Basic issues concerning visually impaired people's use of haptic displays

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ABSTRACT

Haptic displays present a potential solution to the old problem of rendering pictorial information about 3D aspects of an object or scene to people with vision problems. The aim of the paper is to discuss some basic issues of importance for the usefulness of these displays for visually impaired people: (1) The overview of a virtual object or scene available for exploration with only one point at a time, (2) The limited spatial resolution of haptics, (3) The potential effects of learning, (4) The necessity of simplifying pictorial information, (5) The enhancement of tactile information with auditory and visual information.

1. INTRODUCTION

Until recently, people with severe problems in reading visual pictures have been restricted in getting pictorial information about three-dimensional (3D) scenes to real 3D models or tactile pictures in two dimensions (2D). However, real models are rare and expensive, and reading 3D aspects of 2D tactile pictures is a difficult task (Jansson, 1988). Haptic displays presenting virtual 3D scenes mean a fascinating potential opportunity for people with severe vision problems to get information equivalent to what sighted people get from pictures (Jansson, 1999a). However, there are complications. The design of visual displays from a human perception point of view has been rather extensively investigated (Tullis, 1997) and there is a growing research about how to utilise audition for auditory displays (Gaver, 1997), but similar studies on haptic displays have only started.

In most applications of haptic displays they are used as enhancement of visual (and sometimes auditory) information. A haptic display without an accompanying visual display is not very common, but is the only option for a person with severe vision problems. This is a situation very different from a situation with both visual and haptic displays available, as haptics is normally co-operating with vision. The aim of this paper is to discuss some basic issues concerning the use of haptic displays when the information they provide is not supported by visual information. The discussion is concentrated on one of the leading commercially available haptic displays, the PHANToM (Sensable Technologies, Inc.), but it ought, to a large extent, to be applicable also to other haptic displays.

2. OVERVIEW OF AN OBJECT OR A SCENE BY EXPLORATION

Vision presents a (nearly) immediate overview of a scene or object, but haptics usually does not. The closest haptic analogue to a visual overview may be a grasp of an object with many simultaneous points of contacts between object and hand, but normally you get the overview only successively. An object is typically explored by manipulating it with several fingers changing their positions in relation both to the object and relative to themselves. This exploration is as basic for haptics as eye movements for vision, and there are a large variety of exploration methods (Lederman & Klatzky, 1987).

The restricted overview for haptics is to a large extent compensated for when vision is available as well. Vision provides a general overview and can guide haptic exploration by suggesting locations to be explored haptically and by supervising the movements of the relevant body part to these locations. This means that the use of a haptic display together with a visual screen may not suffer too much from the haptic lack of overview. The situation without vision is dramatically different. It is easy to miss significant properties of an object or scene and even the presence of objects. This general restriction of haptics is accentuated when there is only one contact point at a time between observer and virtual object, as is the case with the three-degrees-of-freedom PHANToM. (The new six-degrees-of-freedom device is an improvement from this perspective, but the difference to natural haptics is still large.)

In an experiment the performance with restriction to one point of contact, as with two 1.5 PHANToM options (stylus and thimble), was compared with the performance with corresponding real objects explored naturally (Jansson & Billberger, 1999; Jansson, 1999b). The natural condition allowed all potentials of natural exploration, including the use of several fingers and unlimited skin surface. This means that any differences in performance do not depend on the one-point-of-contact aspect but on other factors as well. The result demonstrates to what extent PHANToM exploration utilises the potentials of natural haptics.

The dependent variables in the experiment were proportion of correct judgements of the form of simple geometric objects and the time used for exploration. The performance with the two virtual conditions differed dramatically from the performance in the real condition. The real objects were always judged correctly in a few seconds, while the virtual objects were judged less correctly after a longer exploration time (Figure 1). This difference in results can hardly be attributed to differences in physical properties. The virtual objects mirrored the real ones quite well, possibly with the exception of sharp borders not being exactly similar. The main aspects separating the real and the virtual conditions seem to be those related to the exploration properties. When several points of contacts are available, as in natural exploration of real objects, the observer gets a rapid overview of the object (at least with objects of the sizes studied) which makes a correct judgement in a few seconds possible.

