

Psychophysical Size Discrimination using Multi-fingered Haptic Interfaces

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Abstract. The use of multi-fingered haptic devices can potentially provide users much more realistic interactions in virtual environments compared to single-point contact devices. The usability of multi-fingered devices necessitates the need for an understanding of their performance characteristics. Multiple Phantoms devices were used in psychophysical size discrimination experiments using two and three fingered grasps. The results of these perceptual experiments were found to be comparable to those of single-finger size discrimination studies as well as results obtained via finger-span methods. The findings imply that multi-fingered haptics can accurately replicate reality for tasks such as these. Additionally our findings indicate that a three-fingered haptic grasp can provide better discrimination than a two fingered grasp.

1. Introduction

Most haptic devices have utilised a single-point interaction paradigm, and although this approach has been generally convincing it does impose certain limits on what a user can feel and do. The ability to interact with objects in virtual environments using multi-fingered haptic devices would seem to offer a number of advantages over single contact devices. For example, they can be used to simulate more natural interactions found in grasping and manipulating objects as well as being more applicable to simulation of real world physics. Furthermore, additional information gained from multi-point contacts may be a useful aid to object identification, such as by blind or visually impaired users [1].

As part of a program of research investigating multi-modal haptic interactions using multi-fingered haptics this paper outlines our initial experimentations on human haptic performance for size discrimination using multiple Phantom haptic devices. Performance comparisons of size discrimination using single-point interface devices provide comparable results between real and virtual environments [2]. However, data for size discrimination using multi-fingered haptics is lacking.

2. Methods

2.1 Design. In order to assess users ability to determine size differences a two-alternative forced-choice methodology was implemented. Participants were required to judge, using touch alone, which of two haptically rendered spheres was the larger. Two studies were carried out utilising a two-fingered grasp and a three-fingered grasp condition. Spheres were chosen since it was felt that they would be more in keeping with the natural characteristics of the grasp position. The spheres were presented within the same time interval in two spatial locations – side by side with 5 cm between them. One of the haptically rendered spheres (the reference or standard stimulus) was 5 cm in diameter, the other sphere varied in 0.5 mm increments, from 4.7 cm to 5.3 cm diameter. There were a total of 132 stimulus trials (six size differences twenty-two times each). The choice of sphere diameters was a result of earlier pilot studies. To counteract any affects that the presentation order may have both sphere position (left/right) and presentation order was randomly assigned.

A visual aid was used to help subjects in locating the haptic spheres. This took the form of graphical spheres displayed via computer monitor (see figure 1). The graphical spheres were positioned to fully enclose the haptically rendered spheres. Thus, not allowing any visual aids to affect judgment. Thumb and fingertip positions were represented by two/three yellow dots.

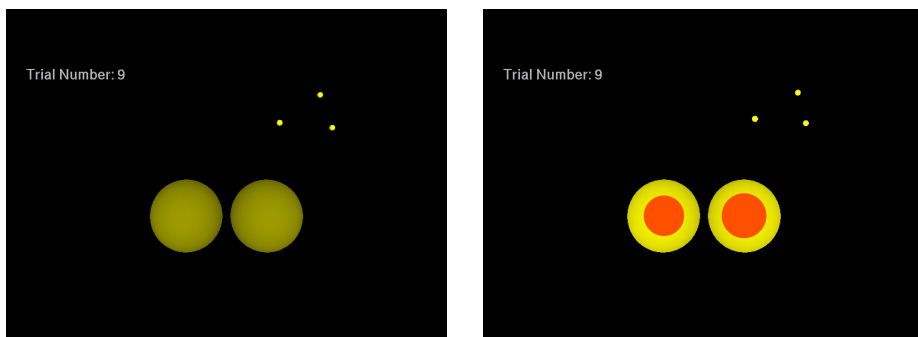


Figure 1. The left image shows the visual aid displayed to the subject and the right image shows the location of the haptically rendered spheres.

