Tactile Cueing in Haptic Visualization

Kanav Kahol
Center for Cognitive Ubiquitous Computing
Arizona State University
Tempe, Arizona 85287
4809651885
kanav@asu.edu

Priyamvada Tripathi
Center for Cognitive Ubiquitous Computing
Arizona State University
Tempe, Arizona 85287
4809651885
pia@asu.edu

Sethuraman Panchanathan
Center for Cognitive Ubiquitous Computing
Arizona State University
Tempe, Arizona 85287
4809653699
panch@asu.edu

ABSTRACT

Haptic visualization is a key aid in presenting real or simulated data to individuals who are blind in a form that is suitable for comprehension. Conventional techniques in haptic visualization convert complex multidimensional data into a visual form such as points, lines, graphs etc. and subsequently add haptic features such as friction and texture to the rendered form. This allows individuals to feel the visual plots. However, this approach is limited to small datasets and restricted visualizations. Human tactile perception is based on numerous tactile sensors perceiving information in parallel. Current haptic visualization schemes have only limited feedback units that cannot present information in a realistic manner. Tactile cues, in the form of vibrotactile sensations, can aid in the haptic perception by providing supporting cues giving users the ability to utilize haptic exploratory procedures as well as parallel tactile cues for perception of haptic information. In this paper, we present strategies of presenting information through tactile cues and discuss verification and validation methodologies for the cueing based systems.

Author Keywords

Haptic User Interfaces, Parallel Haptic Cueing.

ACM Classification Keywords

H5.2. User interfaces: Haptic I/O.

INTRODUCTION

The main goal of haptic data visualization systems is to render complex data in a haptically comprehensible form, enabling users to perceive data characteristics through the sense of touch [3]. Traditionally these schemes convert complex multidimensional data into a visual form such as points, lines, graphs etc. and subsequently add haptic features such as friction and texture to the rendered form. This allows users to feel the formations. However, such systems have had limited success. They require extensive training for individuals who are blind and often the cost of the training far outweighs the benefits.

This approach of enabling users to *feel what is seen* subsumes that visual plots such as graphs can be rendered accurately by tactile and haptic sensations. The human tactile system perceives information in the egocentric reference frames [8]. Global configurations are perceived by employing haptic exploratory procedures [7] that are serial in nature and allow humans to perceive structure of the stimuli. It is however important to note that while haptic exploratory procedures are essentially serial, the human hand has numerous tactile and kinesthetic sensors that perceive information in parallel. Haptic perception is a result of numerous sensors in the hand perceiving time-varying stimuli in parallel where the variations in the stimuli are caused by the hand movements. In order to convey realistic haptic information to the user, and aid the visualization, it is necessary to provide sensations to a substantial number of tactile sensors in the hand.

The current haptic interfaces such as haptic joysticks and datagloves allow contact point based interactions with the virtual environment [3]. Haptic features such as texture and friction are assigned to each vertex of a virtual object. The haptic joystick allows users to perceive a single vertex and then perceive a series of the vertices through haptic exploration. Commercially available haptic gloves such as CyberTouch® have more than one tactile feedback motors on the glove and hence allow users to perceive more than one vertex at any given point in time, thereby allowing limited parallel communication. However both these systems are severely limited when compared to the scale of the human tactile sensory system. Current state of hardware miniaturization and parallel architecture of tactile interfaces is not sufficient to provide tactile feedback to the whole hand in real time. Realistic tactile feedback is necessary in many application areas such as telesurgery, telerobotics, and haptic interfaces for individuals who are blind. There is hence a need to develop innovative techniques for conveying complete tactile information through these limited interfaces.

TACTILE CUEING

The scale of human tactile sensory system allows placement of haptic feedback devices on different regions of the human body. These devices could be programmed to communicate information in parallel to the user and to *cue* a user about certain information relevant to the virtual environment the user perceives. *Haptic cueing systems* present an alternative to conventional haptic rendering of visual forms. Haptic cueing is analogous to audio-visual messaging used in conventional GUI's, where the user's attention is attracted to an event through audio-visual cues. Multimodal interfaces with haptic cueing have been used in various applications such as generation of alerts in cars for possible collisions [9]. However, conventional cueing paradigms are limited to focusing the attention of the user informing him/her of the event occurrence through tactile feedback and do not attempt to deliver informative haptic signals about the type of events. Also, currently available cueing systems were developed for multimodal environments, which include visual feedback and hence are not suited for haptic visualization schemes for individuals who are blind.

