Non Visual Haptic Audio Tools for Virtual Environments

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Abstract. This paper reports the results of a test involving twelve users of different haptic audio navigational tools for non-visual virtual environments. Analysis of the test results confirms the usefulness of a constant attractive force as well as of haptic fixtures to help users locate objects in a virtual environment. The 3D audio turned out to be less useful due to the design of the environment. However, user comments indicate that this type of sound feedback helps spatial understanding. Contrary to expectations, no significant tool effects were seen on spatial memory.

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 Pokluda 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 guiding constraints, referred to as "fixtures", which have been used for tele-operation, shared control tasks, tracking and training, often in a medical context [10], or to have the user cancel forces generated by the haptic device [11].

If we look at the combination of audio and haptic feedback, we see that for 3D (VR) type environments, there is still not much work being done on designs involving both these modalities. In this paper, we will discuss results from a study performed at

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Certec, Lund University in the autumn of 2005. It examines a subset of the implementations suggested in our previous pilot studies [12, 13] which investigated several different navigational tools utilising 3D audio together with haptics.

2 Navigational Tools Test

In two previous pilot studies [12, 13] we investigated several different haptic audio navigational tools. We concluded that with the suggested tool designs, the presence of a haptic search tool shortened task completion times. Two different types of attractive forces were tested, and it turned out that the users preferred a constant force (which the user could resist) to a gravity well type force (which forced the hand of the user). It is important to note that the combination of audio and haptic feedback utilised here makes it possible for the users to use tools such as an attractive force or a fixture more effectively. Instead of having distracting forces coming from all objects as in [3], forces were now only activated for one object at a time (on the basis of the sound information). Furthermore, these pilot tests pointed to a possible conflict between speed/tool use and memory/spatial understanding. The tests showed that the usefulness of different tools was not independent of the task – in the first pilot study, "tabbing through objects" was preferred (the task was to find one specific object), while in the second, nobody liked this interaction technique (here the task was to play a spatial memory game).

The "ears in hand" interaction technique introduced proved to be fruitful, but it was not clear how size was perceived (the audio environment was scaled with respect to the haptic environment to achieve a more distinct spatial sound distribution). It should be pointed out that the "ears in hand" technique is intimately tied to the active exploratory actions performed with the hand. Passive input does not produce the same type of spatial experience.

The aim of this study was to further test the tools most popular in the pilot studies, as well as examine possible influences on spatial perception by different navigational tools. Audio feedback (using the ears in hand metaphor) together with haptic feedback in the shape of either a constant attractive force or a linear fixture was investigated. A task of locating three targets and then reproducing their positions was chosen to test effects on spatial memory.

2.1 Implementation

The targets to be located were small boxes. The size of the side of the cubic box was 5 mm to make it virtually impossible to find objects by chance. Two different types of objects were included in the environment. To determine the identity of an object, the user had to press the PHANToM stylus against the side of the cube. This press/click type action generated either a frog or a ping sound. The design was motivated by a desire to force the user to actually locate the targets. The navigational tools were designed in such a way that they always pointed to the object closest in space. Three different navigational tools were tested:

3D audio using the ears in hand metaphor. This implies 3D radial audio sound sources placed at different object locations in the virtual space, while the "ears of the user" are placed at the PHANToM stylus position. Thus the user can explore the resulting 3D soundscape by moving the stylus around. In contrast to the previ-ous tests, this audio feedback did not contain any information about the nature of the object. A short musical loop was used for navigational feedback. The looped sound enabled users to "hear" borders between areas close to different objects since the loop would restart each time the object the sound led to changed.

Linear fixture. This tool was designed essentially the same way as in [13], except that it used a stronger force to attract the user to the line (-400 ρ êρ vs -200 ρ êρ) and that it was toggled on/off by a keyboard press.

Constant radial force. This force was weaker than in [13] (-0.5 êr N vs -1.0 êr N) to allow the user to easily resist the pull. This way it was easy to move about within the environment without being disturbed by the force. When users wanted guid-ance, they just relaxed their grip on the PHANToM stylus, and were moved to-wards the target object by the attractive force. This force was also toggled on/off by pressing a key on the keyboard.

These tools were all tested separately. In addition, the two haptic tools were tested in combination with audio feedback.

During the first part of the test, the task was to find all three objects in the environment and to count the number of "frogs". No visual feedback was available (i.e. the objects were invisible and the PHANToM pointer was not shown graphically on the screen). Fig. 1 shows a visual representation of this environment.

