HAPTIC REPRESENTATION OF SCIENTIFIC DATA FOR VISUALLY IMPAIRED OR BLIND PERSONS

Jason P. Fritz
Thomas P. Way
Kenneth E. Barner
Applied Science and Engineering Laboratories
A.I. duPont Institute/University of Delaware
1600 Rockland Road Wilmington, DE 19899
Voice: (302) 651-6830 FAX: (302) 651-6895
Internet: fritz@asel.udel.edu,
way@asel.udel.edu,
barner@asel.udel.edu

ABSTRACT

Interpretation and understanding of complex scientific data is enhanced by graphic representation. For those people with visual impairments, this method is inadequate. An alternative, or additional, method is to represent the data using other modalities, namely touch and hearing. Haptic display of such graphical data adds kinesthetic feedback that provides the sense of touch. Audio feedback adds additional information to the haptic display to further improve conceptualization. In this paper, we review some of the existing methods of non-visual data representation, and present two new methods. The first method extends the capabilities of printing tactile graphics. With the aid of image processing techniques, complex images can be printed in a fashion that is more comprehensible as a tactile graphic. The second technique takes advantage of emerging haptic interface technology with a three degree of freedom (DOF) force feedback mechanism. This allows users to interact with two and three dimensional data plots with their fingertip. In addition, aural information and various haptic techniques can be added to aid in navigation and understanding. These two methods of non-visual data rendering extend current techniques and will eventually allow people to gain insight into scientific data without the use of vision.

1.0 INTRODUCTION

The use of computers to model complicated sets of data into a sensable form is a concept that dates back to at least 1960. This idea evolved into "scientific visualization," a broad term encompassing the use of various techniques for the representation of scientific data in a more easily understandable format, such as three dimensional plotting. Advanced computer graphics, in conjunction with auditory and haptic feedback channels including tactile display methods, are common tools for achieving such computerized representations [1,3]. The focus of our research is on the development of interfaces to create, or improve, access to scientific data for visually impaired and blind persons. Specifically, this encompasses the areas of tactile imaging and haptic graphing. After some background, we describe our current work on two unique systems for haptic representation.

The term "tactile" refers to the sense of touch, while the broader "haptic" encompasses touch as well as kinesthetic information, or a sense of position, motion and force. "Tactile imaging" is the process of turning a visual item, such as a picture, into a touchable raised version of the image, so that this tactile rendition faithfully represents the original information. This provides access for blind and visually impaired persons to normally inaccessible information. Typically, there are textual and pictorial components to such information.

For textual data alone, screen reading speech synthesizers operating with scanners and optical character recognition (OCR) software, Braille cell displays and Braille embossing printers are the media of choice for blind computer users. Some users prefer the vibrotactile pin array of the

Optacon, although its use appears to be on the decline. Persons with low vision typically rely on one or more of the these methods, combined with screen magnification software or hardware. Generally, any information obtained as text is accessible to a blind or visually impaired person. [2]

For pictorial scientific information, such as graphs, maps, drawings, and photographs, this is not the case. Static and dynamic means exist for output of many of these two-dimensional graphics. Braille embossing printers (in graphics mode), microcapsule paper and custom hand-made labor-intensive representations of paper, paste and string are used for static rendering of graphical information [4]. For active representation, the only dynamic display in everyday use is the Optacon. Active research in this area promises technologies such as nickel-titanium shape-memory alloy actuated pin arrays, an Optacon-based mouse, electrorheological fluid pads and full-page Braille cell displays [5,12]. These methods work well with simple two-dimensional graphs, maps and line drawings, but cannot adequately represent more complex photographic information. This shortcoming is the motivation for TACTICS, our tactile imaging system for translation of complex visual information into simplified tactually comprehensible form.

