ARIADNE - A Haptic Maze

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ABSTRACT
The Ariadne project aims at exploring haptic navigation in a 3D environment without visual feedback. Users were evaluated in their ability to find their way in a 3D spherical maze with several layers, with the goal of finding the center, starting from the outer layer. Two different types of guidance grooves have been tested, both concave. The half-pipe groove model (1) and the rounded edge groove model (2) were compared in their efficiency in providing users with haptic guidance towards holes leading to inner layers.

The study showed that the rounded edge groove model was slightly more efficient regarding the overall time taken to complete the mazes. Moreover, several remarks gathered during user testing raised relevant yet unexpected problems about how users interact with the haptic device and 3D environment.

INTRODUCTION
Project Ariadne started as an idea for a haptic maze game where the user would not see the maze they navigated with a haptic device. This was enhanced with researching on how differently shaped grooves on a 3D surface help with navigation when the surface can not be observed.

We initially prototype different structure of mazes which are based on different orientation and navigation concepts as such as navigation along a surface of an object to find an entrance to the inside (Fig. 1 and 5) or navigation through a pipe system (Fig. 4).

After some testing with different layouts of the grooves, research started on how the grooves shape has to be designed for it to feel as good as possible and how to maximize the guidance they provide. This is quite interesting since it is seemingly quite a small thing. When designing guidance grooves for the blind and the visually impaired, the most important thing is how the grooves feel. In this project, we focused on the shape of these grooves. We gathered input from two articles [4, 1] which we are discussing in the background section. Based on the input we designed and constructed 3D models with two different types of grooves.

We tested the two different groove types with 6 participants to deduce which performs better in terms of efficiency in guiding the user.

BACKGROUND
As mentioned in the introduction, our primary intention was to explore the possibility of a haptic maze. Haptic mazes

Figure 1. Sphere with halfpipe grooves ("Onion Maze")

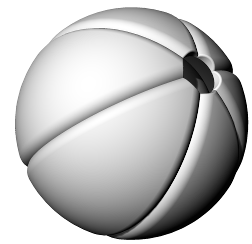

Figure 2. Sphere with rounded-edge grooves ("Orange Maze")

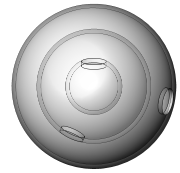

Figure 3. Onion Maze

Figure 4. Pipe Maze

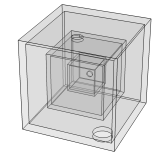

Figure 5. Box Maze

found in research papers are focusing on a regular maze layout, where the user navigates and acts in a first-person view and with visual feedback [2]. We wanted to focus sole on the exploration of an object by hand that is floating in front of the user and without any visual feedback at all.

During our project progress, we found literature that was affecting our direction for the project. Two articles are the primary influence on which we decided to focus on the application of grooves as guides in a haptic maze.

Yu et al.[4] provided us with the first piece to our puzzle. The primary focus of this paper is the design of computer-based haptic graphs of data visualization for blind and visually impaired people. Yu et al. conducted experiments on how to make graphs accessible through haptic and audio feedback. Their results proposed two techniques: engraving and texturing of lines to improve the haptic exploration of graphs. We used the technique of engraving lines in our project.

Miller et al.[1] provided us with the second piece of our puzzle. Miller addresses the importance of haptic interfaces and interactions by presenting haptic qualities that he distilled into so-called haptic "widgets" [3]. The widget of notches and dimples is of particular interest for us. At first it seems to be the same technique as suggested by Yu et al. but Miller proposes an improved version of a notch with rounded edges. This addition helps the user to slip into to grooves/notches much easier without being confused by sharp edges where a direction change is hard to notice.

After applying the insight from the previous articles and after the very end of your project we stumble upon the dissertation by Sjstrm about non-visual haptic interaction design. This thesis covers an immense amount of insight about haptic interaction for blind and visually impaired people. Sjstrm provides guidelines for the design of interactive systems concerning navigation, orientation and gaining overview in a haptic environment. We incorporated the guidelines in our discussion and derived conclusions and recommendation from it.

METHOD

The project Ariadne is based on the code provided in the lab assignments of KTH course DH2660 Haptics. Together with a C++ code file (.cpp) came several project files. Due to structure setup, we chose to not diverge from these original files.

Based on this, we experimented a certain number of features. First was the generation of vibrations with different intensities. When the player reached the point (0, 0, 0) - i.e. completed the maze - the device vibrated as a feedback message that the game was over. Second, we started to create forces at a given space location. After considering to shape the mazes with mere field force functions, we chose another path: designing the 3D objects meshes, and let CHAI3D (a C++ library for haptics) take care of converting these meshes into haptic and visual feedback.

