Navigation and recognition in complex haptic virtual environments – reports from an extensive study with blind users

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Abstract

The following article reports result from an extensive study with 25 blind users from Italy and Sweden performed during the summer 2001. The tasks reported here test recognition of geometrical objects, recognition of VRML objects, mathematical surfaces and navigation in a traffic environment. The outcome of these tests show that blind users are able to handle also quite complex objects and environments, and that realistic virtual environments in some cases appear easier to handle than more abstract test environments. This highlights the importance of context, and thus the usefulness of other input channels beside the purely haptic one. Another factor observed to be important is haptic scanning strategy. Tentative results for age, gender and blindness from birth are presented, and the importance of accurate haptic models is pointed out.

1. Introduction

Haptic applications hold great promise for blind persons. Using a haptic device it may be possible to make VR, pictures and graphs accessible also for blind persons. To be able to develop useful applications for the blind, however, it is important to gather more information about the ability of blind users to interact with different haptic virtual environments. Thus, during the summer of 2001 an extensive user test study using the PHANToM haptic device and including 25 blind users was performed. The tests described below are subset of the full study.

2. Test persons

The 25 test persons had ages ranging from 12 to 85 (mean = 39, median=37, standard deviation =19.4). 16 persons were male and 9 were female. Figure 1 shows the age and gender distribution of the test persons. 14 of the test persons were Italian and 11 were Swedish.

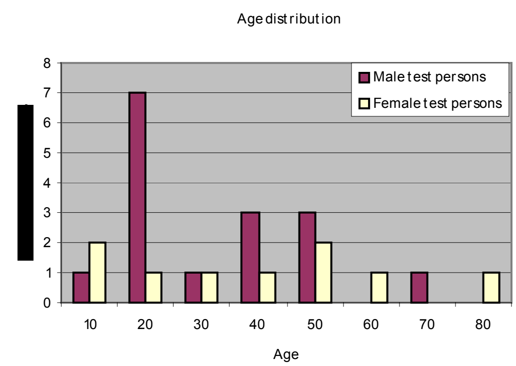

Figure 1. Chart showing age and gender distribution of test persons. The numbers on the X-axis should be interpreted as an age range (10 is the range from 10 to 20).

Only one of these persons (born in 1916, blind at the age of 64) had severe difficulties with the haptic environment. This person appeared to find both the concept of virtual reality and a haptic environment in general difficult to understand. Also, the person seemed to use both hands to a greater extent than the other test persons when exploring the real world. It was interesting to note that the haptic illusion appeared to disappear as soon as this person tried to feel the object with the other hand (the hand not occupied by the haptic device). Despite this, the person could complete a few tests, and might have done better with more training [1].

3. Research questions

The purpose of this part of the study was to obtain a better understanding of how blind persons can understand and interact with more complex and realistic virtual environments. With this in mind, the tests were designed to investigate the questions: Can a blind person understand haptic models of real objects? Can a blind user understand a more complex/realistic haptic virtual environment? Can a blind person navigate in this kind of environment? How disturbing is the VRML approximation perceived to be?

4. Test descriptions and results

Prior to the tests that were conducted, all test persons underwent a pre-test phase, where they had the possibility to get acquainted with the PHANToM device and the concept of virtual haptics. The idea behind the pre-tests was to try to minimize first-time user problems.

The tests that were made are of mixed nature, but the focus has in general been on making qualitative observations although quantitative data was also gathered during the tests.

For most applications, a series of tests with different challenge levels was conducted. Ideally, all users were supposed to succeed with the first test in the series, while the later tests were of a higher challenge level.

About half of the test persons used a pen tool to operate the PHANToM, while the others used a modified thimble with a strap that makes it easier to adjust it to different finger sizes.

Furthermore, all surfaces in all tests include friction as this has been shown to make surfaces easier to follow [2].

4.1. Geometrical objects test

The user should, after navigating in a constrained virtual environment (VE) containing geometrical objects, build a copy of the VE with real geometrical objects. The tests included both a VE with only a single object, and a VE with three objects placed in a 3x3 grid (the grid test). The user had access to number of physical representations of different geometrical objects (a cylinder, a cube, a half cylinder, rectangular parallelepipeds etc). The user was instructed to feel the virtual model, and then to build a copy of the VE with the physical models (see figure 2).

