The Importance of Available Exploration Methods for the Efficiency of Haptic Displays

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ABSTRACT

The way of exploring a virtual object rendered with a haptic display such as the PHANToM differs from the natural way of exploring objects. The aim was to compare identification of objects in the two situations. It was found (1) that proportion correct was lower and exploration time longer for the virtual objects, (2) that two optional ways of exploring virtual objects gave similar results, (3) that the size of the object effected the result, (4) that identification of form is a more demanding task than judging textures, and (5) that the restrictions in availability of exploration methods prevents a maximum utilisation of haptic perception.

Keywords

Haptic display, exploration method, identification of objects

INTRODUCTION

Intuitively, it is reasonable to assume that it is advantageous if a haptic display makes available virtual objects similar to real objects. It may not be equally apparent that it may also be important to make available exploration methods similar to those used when real objects are explored. However, according to the ecological theory of perception [1], it is basic for all the senses that there is a close connection between perception and action, not the least the activity of obtaining information. It can therefore be expected to be beneficial for the efficiency of a haptic display if the display allows exploration patterns similar to those of natural exploration.

The exploration patterns available when using most haptic devices, including the PHANToM (Sensable, Inc.), deviate substantially from natural ones, which may decrease their efficiency. The difference is mainly based on their offering of only one contact point at a time with the virtual object[1].

A COMPARISON OF IDENTIFICATION OF FORM OF 3D VIRTUAL AND REAL OBJECTS EXPLORED HAPTICALLY

Problem

The restriction to one contact point means both that spatially distributed information on each fingertip used as in natural haptics is not available and, in most displays, that the information is restricted to one finger. Thus, information both from the skin and from the joints is missing to a large extent. That the former information is important was demonstrated in experiments investigating the effects on several perceptual aspects of such restrictions applied to exploration of real objects [4].

In an earlier experiment [3] it was found that virtual textures were perceived very similar to corresponding real textures when both were explored in the same way (with a stylus). Another experiment in the same study demonstrated that 3D virtual objects of simple geometric forms could be identified to a considerable degree (for instance, spheres were correctly identified to 100 % in all sizes and for other forms the results varied between about 75 and 100 % correct). However, the objects in this experiment

[1] The reason for this is certainly that providing more contact points would much complicate both hardware and software, and consequently increase the cost of the device. Use of more than one display would increase the number of contact points, but also the cost. A technical development presently going on towards a six-degree-of-freedom PHANToM may also mean a useful increase of contact points. In both cases, however, important differences with natural haptic exploration remain.

were relatively large (maximum dimensions 10 to 100 mm) and rather long exploration times were required (means for each object about 10–35 sec).

The aim of an experiment [2] to be summarised here in some detail was to compare the accuracy and speed of identification of 3D virtual objects rendered by the PHANToM with that of real objects explored naturally. In order to get a more demanding task than in the earlier experiment objects of smaller sizes were chosen for the study.

Haptic Display

The haptic display used (the PHANToM) consists of a robotic arm providing force feedback according to software taking into account users' movements of this arm during exploration of a virtual object. The contact point offered is located either within a thimble into which the user puts a fingertip or at the tip of a stylus held with several fingers.

Virtual and Real Objects

Four virtual 3D forms (sphere, cube, cylinder and cone) in different sizes (maximally 5–9 mm in each dimension) were rendered with the software ENCHANTER (developed by Jens Fänger and Henry König in co-operation with the author[2]). Corresponding real objects were constructed by a professional model maker from layers of thin paper sheets glued together. They were perceived to be similar to wooden objects.

Exploration Methods

Both exploratory options of the PHANToM were included in the experiment: one finger in the thimble or several fingers holding the stylus. The real objects were given to one of the observers' hands. The observers were allowed to use any natural method. Typically, they kept the object between the thumb and two or three other fingers on the same hand and moved it back and forth.

Results

It is apparent from Fig. 1, and highly significant statistically, that the two Phantom exploration methods of virtual objects did not reach the high level of the natural exploration method of real objects, neither in accuracy nor in speed. Further, it is clear that the two PHANToM methods gave very similar, not significantly different, results. There were also statistically significant effects of size of the objects.

[22]This software, which is based on the Sensable software GHOST, can now be downloaded gratis from http//: www.sensable.com/products/GhostDemos/GreatestHitsVolume1.htm.

