Study of Performances of "Haptic Walls" Modalities for a 3D Menu

Antonio Capobianco[1] and Caroline Essert[1,2]

[1] Université de Strasbourg / LSIIT, F-67412 Illkirch Cedex, France
[2] INRIA, Campus de Beaulieu, F-35042 Rennes, France
a.capobianco@unistra.fr, essert@unistra.fr

Abstract. We introduce a new technique of haptic guidance for item selection in 3D menus for VR applications called "haptic walls". It consists in haptically rendering a solid funnel to guide the pointer towards a target located in the angle. We designed a 3D haptic menu using this approach: a thin polyhedral shape with the items at the corners. The "haptic walls" are experimented with 2 different shapes of polyhedra, and compared to 2 reference conditions. We propose the results of our first empirical evaluation of this technique.

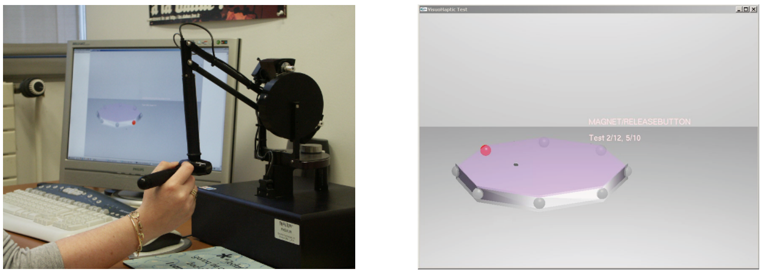
Key words: Computer-Human interfaces, Haptic I/O, Menus, Interaction techniques, Performance evaluation

1 Introduction

Haptically enhanced interaction for guidance (in the sense of Miller and Zeleznik, [7]) 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 [8], or can behave as a gradient force all over the environment [11] to draw the pointer towards points of interest. For object selection, magnetic targets can help by reducing selection times and error rates [1]. However some studies report benefits from magnetic widgets to precision but not to selection times [12]. Moreover, these techniques seem to lead to higher selection times and to a significantly higher overall cognitive load when multi-target selection is considered [9, 4].

As we can see, "snap-to" effects can have contradictory consequences. We propose a technique able to reduce these drawbacks, and apply it in the context of item selection in 3D menus. Our approach called "haptic walls" consists in haptically rendering solid walls shaped like a funnel, leading to a target located at the intersection of the 2 walls. The walls act as virtual fixtures: the targets are accessible while slipping along the interior faces and edges of the convex polyhedron that connects them. This approach differs from a magnetic grid [13] 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.

We presented in [3] some first results on only one haptic wall modality. In the present paper, we extend this study by experimenting several shapes and combinations of haptic modalities, and 2 different selection techniques.



(a) Experimental setup (b) Experimental application

Fig. 1. Experimental setup and application designed for haptic menu tests

2 3D Menu: Haptic and Selection techniques

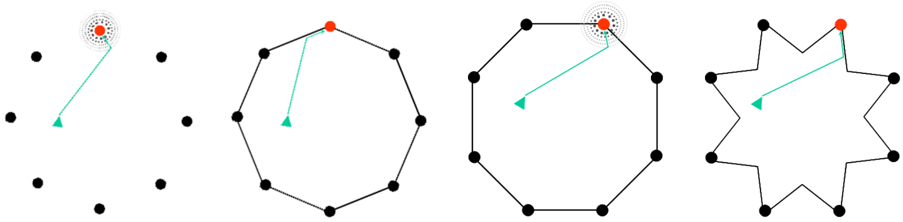
The present study has been restricted to the experimentation of the haptic walls techniques on a 1-level 3D menu, represented as a regular polyhedron (extruded polygon, see Fig.1(b)). The 8 items of the menu, represented as gray spheres, are located on the vertices of the polyhedron. This design is very similar to pie or marking menus which are known to allow precise and rapid interaction for menu selection tasks [2]. Moreover, pie menus are more appropriated to 3D interaction than linear menus [5]. The number of items was selected according to the design recommendations for the conception of marking menus [6]. The polyhedron is lying on a haptic 3D plane to guide the user and help with the perception of depth [5]. The menu presents a 20° tilt from the (x,z) plane. This was chosen to force the use of the in-depth dimension, and assess its impact on the performances. The diameter of the menu was set to 8 cm and each sphere representing an item had a 0.4 cm radius. All these parameters were set after an empirical preliminary evaluation involving 6 participants.

