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Force design for memory aids in haptic environments

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Abstract

This paper presents a study designed to investigate the usefulness of different force designs for haptic memory aids (beacons). The results lead us to recommend constant type forces, possibly with some 1/sqrt(r) like snapping behavior in the vicinity of a beacon point to make sure you actually reach it. This snapping has to be weighed against the possible disadvantage of interfering with user exploration close to the points. We also recommend that the user should be able to adjust the strength of this type of force.

1. Introduction

With one point haptic interaction in a non-visual setting, it is easy to miss objects or get lost in haptic space [1]. Some navigational tools have been suggested, such as "magnets", "crosses" (allowing the user to feel if he or she is aligned with an object) or a "ball" (to feel things from a distance) [2]. The attractive force in particular has been used and found to be helpful in many circumstances (e.g. [3, 4] and is included as a standard tool in the current OpenHaptics software from SensAble). For graph exploration, Roberts et al. [5] and more recently Pok-luda and Sochor [6] presented different versions of guided tours, while Wall and Brewster [7] tested the use of external memory aids, so called "beacons", which the users could place on a surface and which then could be activated to drag the user back to this particular location. Text labels have been used extensively to help users obtain an overview of maps [8] or traffic environments, for example [9].

Other suggested ways to help the user with navigation/learning are automatic guid-ing constraints, referred to as "fixtures", which have been used for tele-operation, shared control tasks, tracking and training, often in a medi-cal context [10], or to have the user cancel forces generated by the haptic device [11].

In our previous work on navigational tools [12],[13] we had confirmed the results obtained by Wall & Brewster [7] which was that attractive forces can be useful for helping users to locate targets when using the PHANToM. We had also noted that the type of attractive force used could influence the results and we decided to perform a small study to compare different types of attractive forces. The results of this study are presented below.

2. Implementation

The current study is motivated by the fact that to make effective attractive force beacons for a PHANToM environment, one needs to know more about how different users are able to work with different types of attractive forces. Thus we decided to test forces that increased towards the target, forces that were kept constant over distance and forces that increased as you move away from the target. Our previous results indicated that an 1/r force probably was too strong at close distances [12], [13], while results from Wall et al [7] indicated that the linear force produced too strong forces at longer distances.

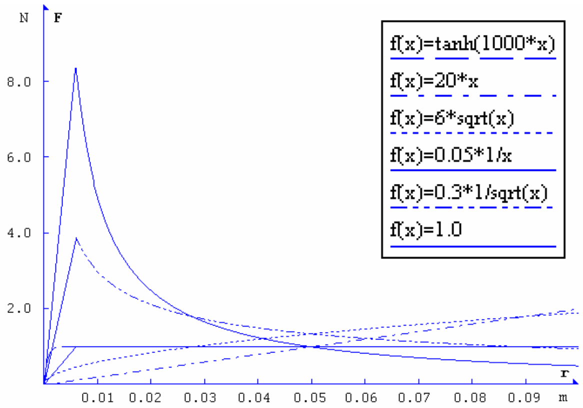

Figure 1: The radial dependence of the different forces used. The tanh and constant forces differ only at very small distances.

Because of this we decided to keep these two types as "endpoints" of our scale and add other forces in

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between. The six different radial dependencies we used were: constant force, tanh(r), 1/r, 1/sqrt(r), sqrt(r) and r.

To avoid vibrations on the beacon position, the forces that did not tend to zero at small distances had a short linear part for very small distances (inside a radius of 0.006m). This linear part was attached so that the force function was continuous throughout the whole space (although the derivative would be discontinuous at the breakpoint). The forces were adjusted by hand to feel roughly the same at medium distance (0.05 m). The radial dependence of the forces is illustrated in figure 1. The forces were always directed along $\hat{e}_r$ towards the target.

For this test the PHANToM 1.0 premium model was used, since it has more precise force rendering. It should be noted that the strength of the forces needs to be adjusted if another PHANToM model is used. The test environment was the haptic-audio drawing program developed at Certec, Department of Design Sciences, Lund University.