While tactile imaging is relegated to two dimensions, "haptic graphing" in Virtual Environments (VEs) allows modeling and exploration of scientific data in three or more dimensions. A haptic interface is a force feedback mechanism that is used to feel computer generated objects or forces that a remote robot is sensing. In the case of computer generated objects, the forces are calculated at a point called the interface point (IP). The IP location is determined in the coordinate system of the haptic mechanism via sensors, and then transformed to the coordinate system of the VE. Once in the VE, the force is determined based on the position of virtual objects with respect to the this point. For example, consider a "virtual wall" placed in the VE workspace. When the user moves the IP through the wall, the motors generate forces to oppose the motion. Given that no motor can have an instantaneous reaction time, the amount of the force is determined as a function of the distance into the virtual wall (e.g., Hooke’s Law $F=kx$ where x is the distance into the wall, and k is a proportionality constant). Thus, the haptic interface determines the coordinates of the IP, sends them to the VE, and then receives the value of the force to display to the user. Haptic display research is limited, but has been used to increase the immersive effect of virtual reality and scientific exploration such as molecule docking, nanoscale manipulation, and virtual surgery [1,3,10].

2.0 TACTICS: TACTILE IMAGE CREATION SYSTEM

tactics (tak'tiks) n.pl. tactile graphics.

TACTICS is a system that converts visual information, such as the abundant computer images available on the Internet, into tactile information. Specifically, it produces a meaningful tangible depiction of a complex visual image. To represent a photograph, for example, in a tactually perceivable fashion, one must reduce detail in the image while retaining meaning. The visual component of our system is implemented in software as a sequence of image manipulation processes. These algorithms segment the image into regions of similar gray-level, detect and enhance edges between regions, filter out unnecessary details or noise, and threshold the image [6]. This process produces a simplified line drawn, or coloring book style, version of the original. The basis for our hypothesis is taken from comprehensive work in tactual perception [7]. Our current implementation is in the C programming language as an extension to the University of Pennsylvania's image processing application "XV" (C).

The hardware components of TACTICS are a Reprotronics Tactile Image Enhancer (C), a supply of microcapsule paper, and a typical office laser printer and photocopier machine. Operation of the system involves loading an image, applying processing algorithms in a predetermined sequence, printing the result, photocopying this result onto microcapsule paper, and finally developing or "puffing" the image using the enhancer.

A pilot study employing the TACTICS system was revealing. We prepared a number of 2.5 inch square images by applying K-means segmentation and Sobel edge detection algorithms individually, together in both orders, or not at all. The images included a number of faces, a hot air balloon and an illustration of a human heart, all oval in shape. The image set also included photographs of a house, laptop computer and space shuttle launch. Blindfolded subjects performed a closed-set matching task, feeling one of the tactilized images and then attempting to find an identical one from among a randomly ordered collection of all similarly processed images. This task was repeated for each of the images and results were tabulated for each of the five possible processing sequences. When no processing was performed on the images, tactile images tended to be virtually indistinguishable from one another, with results only slightly better than chance (12 percent). For images processed using K-means segmentation or Sobel edge detection alone, results were dramatically improved, with recognition rates of 60-80 percent. Mismatches usually resulted from similar shapes among some of the images. When K-means was applied first, followed by Sobel, recognition was better than 70 percent. Best results were achieved by applying edge detection first, then segmentation, yielding a match 97 percent of the time.

These results indicate that simplification of an image can greatly enhance its recognition potential. While this does not address understanding of content, it is an important first step towards that end. To successfully accomplish tactile image comprehension, we feel that it will be necessary to associate textual description with simplified tactile images, much as a photograph in a newspaper usually comes with some brief caption. This is due to the inherent ambiguities involved with representing three-dimensional objects in a two-dimensional medium combined with the lower resolution of the fingertip. We are hopeful that the utility of this system will increase with user experience as well.

