containing 8 males and 2 females) performed the experiment to test the second guide (haptic cone).

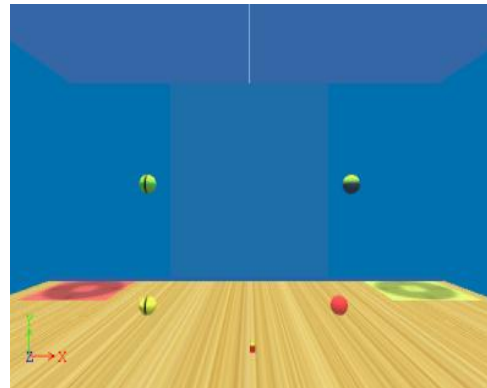


Fig. 6. Snapshot of the experimental virtual environment.

The VE contains four small spheres in the same vertical plane and a baton used as pointer whose movement is directly controlled via the SPIDAR. The experiment starts when the user holds the spidar's grip in hand and the experimenter says "GO". The subjects were asked to select an object and place it on the red zone from where it comes back to its initial position and the user select it again. In this way each object is selected and displaced five times in a single trial. All users did exactly two trials of their respective experiment. Two conditions were used for the experiment. The first condition uses stereoscopic display and visual guide while the second condition uses haptic guide plus stereo and visual guide. In both groups half of the subjects performed the experiment under first condition in their first trial while the second half used the second condition in their first trial. The only constraint on the second group was to select the object from the front. We gave each user a short explanation about the task to perform and how to make the interaction with VE via the SPIDAR, but no training trial was given to them. We recorded the task completion time for both types (without and with haptic guides) of trials. The environment implementing the haptic guides is given in figure 6.

In order to carry out subjective evaluation of our system we collected the user's response through a questionnaire containing the following questions.

1. To what extent the object selection was easy without force feedback? 2. To what extent do you think that force feedback provided you guidance in object selection? 3. Do you think, the interaction becomes more realistic with force feedback?

The user had to respond to each of these questions on a scale from 1 to 7. The scale was formatted according to the table I.

Q1	Not easy	1-2-3-4-5-6-7	Very easy
Q2	No guidance	1-2-3-4-5-6-7	Guidance of high level
Q3	Not realistic	1-2-3-4-5-6-7	Very realistic

TABLE I
SCALE TO RESPOND TO THE QUESTIONS.

B. Results and Analysis

In this section we present and analyze the results based on both task completion time and user responses collected through questionnaire. The general ANOVA for task completion time is ($F(1,9) = 12.13, P < 0.005$) significant. Comparing the task completion time of the two visual guides, we obtained means of 56.7 sec and 88.3 sec with std (18.5, 20.8) for sphere and cone respectively, showing non significant ANOVA ($F(1,9) = 12.77, p = 0.006$). Comparison of the two haptic guides (sphere and cone) give means of 51.9 sec and 67.0 sec with std(13.6,10.9) respectively, having ANOVA ($F(1,9) = 6.99, P < 0.005$) as significant comparing the performance of visual sphere with haptic one gives us means of 56.7sec and 51.9 with std(18.5,13.6) respectively, for which ANOVA is ($F(1,9) = 1.59, P > 0.005$) non significant. Similarly if we compare visual cone vs haptic cone, we get means of 88.3 sec and 67.0 sec with std(20.8,10.9) respectively has significant ANOVA ($F(1,9) = 25.78, P < 0.005$). The analysis of task completion time can be seen in the figure 7(a), where :

- 1) spherical guide (no haptic) + stereo display
- 2) spherical haptic guide + stereo display
- 3) Conical guide (no haptic) + stereo display
- 4) Conical haptic guide + stereo display

Figure 7(b) represents the mean values of the responses for the spherical haptic guide. We observed that the mean value for the first question is 5, for which the standard deviation was calculated as 1. Similarly a mean value of 5.6 has been shown in the graph for both question no.2 & 3, while they have standard deviation 1.1 and 1.2 respectively. It means that object selection in first condition (stereoscopic display + visual guide) is easier, but the haptic guide significantly helped the users.

