The sense of touch provides new computer interaction techniques for disabled people

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Windows and the World Wide Web are two of the keys to the Information Technology explosion that we are all caught up in. Computer capabilities are increasing while they are getting easier to use. But how does a blind person handle a graphical environment like Windows?

This article deals with Certec's efforts to find a way to use haptics (i.e., controlling with movements and getting feedback via the sense of touch), to provide new computer interaction techniques for visually impaired people and people with physical disabilities. Haptic technology makes it possible to extend the range of touch from the length of an arm to a virtually unlimited distance.

Keywords: Haptic interface, Touch Windows, blind, sense of touch, visual disability

1. Introduction

Windows has undoubtedly been a revolution for computer users. Its spatial graphical paradigm with menus, buttons and icons unburdens the user from memorizing commands and reading long sections of text on the screen. But the drawback of all these good things is that Windows makes the computer harder to use for a blind person. The structure of the computer system is represented by pictures, and if you cannot see those pictures it is very hard to grasp this underlying structure, or even to access and use the computer at all. Nevertheless, many blind users prefer Windows to older computer systems even though they are unable to take advantage of all the benefits that Windows offers a sighted user.

However, there is one alternative access method with potential value: computer interfaces that use movements and the sense of touch as a complement to graphics. These interfaces are called haptic interfaces.

At Certec, Center for Rehabilitation Engineering Research at Lund University, we have been working with haptic interfaces for disabled users since early 1995. In one project, we are working on a connection between Windows and a haptic interface called "the PHANToM" [4]. With a connection like this, it would be possible to feel and control the interface components of Windows. We are also working on a connection between a standard rehabilitation robot and the PHANToM. Our aim is to enable the user to control the robot with small movements of one finger, and feel some of the things the robot is doing.

2. The PHANToM

The PHANToM (Fig. 1) is a haptic interface device from SensAble Technologies Inc. of Boston, MA. It is primarily intended for adding 3D-touch to 3D-graphics programs. At Certec, we realized early on that disabled users could benefit from the PHANToM.

With the PHANToM, the user puts one finger in a thimble connected to a metal arm. By moving his finger around, the user can feel virtual three-dimensional objects that are programmed into a computer. Moreover, he can control the computer as if the PHANToM were a mouse or a joystick. The PHANToM adds a new dimension to human-computer interaction, namely haptic interaction. Haptic interaction uses both the sense of touch on a small scale and movements on a slightly larger scale.

The virtual three-dimensional space in which the PHANToM operates is called a haptic scene. The hap-

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Fig. 1. The PHANToM (photo by SensAble Technologies Inc.).

tic scene is a collection of separate haptic objects with different behaviors and properties.

When activated, the PHANToM works together with the computer to interpret the users finger position in three-dimensional space and to apply an appropriate and variable resisting force. Three sensors track the position of the user's fingertip and this position is read by the computer. In the software, the position is compared to the boundaries of all objects in the haptic scene. If the user is not close to an object, the calculated force is zero, but if the fingertip is in contact with an object, the computer calculates a force that pushes the finger back to the surface of the object. The actual force that can be felt is provided by three DC-motors. This process (Fig. 2) is carried out 1000 times per second. The high frequency together with the high resolution of the encoders makes it possible to feel almost any shape very realistically with a device like the PHANToM [4].

The PHANToM has its main users in research and development. It is, among other things, used as a simulation platform for complex surgery tasks, VR research and to enhance 3D CAD systems.

3. Programs for learning and fun

Certec has developed a number of programs for the PHANToM. The programs have been demonstrated at exhibitions and conferences to both sighted and blind visitors. There have also been many dedicated test sessions at Certec with blind children and adults, as well as with a group of deaf-blind persons.

The programs used at these try-out sessions were scenes with simple static or dynamic geometrical objects, a haptic/audio memory game, a game called Submarines, and a simple clay-modeling program (written by SensAble).

"Submarines" is a haptic variant of the well-known battleship game. The ordinary pen-and-paper-based battleship game (Fig. 3) has been used to give school children a first idea of what coordinate systems can be used for. With "submarines" it is possible for a blind child to have even more fun with coordinate systems.