3.0 HAPTIC GRAPHING

Although haptic interfaces are being researched as a computer interface for blind people, no one has investigated using such a device to help interpret data plots in a non-visual fashion. For this purpose, we are using the PHANToM(TM) Haptic Interface from SensAble Devices, Inc. The PHANToM(TM) is a 3 DOF device that generates forces to the user's fingertip or to the tip of a pen-stylus. The PHANToM workspace volume is 13x18x25 cm with a position resolution of less than 1 mm [8]. We have designed techniques for feeling two and three dimensional plots (curves and surfaces), and discrete data points in space. To aid in the understanding of the data, methods for representing grids, axes, and speech output of the coordinates are provided.

A two dimensional plot can easily be represented with static methods mentioned earlier, but dynamic methods are often desired when exploring scientific phenomenon. In a 3D VE, a 2D plot can be rendered on a plane anywhere in the virtual workspace. For example, plots of position, velocity, and acceleration can be generated while performing virtual physics experiments. Similar to graphical representations, 2D curves are represented as piecewise linear line segments connecting the data points.

In order to find and feel very thin lines with a single point (the IP) a technique known as virtual fixturing is used [11]. The purpose of these fixtures are to generate forces to guide the user in performing dexterous tasks, such as teleoperation of a robot. That concept can be applied to feel lines by generating forces to pull the user's fingertip to the line, just as a magnet attracts iron. These forces are only perpendicular to the line, though, which allows the user to easily slide along the line, and thus, follow the data curve.

A three dimensional plot is felt using a different method. A 3D data set can be a 2D matrix of values (the values being the Z coordinates on an XY grid) or an array of vertex coordinates in space (the same way 3D graphics objects are defined). The vertices of either representation are connected with triangular polygons (facets), making the object surface piecewise linear. The methods for haptic rendering of 3D objects in [8,9] only consider objects as simple volumes (e.g., spheres and cubes). The method in [13] can render polyhedral objects, but has several limitations such as the number of polygons that can be used. The general haptics problem is finding the appropriate direction of the force vector. If the IP could not penetrate the surface, the problem would be simple because the direction would be the normal vector of the surface at that point. However, since the IP penetrates the surface, the force direction is calculated by determining which facets the IP would lie on if it could not cross through the surface. This point is called the Shadow Point. For a simple plane, the Shadow Point is the point on the plane that is closest to the IP. The Shadow Point algorithm also considers intersections of multiple planes that are concave (e.g., the inside edges/corners of a box) or convex (e.g., the outside edges/corners of a box).

Feeling discrete data points is accomplished in the same manner used for feeling a sphere with a haptic interface. To feel a sphere, the distance between the IP and the center of the sphere is calculated, and then compared to the sphere radius. If the distance is less than the radius, a force is generated to push the user out of the sphere, with a magnitude proportional to the distance of penetration. Therefore, in order to feel multiple points, a sphere is placed around the IP (the IP is the sphere center), and the distance between the IP and the data points are calculated. After all of the nonzero force vectors are determined, they are added together, and then sent to the haptic interface. In this manner, a user can feel a set of discrete points in space.

Even from a graphical representation of data, it is difficult to understand the nature of the data without numbered axes and tick marks. In a haptic environment, axes are represented with planes with periodic "bumps" for the tick marks. A haptic grid is also necessary to determine the approximate location on a plot without needing to return to the axes. To accomplish this, a grid is created by using thin walls that generate just noticeable forces when the IP passes through them. This allows the user to feel the grid without interfering with the data itself. As an additional aid for navigation, the user can request (at the touch of a button) for the current IP coordinates to be converted to speech via a text-to-speech converter. The spoken coordinates are relative to the origin of the plot currently being examined.

4.0 CONCLUSIONS

Our pilot study of the TACTICS system demonstrates that image processing techniques applied in the generation of tactile graphics is a viable research area. This technique extends to two-dimensional scientific information. For example, consider using TACTICS on an image of the planet Jupiter, sent back to Earth by the Galileo space probe. A blind science student could feel the immense swirling "eye" and the great patches of cloud cover, and gain new insight into the red giant. It is easy to imagine this technique applied to a multiplicity of scientific data, offering access where none before existed.