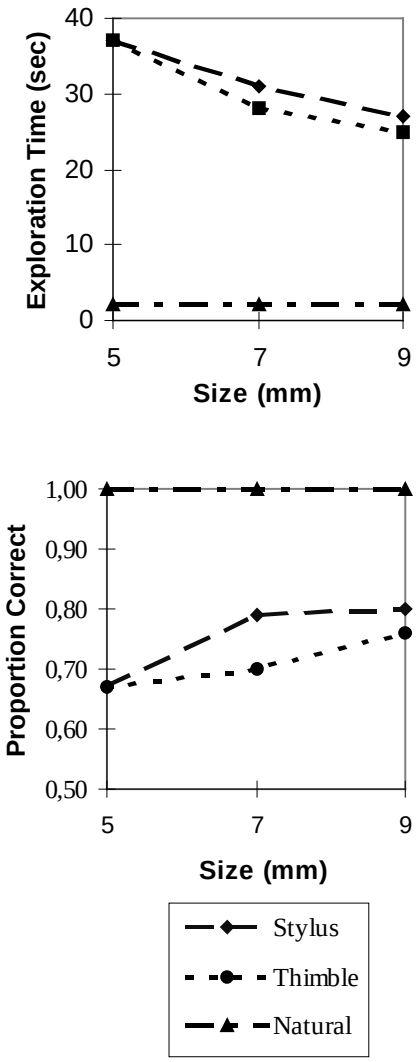

Fig. 1. Exploration time and proportion correct judgements as a function of object size for each of the exploration methods.

DISCUSSION

The Importance of Exploration Method

The virtual and real objects differ in both stimulation provided and exploration methods available. Informal observations indicate that the virtual objects mirror the real objects quite well, possibly with the exception of sharp borders not being exactly similar. Therefore, the main difference between the experimental situations seems to be what exploration methods are available. When real objects are explored simultaneous, as well as successive, stimulation from both several fingers and an extended skin area on each finger involved is made available. The information at a time provided via the thimble is restricted to what is obtained from one

contact point with the virtual object. The stylus is also restricted to one contact point but allows simultaneous information from several fingers holding it.

From the point of view of amount of information provided, it might be expected that the three conditions differ such that natural exploration of real objects gives the best result, followed, in order, by the stylus and the thimble. This expectation is verified concerning natural exploration of real objects compared with exploration of virtual objects, but there is no difference between the two options of exploring virtual objects.

The Similarity of the Two PHANToM Options

It is somewhat astonishing that the two PHANToM options are so similar in efficiency, as the ways the thimble and the stylus are held are quite different. The thimble allows only one finger to explore, while the stylus is held by several fingers. The similarity indicates that the common feature of the two options, to make possible only one contact point at a time with the virtual object, is the most important factor.

The Effect of Size of a Virtual Object

There was a statistically significant effect of size of the virtual objects on both accuracy and speed. This effect is further demonstrated when the present result is compared with the result in the earlier experiment mentioned above where virtual objects up to a size of 100 mm were investigated [3]. The relatively high accuracy obtained in that experiment (about 85–95 % for sizes over all forms) did not return here (corresponding figures being about 70–80). Exploration times were also longer with the smaller objects (not far from 40 sec for the smallest size, compared with about 15–30 sec over all forms of the larger sizes).

Exploration Tasks Compared

The results of the experiment on judgements of texture [3] demonstrated close similarity between virtual and real textures in contrast to the results concerning 3D form. A reason may be that exploring a 3D object for identifying its form is a more demanding task for the observer's exploratory skill than judging a 2D texture surface. For judging the coarseness of a texture only a 1D movement is needed, while exploration in 3D is required for identifying an object. In general, it can be hypothesised that the difference between judgements about virtual and real objects will increase with the complexity of the task.

The Potentials of the Haptic Sense are not Fully Utilised

The results demonstrate that the haptic sense is not utilised to its full capacity in the haptic display studied. It can be expected that better accuracy and speed would be obtained if the display allowed exploration with a larger skin surface at the fingertip and more than one finger.

It should also be observed that some improvement with the present exploration options might be achieved by training the observers in the effective use of them. The available methods do not resemble natural methods very much and thus the observers are probably not very keen in utilising them. The results may improve considerably in both accuracy and speed by special training. Experiments to investigate this possibility are in progress.

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