The player feels 10 x 10 squares in a coordinate system. In the game, your finger in the PHANToM is a helicopter that is hunting submarines with depth charge bombs. If you put your finger on the "surface of the water" you can feel smooth waves moving up and down. The surface feels different after you have dropped a bomb, and it also feels different if a submarine has been sunk. There are four different states for a square with associated haptic feedback:

- Not yet bombed - calm waves
- Bombed, but missed - no waves (flat)
- Bombed, hit part of a submarine - vibrations

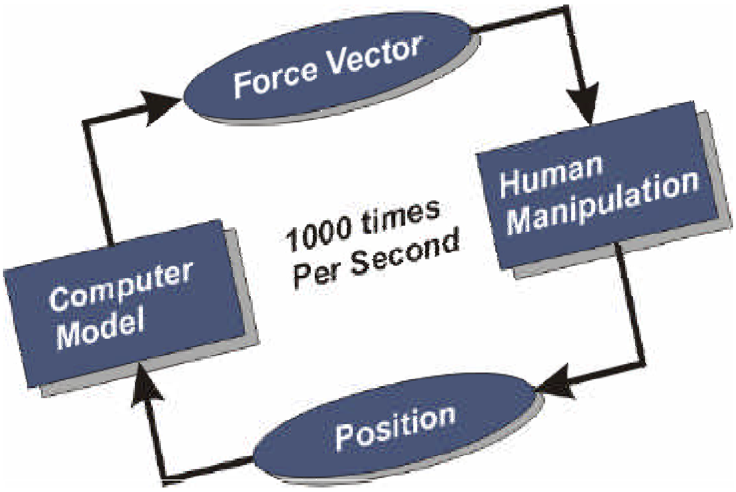

Fig. 2. The control loop.

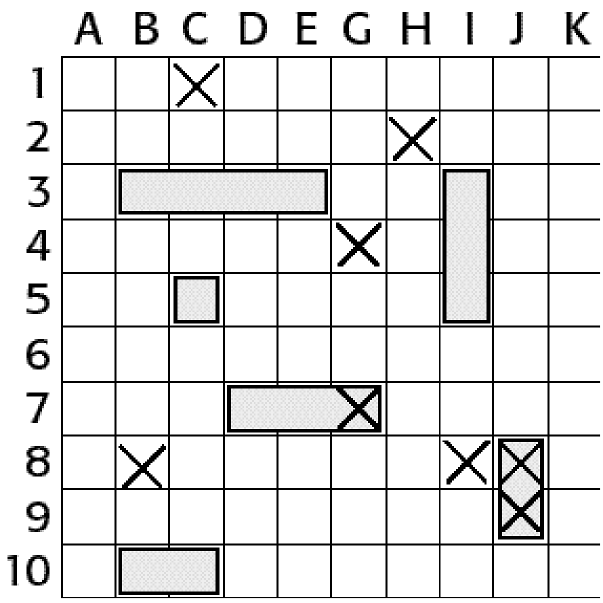

Fig. 3. A paaper-based battleship game.

- Bombed, hit entire submarine - small, rapid waves

This computer game uses the PHANToM, the screen, and the keyboard in the interaction with the user. It also uses sound effects as many current games do. It has been tested by at least 20 blind children and adults and by at least 50 sighted persons. They have all had fun with it.

”Submarines” has also been tried by a group consisted of six deaf-blind persons and their assistants and others that made the grand total of 15. Since the different conditions of the squares are provided as haptic feedback, our hypothesis was that it should work fine for deaf-blind users as well. As it turned out, it seems like the haptic feedback of the game was sufficient, in all but one case. In the game, the space key is used to drop the bomb in the water, and while the bomb falls, a hearing person hears the sound of the falling bomb in the speakers. Not until the bomb has reached the water, does the user get haptic feedback to indicate if it was a hit or not. Since there was no haptic feedback for the falling bomb, this confused the deaf-blind users.

The first PHANToM program at Certec, was a painting program for blind children, ”Paint with your fingers”. With the PHANToM, the user chooses a color from a palette. Each color on the palette has an associated texture that the user feels when painting with it. By changing program mode the user can feel the whole painting, and also print the painting on a color printer.