3. Test design

The test consisted of 5 tasks. In task 1 the user was asked to rate how well they liked the different forces as they were being held to a point in space by the force. In task 2 the user was guided to three different points quite far apart by use of the forces and the user was asked to rate the forces for this type of task. The user initiated beacon changes himself/herself. The task 3 was the same as the task 2 apart from the fact that the test leader initiated the change of beacon. In task 4 the user was guided between two nearby points by the use of the forces and rated the forces also for this case. The user initiated a change of beacon himself/herself.

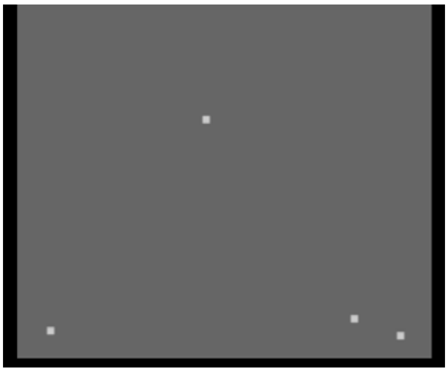

Figure 2: The points used for the test. The top point was used for tasks 1 and 5 while the three points closest to the borders were used for tasks 2 and 3. The two points in the corner was used for task 4.

In task 5 the user was asked to close his/her eyes and to draw a circle starting from the beacon point and then using the beacon force to close the circle, and then to rate the forces for this type of task.

The order the forces was presented was the same for all tasks for one user, but the order was changed between users to avoid learning effects. Figure 2 shows the points used for the five different tasks.

4. Test results

Fourteen participants between the ages of 10 and 73 did this test. Based on the assumption that this kind of basic interaction will provide reasonably similar results for blind and sighted participants, due to the limited availability of blind test persons we did this test with sighted users.

The main result from this test was the ratings of the different force designs. Qualitative observations of the interaction were also made during the tests.

The average ratings for different forces and different tasks are shown in figure 3.

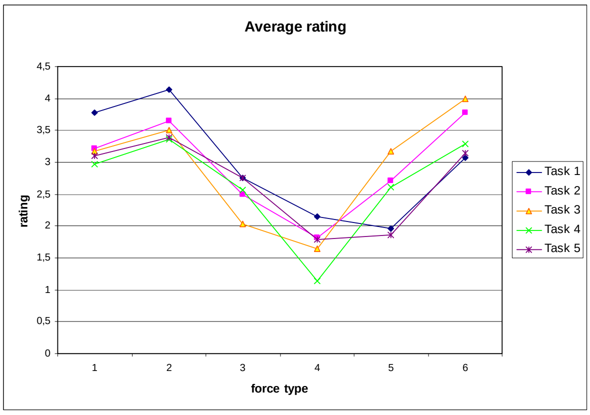

Figure 3: The average ratings for different forces and different tasks. The forces were 1. constant force, 2. tanh(r) type force, 3. sqrt(r) type force, 4. linear force (r type force) , 5. 1/r type force and 6. 1/sqrt(r) type force.

The results were analyzed using five different analyses of variance (ANOVA) with the rating as dependent variable. The independent within-group variable was the six different force designs. Post hoc tests were carried out using the Tukey test. The significance level was set to 0.05 throughout the analyses.

The ANOVA for the rating showed significant differences for all five tasks (F(5,65)=11.9, 14.0, 16.9, 9.2 and 7.8, p<0.05).

For task 1 the post hoc test showed that the tanh(r) type force was rated significantly higher than all other forces except the constant force (Q(6,65)= 5.5, 7.9, 8.6 and 4.2, p<0.05). The constant force was rated significantly higher than the linear force (Q(6,65= 6.5, p<0.05) and the 1/r type force (Q(6,65)= 7.2, p<0.05).

Finally the 1/sqrt(r) type force was rated significantly higher than the 1/r type force (Q(6,65)= 4.4, p<0.05).

For task 2 the post hoc test showed all forces except the sqrt(r) force to be rated significantly higher than the linear force (Q(6,65)= 7.0, 9.1, 4.5, 9.9, p<0.05). The tanh(r) force was also rated significantly higher than the sqrt(r) force (Q(6,65)= 5.7, p<0.05) and the 1/r force (Q(6,65)= 4.7, p<0.05). Also the 1/sqrt(r) force was rated significantly higher compared to the same set of forces (Q(6,65)= 6.5, 5.4, p<0.05).

