Comparative Study of the Performances of Several Haptic Modalities for a 3D Menu

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Abstract

We introduce a new technique of haptic guidance, for navigation and control of applications in virtual environments. We haptically simulate the collisions of the pointer with the borders of a polyhedral menu, making it glide towards the items. We propose the preliminary results of an empirical evaluation of this technique.

Keywords: Haptic interfaces, Menus, Virtual reality, 3D Interaction, Computer-Human Interfaces, Force Feedback Devices

Index Terms: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Graphical user interfaces, Haptic I/O, Interaction styles; I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction techniques;

1 Introduction

Haptically enhanced interaction mainly relies on ”snap-to” effects. They can be local magnetic effects around a target that actively captures the pointer if it enters a specific area [3], or can behave as a gradient force all over the environment to draw the pointer towards points of interest. Magnetic targets can help in object selection, by reducing selection times and error rates. However these techniques also seem to lead to higher selection times and to a significantly higher overall cognitive load when multi-target selection is considered [2, 1].

We propose a technique able to reduce these drawbacks in the context of 3D menu interaction. It consists of proposing a convex haptic shape on which each vertex is a menu item. We then simply allow the pointer to collide the edges and slide along them towards the vertices. In others terms, the targets are accessible by slipping along the interior faces and edges which connect them. This approach differs from a magnetic grid [4] since the edges of our haptic shape are not attracting the pointer towards them. This technique can be adapted to any configuration of targets able to be represented as a convex polyhedron.

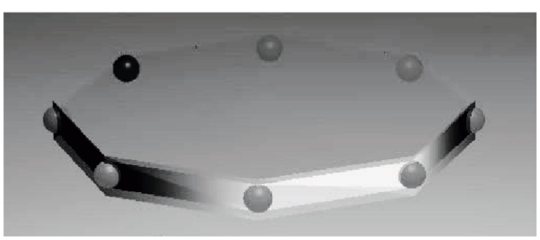

Figure 1: A polyhedral menu is displayed. The pointer can slide along the edges towards the vertices

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2 Experimental study

2.1 Haptic Modalities

In the present study, the application of our approach has been restricted to a 1-level 3D menu, represented as a regular polyhedron. The items of the menu, represented as spheres, are located at the vertices of the polygon. For the present study, we chose to test our menu with the following parameters : 8 vertices, 20 degrees inclination and a diameter of 8 cm. Using these parameters, we compared 5 haptic modalities :

- NoHaptics (NH): the only force feedback guidance is a 3D plane the pointer relies on.
- Magnet (M): the device pointer is attracted towards the target when it arrives inside the radius of influence (fixed to twice the radius of the spheres representing the items), as illustrated on Fig.1(a).
- HardBorders (HB): the menu is represented as a convex cell, the vertices being the items of the menu, forming the constriction polyhedron. The pointer glides on the hedges of the polyhedron towards the vertices.
- MagnetHard (MH): this modality is the combination of the Hardborders and Magnet modalities.
- StarBorders (SB): a star-shaped haptic border is set between the items, as shown on Fig.1(d). This shape acts like a funnel for the pointer. With this haptic modality, the visible menu is the same as with the previous modalities, i.e. the star-shaped haptic border is only felt but not visible, and the visible border is the convex hull of the polyhedral menu.
- StarBordersDisplay (SBD): the star-shaped haptic border is visible, and replaces the visible convex hull.

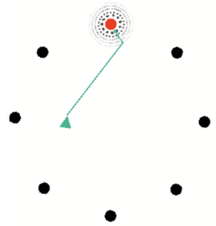
2.2 Experimental setup and results

For each of the 6 haptic modalities presented above, after a short training session, we asked 24 subjects to realize a series of 10 tasks, each task composed of 2 successive selections. The ordering of the tested haptic modalities changes between each subject according to a latin square algorithm, in order to avoid a learning phenomenon.

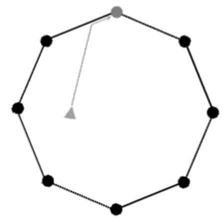
We ran a One-Way ANOVA (ANalysis Of VAriance) on the collected data and a postoc Tukey HSD test to compute the relevancy of the differences between the different techniques. The statistical relevancy threshold was fixed to 0.05.

We present here the data collected and the statistically significant results we obtained regarding each of these data. The results are summarized in table 1.