Early in our work we also developed a simple mathematics program. People who try to explain mathematics to blind persons often notice that to some extent it is a visual subject. A haptic interface helps blind persons to understand equations in terms of curves and surfaces. Our program makes it possible to feel a mathematical curve or surface with the PHANToM. A similar program, but with more functionality, has been developed at ASEL, University of Delaware [2].

4. Touch Windows

Computers are becoming everyday technology. Computers have opened up many opportunities for disabled people. For example, it is now fairly easy for a blind person to access written text. Any text in a computer can be read either with a one row Braille-display or a speech synthesizer. This is done in real time. In addition to being much more flexible, it also saves space compared to books with Braille-text on paper. At present, that is about as good as electronic access gets for computer users with visual impairments.

There is now a strong emphasis on documents with graphics, and increasingly so on the Internet. For blind Websurfers the pictures are not accessible at all. It is possible to define an alternative text in the HTML-document, explaining what the picture shows, but they are sometimes omitted for lack of awareness about the benefit for blind users.

As mentioned in the introduction, the fact that most computers now have graphical user interfaces (GUIs) is another big problem for non-sighted users. Windows and other GUIs are widespread and accepted, so almost all new programs are made for these environments. If Windows can be made accessible to non-sighted users, then Windows programs will almost automatically become accessible as well. That is why we have started the ”Touch Windows” project.

There are many reasons for having Windows on the computer even in the case of a blind user. The biggest single reason is that most programs today are made for Windows. For example one of our test users wanted to connect a synthesizer to his computer, but he was unable to do so without Windows since no DOS-program would work. Another reason for using Windows is that it is the system most commonly used in the workplace. If blind users can have the same type of computer system as sighted users, both will benefit greatly. For example, it is much easier to exchange documents, and they can provide technical assistance to each other.

Rather than making a haptic user interface tailored to the needs of blind users we intend to make the haptic Windows system, the ”Touch Windows” project, as similar as it can be to the graphic Windows. Even though Windows is designed with sighted users in mind we think that the benefits of a system that looks and feels the same are worth while.

In the haptic Windows system under development, we want to use haptic interaction mainly to provide an overview of the system. The idea is to make windowframes, buttons, menus and icons touchable via the haptic interface. That should provide the overall information in a similar way as the graphical images do in the standard Windows system. The text on the screen and other small details will probably be made accessible with more specialized techniques like speech synthesis and/or Braille-displays.

Dividing the functions in the interface also means that a haptic system like ”Touch Windows” would not render unnecessary any of today’s assistive technology for visually impaired computer users. Rather, the systems can complement and enhance each other. With a haptic interface it is possible to feel things in two or three dimensions. That makes it possible to write programs that convert graphics into something that can be felt. It is possible to translate the up, down, left and right of the Windows system on the screen into a touchable environment with the same construction and metaphors. It is a big advantage if blind and sighted users have the same inner picture of the system. Then they can talk about the system and help each other from common ground. Suddenly, it means a lot more to say things like ”the START-button is in the lower left corner”.

5. The Memory House

As a first step, to find out if it is even possible to understand and control such a complicated system as Windows with only haptic information, we created a program called The Memory House (Fig. 4). The Memory House [6] is a haptic/audio memory game. The