In this paper, we propose development of haptic cueing systems that can convey information about the virtual environment by supporting or replacing conventional haptic rendering. In order to optimize the information flow for maximum perceptual accuracy and bandwidth, these human-computer interface architectures are based on the knowledge of psychology, neuropsychology, and neurology of haptic perception [4, 8].

Types of tactile cues

Haptic space is a multidimensional space where the primary dimensions are shape, size, weight, texture, and material [8]. Psychological research on haptic perception suggests that human tactile sensory system is adept at perceiving local contact-based sensations and is specialized to perceive texture and material of objects [7]. From the point of view of designing haptic visualization this poses two serious problems which need to be accounted for.

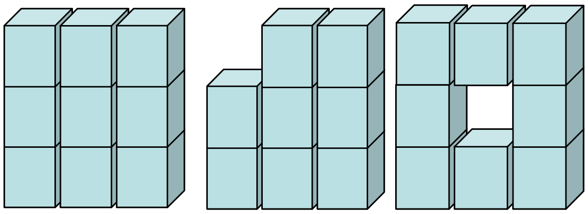
Firstly, although the maximum information flow from a computer to a user can be achieved by representing data as textures and materials, present day haptic interfaces are not suited to convey texture and material information. Tactile cueing can assist in providing cues about local information. For example, information about temperature of a material can be provided through tactile cues. Texture information can also be presented through tactile cues.

Secondly, haptic visualization schemes need to present global information through the limited haptic interfaces. Clark and Horch [2] while reviewing the research on kinesthetic memory concluded that humans have a "remarkable ability to remember positions of their limbs quite accurately and for long periods". Present day haptic visualization schemes rely on this motorical memory of individuals for perceiving global configurations [4]. However, a key element in this ability to remember positions of limbs is the proprioceptory feedback that the human tactile system picks up in the process of exploring stimuli [8]. Current haptic interfaces lack the proprioception necessary for superior kinesthetic memory. Therefore, they do not provide realistic local sensations, and do not allow accurate perception of haptic visualizations such as graphs, edges, and scatter plots by individuals who are blind [4]. Global configuration information can be provided through tactile cues. Researchers have proposed use of audio-cues for conveying global configuration information [3]. Tactile cues on global configuration information could be presented in a similar manner. In addition, parallel cues can be provided through different tactile channels. For example, information about global curvature and orientation of a surface can be presented simultaneously to a user through tactile cues.

In addition to the global configuration and local sensations, tactile cues can also be utilized for navigation. Studies done with tactile maps have shown that individuals who are blind are skilled at interpreting maps if the orientation of the map is aligned with the orientation of the individual [4]. When navigating a virtual environment with graphs such as line graphs or surface graphs, it maybe helpful to present tactile cues guiding the user on how to traverse the graph. However these cues should be based on the present orientation of the user in the environment rather than a global coordinate system such as a global north-south-east-west system that is utilized in the visual environments.

Determining optimal tactile codes for haptic features

While being supportive of perception and haptic visualization, tactile spatial cues can in certain cases lead to information overload and confusion for the user. It is hence important to systematically develop a cueing vocabulary to assist in haptic visualization. We developed a haptic system that incorporates cueing and conveys information about shape, weight, texture, and material of virtual object through user-determined cues [6]. Psychophysical experiments were conducted to design and test our system. The first set of experiments was conducted with blind and sighted individuals to determine the resolution of spatial information that is required to effectively recognize and represent objects haptically. In order to systematically vary haptic features we designed a block prototype similar to the 9 point stimuli used in visual pattern memory experiments. Figure 1 (a) shows the initial prototype which is varied for creating the haptic stimuli used in the experiment. The prototype model consisted of 9 square blocks each of the same dimensions and material. For shape variations, five stimuli were created with removal or 1 or 2 blocks from the 9 block grid. Sample variations are shown in 1(b) and 1(c). Similarly material variations were simulated by developing the prototype in different materials.