Out of 25 users 20 identified the single geometrical object correctly (80%). This is in line with the results reported in [3]. All users correctly identified the general shape, but errors were made when judging the exact proportions of rectangular parallelepiped objects.

The grid test was significantly more difficult, and although 20 users out of 23 picked the right number of objects, and 18 out of 23 placed them in the right squares only 9 out of 23 (39%) managed to present the correct solution. Looking at the errors we see that 5 persons had the right number of objects in the right places, but did not pick the right 3D shape, although the objects selected were judged correctly in 2 of the 3 dimensions. Furthermore 3 users misjudged the proportions of one object, but otherwise solved the task correctly.

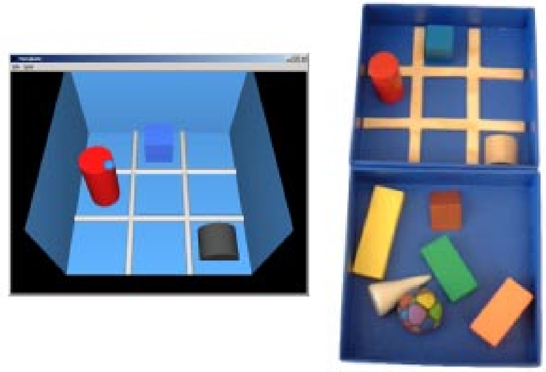

Figure 2. The 3x3 grid environment. To the left, a screen dump of the VE, to the right the physical models to build the copy with.

Looking at different groups of test persons we see that 8 of the 14 errors (57%) are made by persons younger than 30 years old. 11 users below 30 did this test, and we see that 72% of those failed (42% of the older users failed). 9 of the 14 errors (64%) are made by persons who are blind from birth. 13 users blind from birth did this test, and thus 69% of these failed on the overall level (50% for those not blind from birth). 7 of the 8 women (88% of the women who did this task) made errors and 7 of the 15 men (47% of the men).

The use of thimble or pen does not appear to have had any influence on the overall success rate.

4.2. VRML test

The user should feel different VRML objects, and discuss their physical properties with the test leader. The first test was a recognition test where the user was asked to identify the VRML object (a vase) and the difference of surface friction on the outside and inside of the vase (figure 3). It should be noted that the answer to the recognition test was considered correct also if the user answered with a shape that was similar to a vase (e.g. basket, fish bowl etc.).

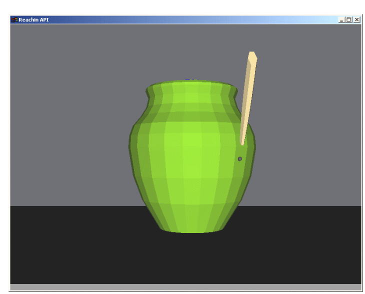

Figure 3. VRML model screen dump; a vase.

In the two following tests the users were told what the VRML objects represented (a grand piano with a stool and a satellite, see figure 4) and were instructed to describe the object and to locate different parts of it.

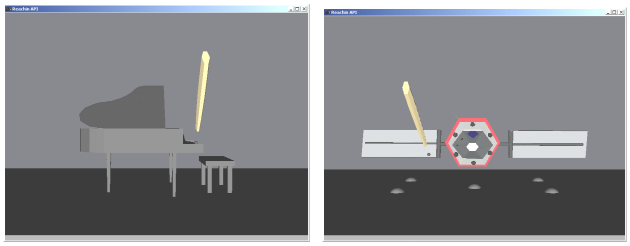

Figure 4. VRML model screen dumps; a grand piano with stool and a satellite.

Additionally, four users were also asked to describe and identify a VRML model of a guitar and a sword in the form of a recognition test (figure 5).