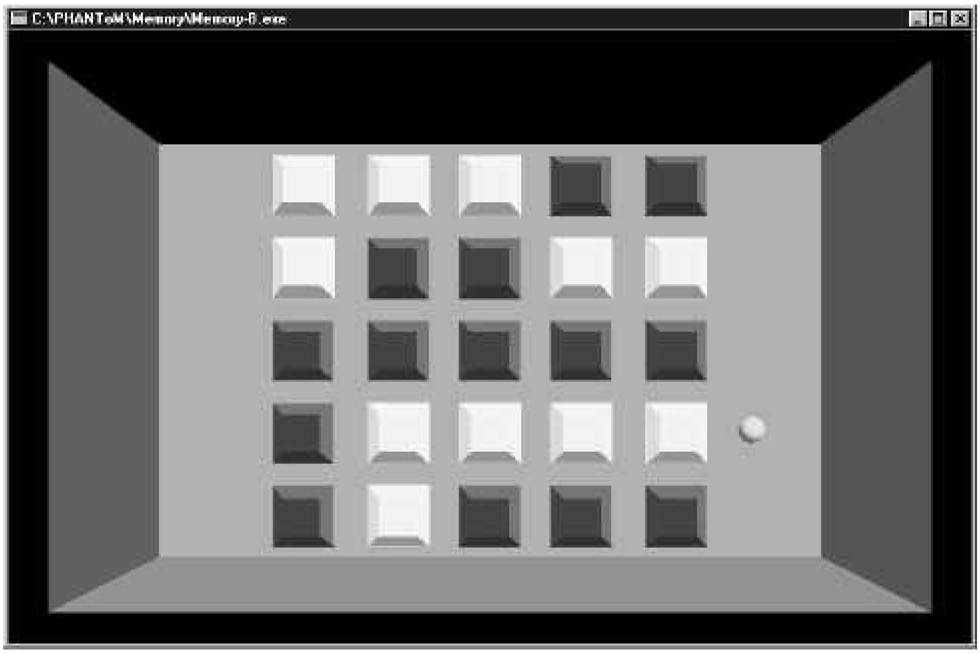

Fig. 4. The Memory House (original version).

game consists of 25 pushbuttons that produce a sound when pressed. There are 12 sound-pairs, and one ”Old Maid”. The buttons disappear when the player presses two buttons with the same sound in sequence.

In the Memory House the buttons are placed on five different floors. Between each row of buttons the user can feel a thin wall that helps him to stay within one set of buttons. It is possible to move from one floor to another anywhere, there’s no ”staircase” or ”elevator”, the user only have to push a little bit harder on the floor or ceiling to slip through it. To make navigation among the floors easier there is a voice that reads the number of the floor each time the user moves from one floor to another. Many of the blind users liked this feature and used it for reference, but some of them found the voice annoying rather than helpful.

We have also made a few different versions of the Memory House. The original version (Fig. 4) had 15 buttons on the back wall and five on each side wall. Even though this approach makes good use of the three-dimensional space provided by the PHANToM we also wanted to have a version that is more similar to what can be seen on a monitor. Consequently we made a version of the memory house with all the buttons on the back wall (Fig. 5). The program has been tested, together with all the programs mentioned earlier, in a study comparing sighted and blind people. The sighted testers used a regular mouse and pictures or sounds, while the blind testers used the PHANToM and sounds.

Our tests show that it is possible for almost any blind user to navigate among the sounds and buttons in the game. Of the nine blind persons in our initial test only two were unable to finish the game (although they managed to find a few pairs). The other seven users managed to find all the pairs and many of them finished the game using about as many button pushes as the sighted testers. However, most of the blind testers needed more time than their seeing counterparts.

Perhaps the most interesting result was that our tests showed that it is actually possible for a blind person to use virtual touch to create an inner picture of rather complex environments. And, apparently, they are also able to connect sounds to objects in this inner picture.

Another interesting result from these tests is that some of the subjects were able to compare what they felt with the PHANToM to earlier experiences. For example, one tester likened a virtual model of a small house (Fig. 6) to ”The money-box I got from the bank when I was a child”. The money-box he mentioned has the form of a small house and he remembered it from the time when he could still see.

We conclude that it is meaningful to make graphical user interfaces accessible for blind people using haptic technology. Most of the blind users showed substantial confidence when using the haptic interface even with the rather limited experience they had.

These results have also been confirmed in less formal tests subsequent to the initial test described above.

