Design of a Multiple Contact Point Haptic Interface

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Abstract

This paper addresses key perceptual and psychophysical issues concerned with the design of a multiple contact point haptic device. The majority of commercially available haptic devices operate based on a principle of point interaction. Thus, contact between the operator and the simulated virtual environment occurs only at an arbitrary single point, typically the tip of a stylus or thimble used for interaction. However, this can severely impair, or even exclude, perception of object material properties. It is shown that a haptic interface mechanism incorporating several points of contact, corresponding to the tips of different fingers, for example, may facilitate more optimal acquisition of information regarding object properties. An example of how several grounded devices may be positioned to combine their workspace is presented, achieving a workspace of roughly 20x30x15 cm.

1. Introduction

When haptically exploring an object, it has been shown that the explorer unconsciously adopts a series of stereotypical hand movements, in order to extract the desired information in an optimal fashion [4]. Each exploratory procedure (EP) is associated with a particular object dimension, for which it is the optimal and preferred method for determining the property under unconstrained haptic exploration. Experimental results clearly indicated that in a free exploration t ask, hand movement was related to desired knowledge. EPs adopted during free exploration are usually optimal, if not necessary, for extracting the information required.

When using a haptic interface in order to explore a simulated or remote environment, it is inevitable, given the mechanical constraints imposed by the design of such devices, that performance of EPs is impaired, and in some cases totally occluded. Thus, the user is forced to adopt sub-optimal exploration strategies in order to extract properties of objects. This problem is particularly accentuated for those devices that operate on a principal of point interaction via a thimble or probe.

Given such constraints, table 1 summarises the principle EPs and their availability during point interaction. Hence, lateral motion, pressure and contour following are unaffected by the point interaction method, though the cues they elicit will differ from those obtained via direct contact. Unsupported holding, given the formal definition above, is not possible. However, it is possible to simulate weight sensations by allowing virtual objects to be "stuck" to the distal point of the probe. In theory, static contact is also possible, though temperature actuators have yet to find widespread application in the field. Finally, enclosure is impossible to perform via point interaction, as at least two points are required to begin attempting to mould to an object's global shape.

It has been shown that material properties of objects (for example, stiffness and texture) obtain a higher salience under purely haptic exploration, whereas structural cues are more easily obtainable and, hence, more salient for discrimination under visual exploration [2].

However, results suggest that perception of material properties, such as texture, is impaired due to the bandwidth of currently available haptic interface technology [7, 11, 12]. Thus, operators of haptic interfaces are forced to adopt a "visually mediated" approach to object discrimination, that is to say, that performance must rely on visual stimuli provided by a suitable display, or that the user must gather information regarding object properties that are more readily encoded by vision, such as size and shape.

Current haptic interface technology, however, provides no facilities for the enclosure EP, which is optimal for global shape and volume. Point interaction devices are also deleterious to the execution of contour following, which becomes time consuming and difficult due to the greater memory demands for temporal integration of cues. It was shown that exploration via a single contact point increases response times in tasks requiring comprehension of geometric data [5]. A similar effect was observed between full handed and single fingered exploration of objects[3].

Exploratory Procedure	Description	Availability under point interaction
Lateral Motion	Movement back and forth between skin and object surface.	Available, though cues will be temporally varying (vibration) instead of spatially varying.
Pressure	Applying normal force.	Available
Static contact	Resting passively without moulding.	Available, though no temperature or distributed force cues are available through probe.
Unsupported Holding	Object is lifted and maintained.	Available, by attaching simulated object to distal point of probe.
Enclosure	Hand maintains simultaneous contact with as much of object as possible.	Unavailable in absence of multiple contact points.
Contour Following.	Smooth, non-repetitive movement with a contour of the object.	Available. Difficult to execute due to small contact area.

Table 1: *Availability of EPs with point interaction.*

2. Multiple Contact Point System

Given the limitations of currently available point interaction devices, a system is proposed in which several commercially available devices (the PHANToM (www.sensable.com)) are combined in order to facilitate multiple fingertip interactions. It is envisaged that the system will allow grasping and enclosure procedures previously unavailable with haptic devices, and will also potentially improve efficiency in extraction of object properties. For example, increasing the number of fingers stimulated by similar tactile sensations increases the perceived vibration magnitude by a rule of diminishing returns; thus, by using multiple stimulation points it may be possible to increase the perceived sensitivity range [6].

Srinivasan and Basdogan [8] identified multi-finger displays as an important future development in the field of computer haptics, though early exponents of the idea were Atkinson et al. [1], who outlined an idea for a "magic glove" which used miniature gas jets to stimulate the users hand. It was also proposed by Lederman and Klatzky [5] that multiple end effectors may be important for providing additional kinesthetic information.

We have adopted a design strategy incorporating several "grounded" interfaces, as opposed to an "ungrounded" device, such as a glove, or exoskeleton, as such devices have previously been shown to impair performance, whereas it is widely accepted that grounded interfaces such as the PHANToM are capable of supplying realistic force cues.

