THE EFFECT OF HAPTIC GUIDES ON HUMAN PERFORMANCE IN VIRTUAL ENVIRONMENTS

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Abstract: In order to make the virtual environments(VE's) more realistic and to increase human performance, the inclusion of haptic modality becomes more important. In this paper we present two new haptic guides. The haptic guides are fundamentally aimed to assist users for object selection in VE's. We divide the virtual environment into three zones. In the first zone the user can freely move and don't use any sort of guides. In the 2nd zone, user is given visual guidance and the 3rd zone contains haptic guides along with visual guides. As the paper presents two different models of the haptic guides, one for free and multidirectional selection and the second for precise and single direction selection. We not only study the effect of these guides on human task performance in the VE but also investigate a comparison of the two haptic models.

1 INTRODUCTION

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 objects (Bowman, 1999), (Pierce et al., 1997), (Stoakley et al., 1995). 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 (Ouramdane et al., 2006). The second zone we propose contains a visual guide (Otmane et al., 2000b) which is dynamically activated to guide the user for object's selection.
The third zone that we propose contains haptic guides 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 applications 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 and hardware/software setup. Section 4 describes experiments and evaluation. Conclusion is given in section 5.

2 RELATED WORK

A lot of work related has already been done in VR systems, Bowman (Bowman, 1999) has carried out a detail taxonomy of object selection and manipulation based on task decomposition. Similarly (Poupyrev et al., 1998), (Poupyrev and Ichikawa, 1999) 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 (Stoakley et al., 1995) and automatic scaling (Mine et al., 1997) are examples of exocentric type interaction. In egocentric interaction, the user interacts from inside the environment. The egocentric interactions are further divided into two metaphors: virtual pointer and virtual hand. The virtual pointer uses a vector for object selection and manipulation (Pierce et al., 1997). similarly we may refer to the Ray-Casting technique (Mine et al., 1997), uses a laser pointer - an infinite ray extending from the virtual pointer. The flash light technique (Liang

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and Green, 1994) use the same principle as the Ray-casting technique, but the laser pointer is replaced by an infinite cone. In the case of virtual hand metaphors, virtual representation of the real hand is used. Here, an object in the VE can be selected and/or manipulated when the virtual hand touches the object (Sturman et al., 1989),(Poupyrev et al., 1996). The PRISM (Frees and Kessler, 2005) technique is used as an addition to other existing techniques to increase precision.

In order to make the interaction easier and increase user performance, various aides like stereoscopic display, 3D audio or haptic feedback may be exploited. In the context of assistance for 3D interaction, virtual guides (Rosenberg, 1993) are valuable tools, for example in the context of teleoperation (Otmane et al., 2000b). The haptic virtual Fixtures (virtual Fixture), currently being used mainly 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 (Abbott et al., 2005). In these type of haptic virtual fixtures users not only have very little freedom but also lack visual guides that may reduce performance. Similarly (Ren et al., 2007) has proposed haptically augmented surgical system limiting the surgeon movement in certain areas. Oakley et al. have investigated the use of haptic feedback in GUI's and have concluded that carefully designed force feedback may bring best performance (Oakley et al., 2002). Alex B. (Alex B. et al., 2004) have used virtual fixtures for targeting tasks in a desktop environment, but these can only be used with static objects with predefined path. Similarly they superimpose the visual and haptic fixtures on each other.

3 PROPOSED SYSTEM

3.1 Proposed Models for Haptic Guides

Concerning the spherical guide, all objects in the VE share the same "free manipulation zone". Furthermore each object in VE is separately 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 $D_p \leq R_v$ 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 $D_p \leq R_h$ 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 is calculated according to the following equation.

$$F = K + \frac{(V_{t+1} - V_t)}{\triangle t} \qquad (1)$$

Here $K > 0$ is a constant which not only signify the minimum attractive force felt by the user but also gives a sense of transition between the spheres, it is always present as long as the user is inside the haptic sphere. 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 change of velocity i.e. if his/her velocity V_{t+1} is greater than that of V_t , the attractive force increases as a consequence and vice versa. Referring to (Abbott et al., 2005) 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. 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 of the minimum force of magnitude K is always present inside the haptic sphere, and increase and/or decrease in it depends on user's velocity towards the object. The spherical guide is illustrated in figure 1.

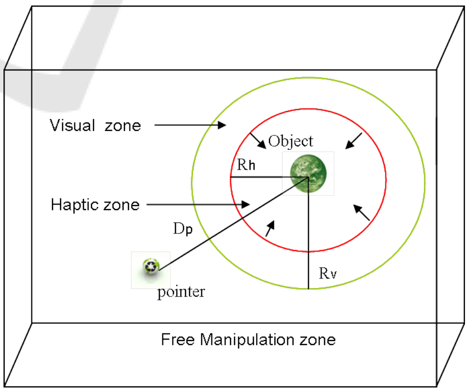

Figure 1: Illustration of the spherical guide.

Like the spherical implementation here the "free manipulation zone" is common to all objects but the inner two zones (visual and haptic) are implemented using cones, 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 selection. The visual guide is activated over the nearest object in virtual world through which not only the laser ray passes but the condition $D_p \leq L_v$ 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 $D_p \leq L_h$ occurs, where L_h is the length of the haptic cone. The attractive force is calculated as follows:

$$F = \frac{K}{1+D_c} + \frac{(V_{t+1} - V_t)}{\triangle t} \quad (2)$$

Here again $K > 0$ is constant signifying the minimum attractive force and acts as a transition signal between the two zones. In this model the resultant force is dependent on two factor, first is D_c which is the distance between the pointer and axis passing through the center of the cone, and second is the user's change in velocity towards object. 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 (Ouramdane et al., 2006). 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) (Sato, 2002), (Tarrin et al., 2003), (Richard et al., 2006), thus providing more realistic interactions. The conical guide is illustrated figure 2

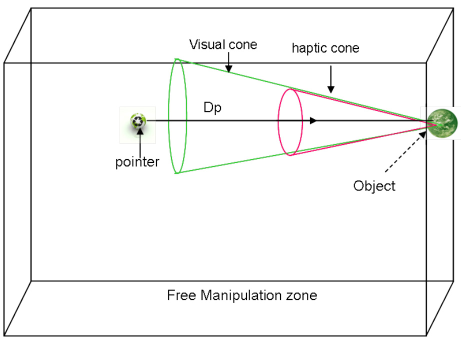

Figure 2: Illustration of the conical guide.

