Using More Salient Haptic Cues in Data Visualization

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ABSTRACT
This position paper advocates the use of material properties in haptic visualization systems. Under manual haptic exploration, material cues such as texture and compliance have been found to be important for identification and discrimination of objects. However, traditional visualization techniques employed with haptic interfaces, such as line graphs, bar charts and surface plots all rely on the perception of trends in shape, size and global distributions which are time consuming to explore due to the point interaction nature of most commercially available haptic devices. We propose two possible solutions to brainstorm: the adoption of alternative, material cues for haptic representations of data, and the reduction of working memory demands incurred through spatially diffuse material, either by a reduction in spatially distributed cues or by use of multiple modalities to provide greater contextual information.

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Haptic, visualization, blind

ACM Classification Keywords
H5.2 User Interfaces. (D2.2, H1.2, I3.6). Haptic I/O.

INTRODUCTION

Current implementations of haptic visualizations for providing access to digitally stored data have sought a direct analogy with their more visual-centric counterparts, such as bar charts and line graphs[1, 2]. However, the lack of distributed, contextual information available through point-interaction style haptic devices often makes it difficult to obtain an overview of the data being represented in an efficient manner, or make rapid comparisons between spatially disparate elements of the visualization. The rich, spatially distributed nature of visual cues is not available during haptic perception, hence, users must successfully integrate a series of temporally varying cues as they traverse objects and surfaces that represent the data. For large or complex data sets this can place considerable short term memory demands on a user, thus impairing their comprehension of the information contained in the visualization.

MEDIATION OF EXPLORATORY PROCEDURES BY FORCE FEEDBACK INTERFACES

When exploring an object via the sense of touch, it has been shown that a series of stereotypical hand movements are unconsciously used, in order to extract the desired information about the object in an optimal fashion. Each exploratory procedure (EP) is associated with a specific object property, for which it is the optimal and preferred method of exploration [3]. When exploring simulated virtual objects via a haptic force feedback device it is inevitable that performance of the EPs is impaired, or in some cases totally occluded, forcing adoption of sub-optimal EPs. Table 1 summarises EPs, as described by Lederman and Klatzky, and their relative availability when mediated via point interaction. In all cases we are assuming the use of a force feedback device employing a point interaction method of haptic rendering, analogous to using a PHANToM haptic interface (Sensable Technologies Inc.).

When exploring objects manually, information regarding object properties has been shown to be differentially salient under conditions of purely haptic exploration when compared to combined haptic and visual exploration. When visual information is available, structural cues such as global size and shape become the most salient factors for rapidly identifying and discriminating objects. Conversely, under purely haptic exploration, material cues such as texture and compliance have a greater significance. It was hypothesized that the relative salience under the different conditions of exploration was due to the ease of encoding the properties. Shape information is quickly and easily extracted through visual means. In contrast, the optimal EPs for identification of texture and compliance – lateral motion and pressure, respectively – are simple and fast to execute [4]. It is hypothesized that when exploring via a haptic device, the hierarchy of salience for object properties will be different to that for manual haptic exploration.

It is inferred that size and shape will take on a relatively low salience due to the difficulty involved in extracting the information. Studies by Lederman and Klatzky [5], and Jansson et al. [6] have indicated that in the absence of visual cues, the point interaction nature of haptic force feedback devices greatly impedes the user's perception of size and shape. The most efficient EP for extracting size and shape is "enclosure", which is unavailable through a single point of contact. Therefore, the user of a haptic

Exploratory Procedure	Property Sensed	Description	Availability under point interaction
Lateral Motion	Texture	Movement back and forth between skin and object surface.	Available, but cues will be temporally varying (vibration) rather than spatially varying.
Pressure	Compliance/Stiffness	Applying force normal to object surface.	Available, but discrimination will be degraded due to lack of spatially varying cues.
Static Contact	Temperature	Resting passively without molding to surface contours.	Temperature actuators generally not available.
Unsupported Holding	Weight	Object is lifted and maintained.	Available, by attaching simulated object to distal point of probe.
Enclosure	Global shape	Hand maintains simultaneous contact with as much of object as possible.	Unavailable in absence of multiple contact points.
Contour following	Local/global shape	Smooth, non-repetitive movement over a contour of the object.	Available, but significantly impaired due to lack of spatially distributed cues (for edge following).