For example, Turner et al. [9] present results pertaining to a system for dexterous telemanipulation. The user wears a force feedback augmented instrumented glove (CyberGlove ® from Virtual Technologies) which transfers the user's movements to a two fingered dexterous robot hand mounted on the end of a 4-DOF industrial robot manipulator. Forces applied to the fingers are uni-polar, serving to only straighten the finger. The results indicated that the single axis of force feedback presented by the system did not increase speed of performance for simple telemanipulation tasks. Subjects pointed out that the force feedback could be misleading in a "block stacking" test, whereas provision of force cues actually had a negative effect on performance in a "knob turning" test. These examples serve to illustrate the importance of the device used to display force cues, and how they affect task performance when they are limited, unavailable or inappropriate to the task at hand. The force feedback system had a cut off frequency of 40 Hz, which means it would have difficulty displaying higher frequency slip sensations and vibrations, which are important in manipulation tasks.

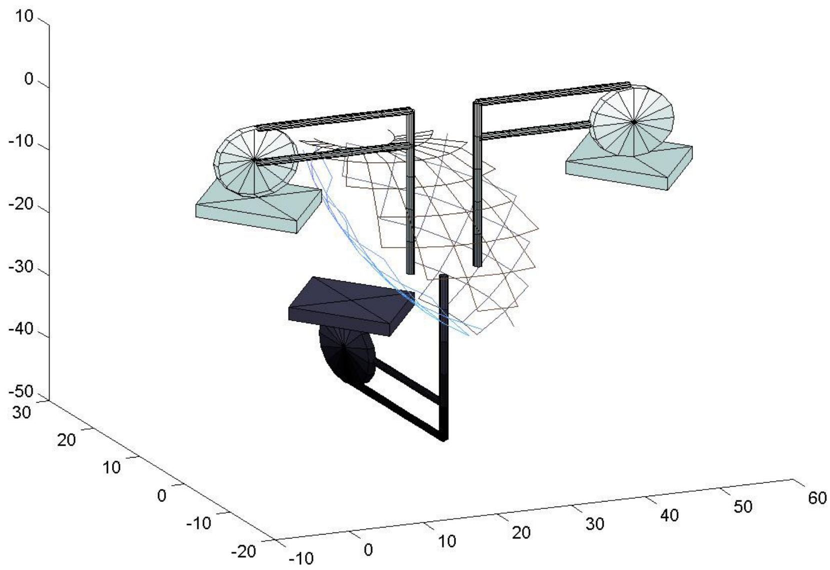

Figure 1. *Workspace of three PHANToM composite system.*

3. Workspace Configuration

The advantage of ungrounded devices is that they are often designed with regards to the range of movement / degrees of freedom of a particular human joint or limb, such as is the case with hand or arm exoskeletons. Ungrounded devices, such as the PHANToM, or Impulse Engine (www.immersion.com) often have a much more limited and less intuitive workspace.

As the composite device will incorporate several grounded interfaces, it is inevitable that their combined workspace will amount to less than that which is afforded by a single device of that type. It is an important factor in the design of the interface, however, to consider the extent of this available workspace, and how this will facilitate employment of stereotypical grasp mechanisms (e.g. pinch, key grasp etc.), and EPs.

Figure 1 illustrates one such suitable configuration for the three PHANToM devices. Thus, two PHANToMs are placed opposite each other, facing each other in the reset position. The final PHANToM is positioned immediately below the first two devices, and is inverted. The workspace is roughly 20x30x15 cm. A typical configuration for a two PHANToM 3.0 system offers a workspace of 30x40x40 cm [10].

It is also important to establish the range of flexion and extension available to the fingers and wrist, and the range of grips that can be performed. With three contact points, it is, in theory, possible to perform pinch grasps, tripod pinch (pen grasp) and key grips. However, more investigation is required to fully quantify the extent to which these procedures can be executed under a given 3 PHANToM setup.

4. Future Work

It is planned to investigate several other possible configurations, in order to ascertain which arrangement will offer the best workspace, and possibilities for user interaction techniques. A similar study involving two PHANToM devices highlighted the difficulties involved in calibrating the two devices [10]. Results showed that careful calibration of the two devices produced an average position error of below 1mm between the physical point and the point in the virtual space. Inevitably, this problem will be more complex with 3 devices, and potentially detrimental to the illusion of physical contact and grasp stability in the simulated environment.

Typical grasping mechanisms employed by users have been considered, though formal verification of which grasps can be performed and their efficiency must be investigated.

5. Conclusion

This paper has outlined the need for consideration and development of multiple contact point haptic interfaces. It was illustrated that current devices tend to impair performance of stereotypical EPs, and inhibit acquisition of information regarding object properties. This mostly occurs due to the point interaction method of simulating contact, though the devices bandwidth and physical properties are also a contributory factor. It is envisaged that a device incorporating several, grounded, point interaction type devices will allow more natural exploration of simulated environments, potentially increasing their efficiency, and ease of use.

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