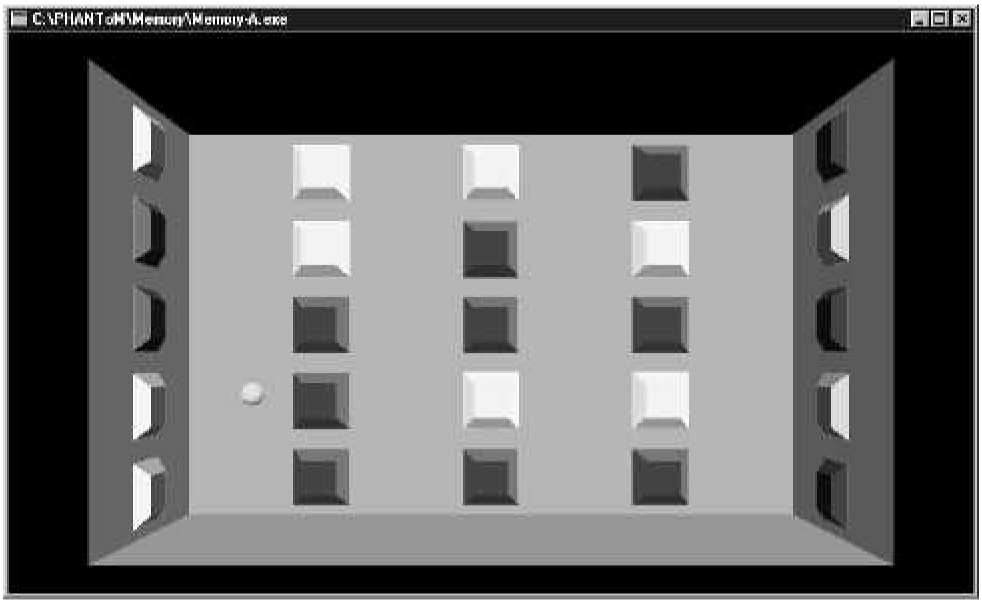

Fig. 5. The Memory House (version B).

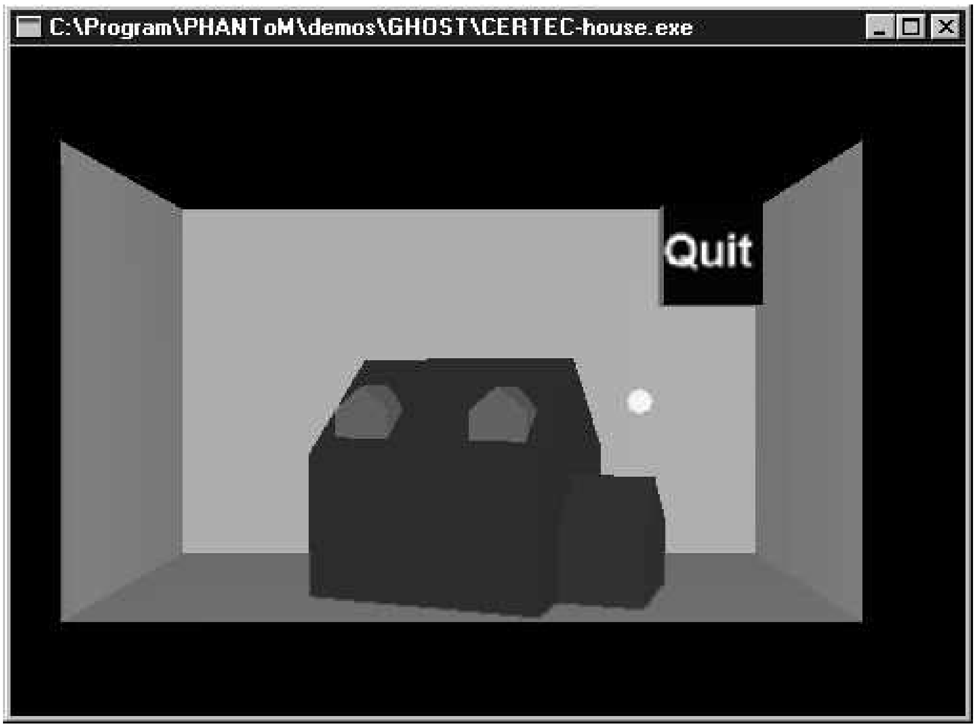

Fig. 6. A virtual model of a house.

6. 2D force feedback devices

The PHANToM is a high performance force feedback device with many benefits. The drawbacks for the end user are its complexity and high cost. Conse quently, we have now started to transfer our experience from the PHANToM to new and much cheaper devices. A force feedback mouse like Immersion's FEELit [5], for example, may be a good platform for a haptic user interface with much of the functionality of the more

Fig. 7. The FEELit mouse (photo by Immersion Corp.).