(a) (b) (c)

Figure 1. (a) The initial prototype, (b) and (c) sample shape variations

Texture variations were controlled by covering the surface of the prototype with different grades of sandpaper. The proposed methodology of varying tactile stimuli is configurable and can be subjected to multimodal variations. For example, stimuli could be designed to vary in both material and shape simultaneously. Within a dimension, the variations of the stimuli are allowed at the global level as well as at the local level. The stimuli could be designed to accommodate 9 different materials within the same stimuli. The proposed stimulus, hence, provides a novel and effective haptic experimental paradigm and various experiments can be designed with this stimulus for research in haptic cognition and perception.

We developed a memory retrieval methodology where the subjects were requested to explore real objects and then after a time interval reproduce the hand movements that they utilized to explore the original objects. The subjects were instructed to represent the object through descriptive exploratory movement so that a viewer could decipher its identity and salient characteristics by the subjects' hand movements. The conceptual framework that guides this experimental design is that the user only stores significant details about the objects and the order of retrieval of the feature is indicative of the perceptual salience of the feature [8]. Subsequently for presentation of a virtual representation of the real object back to the user, the features will need to be recreated and presented.

Objects (variation of 9 block stimuli) were presented in 5 sets. Each set consisted of objects that represented a controlled variation of shape, size, material, texture, or proportion. The hand movements used to re-present an object by the user are measured through the CyberTouch® gloves and stored. For each of the objects, annotation of the hand movement is done to find the order of retrieval of the features. In an earlier experiment, we had shown that it is possible to train a Hidden Markov Model (HMM) library to recognize exploratory hand movements [5]. We trained a (HMM) library to recognize movements utilized to re-present shape, size, weight, material, and texture in our experiment. This library aids in automatic recognition of the salient features for each object. These salient features form the set of communicative elements that were presented to the user to ensure recognition of the stimuli and its features.

In the second set of experiments, we employed CyberTouch® datagloves that contain six vibrotactile motors (one on each finger and one at the center of the palm) to present haptic stimuli to the user. The objective of this experiment was to test the validity of communication units that were discovered through experiment 1 and develop a cueing mechanism between the system and the user. In this experiment, the participant determined the code to communicate the quantization level for a particular feature. Each of the vibrotactile motor was dedicated to presentation of quantization levels of a particular feature. The assignment of a feature to a finger motor was based on neurophysiological distribution of tactile sensors. For example texture information was assigned to the index finger vibrotactile motor as the index finger contains Merkel receptors that are specialized to perceive texture information [6]. In a similar manner, shape information is sent to the palm, material information is sent to the ring finger, size information is sent to the thumb and so on. A training phase was employed for each of the users. In the training phase, users were presented with haptic cues and were requested to recall the quantization level represented by the code. Feedback was provided to the users on their recognition accuracy and adjustments to the code were made based on the user's request. This iterative process led to development of the final haptic cues vocabulary that was used to convey spatial information. In the test phase, features of the unknown objects (created by variations of the initial prototype) were presented in a pre-determined serial order and the participant's task was to recognize the object. The cues were presented in six phases. The first phase of cues provided information about the overall shape, size, texture and material of the object. The second phase cues were programmed to convey information about objects base. The third, fourth and fifth phase were designed to provide information about the vertical regions of the object and the last phase provided information about the rim or the top of the object. This phased information delivery mimics the human exploratory procedure that initially perceives the overall object characteristics and then proceeds from the base of the object to the rim of the object. The recognition accuracy of the objects was measured for each participant. In our experiments, users were trained with 5 objects. An average training time of 0.5 hours was required for each of the user following which users were able to recognize a set of 55 objects through tactile cues only.

In the third experiment, we tested our hypothesis that interactive object exploration allows better haptic object recognition. We define interactive object exploration as the process of command-response interactions between the user and the system wherein a user can command the system to present information about a feature through a hand gesture. The system responds with a haptic cue that is coded to represent a specific quantization level. The experimental results confirmed the hypothesis. In addition, the performance of the haptic object recognition task in experiment 3 was better than the performance in experiment

2. Note that the communication between the system and the device in experiment 2 was unidirectional (from the system to the user). Initial results from these experiments suggest that a haptic cueing mechanism has the potential to serve as a powerful haptic communication strategy to convey spatial information. User determined cues can convey complete tactile information and lead to object characterization and recognition.