After trying a few simple shapes and fixing the problems of scaling and rotation, we started to design mazes. The 3D models were built in Rhinoceros, a free-form NURBS surface modeler (`http://www.rhino3d.com`. We prototyped three different kinds of mazes that we loaded into the CHAI3D environment.

First Prototypes

The Onion Maze (Fig. 3) is a layered spherical maze with one hole in each layer. The intent is to either escape the maze from the center or reach the center. We found that the outside-inside approach is much harder to achieve since the user is always slipping off the spherical surfaces. The inside-outside approach feels too easy since the user primarily finds the hole by spiraling along the surface until she finds the hole by accident.

The Pipe Maze (Fig. 4) is, as the name states, a pipe system expanding in 3 dimensions. The first version had a funnel and one exit with no dead end. The turns were rounded which is very confusing to navigate. Due to the bad mechanics and rigidity of the Falcon Interface the user was unable to have a distinct feeling of direction. We added harsher changes in directions no curved edges and tested the maze on the Phantom OMNI, which has a better rigidity.

The Box maze (Fig. 5) arose during the first experiments with the other mazes. By switching on the rotation of the maze allowed the user to push the maze around. We used visual

Figure 6. Spiral grooves

Figure 7. Circular grooves

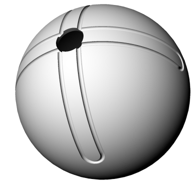

Figure 8. Axial grooves

Figure 9. Spiral nobs

Figure 10. Circular nobs

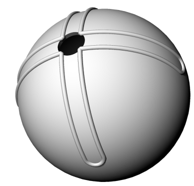

Figure 11. Axial nobs

feedback wireframe rendering of the box maze to have some a sense of orientation. The task was both challenging and fun but not tiring.

Further Investigations

From the three previously described mazes, we chose to go further with the Onion maze, because it provided richer exploration possibilities as well as a good challenge calibration in terms of difficulty to get from the outside to the inside.

The use of guidance grooves for enhanced haptic exploration has been discussed in Yu et al.[4]. We aimed at developing several types of grooves with various shapes on the spheres surfaces: spiral, circular and axial. Six types were set up in total, three concave grooves (Fig.6 - 8) and three convex grooves (Fig.9 - 11)

After exploring these spheres with various groove types, we discarded most of them. Convex grooves provided the feeling of obstacles, similar to a wall, obstructing the way to the holes rather than facilitating their discovery. Concave circular grooves were felt as barriers protecting the hole where the haptic proxy would fall into and get stuck. Finally, following the concave spiral trace would successfully lead to the hole, but within more time that it took to find a hole without any groove. For all those reasons, we kept the concave axial traces to investigate further.

Final Design

The sphere with concave axial grooves inspires our final designs. As suggested in Miller et al.[1], grooves with rounded edges might lead more efficiently towards the end-point than other types of concave grooves. That is why we set up two

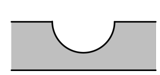

Figure 12. Half-pipe groove section

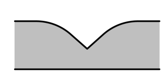

Figure 13. Rounded-edge groove section

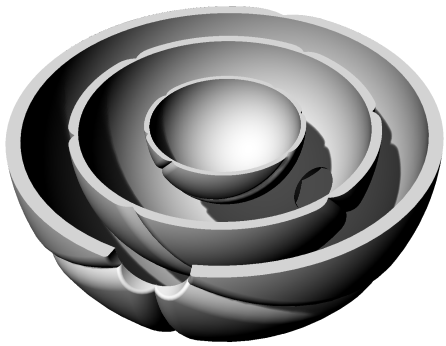

Figure 14. Section view of a maze .

mazes. The first maze, called "Onion" (Fig. 1) had grooves with a half-pipe shaped edges (Fig. 12). The second maze, called "Orange" (Fig. 2) had grooves with a rounded edges (Fig. 13).

Getting a frustration-free experience from those mazes required a few adjustments for the proxy radius. The proxy had to fit in the first mazes half-piped grooves while not getting stuck in the core line of the second mazes grooves. When we reached the point where our user experience felt suitable enough for testing on non-experienced users, we set up a user study.

User Study

We conducted the study with 2 pilots and 6 participants with an equal distribution between male and female. Users were tested upon their ability to navigate from the outer layer of the spherical mazes to the center, using the haptic device Phantom OMNI. Their task was to find the center of the maze.

We would start by running a haptic environment where there was nothing but a smooth sphere, so that the user could get familiar with the haptic device itself: holding the pen, rotating and moving the pen, feeling a surface.

Secondly, we would show the user a picture of a section of the whole maze (Fig. 14) as well as what the outer layer looked like (Fig. 11).When the user felt ready, we ran the half-pipe maze or the rounded edge maze (alternatively between users) and started recording time. We would notify the user orally whenever a new layer was entered or left, and when the maze was completed.