Figure 7(c) shows the mean of responses given to the questionnaire by the second group. We observed that the mean of the responses of the first question is 5.1 with std 1.36. Similarly the graph shows a mean of 5.5 for the second and 5 for the third question, while they have standard deviation

of 0.79 and 1.5 respectively. It means that object selection in the first condition is easier but the haptic guidance has a significant effect on the user's performance.

If we compare the task's completion time for the two groups we observe that it has increased for the second group mainly because they were restricted to precisely select the object from a specified direction. This restriction increased task's complexity and caused the user to move the virtual pointer towards the object in comparatively slow manner. Similarly if we compare the subjective evaluation of the two groups, we see that haptic guidance level is almost the same for both groups. On the other hand the task easiness level in first condition (stereoscopic display + visual guide) and level of realism with force feedback is higher for the first group.

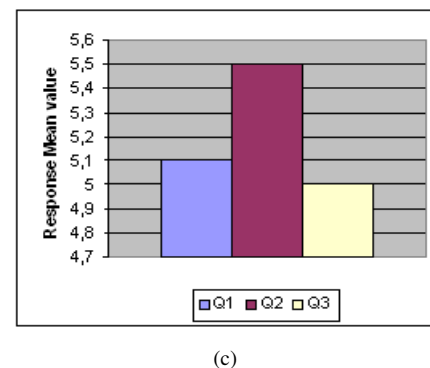
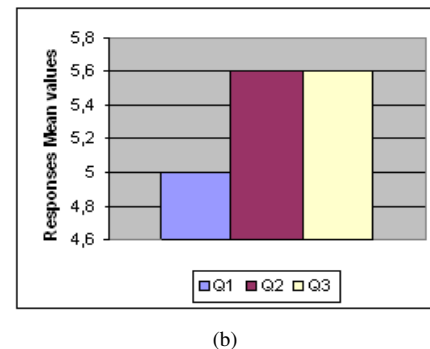
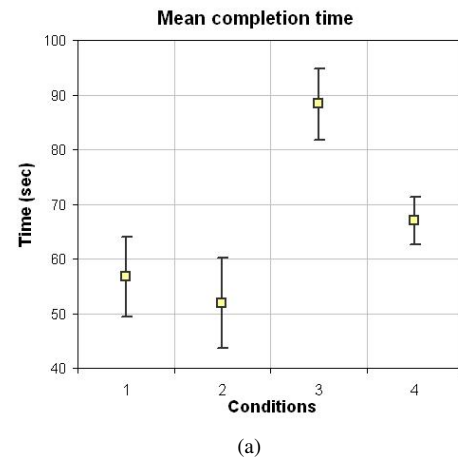


Fig. 7. Illustration of task completion time & level of guidance under various conditions. (a) Task completion time 1st and 2nd group (b) questionnaire responses 1st group (c) questionnaire responses 2nd group

V. CONCLUSIONS

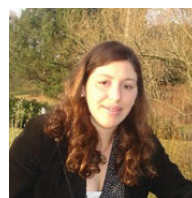
We presented new haptic guide models to assist the user in object selection in the virtual environment. In order to improve the *Follow-Me* 3D interaction technique, we proposed new haptic guides which not only provide active guidance for object selection but also physically constraints the users hand's movement whenever required. The first (spherical) haptic guide provides assistance in object selection from all directions. The second is a conical haptic guide which impart guidance when the object selection is required from a specific direction. This guide not only gives attractive force towards the object but also prevent the virtual pointer to exit the cone through its sides. Two groups, each composed of 10 volunteers performed experiments in the VE. The task was to select four targets using both visual and haptic guides. We observed for both types of haptic guides a reduction in task completion time, especially for the conical one. It was also noted that task completion time increased in case of conical haptic guide as compared to the spherical haptic guide. All participants reported that it was easier to select objects under the first condition (spherical guide-no haptic). However they reported that haptic guides provided them significant guidance in object selection.

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