3.2 Platform 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. We used 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 3. 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, so it is transparent, safe and simple.

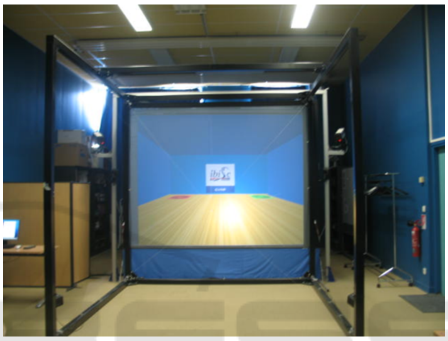

Figure 3: Illustrations of SPIDAR (a) Motors and strings (b) HDHC (c) Computer.

3.3 Software Architecture

The software we used to implement the haptic guides in VE has client-server(installed on two different machines) architecture as illustrated in the figure 4

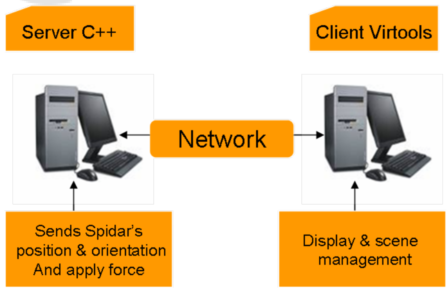

Figure 4: Illustration of the software architecture.

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.

4 EXPERIMENTS

4.1 Experimental Protocol

In order to investigate the effect of the proposed haptic guides on human performance, 20 volunteers males subjects participated in the experiments. They were all 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 performed the experiment to evaluate the spherical guide, while the second group performed the experiment to test the second guide(hatpic cone). 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 SPIDAR, but no training trial was given to them. We recorded the task's completion time for each user. In order to carry out subjective evaluation of the 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 extend 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 1.

Table 1: Scale to respond to the questions.

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

4.2 Experimental Task

The VE (see figure 5) contains four small objects(i.e two spheres, teapot, clock) in the same vertical plane and an other small sphere is used as 3D pointer whose movement is directly controlled via 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 selects 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 make use of stereoscopic display and visual guide while the second condition use 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.

Figure 5: Illustration of the environments used for experiments.

4.3 Results and Analysis

4.3.1 Task Completion Time

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 ($F(1,9)= 8.72$, $P < 0.005$) significative.

Visual Sphere vs Haptic Sphere. Comparing the performance of visual sphere with haptic one gives us means of 55.7 and 46.0 with std(18.83,14.18) respectively, for which ANOVA result is non significant.

Visual Sphere vs Visual Cone. Comparing the task completion time of the two visual guides, we have means 55.77 and 84.88 with std (18.83, 20.93) for sphere and cone respectively, showing non significant ANOVA result.

Haptic Sphere vs Haptic Cone. Comparison of the two haptic guides (sphere and cone) give means 46.44 and 69.66 with std (14.18, 12.74) respectively, having ANOVA result as significant.
The analysis of task completion time can be seen in the figure 6, 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

4.3.2 Subjective Evaluation

In this section we analyze the users' responses and comments collected through questionnaire. Summarizing the response we observed that both visual and haptic guides provide assistance to users in objects' selection but they preferred haptic guides because of their active nature. The spherical guide enabled them to complete the task in lesser time as compared to the conical one because it restricted the users to make selection from a single direction for the sake of precision.

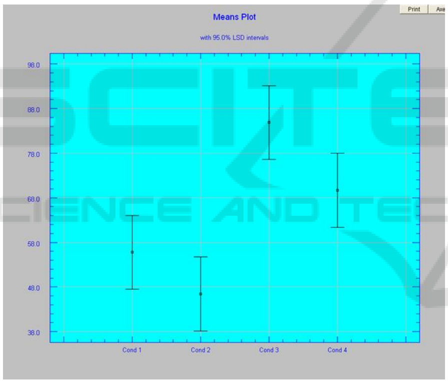

Figure 6: Task completion time & level of guidance under various conditions.

5 CONCLUSIONS

In order to remove the inconveniences observed in *Follow-Me*, we proposed haptic guides which not only provide active guidance (attractive force toward the object) to the user to select an object but also physically restricts his/her hand's movement whenever required. We implemented two versions of haptic guide. The spherical haptic guide that 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. Here the guide not only gives attractive force towards the object but also resist the exit of virtual pointer through the walls of the cone. Two groups, each composed of 10 young volunteers performed the task to evaluate the haptic guides.
We observed for both types of haptic guides a reduction in task's completion time, especially for the conical haptic guide. It was also noted that task's completion time increased in case of conical haptic guide as compared to the spherical haptic guide.
Evaluating the subjective responses collected through questionnaire, both the groups reported that haptic guides provided them significant guidance in object selection, made the task easier and thus resulted in increasing performance. Another important point is that SPIDAR can be successfully used in large scale virtual environment not only to have free movements (without force) in the environment but also to generate realistic forces if required.

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