Table 1. Mediation of EPs when employing a point-interaction force feedback device.

device must instead adopt a "contour following" strategy to trace the outline of a shape rendered by the system. However, the lack of spatially distributed cutaneous information on the fingertip regarding the object is detrimental to the task of edge detection – an essential factor of the contour following EP.

Material properties such as texture, stiffness/compliance and weight would likely take on a higher salience during free exploration tasks given the affordances of the haptic sense, and the impact of mediation via a force feedback device. Perception of texture, weight, and compliance is possible through a force feedback device, but more research needs to be performed on exactly how perception is mediated by a device.

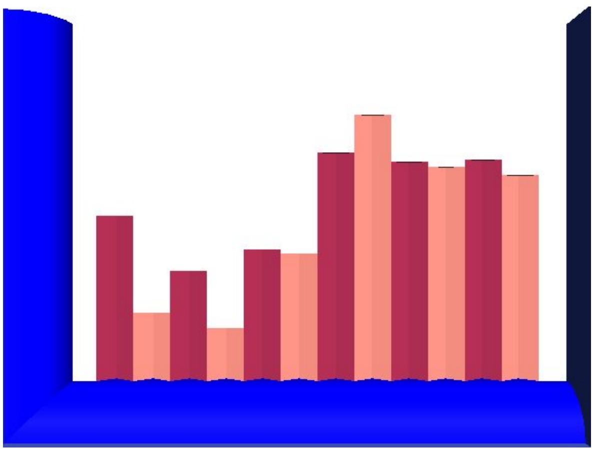

Figure 1. Visual representation of a haptic bar chart. Bars were rendered as grooves in the surface.

IMPLICATIONS FOR HAPTIC VISUALIZATIONS

Current implementations of haptic visualizations that adopt a direct analogy to visual graphs rely heavily on the perception of size and shape distribution in order to detect trends and identify interesting data. However, in the absence of visual cues, it would seem that perception of these attributes is potentially time consuming and frustrating. Comparatively, material properties of objects, such as texture, weight and compliance would appear to be easier to extract via haptic exploration, but are little used in haptic visualization software.

A haptic visualization system based around scaling of material properties to represent data may be potentially faster for users to obtain an overview of the data with. Previous research in this area [7] has investigated discrimination of haptic properties that are potentially suitable for visualization techniques with a phantom force feedback device. These could be used in an entirely non-visual manner, for example, with visually impaired users, or used to provide extra dimensions with which to encode data in a representation that exploited both haptic and visual properties. The properties tested were friction, stiffness and spatial periodicity of sinusoidal textures. Using a forced choice procedure whereby participants chose the "odd one out" from three stimuli, it was found that discrimination of friction was significantly better than the other two properties [7]. Subsequently, bar charts were evaluated with visually impaired users in which the data to be represented was scaled to either the height of the bar, the friction of the bar, or both simultaneously (see Figure 1 for a visual representation) [8]. In the friction condition, the bars were all of the same height, and a bar representing a higher data value would have a higher friction ("more sticky") while one representing a lower value would have correspondingly less friction ("less sticky"). However, answers to questions regarding the data represented by the graphs were significantly less accurate when the friction cues were employed alone. Qualitative comments from *post-hoc* interviews with the participants revealed that their unfamiliarity with force feedback technology and the method of representing data may have contributed to their poor performance. Anecdotal evidence obtained during the experiment suggests that the participants were visualizing standard bar charts based on height cues when constructing mental representations, even when solely frictional cues were used.

DISCUSSION

Results from psychophysical and perceptual studies would seem to promote the use of material properties in haptic virtual environments. The design that was tested still represents a compromise between use of material cues and a traditional, visual-centric representation of data, as the elements of the chart were still composed of bars ordered along a horizontal axis. This design resulted in the cues being spatially distributed over the workspace of the chart, thus making comparisons difficult.