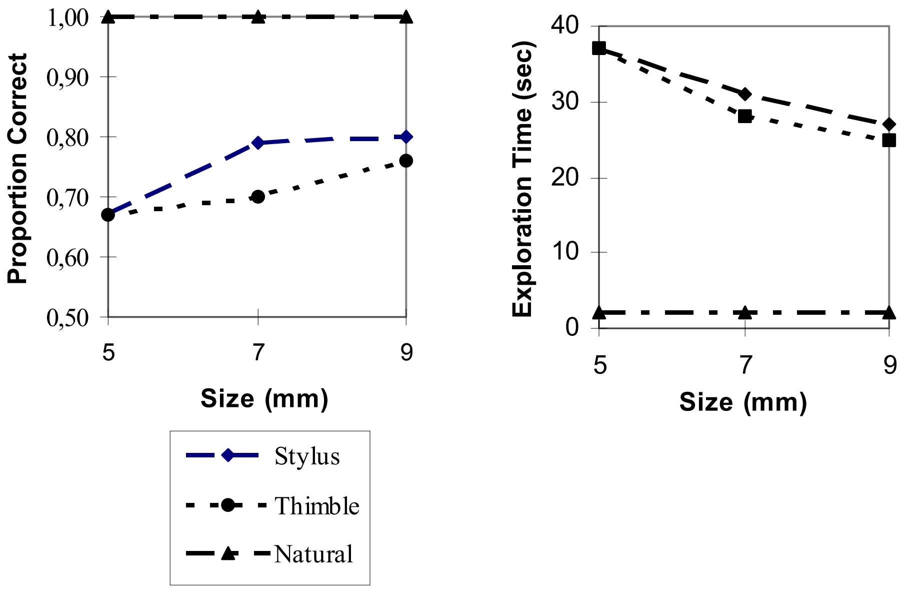

Figure 1. *Exploration time and proportion correct judgements as a function of exploration method and object size (Jansson & Billberger, 1999).*

It should also be observed that the results for the two PHANToM options were very similar. This was not expected, as the two options engage a different number of contact points between the hand and the device; the stylus is held by several fingers (similar to a pen), while only one finger is used with the thimble. This difference does not seem to be significant, however. The result indicates that the important difference in the performance between real and virtual objects is the common character of the latter: that the objects are explored with only one point at a time. This prevents a maximum utilisation of haptic perception.

One possibility to facilitate the user's exploration along a contour or over a surface is to use "magnetic" attraction (Fänger, 1999; Sjöström, 1999). This makes it easier to avoid loosing track with the feature being followed, thus being useful for the integration of the feature. Sjöström also suggested that it is useful, in order to favour exploration, to modify sharp edges by evening them out.

3. SPATIAL RESOLUTION

It can not be generally stated that a haptic display such as the PHANToM presents properties of virtual objects that can not be as effectively judged as those of real objects. It has been shown experimentally that virtual textures explored with a stylus-equipped PHANToM are judged very similar to corresponding real textures explored in the same way (Jansson et al. 1999). However, when it concerns judgements of form the proportions of correct judgements about virtual objects are lower and the exploration times longer than for real objects judged by natural haptics as reviewed above.

3.1 The Percentage of Correct Judgements of Form and Exploration Time as a Function of Size of Object

It is reasonable to expect that the size of an object has effects on both the correctness of judgements about its form and the time it takes to explore it. However, it is not self-evident what effects to expect. It may take more time to explore a large object than a small one if the exploration is straightforward, but the decision about the form of a small object may be more difficult than that for a large one because of limitations of tactile acuity and uncertainty motivating prolonged exploration. In two experiments the ability of observers to identify the form of objects in two different size ranges was investigated. In one of them (Jansson et al., 1999) the object sizes, in terms of maximum length in each dimension, varied between 10 and 100 mm, and in the other (Jansson & Billberger, 1999) they were in the range of 5-9. The observer's task in both experiments was to judge the form of virtual objects in different sizes and simple geometric forms explored with a 1.5 PHANToM stylus.

In Figure 2 the results are combined. For the larger objects (10-100 mm) it was found that the percentages of correct judgements were not very far from 100 % and that the exploration times of the largest objects were around 15 sec. For the smaller objects (5-9 mm) the percentages were lower and the exploration times longer. The results demonstrate that observers can make judgements above chance level (25 %) also for objects as small as 5 mm, but that the percentage increases only slowly with size being clearly below 100 % also for much larger objects. Apparently it has reached an asymptotic level less than 100 % at the size of 50 mm. At the same object size an asymptote for exploration time at 15 sec is also indicated.