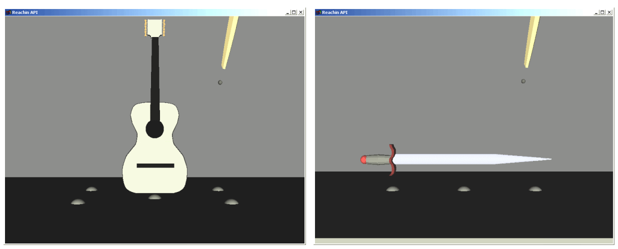

Figure 5. VRML model screen dumps; a guitar and a sword.

19 out of 24 users could identify the vase (79%). 20 of 24 identified and described both the grand piano and the stool (83%). 22 of 23 could find the parts of the satellite (96%). Of the 4 users asked to identify the guitar 3 succeeded despite some imperfections in the guitar model. Of the 4 users asked to identify the sword 3 could locate and explore it, but none of them identified it as a sword. The fact that the models were made up of flat triangles was not found very disturbing (1.6 on the average on a scale from 1 to 5).

4.3. Mathematical surfaces

A general curve display program was tested (figure 6). This program makes it possible to submit an equation corresponding to a mathematical surface and get a haptic rendering of it. This haptic rendering is made up of small triangles just like a VRML model. During the test the users were asked to feel and describe different 3D surfaces. This test was performed by 7 users and all of them could feel and describe the surfaces. Only one of the 7 who did this test was a woman (the test was only made with users who had a particular interest and knowledge in mathematics). The challenge was judged as 1.5 on the average. Just as in the VRML case the fact that the objects were made out of triangles were not considered very disturbing (1.2 on the average on a scale from 1 to 5).

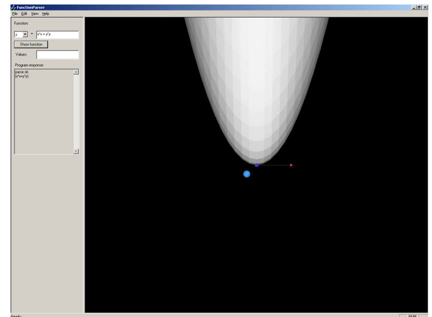

Figure 6. Screen dump of curve display program; z=x*x+y*y surface.

4.4. Traffic environment test

The VE consisted of 6 houses (2 rows, 3 columns) with roads in between. The roads, sidewalks and houses had different surface properties. The first task was to explore and describe the environment. Then, the user was asked to find a way from the leftmost house (house A) in the front to the rightmost house (house B) in the back (see figure 7). The user was asked to find the shortest route between the two houses while staying as much as possible on the sidewalks (flying was not allowed). The houses A and B each emitted a sound (non-speech) when pressed to confirm to the user that it was the right house. As a third test, dynamic objects (cars) were added to the environment and the user was again asked to go from house A to house B without being run over. Four users also tested a simple "move the world" function on this world. The four users could move the contents of the world using the up (move back), down (move front), left, right keys on the keyboard.

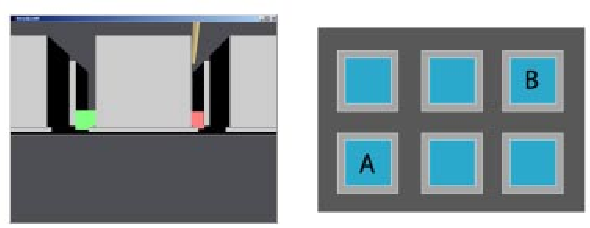

Figure 7. Screen dump and birds eye view of traffic environment.

21 users of 21 could identify houses, pavements and roads. 17 of 21 (81%) completed the house-to-house exercise successfully. All 4 persons that tested the move the world function could handle it after some initial confusion.

5. Discussion

5.1 Geometrical objects test

The fact that proportions may be difficult to judge accurately has been discussed in [4]. In the test 4.1 this was shown to hold also for proportions in different directions on the same object. At the same time the test confirms the observation in [3] that blind persons are able to identify simple shapes using the PHANToM despite the fact that a one-point interaction is very different from their natural mode of exploring objects. The test also confirms the observation made in [4] that the use of a thimble or a pen for the interaction does not influence the results in this kind of tasks.