For task 3 the constant, tanh(r), 1/r and 1/sqrt(r) forces are all rated significantly higher than the sqrt(r) and linear forces (Q(6,65)= 5.2, 6.7, 5.2, 9.0, 7.0, 8.5, 7.0, 10.8, p<0.05).

For the task 4 all forces are rated significantly higher than the linear force (Q(6,65)= 6.8, 8.3, 5.4, 5.5, 8.0, p<0.05).

Finally, for task 5 the constant force and the tanh(r) force were rated significantly higher than the linear force and the 1/r force (Q(6,65)= 5.3, 5.1, 6.5, 6.2, p<0.05). Also the 1/sqrt(r) type force was rated significantly higher than these two forces (Q(6,65)= 5.5, 5.2, p<0.05).

These results are confirmed by the qualitative observations for the different forces showed particular problems with both the linear and the sqrt(r) type force since both these forces tended to be too strong at long distances while at the same time not being able to guide the user all the way to the target, since they became too weak at short distances. Figure 4 shows a drawing which illustrates this point.

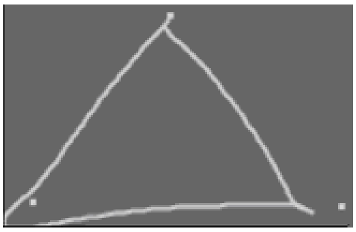

Figure 4. A drawing showing a result from task 2 with the linear force. One observes that this force was not able to guide the user all the way to the different points (the white dots in the picture).

It was also observed that the 1/r type force tended to be too strong at short distances, and the users found it much easier to interact with the 1/sqrt(r) force behavior, particularly for the task where they were supposed to draw a circle – it took quite a lot of force to “break free” from the beacon. Despite this they were still able to draw quite nice (and closed) figures as can be seen to the left in figure 5. To the right is a figure showing the circle resulting from the linear force. Also for this type of task the fact that the force gets too weak at short distances generates problems.

Figure 5. To the left a circle drawn from a beacon using the 1/r type force. To the right a circle drawn from a beacon using a linear force.

During the test we also noted that users needed different strengths of the forces, which indicate that it should be possible for the user to adjust the strength of the force.

Finally we did not note any real difference between the smooth tanh(r) force and the non-smooth constant force, although some users rated them slightly differently.

5. Discussion and conclusion

The results in the previous section show that the constant type forces (the constant force and the tanh(r) force) generally do well. Also the 1/sqrt(r) type force gets good marks by the users. The ratings are supported by the qualitative observations made during the test. It is interesting to note that this shows that users are able to deal with very much larger forces towards the end of a movement, compared to what can works at the start. Another way to say the same thing is that when forces increase continuously during the motion they are much easier to deal with compared to when sudden changes in the forces experienced.

To conclude, the advantages and disadvantages for the investigated forces can be summarized as follows:

Constant force and tanh(r) type force: Easy to predict. Takes the user to the targets while not interfering too much with user exploration. Does not snap to the targets which can cause overshooting before the user actually gets to the target.

Sqrt(r) type force: Does not interfere so much with user exploration, but does not reliably take the user to the targets. Increasing the strength to improve this makes the force too strong at large distances.

Linear force: Similar to the sqrt(r) force only more pronounced. Does not work at all at short distances while being very strong at large distances.

1/r type force: Gets the user reliably to the points. Outside the vicinity of the point it does not interfere much with user exploration. Too weak at large distances and very hard to pull free from a point.

1/sqrt(r) type force: Gets the user reliably to the points. Outside the vicinity of the point it does not interfere much with user exploration. Less hard to pull free from a point, although some users thought it was still a bit difficult to pull free from a point.

To summarize the above, we can say that for the type of tasks studied, users like forces which do not interfer too much with exploration and that, depending on the task, some short distance snap-to-point behaviour is useful. In later applications we have tested these types of forces also for mobile beacons (such as when the PHANToM is dragged by the mouse in the haptic-audio drawing program) and they have been shown to work well. In the current implementation of our program we use the 1/sqrt(r) type force both for stationary and mobile beacons.

Thus we recommend constant type forces, possibly with some 1/sqrt(r) like snapping behavior in the vicinity of a point to make sure you actually reach it. This snapping has to be weighed against the possible disadvantage of interfering with user exploration close to the points. We also recommend that the user should be able to adjust the strength of this type of force.

6. Acknowledgements

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