Spatial Haptic Orientation for Visually Impaired People

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Abstract

Is it possible to show space relations to blind people ? Techniques and experiments described in this article explore several ways of accessing spatial information by blind people using one point force-feedback device. The study focuses on two techniques supporting an orientation in buildings. Preliminary results show that a wider spectrum of different techniques suitable for blind people is needed.

CR Categories: K.4.2 [Computers and society]: Social Issues—Assistive technologies for persons with disabilities; H.5.2 [Information Interfaces and Presentation (e.g., HCI)]: User Interfaces—Haptic I/O; I.3.7 [COMPUTER GRAPHICS]: Three-Dimensional Graphics and Realism—Virtual reality;

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1 Introduction

Using haptics for blind people is a well known idea, described in many works. For example, Ramloll et al. [**?**] describe how line graphs can be presented to blind people. [**?**], [**?**] discuss automatic translation of visual to tactile modality and they discuss human factors and methods associated with image manipulation. Fritz [**?**] studies how scientific data can be presented to visually impaired or blind people. Many works are concerned with finding the way of utilizing a computer screen for a blind user. With the special device and haptic icons blind people can use Windows GUI system, see [**?**]. Miller [**?**] addresses the problems of implementing force feed-back to X window system.

One of the most demanding challenges is to find a way to explain a map to visually impaired peoples. This problem was studied recently by Sjostrom [**?**].

In this paper we describe several approaches to the problem of orientation of visually impaired peoples in buildings. Visually impaired people need to know how to find their way around a building. In real world they walk closely to one of walls with white stick and search for doors and sudden changes in the direction of a wall. For the moment we will ignore one of the most annoying things perceived by blind people, i.e. unexpected obstacles placed randomly in their way in a path that they routinely follows.

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Blind people need long practice to remember the way to location that are important to them. It takes a significant amount of time both for them and their helper. Previous research shows that the process of learning the blind walk-through might be shortened by the usage of a computer with haptic device. To support this approach we studied what interaction scheme should be used to show the way through building without human helper. We use PHANToM device because the user can perceive the similar feeling as with white stick.

2 Utilization of Haptic Force Feedback

Haptical feeling arises during contact with a surface and it is mediated to the human being via the nerve tips in the skin, in contrast to muscle forces that balance e.g. the weight of a carried object. In this paper we deal with haptic type of force-feedback. *Haptic interface* is a device capable of exerting force with controlled magnitude at any point in space to simulate the fact that a user is holding or touching virtual surface. This work is based on our experiences with PHANT*o*M (Personal HAptic iNTerface Mechanism, a product of SensAble Technologies). The device is designed to measure 3D or 6D position/orientation data on input and to affect the user by force at single finger effector. PHANToM can be used in three ways:

Passive movement PHANT*o*M is moved by user, spatial information is used for computing the force which is exerted by device. Force can be computed from the depth of penetration into a virtual surface (e.g. a triangle mesh) or directly as some spatial function. Viscosity and friction are usually applied as a function of velocity. More information could be found in [**?**].

Active movement PHANT*o*M effector is moved by a control system, user can touch or hold effector and feel its path. It allows to move users hand from one virtual object to another or to present a more complex path, i.e. a gesture. Device moves according the list of vectors showing the path of gesture, which is independent of scene topology.

Combination of passive and active movement A user is allowed to explore freely the space data using haptic feedback, moreover under certain conditions he receives active force suggestion. The possible movements are controlled by collision detection techniques.

2.1 Active movement

The exerted force F of PHANT*o*M effector is computed as:

$$F = -K.x - B.v \tag{1}$$

$$x = Spos + t.Vect - PHpos \tag{2}$$

t - time $\in \langle 0,1 \rangle$
$Spos$ - starting position
$Vect$ - movement vector

Figure 1: First, second and fourth floor of building

K - stifness coefficient
$PHpos$ - actual position of device
x - distance between device and position on vector
v - actual velocity of device
B - damping coefficient

The movement is controled by proportional derivative law.