In general, the haptic sense offers a high resolution when making relative judgments, for example, searching for the end of a roll of adhesive tape using a fingernail, or comparing two sandpapers of subtly different grade. However, subsequent recall and unique identification can be more problematic. Whilst the visual sense is excellent at comparing many datums in parallel on a standard graph, comparisons using haptics are necessarily sequential, thus with only a small number of bars, working memory can become overloaded.

Anecdotal evidence from participants would also suggest that the mapping strategy was non-intuitive to some of them. It seems there is no accepted convention what constitutes a "high" or a "low" value of friction. Some participants expected a low friction, or "high smoothness ", bar to represent higher data values. However, this problem is not unique to haptics and can occur with other, more established, modalities such as sonification (the use of non-speech audio to convey data). For example, sonification systems have mapped the Y-axis values of 2D graphs to pitch, yet a low pitch can be perceived as "larger", especially by the visually impaired, due to its connotations of a larger or more dense object. Spatial frequency of a sinusoidal surface texture may present a more intuitive mapping, but this has not yet been tested, as friction discrimination was found to be of a significantly higher resolution during earlier experiments. "Roughness" was deliberately not referred to during these same studies as the perception of roughness seems relatively poorly understood when mediated via a force feedback interface, and users' perceptions can be volatile (e.g. [9]).

FUTURE RESEARCH

Two potential solutions are proposed for surmounting the problems with spatially distributed data. Firstly, in order to preserve the spatial relationships between datums observed in traditional graphs, it may be possible to provide more contextual information through either the audio or tactile modalities. Preserving spatial relationships is important as the late-blind will have had prior experience of visual graphs, which they may want to continue using. A common representation would also improve communication with sighted teachers and colleagues. Providing additional redundancy through audio cues has been shown to improve performance with haptic representations of traditional bar charts [10]. Non-speech audio cues can be used to improve response times by providing a more immediate indication of data values. Speech audio cues can be used to provide exact data values where required by the user. Using techniques such as stereo-panning, it may be possible to provide additional information regarding data adjacent to that on which attention is focused with the haptic device. Contextual information regarding adjacent data could also be provided using either pin-array or vibrotactile transducers, although more research is required to identify suitable parameters with which to encode information [11].

A second solution is to attempt to eliminate the spatially diffuse nature of haptic data visualizations. The duplex nature of the haptic channel is often touted as a benefit but the need for active movement in order to produce stimulation, particularly over spatially disparate stimuli, could be seen as a disadvantage in this case. Sonifications of data often require that the listener navigate through the data using a second, more conventional, interface device such as the mouse or keyboard (as opposed to actively moving their head). Exploration in this fashion could be adopted by haptic visualizations, whereby the user adopts a "semi-passive" exploration strategy, generating haptic stimulation to the non-dominant hand (or an alternative body location) by navigating through a data plot using a mouse, cursor keys or an alternative input device in the dominant hand. Although experimental results are often contradictory, there is some evidence to suggest that passive exploration of stimuli offers scope for better performance than active exploration.

CONCLUSION

In this paper we have proposed a new approach to rendering haptic visualizations of digitally stored and manipulated data. It was shown that perception of shape and size may be impaired when mediated via a point-interaction style force feedback device, which may prove detrimental to traditional representations of data. Therefore alternative representations are required which surmount the difficulties inherent in haptic perception of spatially distributed information using a point interaction force feedback device.

It was suggested that material properties, such as object texture and compliance, may be more readily encoded when using a haptic device, and some preliminary results in this area were discussed. Further, using the tactile and audio modalities to provide additional contextual information was considered. The amount of exploration of spatially distributed material that is required may potentially be reduced by adopting a more “passive” method of haptic exploration, augmented with a second input device for navigating data. Potential questions to be brainstormed and activities for the workshop in this area are as follows:

- Identify possible parameters for haptic mapping of data. Rapidly prototype examples of these using physical props.
- Brainstorm ways in which more contextual representation can be incorporated, either through the haptic modality, or other channels such as audio or tactile.
- Discuss methods by which spatially distributed content can be reduced in haptic visualization. Create physical prototypes where possible to illustrate designs.

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