Fig. 8. The Microsoft sidewinder Force Feedback Pro joystick (photo by Certec).

expensive devices but at a significantly lower cost.

Force feedback devices using only two dimensions are sufficient for working in 2D environments like Windows. Unfortunately, the FEELit mouse (Fig. 7) is not yet available on the market, so we have done no tests with this hardware. However, Immersion staff have held a couple of pilot sessions with blind people using the FEELit mouse and speech synthesis, and we are engaged in an open discussion with them on the subject.

Other force feedback devices, such as game joysticks (Fig. 8), developed by companies like Microsoft, Logitech and Immersion, are beginning to enter the market on a large scale. These simpler devices can also be used by blind people, for both business and fun.

Certec is collaborating with two scientists who are working on the Microsoft Sidewinder Force Feedback Pro device [3] in order to test its potential usefulness to blind users. A labyrinth program has been written for this purpose.

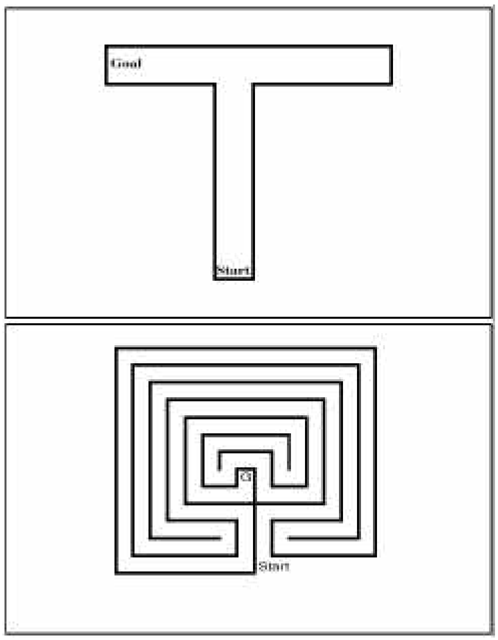

Fig. 9. Mazes (image by Anders Johansson).

In the ”Labyrinth” application, the user chooses a labyrinth, or maze (Fig. 9), with the push buttons on the base of the joystick. The joystick then pulls the user to the starting point of the maze. With the joystick, the user can explore the maze haptically, since its walls are simulated as force feedback in the joystick. When the user finds the goal of the maze the joystick oscillates.

There are a number of different mazes in the program, from simple examples to representations of complex historical labyrinths. The simplest maze is a ”T” labyrinth, and the most complex is that of the garden at Versailles. It turns out that by finding his way through the simpler mazes with the joystick, the user develops an inner picture (or representation) of the structure, while the more complex ones are almost impossible to successfully traverse. The more complex labyrinths consist of a large number of aisles, and the limited workspace of the joystick makes the aisles narrow and the walls too thin to recognize.

7. Haptic robot control

Another area to be explored is haptic robot control. For many years, Certec has been working with robots as assistants to people with physical disabilities. One of the problems has been how to control the robot. Among other things, we have tried to determine when free control is best and when it is more efficient to use programmed path control [1]. When it comes to free control, a haptic interface can be a great help. It provides a natural conversion between the movements of the hand and the movements of the robot, and it also gives feedback so that the user can feel what is happening. Many robot experts say that force feedback is essential to good robot control in these circumstances.

One benefit of using a universal high performance haptic interface for robot control is that it is possible to use personalized settings to control the magnitude of the users movements as well as how much force is exerted against the finger.

8. Around the corner

An interesting and very useful application for blind people is to create haptic maps and models of public spaces. If one can find one's way in a virtual environment before attempting to do so in the physical world, the chances of avoiding some potentially serious mistakes are much better. Haptic maps could be the key to better public environments for blind people by making it possible for them to have an influence in the design phase.

One step of the way to creating haptic maps would be a program that automatically converted line drawings into haptic information. It could be used not only for maps but also for much of the graphics on the World Wide Web. In fact, such a line drawing interpreter would constitute a big step towards a haptic WWW-browser.

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