2.2 Haptic Devices. Phantom 1.5 haptic interfaces were used running rt-linux version 2.4. The Phantoms are being updated internally at 1000Hz while the phantom positions and forces are calculated at 700Hz. The graphic environment was updated at 25Hz. The Phantoms provided a total virtual workspace of approximate dimensions 27x25x19 cm. Haptic rendering was implemented using the friction cone algorithm where friction coefficients are set to zero i.e. the spheres are frictionless [3]. To enable finger and thumb grasps to be made the Phantoms were fitted with thimbles. Pre-trial investigations highlighted the necessity for accurate calibration of the Phantoms, where precise alignment of the two workspaces was vital. It was found that there were two main components of calibration error - horizontal and vertical displacement errors and rotational displacement errors.

The horizontal and vertical displacement error is due to compliance in the system and sensor resolution of the encoders. This leads to increasing alignment errors from the calibration centre towards the edges of the common workspace. In order to reduce the effect of this calibration error, calibration of the workspace was confined directly within the experimental workspace 20x10x10cm.

The rotational displacement error is due to the fact that the calibration methods calibrate both Phantoms in one point, whereas they should be calibrated taking into account the thicknesses of the thimbles. In order to minimise this error an offset is required to counteract the change in distance between the transformed endpoints when the thimbles are rotated. Inaccurate offset displacements leads to increasing positional errors upon rotation. A finger thickness offset of 1.6cm was used in addition to participants being requested to maintain the orientation of the thimbles for the two-fingered grasp. For the three-fingered size discrimination task, constrained alignment of the thimbles is unnatural and consequently rotations need to be allowed. However, this leads to an increase in rotational displacement error.

Figure 2, shows an error map of the experimental workspace. The average error for the two-fingered grasp was 0.51 mm, whereas, for the three-fingered grasp the average error was 0.56 mm. However, these error values are based upon the full range of possible hand movements and rotations. Since the highest errors are recorded when the fingers are fully rotated and the movements used within the experiment was nominally $<90^\circ$ around each of the axes, the actual average error could be considerably less.

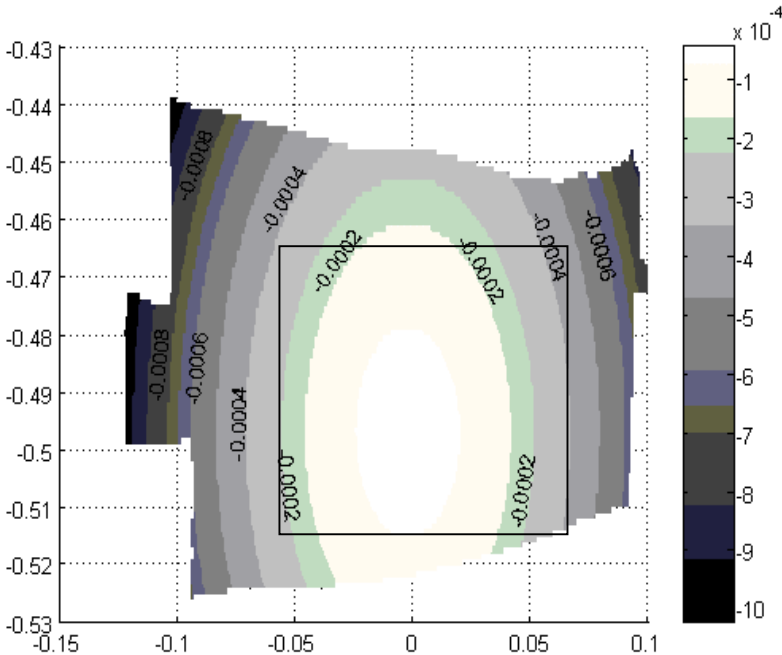


Figure 2. Error map showing the experimental workspace through the xz plane. Error contours are labelled in metres.