The data plots that have been represented with our haptic graphing system show great potential for opening a new door for humans to explore information without using vision. This is especially true in light of the current methods commercially available. Beyond the application for blind students, even sighted students can gain insight into scientific data through an additional medium. It is quite fascinating to be able to feel information that has previously been represented only on paper or a computer monitor.

5.0 FUTURE WORK

As research in progress, both the TACTICS and Haptic Graphing systems need further development. The desired goal is to create systems that are practical for consumer use, but a large factor in reaching that goal is feasibility and economics.

Expected development of the TACTICS system includes improvements to the prototype and subsequent development of a stand-alone application, and ultimately an affordable end-user system. The theories and applicability demonstrated by the TACTICS system should prove invaluable in the production of an active dynamic tactile display system. A display is only as good as the information it displays, and a TACTICS based system should provide a viable front-end for such emerging technology.

More research is necessary to determine the usability of the Haptic Graphing system. For one, human subject studies must be done to determine that a person can understand the contents of a haptic graph without the usual visual aids. More work is also needed to test and extend the limitations such as the complexity of the curve or surface, and the number of curves or surfaces on one plot. In the graphics community, interpolation schemes such as Phong shading are used to make a surface appear smoother without adding polygons. A similar interpolation of the facet normals in the haptic environment should allow a surface to feel smoother without adding facets.

REFERENCES

[1] Brooks, F., "Grasping reality through illusion - interactive graphics serving science", Fifth Conference on Computer and Human Interaction, CHI ‘88 Proceedings, 1988.

[2] Burger, D., "Improved access to computers for the visually handicapped: New prospects and principles". IEEE Transactions on Rehabilitation Engineering, vol. 2, no. 3, pp. 111-118, 1994.

[3] Durlach, N., Mavor, A. ed., "Virtual Reality: Scientific and Technological Challenges", National Academy Press, 1995.

[4] Edman, P.K., "Tactile graphics". American Foundation for the Blind, 1992.

[5] Fricke, J. and Baehring, H., "Design of a tactile graphic I/O tablet and its integration into a personal computer system for blind users". Electronic proceedings of the 1994 EASI High Resolution Tactile Graphics Conference (http://www.rit.edu/~easi/easisem/easisemtactile.html).

[6] Lindley, C.A., "Practical image processing in C", John Wiley & Sons, New York, 1991.

[7] Loomis, J.M. and Lederman, Susan J., "Tactual perception. Handbook of perception and human performance", ch. 31, 1986.

[8] Massie, T. and Salisbury, K., "The PHANToM haptic interface: a device for probing virtual objects". ASME Winter Annual Meeting, Symposium on Haptic Interfaces for Virtual Environment and Teleoperator System, 1994.

[9] Massie, T., Salisbury, K., Brock, D., Zilles, C., "Haptic rendering: programming touch interaction with virtual objects". ACM Symposium on Interactive 3D Graphics, ACM, 1995.

[10] Minsky, M., Ouh-Young, M., Steele, O., Brooks, F., Behensky, M., "Feeling and seeing: issues in force display". Proceedings of the Symposium on 3D Real-Time Interactive Graphics, ACM, 1990.

[11] Sayers, C., Paul, R., "Synthetic Fixturing". Advances in Robotics, Mechatronics, and Haptic Interfaces, vol 49, ASME, 1993.

[12] Vanderheiden, G.C., "Dynamic and static strategies for nonvisual presentation of graphical information". Electronic proceedings of the 1994 EASI High Resolution Tactile Graphics Conference (http://www.rit.edu/~easi/easisem/ easisemtactile.html).

[13] Zilles, C., Salisbury, K., "A constraint-based god-object method for haptic display". IROS Proceedings, 1995.