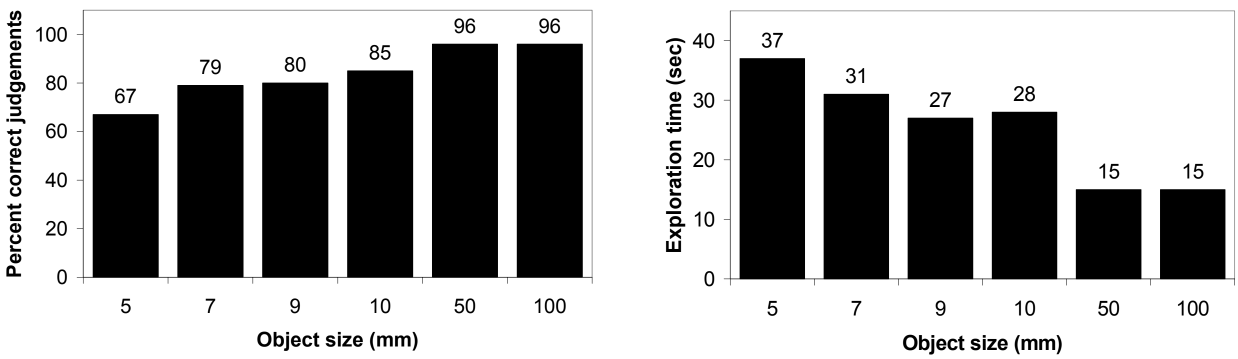

Figure 2. *Percent Correct Judgements and Exploration Time as a function of Object Size (See text for explanation).*

These results demonstrate that within the size range studied the percentage of correct judgements increases and exploration time decreases with object size. However, even if an asymptote is indicated within this range it can not be excluded that an extended range would have some kind of U-form, as it is unavoidable that it take more time to explore very large objects and that the integration of information over their surface may be more difficult. It should also be noted that the asymptote levels are far from what haptics can achieve with real objects explored naturally.

4. POTENTIAL EFFECTS OF LEARNING

The natural ways of exploring real objects have a long history of learning, both biologically and individually. The observers in the experiments just reviewed had no experience in using the special exploration methods of the PHANToM before the experiment. It can be assumed that their experience of similar methods in real life was also quite restricted, if they had any such experience at all. It is reasonable to assume that the results obtained in the experiments would be improved if the observers were given the opportunity to learn to use them. However, large differences both between users and for a user over time can be expected.

That there are differences between novices and experts in the use of computer-based devices is generally known, and there has also been research concerning a more basic understanding of what functions are involved (Mayer, 1997). One probably very important function, not the least in the case of haptics, is exploration skill. There are several reasons to believe that the development of skills of this kind is important for the functioning of interaction between display and user (Gibson, 1979; Pejtersen & Rasmussen, 1997). A possibility that may be applicable to a haptic display such as the PHANToM is that it requires a special skill of exploration which varies quite a lot between users and that is not very well developed at the start of using the device. However, it may develop rather rapidly if there is some basis in related natural and/or well learned other movements

4.1 Can the Performance with a Haptic Display be Increased by Short-Time Learning?

The main aim of an experiment by Jansson & Ivås (2000) was to investigate if performance can improve already after short-term learning of identification with the PHANToM of the form of objects. Secondary aims were to get some preliminary hints on the possibility of some exploration methods being more effective than other methods are. The participants explored with the stylus option of a 1.5 PHANToM nine blocks of 24 objects distributed over three different days. Percentage of correct identifications and exploration times were measured. The exploratory behaviour of the observers was also videotaped in order to find out if there were any differences between spontaneous exploration methods used by successful and less successful observers, and if the observers changed exploration method during the learning.

The result was that there were large individual differences between the observers, but a majority among them increased significantly their percentage of correct identifications; in fact, the mean percentage in this group was doubled from the first to the third day. However, exploration times decreased only slightly. The minority group did not show any improvement of percentage correct judgements and had in general results only slightly above chance level. The main conclusion that can be drawn is that the percentage of correct identifications can, for many observers, be increased by spontaneous learning over a few days.