Thirdly, we would run the other maze ("Onion" or "Orange") and repeat the same procedure. For both mazes, we measured the completion time, beginning with the first contact with the outermost sphere until the user reached the center of the maze.

Once the user was finished with both mazes, she would fill in a questionnaire (`http://goo.gl/forms/IitX3ariQs`) designed to gather their impressions about both experiences and potential remarks. We would also leave a special field for us to keep track of our own remarks about the user behavior during the tests and the completion time.

RESULTS

The analysis of time data collected from 6 participants performances led to the conclusion that completing the Orange maze (rounded edge) was slightly easier - 100 seconds on average - than completing the Onion maze (half-piped) - 106 seconds on average. Since we alternated between users starting with the Onion and users starting with the Orange, we could measure the average time taken to complete the first maze - 110 seconds - versus the second maze - 96 seconds. This accounts for the learning effect during the process of completing the first maze (Fig. 14). Since the Onion maze has been on average completed 6% slower, one of the outcomes of this experiment is the relative advantage of carving rounded edge grooves rather than simple half pipes to help haptic navigation on a surface in a 3D environment.

Another persistent conclusion that we came across was that haptic discrimination is excessively hard when we reach down to a minimum size. Indeed, most participants pointed out that finding the last layer, i.e. the sphere with the smallest radius, was a lot more difficult than finding the second layer after entering the first - while the actual 3D object was but a set of three spheres with linearly decreasing radii (see Fig. 14).

Some users had trouble exploring the spheres the right way. Once they came past the first layer, they would stick to the inner surface of that same layer rather than searching for the outer surface of the smaller sphere. Detaching the haptic proxy from the wrong object to explore empty space was seemingly impossible. Explaining to the users who faced this problem that they were exploring the wrong surface and how to proceed would not help them to let go of the surface.

Audio feedback from a moderator was also needed to know when they would reach a new layer of the maze, this time by all users. When falling into a hole, the haptic proxy would fall "in the air" towards the center for a very short time - most often, the user could not feel it.

We gather two last persistent remarks. First, navigating upwards and front-facing surfaces of the mazes was way easier than navigating back-facing and downwards surfaces. Second, the use of a pen as imposed by choosing the Phantom OMNI as a haptic navigation tool was confusing for some users due to an overly high number of degrees of liberty.

In overall, the user satisfaction after successfully completing the mazes was high. Most tested users were willing to start anew, repeat the experience with visual feedback or try some of our former maze designs.

DISCUSSION

Based on our results we think that the improved rounded edge groove increases the efficiency in guidance but we believe the results are not significant enough. Although the participants seem to enjoy the challenge but we would need to add more diversity of to the game features like obstacles, riddles, etc. to sustain the enjoyability. There are several improvement we could apply.

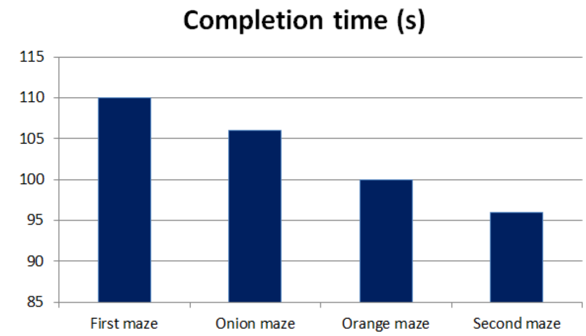

Figure 15. Completion Time in seconds.

First, the design of your evaluation and the procedure. To strengthen our results we would need a more diverse group of participants. Particularly diversity in dexterity, spatial perception, age and blind participants or with visual impairment. The procedure would need a repetition of the two tasks to compensate for the learning effect. Eventually we would measure not only the completion time for the entire maze but also time spent on each layer and furthermore record the hand and proxy movement on video.

Second, the 3D model can be improved by adding different textures and/or friction to the grooves and the other surfaces as it is suggested by Yu et al. [4]. Also removing all the grooves which are not touch by the proxy. This would help the user do differentiate more clearly between the surface features. A critical part of the maze is the passage to the interior of the sphere. All users needed a cue by the moderator to realize they passed on to the next level. To give a automated and immediate cue the usage of an audio signal and/or a portal with a higher viscosity to generate the feeling of pushing and pulling the proxy through water or oil.

Thirdly, an additional feature to the meeting point of all grooves on the opposite side of the entry helps the user to find orientation. Sjstrm refers to it as a reference point which is necessary for a user to gain an overview and the ability to navigate. Possible features are roundabouts or a change in texture/friction.

Eventually to make this project into a game, an introduction and a guidance tutorial are necessary to enable the user to explore the game by herself.

AUTHOR CONTRIBUTIONS STATEMENTS

The authors contributed equally to this project, part of the course DH2660 ”Haptics” at KTH the Royal Institute of Technology in Stockholm, Sweden.

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