Equation **??** is classic spring and damper approach of force computation.

The spring part defines force from device position in space and position on current movement vector. Equation **??** represent attachement of spring between actual position of device and location on desired movement vector.

With spring part only, we could not achieve velocity greater than $10cms^{-1}$. Exceeding this limit led to strong vibrations in force-feedback loop. Stiffness coefficient was set to $K = 800Nm^{-1}$ (using rt-linux drivers).

Damper part reduces vibrations. Experimentally we have set $B = 3Nms^{-1}$. In the range of velocities up to $30cms^{-1}$ there were none or only negligible vibrations. In all cases force F was clipped to $8N$ because of device characteristics.

When t is not changing (paused) damper part of formula should be not used because of static vibration of device which leads to delivering more energy to device than is needed for staying in position and heating it up.

3 Human-machine movement control diagram - continuum of user independance

Human-machine interaction is flow of information passing from machine to human and vice versa. It can be seen as two streams with some dependancy. It has wide range of interrelations. This provide us some continuum of cases.

We devided this continuum to four stages; restricted, with decision, help on demand, free (pure simulation of shape of building)

The first stage is one of extremes of this continuum. User is passive and movement of device is controlled by machine. User follow path provided by it.

The last stage is extreme on the opposite side of the continuum. Haptic model of real thing is provided by machine and user actively explore this model.

The intermediate stages are mixture of previous extremes. At some point user make decision and in reaction to it machine provide some stuff so user is active, but machine provide some aid for him. Second stage has a flavour of restriction but user can moderate what happend next. Third stage is nearly the same as fourth stage but user can ask machine for some aid.

In the field of our interrest

First stage: User is trained about layout of building by showing a map.

Second Stage: Machine provide motion of device to some place of interest in model of building. User is offered with set of possible moves to next places. When decision is made machine moves to next place and proces continues. User glean information about building topology from conceptual model through witch is able to move freely.

Third Stage: User moves freely through building but when he feel lost he can ask machine for navigation to choosen target.

Fourth Stage: User groped through model of a building.

3.1 Path planning

In first two stages of the continuum machine can provide user only part of whole building. This is tractable for showing way from A to B. To do it user must choose desired target location. Machine then use path planning algorithm to construct proper path.

3.2 Gestures

4 Experiments

4.1 Introduction: Gesture recognition test

The study of a gesture recognition is based on the simple task. PHANToM's arm driven by computer moves in space performing a selected gesture described by the list of movement vectors. Tested subjects attempt to recognize gesture shape when holding the moving single-point effector of haptic device.

We have used the gestures with shapes of A,V,X,O,I,-,+,* with the size ranging from 1 cm to 4 cm. Several combinations of gestures were also tested. Each shape was presented to the subject repeatedly in the loop with or without pause at the end of each pass. Visual and audio channel were not used.

4.2 Experiment 1: Walk-through a simplified 3D model of a building

Task is to walk through the model of a building from entrance at the first floor to the fourth floor and to find a treasure. The building contains doors and windows (holes in front walls) and stairs with banisters.

The technique models the building as a set of voxels with different features, see Tab.3.2 . Passive principle is used for controlling haptic device. A user is responsible to select the direction and to move the haptic effector's end to the desired position. Collision detection combined with force feedback prevents the user to perform unrealistic movements. Audio channel is used to inform user about actual floor number. Visual channel was used only to show the position of the device in space, the structure of the building was not shown to testing subjects.

#	meaning
0	free space
1	wall
2	viscous ball
3	wall with friction
-1	floor (with info)

Table 1: Voxel types used for building assembly

Fig.1 shows (left to right) the first, the second and the fourth floor of building, occluding walls removed. Banisters are modelled by thin walls. Some cells contain viscous ball. These cells can be passed through, but not as easily as empty cells. They could be used to inform a user of forbidden places. In our tests they were utilized to cover the treasure at the fourth floor.