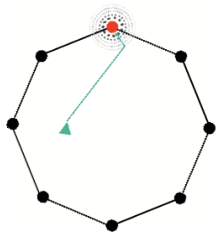
- *Precision (PRE)*: distance between the center of the target and the location of the pointer at the moment of the selection. The techniques can be regrouped as follow : SB and SBD perform significantly better than HB and MH, which are significantly more precise modalities than M and NH.



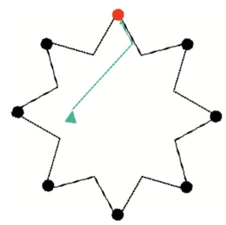
(a) Magnet



(b) HardBorders



(c) MagnetHard



(d) StarBorders

Figure 2: Haptic modalities (2D projection): the target, the initial pointer position and its trajectory are represented in light gray

- *Task Completion Time (TCT)*: time necessary to select the item. The HB modality leads to significantly better results than all other techniques, except MH. We also tried to know if there was an interaction between the haptic modality and the position of the target. We found no such statistical result : the time necessary to reach a particular target is statistically independent from the haptic modality. However, the targets can be gathered in two statistically different clusters regarding TCT : targets $\{0, 4, 1, 5\}$ obtain the worst results, whereas targets $\{2, 6, 7, 3\}$ obtain the best results (see figure 3).

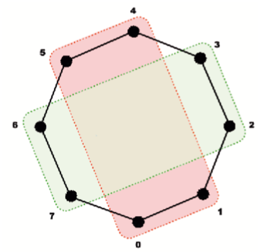
- *Number of Target Re-Entry (TRE)*: number of times the pointer leaves the volume of the target and then goes again inside the target. The M modality performed significantly worst than all the other techniques except NH. On the other hand, SBD performed significantly better than M and HB.

- *Extra Distance (ED)*: the difference between the optimal distance between starting point and center of the target, and the actual covered distance. HB performed significantly better than all other techniques.

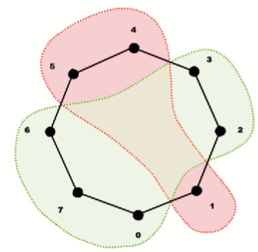
- *Error rates (ERR)*: the percentage of wrong selections for a given condition. We found no significant influence of the haptic modality regarding ERR. However, it was influenced by the position of the target. The error rates results showed the existence of two statistically different clusters $\{1, 4, 5\}$ and $\{0, 2, 3, 6, 7\}$ (see figure 3).

Table 1: Results of each modality regarding PRE, TCT, TRE and ED

	PRE	TCT	TRE	ED
NH	0.501	1.429	0.632	1.419
SB	0.423	1.390	0.557	1.456
M	0.488	1.389	0.664	1.398
SBD	0.427	1.347	0.541	1.506
MH	0.470	1.253	0.599	1.434
HB	0.464	1.204	0.598	0.826



(a) TCT



(b) ERR

Figure 3: Influence of targets position on TCT and ERR. Dark gray: worst results, and light gray: best results

3 Conclusion

The overall results we obtained with our experiment suggest that for any of the measurements, 2 techniques detach as those having the worst results: NF and M. We think that these results rely on the "snap-to" paradigm. This haptic modality induce unexpected drifts in the trajectory of the pointer that the users cannot anticipate, as the area of effect is not visible. This can lead to an unwanted resistance from the users that may try for a while to continue their initial movement. This should explain the low performances of M regarding PRE, TCT and TRE. On the contrary, the help provided by hardborders techniques, especially HB and SBD, can be more easily anticipated. They correct the trajectory to guide the pointer towards the target in a smoother way than M does. The results also suggest that a more constraining technique leads to an increased precision (SBD) but increases the selection time, especially when multiple selections are involved. MH and SB led to intermediate results when compared to M or HB and SBD. We think MH was penalized because of its magnetic attraction component while SB might have suffered from the invisibility of its haptic guidance.

The clusters configuration according to targets numbering (see figure 3), suggest the existence of an "accessibility axis" corresponding to the "left-right" direction. We think that the slight rotation to the left that can be observed appeared because all participants were right-handed.

These first results are very encouraging for the HardBorders modality. We will continue our study by analyzing more precisely the differences between the "haptic wall" modalities (HB, MH, SB, SBD) and by refining the parameters of the menu (diameter, maximum number of items, best inclination, etc.). We also intend to extend this single-level 3D menu, to have a complete hierarchical menu.

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