Using this configuration, we compared 6 haptic conditions, among which HB, MH, SB, and SBD are different implementations of the haptic walls approach:

- **NoHaptics** (**NH**): the only force feedback guidance is the 3D plane the pointer relies on. This technique was designed to have a reference situation with no haptic guidance to help selecting the targets.
- **Magnet** (**M**): the device pointer is attracted towards the target when it arrives inside the radius of influence (fixed to 5 times the radius of the spheres representing the items), as illustrated on Fig.2(a). The attraction is increasing while the distance to the target decreases, until a threshold of 80% of the distance, then it decreases to avoid oscillations.
- **HardBorders** (**HB**): the external faces of the menu are made haptically solid and slippery, to guide the pointer towards the corners (see Fig.2(b)), like a funnel with obtuse angles.
- **MagnetHard** (**MH**): this technique is the combination of the HardBorders and Magnet techniques (see Fig. 2(c)). It was designed to know if the association of 2 haptic guidances could take advantage of the best of each

one. Hardborder could provide a smooth guidance in the first phase of the selection by helping the user to enter in the attraction area, while in the end of the movement magnet could dynamically attract the pointer.

- **StarBorders** (**SB**): a star-shaped haptic border is felt, as shown on Fig. 2(d), but the visible border is the convex hull of the polyhedral menu, as with the previous techniques. This haptic shape also acts like a funnel, with more acute angles : it allows us to evaluate the impact of the parameters of the shape.
- **StarBordersDisplay** (**SBD**): the star-shaped border is felt and visible, and replaces the convex hull. This technique has been added to quantify the possible effects of the invisibility of the haptic border in the StarBorders modality, since in the HardBorder modality the haptic walls match the visual representation.



(a) Magnet (b) HardBorders (c) MagnetHard (d) StarBorders

Fig. 2. Haptic modalities (2D projection): the target is in red, and the initial pointer position and its trajectory are represented in green

We also wanted to know if the most appropriate selection technique was depending on the haptic modality. We chose to test 2 different selection modalities. The first one,"**ReleaseButton**", is very common. It requires the user to validate his selection with a button when pointing at the chosen item. The other one, similar to the "**ExceedBorder**" technique used in [5], requires the user to simply enter in the accessible volume of a menu item (*i.e.* a conical area inside the polyhedron). The selection is then automatically validated.

3 Experimental Setup and Results

We performed all our experiments using a quadro processor PC at 2,60 GHz, equipped with a 17 inch 2D screen with a resolution of 1280*1024. The haptic device was a PHANToM Premium (Sensable) with 6 degrees of freedom (dof), even if this specific application only uses 3 dof (see Fig.1(a)).

For each of the 6 haptic and the 2 selection conditions 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. This makes a total of 6*2*10*2=240 selections for each subject. The ordering of the tested combinations has been balanced in order to avoid a learning phenomenon.

For each task, the menu appears centered at the point where the button was pressed. One of the spheres, randomly chosen as the target, is displayed in red, and has to be selected by the user. Then a second target is randomly chosen among the remaining spheres, displayed in red, and selected by the user. The 2 successive selections were asked in this protocol to place the user in the situation of hesitation, and test the ergonomics of the modalities in this case. An item is considered as selected even if it was not the required target. In this case, it is considered as a wrong selection.

We present below the experimental datas collected during the experiment. We ran a One-Way ANOVA (ANalysis Of VAriance) on the collected values and a post-hoc Tukey HSD test to compute the relevancy of the differences between the different techniques.

- **Precision (PRE)**: distance between the center of the target and the location of the pointer at the moment of the selection. The haptic modality as a significant impact on precision (F(5, 138)=340.3, p<.0001). The techniques can be grouped as follows: SB and SBD perform significantly better than HB and MH, which are significantly more precise modalities than M and NH (see Tab. 1).

Table 1. Mean values for the precision (PRE, in mm)

	Mean	Standard	Pairwise comparison (p-value)					
Modality	PRE	deviation	NH	M	MH	HB	SBD	SB
NH	0.501	0.16	-	0.206	<.001	<.001	<.001	<.001
M	0.488	0.17		-	0.014	<.001	<.001	<.001
MH	0.470	0.18			-	0.887	<.001	<.001
HB	0.464	0.19				-	<.001	0.001
SBD	0.427	0.2					-	0.974
SB	0.423	0.2						-

- **Task Completion Time (TCT)**: time necessary to select the item. The haptic modality as a significant effect (F(5, 138)=41.7, p<.0001) on task completion times. The HB modality leads to significantly better results than all other techniques except MH (see Tab. 2). We also looked 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 (p<.0001) clusters regarding TCT: targets {0, 4, 1, 5} obtain the worst results, whereas targets {2, 6, 7, 3} obtain the best results (see Fig.3(a)).
- **Number of Target Re-Entry (TRE)**: number of times the pointer goes out the accessible volume of the target and then goes again inside the target

Table 2. Mean task completion times (TCT, in sec.)