4.3 Experiment 2: Show me the map

The goal of this task is to understand the topology of a building. The level of understanding was tested by questions about the number of

Figure 2: Symbolic map of building using gestures

rooms and their locations. Test building had four rooms in the first and one room in the second floor.

The technique employs the symbolic map of building presented as the graph of active movement gestures. Gestures may express either topology or geometry or they provide to a user hints about available steps and processing. The map used in our experiment is in Fig.2. Due to a limited haptic space the position of a map has to be fixed with respect to coordinate system of haptic device. To avoid confusion of users we begin with active movement to the start position of map. The process of performing gestures is controlled with keyboard by a user. He can stop, return or go to the start of a map whenever he wants. Audio and video channels were not used. The quality and speed of the learning process were not evaluated.

Fig. 2 shows the map of building with four rooms in the first floor and just one room in the second. At the beginning haptic device performs the *start* gesture. Then it proceeds to the first crossing. It waits for awhile (shown as a ball at crossing). Then it goes to the right, performs the room gesture, and returns back to the crossing. Similarly it scans and passes through all other rooms at this floor. Afterward it "walks" upstairs and to the farthest room. The end of tour is signalled by *finish* gesture.

4.4 Experiment 3: Where am I ? Haptic compass-like aid

The task is the same as in Experiment 1, but with the aid of active movement of haptic device.

This technique combines passive and active motion principles. User can move freely with supplementary audio information about where he is. User chooses a target object by keyboard and the selection is acknowledged by audio channel.

Whenever user asks for aid, the vector from actual user position to the target object is computed. Only a part of that vector is used as direction hint ($1/5$ of distance). Device starts to move along that vector. User can repeatedly ask for help from different places (e.q. from left part of room then from right part of room) or let the device continuesly moves (him) so he get closer to target object.

As was said earlyer user take active part in building exploration but he can ask for hint so unlike path planning only direction is showed to user not whole path.

Forces from aid movement are combined with the forces derived from a collision with the building. A contact with a wall can be thus perceived even when using active moving haptic device. When device "hit" a wall and goes deeper and deeper forces from aid movement and collision of wall equalize. When force from aid disapeare collision force grows up and user is pushed out of wall, so he can percieved obstacle on direct path to the target. This situation occurs often when a user tries to get to the target on another floor.

5 Implementation issues

5.1 Voxel building

Our building compose from $20 \times 16 \times 10$ voxels of $0.014m$ size . But border voxels was set to 0 for right function of algorithm, so usable space is $18 \times 14 \times 8$ voxels witch gets $25.2 \times 19.6 \times 11.2m$.

For voxel building we apply this algorithm:

We use same algorithm for all three axes, further we show only one axe arrangement.

we use some variables:
iu - index of actual cell where is user
p - actual possition of device
ip - index of cell where is device
d - actual direction of movement ($+1, -1$ or 0)
$B[]$ - building data - array with elements from Tab.3.2
F - force
K - stiffness coeficient

func index PosToI(position) - position to index function
func force ForceFunc(penetration) - returm force from penetration (distance from device position to wall)
Initialization:
$iu = PosToI(p)$
$d = 0$

Main loop:

```
loop
    ip ← PosToI(p)

    if ip = iu then
        d ← 0
    else if ip < iu then
        d ← +1
    else if ip > iu then
        d ← −1
    end if
    if B[iu + d] == WALL then
        F ← ForceFunc()
    else
        iu += d
    end if
    if iu changed then
        ShowInfo(B[iu])
    end if
end loop
```

5.2 Map

5.3 Compass

6 Results

6.1 The Testers

6 volunteers participated in our experiments . Three of them were totally blind (two females and one male) and three were seeing (all males). They all were $20-26$ years old. At the beginning they were familiarized with haptic device using a simple haptic environment with sphere and box and active movement along one vector.

6.2 Active movement test

Sighted people had no problem with recognizing gesture shape because they mostly used eyesight. Blind people were pleased to learn simple open shapes (they preferred v instead of a) and they also appreciated the loop presentation of gesture shape without pausing. Preferred velocity was $7cms^{-1}$. Velocity greater than $10cms^{-1}$ was not acceptable. Testers were not disturbed with starting and stopping force jumps, which cause additional movement of haptic effector.