This methodology could be generalized to the development of tactile codes for haptic visualization and aiding in development of local, global, and navigational cues. Previous research on haptic interfaces has yielded clues on the features that can be realistically rendered and the features that are hard to recreate in a virtual environment. Tactile cues could support realistically rendered visualization schemes.

A Case for multiple parallel communication channels

Sighted individuals use vision to perceive numerous spatial features that are sensed and perceived in parallel [1]. Conventional audio-based cueing paradigms can only communicate information in a serial mode. However, tactile cues can be presented through multiple parallel channels to the user with cues being presented simultaneously. Parallel information processing and communication can lead to faster perception and facilitate cognitive processing that can draw correlations between various stimuli and develop models of spatial representations for typical environments and visualizations. There are however two fundamental research problems that need to be addressed specifically for the design of parallel communication channel based cueing methodology. The first problem applies to finding optimal physical placement of the feedback units. Research has been conducted to find optimal configurations in assistive devices [1]. There is a need to systematically study various configurations in the visualization scenario and its effect on perceptual accuracy. The second research problem applies to the architecture of information flow. Information flow from the virtual environment to the user could be through dedicated channels to convey information about a particular feature (such as surface temperature) or could be configured to be adaptive and variable. These configurations need to be validated and verified against perceptual accuracy and perceptual efficiency of the user to recognize the stimulus. Our design of the cueing system is an example of how parallel cues about features can lead to efficient object recognition. While our system was based on dedicated channels for a cue and based on fingers, other configurations need to be systematically explored.

CONCLUSION

Tactile cueing presents an exciting opportunity to further the goals of haptic visualization. Cues can aid in perception of local haptic features and global structure of the data. They can also assist in navigation (exploration) of the environment. These tactile features are critical for the observer to form mental models of the stimuli and perceive the visualizations. Our experiments have shown that tactile cues can both support and replace conventional haptic rendering techniques. These cues can be presented through single-channel or multi-channel systems. Future work in this direction will include finding optimal configuration of the parallel cueing systems and testing the systems with complex multidimensional haptic environments.

REFERENCES

1. BachyRita, P., *Brain mechanisms in sensory substitution*. New York: Academic Press, 1972.
2. Clark F. and Horch K., “Kinesthesia,” in Handbook of Perception and Human Performance v.1 Sensory Processes and Perception (K. Boff, L. Kaufman, and J. Thomas, eds.), New York: Wiley, 1986.
3. Fritz, J. P. and Barner, K. E., "Design of a haptic data visualization system for people with visual impairments," *IEEE Transactions on Rehabilitation Engineering*, vol. 7, pp. 372-384, 1997.
4. Hatwell, Y., Streri, A., and Gentaz, E., *Touching for Knowing. Cognitive psychology of haptic manual perception*. Philadelphia, PA, USA: John Benjamins Publishing Company, 2003.
5. Kahol, K., Tripathi, P., Panchanathan, S., and Goldberg, M., "Formalizing Cognitive and Motor Strategy of Haptic Exploratory Movements of Individuals who are Blind," presented at IEEE International Workshop on Haptic Audio Visual Environments and their Applications, 2004.
6. Kahol, K., Tripathi, P., and Panchanathan S., "Haptic User Interfaces: Design, testing and evaluation of haptic cueing systems to convey shape, weight, material and texture information," presented at Human-Computer Interaction, Las Vegas Nevada, 2005.
7. Lederman, S. J. and Klatzky, R. L., "Action for perception: Manual exploratory movements for haptically processing objects and their features," in *Hand and brain: The neurophysiology and psychology of hand movements*, A. M. Wing, P. Hagard, and J. R. Flanagan, Eds. New York: Academic Press, 1996.
8. Revesz, G., *Psychology and art of the blind*. London: Longmans Green, 1950.
9. Tan, H. Z., Gray, R., Young, J. J., and Traylor, R. “A Haptic Back Display for Attentional and Directional Cueing”, *Haptics-e Journal* Vol. 3, No. 1, June 11, 2003.