The difficulty of the grid test (with 3 geometrical objects in a 3x3 grid, described in 4.1) was actually something of a surprise. Even if the difficulty to judge proportions accurately is disregarded (raising the success rate to 12 out of 23) this result was somewhat unexpected. A closer analysis of the kind of errors performed indicate that the majority of the errors were due to inefficient and/or incomplete haptic scanning. The users would not explore the object fully in all three dimensions, but would limit his/her exploration to two dimensions (usually by following the floor). As the haptic scanning strategy is something that can be learned, the results may be expected to improve with training [1]. It is an interesting question how one best should guide the users towards an efficient exploration technique – some users appear to have an efficient way of scanning almost from the start, while others need more training (and may be expected to benefit from guidance – possibly from an agent advising the user with respect to the scanning technique used).

18 persons out of 23 (78%) had the right number of objects at the right places which indicates that inefficient and/or incomplete haptic scanning has less effect on tasks that include locating positions only. However, users that did not succeed with this task were often seen to follow the outline of the grid square and would therefore entirely miss the object placed in the interior of the square.

There appears to be a higher error frequency among the users below 30 on this test, and furthermore a substantial difference in performance between men and women was noted. Whether this reflects real differences or whether this is due to the limited statistics available is still an open question. It is however possible that this difference may be connected to the ability to do mental rotations (an overview of cognitive sex differences can be found in [5]) as the haptic objects and the real objects sometimes were rotated with respect to each other. More tests are needed to verify this point.

Factors which may influence the results are:

- training - this was the first test in the series
- motivation – several of the users did not appear as motivated during these tests as they did later
- stress – the users knew we were timing the exercise, and thus some tried to complete as quickly as possible even though we told them not to bother about the time

5.2 VRML tests

This test showed that the users could identify and understand also fairly complex objects. It also shows that the users are not particularly bothered by the VRML approximation.

In view of the poor results on the grid test this result again was somewhat surprising even though the tests are not strictly comparable. Apparently complexity does not necessarily imply difficult – a well known but complex object may be more readily understood than a simpler but unfamiliar object. A complex object may actually contain more hints that can help the user in the identification and exploration. The previous experiences and understandings of the user thus come into the picture. This may be both helpful and hindering. It was apparently helpful for the users who managed to find the thin support rod, which holds up the lid of the grand piano. It was probably also helpful for the one user, who had a grand piano himself, and who could comment on the size of the stool in front of the grand piano (the stool is too large in comparison with the piano). And it was probably helpful in general for all users when it concerned both the vase and the grand piano. In contrast, the user who had imagined the piano with the keyboard facing him was initially hindered by his preconception, and it took much longer for him to understand the object.

Another observation made during the test was the importance of haptically accurate models. Already before the tests the problem with holes (i.e. the user could "fall through" the object at certain points) was noted. Already for a seeing user this kind of error often has great consequences for the haptical illusion, and models with obvious holes were not included in the tests (this problem is discussed already in [6]). Despite our efforts to select good models, the models we had access to were made for seeing persons and thus invisible parts were often carelessly modeled. The vase had a funny ridge on the inside, the grand piano had no strings and neither the piano nor the stool was well modeled underneath. These inaccuracies were in most cases not serious enough to hinder the identification tasks. The one exception was the sword used in the four-user test, which was elliptical (not sharp). This had the effect that none of the three users who could find and describe the object could identify it as a sword. The hole on the guitar from the same test was not really a hole, one could not explore the inside of the guitar, and furthermore it was possible to get stuck unpleasantly under the strings. Despite this three out of the four users who tried this model identified it as a guitar. Thus some inaccuracies may be tolerated, but it is clear that key features of an object have to be correctly modeled (a sword should be sharp for example).

In this test the users did not have access to additional sound information, helping agents, guided tours etc. The only help accessible was bumps on the floor, which served as reference points [7]. These bumps were used to some extent in the four person tests (particularly the sword), but were otherwise ignored to a large extent. That the blind users still could handle complex objects such as the grand piano and the satellite (the screen dump of the satellite looks somewhat simple in figure 4, but it contains a lot of detail) so well is very encouraging. With haptically accurate VRML models and additional help we feel that it is reasonable to expect users to be able to handle significantly more complex environments.