6.3 Simplified 3D Model of the Building

All sighted testers were able to finish task. One subject easily went up to the top floor using the unrealistic, yet efficient walk on ceiling. He was disturbed by visualization (visualization showed only

haptic device position and trace of movement, not the structure of building). Other subject quickly went up to the top floor with slow and fluent movements. One person could not find stairs because of banisters. It took a long time before he understood where were the stairs.

One of blind testers did not finish the task and she got lost in building. She walked touching the virtual floor but some time suddenly changed direction and moved along wall and ceiling. Because of rectangular shape she thought that it is a window, when in fact it was the interior of a room. She did not managed to go upstairs to third floor because the stairs from the first floor to the second were oriented reversely than the stairs to the forth floor. She claimed that her orientation in real building is not good, either. Other blind testers liked the voxelized model of building. They had no problems with stairs and they oriented themselves very well. One tester asked for additional signs to let him know where he is.

Visually impaired people appreciated the possibility to walk around a building from outside because it was first time they had a chance to feel the "real" shape of whole building.

6.4 Show me the map

Stairs gesture was easily understood by all people from the first moment, even without explanation of its meaning. Sighted people were able to recognize the shape and topology of building after looking at the picture of gesture map (Fig.2. They were able to synchronize the remembered picture of gesture map with later haptic exploration. One of volunteers guessed the meaning of room gesture without clue, however in general the meaning of gestures had to be explained.

Visually impaired testers have different opinions about usability of this technique. One of them claimed he could not recognize anything when a gesture was encapsulated between two displacement movements; e.g. from a current position to a gesture position followed by return to the initial position. He dislikes to be moved by device. He solved the task in 6 trials.

Second tester wanted to stop roll-like movement of haptic effector. She preferred to grasp PHANToM arm with effector directly, without gimbal thimble. She was able to understand the topology of building within 5 passes. She proposed the simplification. She expressed opinion that rooms should not be presented as circles but it is sufficient to indicate the doors with repeated bidirectional movement.

The third blind tester liked this technique. Even if she needed 7 passes to learn topology she still preferred it. She was the same person who got herself lost in voxelized model of building but who had no problems with the gesture map.

She also proposed another simplification - it is sufficient to show just left or right part of a map. This approach is analogical to the behavior of blind people in real world. They tend to find the nearest properly oriented wall (or sidewalk edge) and follow it till they find another recognizable feature.

6.5 Where am I ?

This technique was well accepted by almost all testers. They found it useful and feasible. One drawback is that this technique helps a user to get closer to the target object, but it does not show the direction of exploration. The option of variable speed of motion is necessary to meet the individual needs for all testers.

7 Experimental setup

We used PC, 1.7GHz, RT/Linux. Force feed-back device PHANToM 1.0a from SensAble ,Inc. was controlled with RT/Linux drivers programmed by HCI lab team. Achieved frequency of force feedback loop was approx. 3000 Hz. The code was written in C.

8 Conclusion and future work

We have described several experiments with auxiliary techniques which apply passive and active motion of haptic device.

Blind people have different rank of orientation and they individually need the different techniques to navigate through building. Some people are able to move freely, only with optional feedback information that they are going in a wrong direction. Others like to be moved through the important places. This work tested techniques for both cases.

Testing application used a very simple map of building (cells) only. For real building a more complex information structure might be used , maybe VRML for geometry and some kind of finite state machine for semantics. The questions *Where I am ?, How can I go somewhere ?* should be supported with different level of haptic and sound feedback.

Many improvements could be done to *Show me the map* technique. Map may be not presented as a whole but only as the part which is selected according the direction of motion at crossings. The initial experiments not described here, and also discussion with blind people uncovered the problem of scale. Blind people are very sensitive to a sudden change of haptic scale as it is something they never meet in real world. Therefore the classical LOD approaches have to be evaluated in this context very carefully.

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