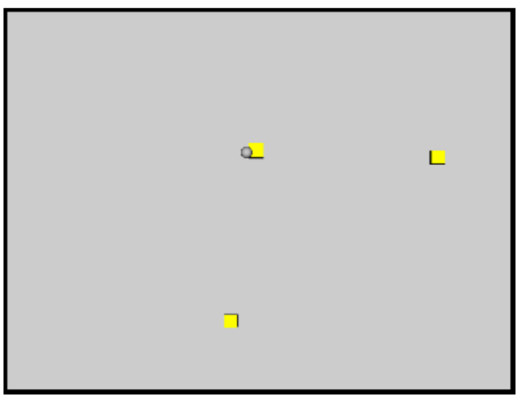

Fig. 1. A visual representation of the test environment. To identify an object such as a "frog" or a "ping" the user had to move the PHANToM pointer to the object and press it. This pressing action activated the sound file identifying the object.

When the user felt confident that all objects had been found, he or she informed the test leader, and the test person then entered the second part of the test. The user was instructed to put the PHANToM pointer at the remembered position of each object and click the button on the PHANToM stylus. This would place an object at this position. The type of object could be changed by pressing a key on the keyboard. This enabled the user to build a model of the test environment encountered in the first part of the test.

Finally, when the user was satisfied with object positions and types, the result was displayed visually on the screen as shown in Fig. 2.

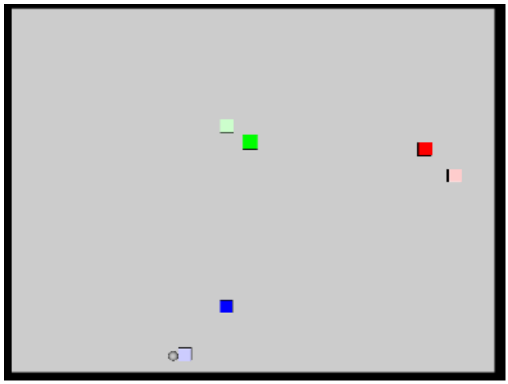

Fig. 2. The visually displayed test result. The intensely coloured boxes are the originals, while the positions assigned by the user are shown in a lighter shade. The computer assigned the object pairing by minimising the total difference in distance between test object positions and as-signed object positions.

2.2 Technical Detail

The PHANToM premium with the ReachIn API were used for the haptics. Zalman ZM-RS6F 5.1 Surround Headphones with Direct3DSound were used for the sound feedback. The following set of sound parameters was used:

Scaling factor (from haptic size to audio size): 100
Rolloff: 1.0
Minimum distance: scaling factor 0.0025 m
Maximum distance: scaling factor 200.0 m

The haptic world was enclosed by a limiting box of 0.2x0.15x0.08 m^3. The sides of the cubic boxes were 0.005 m. A constant force of $-0.5\hat{e}_r$ N was used for the attractive force to make it easy to resist. It should be noted that the strength of such a force needs to be adapted to the haptic device used, since it should be strong enough to move the stylus to the target. The linear fixture was implemented as a spring force attracting the PHANToM tip to a line towards the target. No force was applied along the line – the user had to move actively to reach the target. The force used to attract the PHANToM tip to the line was $-400.0\ \rho\ \hat{e}_\rho$ N where ρ is the perpendicular distance from the line.

2.3 Test Users

Eleven sighted persons and one visually impaired person performed the test. Their age and gender are summarised in the Table 1.

Table 1. The test users

Age	Gender (F/M)	PHANToM experience
37	F	Expert
44	M	Intermediate
58	M	Never used
25	F	Never used
51	M	Few times
53	M	Few times
49	F	Few times
30	F	Never used
43	F	Expert
40	M	Expert
29	M	Few times
35	M	Never used

2.4 Test Setup

This test consisted of two phases. In phase one the user was asked to locate and iden-tify the three objects found in the environment. In phase two the user was asked to build a copy of the environment encountered in phase one. Each test person carried out this task three times for each navigational tool combination (audio only, fixture only, force only, fixture + audio and force + audio). The order of the test tasks was varied to minimise the learning effect. The users received no visual feedback from the environment (from objects or from the PHANToM pointer) except after the test when they were allowed to see how well they had managed to reproduce the initial phase one environment. After the test, each user was asked about preferences and was en-couraged to comment on the experience and the different navigational tools.