5.3 Mathematical surfaces

Seven persons tested a general haptic curve/surface display program. All of them could feel and describe the surfaces. Just as for the VRML case they were not particularly disturbed by the fact that the surfaces were made up of small triangles. This strengthens the case for VRML type models in this kind of applications, as long as the models are haptically accurate as discussed above.

At the same time this test illustrates the problem of testing this kind of more advanced mathematics programs. The testing of a general curve/surface display program requires some level of mathematical knowledge, and the number of test users thus becomes quite restricted. A way around this obstacle is to create specific tasks that allow testing of program properties without requiring a high level of formal mathematical knowledge. In another test in the same test series, the users had to solve tasks relating to a model eco system, and although the mathematics involved was fairly advanced it was possible to solve the problems also with limited mathematical knowledge (the tasks were to verbally describe a 2D curve, to point out maxima and minima and to solve a simple optimising problem). This problem setting made it possible to perform the tests also with our youngest two test users who were 12 years old. To find good tasks for more general 3D surface properties remains an open challenge.

5.4 Traffic environment test

The street environment did not present any particular problem to our test persons. This environment was generally enjoyable. Even though the navigational task did contain some difficulty (81% success) it got a low challenge rate. This kind of environment could readily be extended to training, games and map applications.

It should be noted that the rendering of the moving cars actually could be said to be haptically accurate. As the PHANToM is a one point haptic device, the shape of a car hitting you is unimportant. A moving box works fine. It is also important to note that this environment with several moving objects would be fairly confusing if it were presented without the information that it represents a traffic environment.

To further enhance this kind of environment, realistic 3D sound should be added to make it possible to hear the direction the cars are coming from. Also, test users asked for pedestrian crossings with sound.

To allow users to explore larger worlds some kind of zooming or moving operations are necessary (preferably several). Four persons tested a simple move function, and the results were encouraging. After some initial confusion (the move function was quite crude, and it was possible to end up inside the houses) the users appeared to find a working strategy: they would put the finger close to a surface and then move the surface away. That already this crude moving function could be made useful makes it reasonable to assume that more elaborate moving functions will make it possible in the future for blind persons to get haptic access to worlds considerably larger than the small PHANToM working space.

6. Conclusion

The outcome of these tests show that blind users are able to handle and understand also quite complex objects and environments, and that realistic virtual environments in some cases appear easier to handle than more abstract test environments. Thus context is seen to influence results significantly also in haptic surroundings. The result of a line drawing test performed within the same test series furthermore supports this conclusion. In this test the success rate raises from 33% to 83% once the user knows that the unknown line drawing represents an elephant. The importance of context is a fact, which again [8], [9] highlights the importance of additional input such as sound in a complex haptic VE [9]. Another factor observed to be important is haptic scanning strategy (cf. exploration path in [10]). An indication that proportions in different directions can be difficult to judge accurately is furthermore obtained, as well as an indication that age and gender may influence test results in this kind of tests. Surprisingly enough the influence of blindness from birth appears less significant. It is possible however, that the age indication actually is connected to blindness from birth as many of the test users younger than 30 actually also are blind from birth. But the exact influence of these two factors, or the combination of them, cannot be separated in this test.

The evidence from the tests when it concerns shape recognition versus orientation/navigation is somewhat conflicting. The test results support the conclusion that navigational tasks also in quite complex virtual haptic surroundings can be handled by blind users. The evidence when it comes to shape identification is somewhat conflicting, the geometrical objects appear hard while the VRML models appear easier (as long as expected key features of the object are present). This may to some extent just reflect the test setup, and further tests to resolve this issue should be performed.

It has been shown that for the objects included in this test, the blind users are not greatly disturbed by the VRML approximation. What does disturb the illusion however is if the model is not haptically accurate. Holes, unmodeled or poorly modeled parts makes it more difficult to understand objects, and if the imperfections are bad enough it may actually make it impossible for a user to obtain an understanding of an object.

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