	Mean	Standard	Pairwise comparison (p-value)					
Modality	TCT	deviation	NH	SB	M	SBD	MH	HB
NH	1.429	0.72	-	0.884	0.870	0.194	<.001	<.001
SB	1.390	0.94		-	0.999	0.833	0.002	<.001
M	1.389	0.72			-	0.85	0.002	<.001
SBD	1.347	1.1				-	0.086	0.001
MH	1.253	0.67					-	0.738
HB	1.204	0.59						-

before selection. The haptic condition significantly influences the number of target re-entry (F(5, 138)=14.451, p<.0001). The M modality performed significantly worst than all the other techniques except NH (see Tab. 3). On the other hand, SBD performed significantly better than MH and HB.

Table 3. Mean number of target re-entry (TRE)

	Mean	Standard	Pairwise comparison (p-value)					
Modality	TRE	deviation	M	NH	MH	HB	SB	SBD
M	0.664	0.79	-	0.440	0.002	0.002	<.001	<.001
NH	0.632	0.75		-	0.364	0.329	<.001	<.001
MH	0.599	0.71			-	0.999	0.138	0.008
HB	0.598	0.72				-	0.159	0.01
SB	0.557	0.63					-	0.924
SBD	0.541	0.59						-

– **Extra Distance (ED)**: difference between the shortest path authorized by the haptic modality from starting point to target, and the actual covered distance. The haptic modality has a significant effect on extra distance (F(5, 138)=38.13, p<.0001). HB performed significantly better than all other techniques (see Tab. 4).

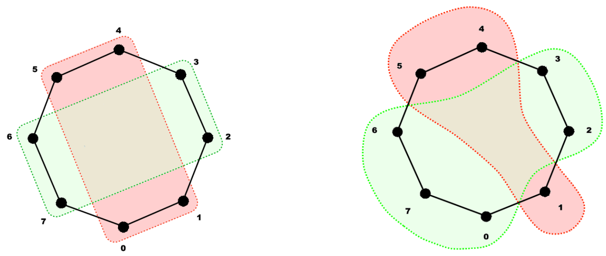
Table 4. Mean extra-distance (ED, in mm)

	Mean	Standard	Pairwise comparison (p-value)					
Modality	ED	deviation	SB	SBD	NH	MH	M	HB
SB	1.4	2.76	-	1	0.48	0.088	0.061	<.001
SBD	1.4	3.54		-	0.62	0.147	0.106	<.001
NH	1.3	1.95			-	0.955	0.918	<.001
MH	1.2	1.49				-	1	<.001
M	1.2	1.21					-	<.001
HB	0.3	0.98						-

Table 5. Comparison of target placement according to TCT and ERR

Target	#0	#4	#1	#5	#3	#7	#6	#2
TCT	1.524	1.431	1.429	1.403	1.305	1.255	1.182	1.161
ERR (%)	0.14	1.00	0.69	0.59	0.27	0.14	0.40	0.42

– **Error rates (ERR)**: the percentage of wrong selections for a given condition. ERR is globally low (average 0.45%). We found no significant influence of the haptic modality regarding ERR. However, it was influenced by the position of the target. The results showed two statistically different (p=.008) clusters {1, 4, 5} and {0, 2, 3, 6, 7} (see Fig.3(b) and Tab. 5).



(a) TCT (b) ERR

Fig. 3. Influence of targets position on TCT and ERR. In red the worst results, and in green the best results

We also analyzed the influence of the selection modality and the order of the selection (first or second) on TCT. There is a statistically significant difference between both selection modalities (p<.0001): ExceedBorder is significantly faster than ReleaseButton. The order of the selection also influenced TCT (p<.0001): first selections are significantly faster than second ones (see Tab. 6).

4 Discussion

Influence of the Interaction Technique The overall results suggest that for any of the measurements, 2 techniques detach as those having the worst results: NH and M. We think that the bad results of M rely on the "snap-to" paradigm. This haptic modality induces 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 "haptic wall" techniques, especially HB and SBD, can be more easily anticipated.

Table 6. Comparison of TCT according to selection modality and selection order

	Overall	HB	SB	SBD	MH	M	NH
ReleaseButton	1.553	**1.421**	1.619	1.522	1.499	1.615	1.640
ExceedBorder	1.118	**0.987**	1.161	1.173	1.007	1.162	1.218
First selection	1.286	**1.182**	1.328	1.240	1.234	1.355	1.379
Second selection	1.384	**1.226**	1.452	1.454	1.272	1.423	1.479

Of course, setting larger areas of attraction for M might have changed the results of TCT, but would probably have harmed the control of the pointer, leading to increased error rates.