The test program logged PHANToM position, object positions, object types as well as toggle actions (fixture and force tool), object presses, elapsed time and the time at which different events occurred.

2.5 Results

The user preferences are summarised in Table 2. The attractive force was a clear winner, while it was unclear whether the 3D sound helped. A summary of the results for the different navigational tools is presented in Table 3.

The results were analysed using five different analyses of variance (ANOVA) with the measures, 1) Time to complete, 2) Distance (total difference between assigned positions and actual positions), 3) Correct number of frogs/pings (even if the sound was assigned to the wrong object), 4) Object clicks per second, and 5) Fully correct object assignments, as dependent variables.

Table 2. Preferred navigational tool

User nr	Preferred tool	Comments
1	Force only	The strength of the force is just right. The audio feedback is confused with the sound tags of the objects (harder to remember them).
2	Force (with or without sound)	Possibly better without sound, since the sound may be disturbing.
3	Fixture with sound	The line is more fun – you get to do something by yourself (the force is automatic).
4	Force only	The sound is not necessary.
5	Fixture with sound	Easiest.
6	Force with sound	Better to use two senses.
7	Force with sound	Easiest.
8	Force with sound	Much faster. The sound helped you feel sure.
9	Force (with or without sound)	The fixture with sound somehow helped with the relative positions, but in a complex environment, I believe the force will be better.
10	Force only	Force more intuitive. But the fixtures were good too, once you learnt to use them. The force works just as well without sound (in contrast to the fixture).
11	Force only	The sound is distracting (harder to remember the object sounds).
12	Force with sound	But this depends on the application – I often neglected the sound.

The independent within-group variable is the navigation tool with five conditions: Fixture, Sound, Force, Fixture with sound, Force with sound. Post hoc analyses were carried out using the Tukey test. The significance level was set to 0.05 throughout the analyses.

The ANOVAs on time to complete ($F(4, 44) = 28.9$, $p < .05$), correct number of frogs/pings ($F(4, 44) = 3.18$, $p < .05$), and object clicks per second ($F(4, 44) = 21.6$, $p < .05$) revealed significant differences. For time to complete, the post hoc test showed sound took significantly more time compared to all other conditions (fixture $Q(5, 44) = 10.8$, $p < .05$, force $Q(5, 44) = 12.0$, $p < .05$, fixture with sound $Q(5, 44) = 11.9$, $p < .05$, and force with sound $Q(5, 44) = 12.9$, $p < .05$). For correct number of frogs/pings, the post hoc test showed no significant difference. Force, however, tended to have more correct numbers of frogs/pings than fixture $Q(5, 44) = 3.93$, $p < .10$ and sound $Q(5, 44) = 3.93$, $p < .10$. Sound had significantly fewer object clicks per second than all other conditions (fixture $Q(5, 44) = 9.85$, $p < .05$, force $Q(5, 44) = 10.1$, $p < .05$, fixture with sound Q(5, 44) = 8.67, $p < .05$, and force with sound Q(5, 44) = 11.7, $p < .05$). No other differences reached significance, including the ANOVAs on distance and fully correct object assignments.

Table 3. Results for the different navigational tools on the five dependent measures

Measure	Navigation tool	Fixture	Sound	Force	Fixture with sound	Force with sound
Time to complete (s)	Mean	133	388	104	107	83
	Standard deviation	59	133	87	90	50
Distance (mm)	Mean	46	44	38	41	40
	Standard deviation	17	15	18	16	13
Correct nr of frogs/pings	Mean	2.69	2.69	2.94	2.78	2.89
	Standard deviation	0.10	0.08	0.04	0.07	0.06
Object clicks per second	Mean	0.178	0.033	0.182	0.161	0.206
	Standard deviation	0.086	0.020	0.092	0.070	0.087
Fully correct object assign-ments	Mean	2.50	2.47	2.78	2.50	2.78
	Standard deviation	0.522	0.521	0.296	0.503	0.296

The user comments are listed below. The items are grouped by content. Each list item is from a different user.

User comments:

The sound is somewhat confusing – one tends to confuse it with the object identification sounds. The navigational sound actually makes you somehow forget the object sounds.

The navigational sound somehow made it harder to remember the object identifica-tion sounds.

The 3D property of the sound is not very good – it is more like stereo + feedback from your moves (the volume/stereo changes as you move).

The 3D sound had good stereo, but up/down and back/front is hard. The sound also makes the object identification sounds harder to remember.