No differences in exploration method could be found between successful and less successful observers, nor between different days for the successful observers. However, it should again be noted that also after this learning the performance with virtual objects was far from the performance with real objects explored naturally.

5. THE NECESSITY OF SIMPLIFYING PICTORIAL INFORMATION FOR HAPTIC READING

It can not be excluded that a user of a haptic display will reach a very high level of performance after long-term learning. The results reviewed above indicate, however, that a novice has usually a limited capability of using such a device. Even if performance for many users can be improved already after short-term learning, the problems of haptics to get en overview and to identify detailed information make it necessary to modify originally visual information when presented for haptics in order to make it sufficiently useful.

This has for a long time been known concerning the production of 2D tactile pictures from visual originals (Edman, 1992; Eriksson, 1998). In most cases such pictures are manually modified on the basis of practical experience with the goal to make them more readable for people with vision problems. To make this professionally is a time-consuming and therefore expensive undertaking that reduces the amount of pictures made available for visually impaired people.

An early effort to use numerical image analysis for this task was made by Pun (1982). More recently, Michel (1999) discussed the possibilities of individual tactile maps and analysed possible simplifications of digital maps for tactile presentations. It is a huge task already to continue the development of such analyses for tactile maps and other 2D representations, and a still more complex assignment to do this work for 3D representations, such as virtual objects and scenes presented via haptic displays. The solutions hoped for may contain automatic procedures and/or possibilities for the user to accomplish modifications by simple commands, such as simplifications (e.g., deletion of some kinds of information) and useful distortions (e.g., enlargement of difficult parts of a route map at the sacrifice of easier parts). Without the development of procedures of this kind, the enormous amount of pictorial information on the net will not be available for people with severe vision problems, even if they have a haptic display at hand.

6. ENHANCEMENT OF TACTILE INFORMATION WITH AUDITORY AND VISUAL INFORMATION

6.1 Enhancing by Audition

That multimodal information is advantageous in many contexts is well known. It is reasonable to assume that the restrictions of haptics in some respects when haptic displays are used can, at least partly, be remedied by adding auditory information. This has been demonstrated in other technical aids for the visually impaired. Pioneering work to combine auditory information with tactile information was made by Parkes (1988) for 2D tactile pictures placed on a touch tablet. More recently, efforts to make multimodal programs where haptic displays are enhanced by auditory information to be used by people with vision problems have been made for architectural models (Fänger, 1999; Weber, 2000) and for computer games (Sjöström & Rassmus-Gröhn, 1999). Verbal information, for instance, can contribute to the user's getting an overview of the scene and to finding relevant parts of it for detailed exploration. Not only verbal information may be useful, but also other kinds of auditory information may be quite advantageous, for instance everyday sounds strengthening the perception of the identity of an object (Gaver, 1997).

6.2 Enhancing by Residual Vision

Visually impaired people are usually not totally blind but have some residual vision that can be useful under specific conditions. If it is possible to benefit from such residuals in the context of haptic displays does not seem to have been studied so far. However, it is extensively used in hard-copy tactile pictures, for instance, by the use of colour that simplifies the task of reading pictures for many people with vision problems. A difficulty in general implementation of such enhancement is the large variety of residual vision, which means that the arrangements have to be adapted to the functioning of each individual's remaining sight.

Such arrangements can of course be tried in the so far most common situation with visual and haptic displays not being spatially co-ordinated, which means that there are separate perceived visual and haptic spaces. However, the recent development of a device with co-ordinated such spaces (ReachIn Technologies AB) provides an interesting option also for people with vision problems. To investigate the usefulness of such an arrangement for visually impaired people would be a most interesting undertaking. However, one problem for its application to all people with residual vision is that it is based on binocular vision which many of these people have not available.

7. CONCLUSIONS

The fascinating options provided by the haptic displays to solve the classical problem of providing the visually impaired with pictorial information, especially about 3D aspects, has to be investigated both from the point of view of possibilities and the point of view of limitations. Some issues important for both facilitating and aggravating aspects of these devices were reviewed here. It is yet too early to draw definitive conclusions about the usefulness of haptic displays for visually impaired people.

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