The results also suggest that among haptic walls modalities, a more constraining technique such as SB or SBD leads to an increased precision, but also increases significantly the selection time, especially for the second selections (see Tab. 6). In fact, for first selections the pointer starts from the center whereas for second selections, the pointer starts from the previously selected target. This implies in average a longer path towards the next target, increasing inevitably the TCT. But the star-shaped haptic walls may also have been experienced as an obstacle while users tried to follow the shortest path between 2 successive items. This could also account for the results observed concerning the Extra Distance (ED), with SB and SBD leading to the worst results. To better understand this phenomenon, a further analysis, involving acute control of the direction of the selection and difficulty of the path will be necessary [10].

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.

Influence of the Targets Placement The clusters configurations according to targets numbering (see Fig.3) suggest the existence of an "accessibility axis" corresponding to the "left-right" direction. We think that this could be explained by an increased difficulty of the selection task in the in-depth direction. A lower muscular requirement may also explain this phenomenon, since when performing a "left-right" movement, users used a wrist movement, while "in-depth" movements involved the whole arm. We think that the slight rotation to the left that can be observed appeared because all participants were right-handed, and the axis is rotated in the direction of their forearm.

Influence of the Selection Modality ExceedBorder is faster than ReleaseButton whatever the haptic modality used for the guidance. However, there is no significant influence of the selection modality on the error rate ($p = 0.238$). The best results are obtained with the HB technique. We think that the combination of HB and ExceedBorder is probably the most appropriate modality for menu selections. It allows good overall performances regarding TCT, PRE and ED with successive selections.

5 Conclusion

In this paper we reported our experiments on several "haptic walls" modalities for 3D menu, *i.e.* haptic techniques acting like a funnel. These results are very encouraging, especially for HardBorders. These techniques seem to provide a better control over the movement of the pointer, that can be more easily anticipated than with magnetic techniques. We will continue our study by refining the parameters of the menu (diameter, max. number of items, angle of tilt, etc.). We also intend to extend this single-level menu to a complete hierarchical menu.

6 Acknowledgments

The authors wish to thank Alex Ocampo for his participation to this work, and all the participants of our evaluation.

References

1. Akamatsu, M., Sato, S., A multi-modal mouse with tactile and force feedback. Int. J. Hum.-Comput. Stud., 40(3), 443–453 (1994).
2. Callahan J., Hopkins D.,Weiser M. and Shneiderman, B., An empirical comparison of pie vs. linear menus. CHI '88: Proceedings of the SIGCHI conference on Human factors in computing systems, 95-100 (1988).
3. Essert-Villard C., Capobianco A., HardBorders: a New Haptic Approach for Selection Tasks in 3D Menus. In Proceedings of ACM VRST'09, 243-244 (2009).
4. Hwang, F., Keates, S., Langdon, P., Clarkson, P. J, Multiple haptic targets for motion-impaired computer users. In proceedings of the ACM CHI '03, 41-48 (2003).
5. Komerska, R., Ware, C., A Study of Haptic Linear and Pie Menus in a 3D Fish Tank VR Environment. In proceedings of International Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, 224-231 (2004).
6. Kurtenbach, G. P. The Design and Evaluation of Marking Menus. Doctoral Thesis, University of Toronto (1993).
7. Miller T., Zeleznik R., The design of 3D haptic widgets. In Proceedings of the 1999 Symposium on interactive 3D Graphics, 97-102 (1999).
8. Oakley, I., McGee, M. R., Brewster, S., Gray, P., Putting the feel in "look and feel". In proceedings of ACM CHI '00, 415-422 (2000).
9. Oakley, I., Brewster, S., Gray, P., Solving multi-target haptic problems in menu interaction. In proceedings of ACM CHI '01: extended abstracts, 357-358 (2001).
10. Soukoreff W., MacKenzie S.I., Towards a standard for pointing device evaluation, perspectives on 27 years of Fitts' law research in HCI. International Journal of Human-Computer Studies, 61(6) 751-789 (2004).
11. Vidholm, E., Nystrom, I., A Haptic Interaction Technique for Volume Images Based on Gradient Diffusion. In proceedings of WHC '05, 336-341 (2005).
12. Wall. S.A., Paynter K., Shillito A.M., Wright M., Scali S., The Effect of Haptic Feedback and Stereo Graphics in a 3D Target Acquision Task. In Proc. Eurohaptics 2002, 23-29 (2002).
13. Yamada, T., Ogi, T., Tsubouchi, D., Hirose, M., Desk-sized immersive workplace using force feedback grid interface. In proceedings of IEEE VR, 135-142 (2002).