It is harder to remember the object identities (frog or ping) than to remember the positions.

I would like object specific navigational sounds.

The sound loop restarting every time you cross the border to an area close to a new object is a really good clue.

The borders where the sound loop restarts are really important! They tell you that you are approaching a new object.
I tried to listen for the restart of the sound loop – this tells you it is a new object.
Had to visit the objects several times to know where they were. Thought hearing was more demanding – the object positions were somehow easier to remember.
The sound makes you aware of the room – this could be used for theoretical training of spatial ability (visually impaired user).
With the sound you really notice the space of the room – I did not notice it that much before. It is really first now that I understand how to move my hand.
The sound gets better if you close your eyes.

3 Discussion

The results of these tests confirm the usefulness of the constant, weak, radial attractive force (on its own or with 3D audio). For the fixture, which was also considered useful, the sound may have been more important since it provided directional feedback. As for spatial memory, there is really no significant difference between the tools. The force showed a tendency to give better results than the fixture on the recall of the number of frogs/pings. This may be interpreted as if the force interfered less with the recall of the audio object type feedback. However, since no effect was seen for the fully correct object assignments (which also includes object type feedback), it is not clear if this effect is real. No effect was seen for the fully correct assignments or for the distances. If this effect exists, it does not have anything to do with spatial memory. In previous tests, there was a tendency to remember the environment better if you spent a longer time in it, but here, spending a long time in the environment did not appear to help. Another possible effect that would tend to influence the results in the opposite direction is the number of times you can "check back" or rehearse the object positions. Since no really significant effect on spatial recall was seen, it is possible that these two effects cancel each other out with the present test design. Even though the sound with this set up generated significantly longer completion times, the user comments indicate that the 3D sound (ears in hand) may enhance the spatial under-standing – it seems as if this sound feedback may heighten the sense of immersion (we cannot say anything definite on this point though, since immersion was not tested). A factor that may influence the results was that we used the same navigational sound for all objects. We chose this design because we wanted to force the users to actually locate the targets. One of the advantages of sound, however, is that it can be heard from a distance (i.e. it provides a possibility for accessing object information before actually reaching the object). This test also indicates that navigational feedback may interfere with the actual task, although this most likely depends on design as well as modality.

An accidental artefact in the design was the restarting of the audio loop at the borders between spaces close to different objects. This artefact turned out to be quite useful, and implies that when the same navigational sound is used, it should be possible to hear this type of border.

4 Conclusion

A weak constant attractive force has been shown to be useful. This force should be weak enough to allow the user to resist it, while at the same time strong enough to attract the user to the target once the grip is released. With this design, the type of problems associated with attractive forces reported in previous studies [3] did not seem to cause problems in the present set up (we used only three objects, but these would, on occasion, be located quite close to each other). It is, however, important to note that the strength of the force needs to be adjusted to the type of hardware used – the present results were obtained with the PHANToM premium. The use of a fixture to restrict the user to a path leading to the object was also useful, although there was a possible tendency for the users to perform better on the recall of the audio object type feedback with the attractive force. More users preferred the attractive force, but one user liked the fact that with the fixture he had to perform the movement himself. 3D sound feedback with the ears of the listener attached to the PHANToM position ("ears in hand") is a type of feedback which may help users to gain an understanding of a spatial environment and which may also increase the sense of immersion within the environment (this, however was not tested). This type of audio is also a tool for navigation, but in this kind of environment (with few, small objects) it is less effective, and thus it also limits the ability of the user to "check-back" to rehearse object positions. User comments (as well as results from the earlier pilot tests [12, 13]) show that if possible, it is useful if the sound feedback allows object identification from a distance. The borders between different object spaces provide important information, and it is useful if the sound feedback gives this type of information. In the case of sound identi-fication from a distance, this is provided automatically since the sound will change as the object changes, but in the case of a general navigation sound, this is something that needs to be considered. This test also highlights the possibility that navigational feed-back may interfere with the actual task, which indicates that particular care needs to be taken in the design of navigational tools to avoid such interference.

Furthermore, this test, in contrast to what had been suggested in the pilot tests [12, 13], did not show any significant tool effects on spatial memory. This may be due to the test design, and further investigation is needed to resolve this issue. Another issue that remains to be investigated is the effect of a turning of the ears in the virtual envi-ronment – so far we have always used a fixed facing-forward avatar orientation.

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