Tactile computer mouse: high-tech novelty or start of a revolution?

News-Journal wire services

FREMONT, Calif. - Run this computer mouse over an image of a tennis racket and it gives a series of small twitches, as if hitting the racket's hard plastic cords.

Guide the iFeel MouseMan mouse over a picture of an ice cube, and it seems to glide more smoothly across the middle.

A novelty for geeks or a milestone in the evolution of computing?

Logitech, the world's largest maker of computer mice, is betting this new mouse that "feels" will change the way we interact with PCs.

The iFeel MouseMan, for sale this fall, looks like most other mice but contains a motor that relates a sense of texture to the hand guiding it.

It's basically a gimmick borrowed from the world of video games.

But to Logitech's executives, this is a mouse that roars. They say it activates a part of human intuition now dormant in computing - and that someday nearly every Web page will have something to touch.

"If you look at how people use their PCs today, it's visual," said Wolfgang Hausen, senior vice president and general manager of Logitech's control devices division. "You look at it. You get sound back from speakers, but that's it. Well, people have other senses."

Logitech's chief executive, Guerrino De Luca, calls the mouse a "seed for a revolution in user interface."

It remains to be seen whether consumers will be so excited.

"I'd score it on the weak side ... but it's certainly interesting and it does have potential," said Martin Reynolds, a vice president at Dataquest, a market research firm.

The premise is known as force-feedback technology, which is used in military simulators and medical training devices. In video games, it makes the steering wheel shake when a virtual driver crashes or causes the joystick to shudder when a player fires a virtual machine gun.

Logitech and its biggest competitor, Microsoft, make many of those video game devices.

Logitech, which claims about 60 percent of the market for computer mice, came out last year with another mouse that used force-feedback technology. But that was a clunky model that had to remain on a console.

The sleek new mouse uses optical technology, meaning there is no need for a track ball to register its movement. It is expected to list at $39 in a standard mouse shape and $59 in a contoured shape for right-handers.

The technology is licensed from Immersion Corp. of San Jose, in which Logitech owns about an 8 percent stake.

The two companies hope the mouse will lead to textured Web pages that will allowing online shoppers, for example, to get a feel for the material they're buying.

"You can't underestimate how important the sense of touch is to the basic human experience of engaging," said Immersion's chief executive, Louis Rosenberg. "Once you have it, you want that natural intuitive experience. You don't want to go back."

Microsoft has decided not to sell force-feedback mice because people find them distracting and not advanced enough to be of much use on the Web, said Mary Starman, a spokeswoman for Microsoft's hardware division.

On the Net:

Logitech Inc.: http://www.logitech.com

Immersion Corp.: http://www.immersion.com

Perceptualisation using a Tactile Mouse

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ABSTRACT

Whilst there has been considerable effort in constructing force feedback devices for use in virtual environments, and in the use of touch as a prosthesis for the blind, there has been little work on the use of touch in the visualisation or more properly, perceptualisation of data. Touch potentially offers an additional dimension of perception where visualisation is limited by screen size, resolution, and visual overload. In this paper we describe some tactile mice and experiments in using tactile mice for a variety of perceptualisation tasks.

1 INTRODUCTION

In their comprehensive and instructive book on visualisation techniques Keller and Keller [12] classify problems in terms of the number of dependent and independent variables. Figure 1 lists most of the examples in their book. As we might expect the majority of examples are for data for which there is a single dependent variable whilst the number of independent variables ranges from 1 to 4. Typically the independent variables are associated with space and time. There are very few examples where the number of dependent variables exceeds 3 (Keller and Keller include examples with 11 variables, 21 variables, 12 dependent variables with 4 independent variables, and 20 dependent variables with 1 independent variable, but these examples are treated in a rather different way from others in the book). We might ask why problems with more than 3 dependent variables are infrequent. One possible explanation lies in the use of graphics. We can assign factors such as size, orientation, colour and glyph to the dependent variable dimensions but two difficulties intrude: the low resolution and small size of typical screens can induce visual clutter, and the human visual system may simply be presented with too much data to absorb. Screen size and resolution seem unlikely to increase to match conventional visualisation systems such as engineering drawings and maps, so visual clutter is likely to remain a problem for the foreseeable future. In our work at the University of East Anglia we have sought to extend the possible range of problems which can be visualised by investigating first the use of sonification [17, 18] and more recently touch. Our hope is that by this means we can extend the dimensionality of data which can be visualised or more properly perceptualised.

Dependent Variables	1	2	3	4
7		1		
6			1	
5		1	1	
4		1	2	
3	3	2	5	1
2		7	9	1
1	1	22	44	1

Independent Variables

Figure 1: Examples of Visualisation Problems Classified by Dependent and Independent Variables

2 MOTIVATION

In the early 1970's, one of the authors experimented with a computer peripheral for rapid production of three-dimensional models machined from rigid plastic foam [9], a precursor of rapid prototyping first implemented by Bézier [3]. One of the models made during that era is shown in Figure 2. It represents two 4x4 arrays of bicubic surface patches. In the pre-Bézier/B- spline era, surfaces were defined in Hermite form, necessitating the specification of cross- derivative vectors at patch corners. These so-called twist vectors were difficult to understand and in practice it was common simply to set them all to zero. The resulting surfaces were known to have a lack of fairness although it was difficult to illustrate this by conventional graphics. The model in Figure 2 was an attempt to demonstrate this effect. The left "bump" is the uniform bicubic B-spline basis function; the right "bump" is nearly similar but has all the twist vectors set to zero: as can be seen, the two are visually indistinguishable. However, running a finger or thumb around the bumps reveals a very distinct local flattening at some of the patch corners where the twist vectors are zero. Once these regions are isolated by touch it is possible with some care to orient the model such that the viewing direction and appropriate lighting will show up the flattening visually.

In another case, the experimental ship hull in Figure 3 was cut in order to show a lack of fairness which was thought to exist in one part of the hull but which had not shown up on conventional cross-section plots. The model revealed not only the expected anomaly but also another lack of fairness in a different part of the hull, to the surprise of the data suppliers. Three-dimensional hard copy is often overlooked as a method of rendering or visualising complex shapes, but clearly the scope for interaction and manipulation is limited.

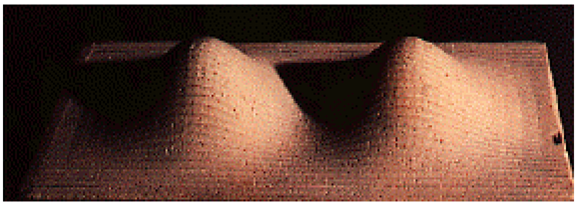

Figure 2: Bicubic Surface Patches: left-hand bump is a bicubic B-spline basis function, right- hand bump is similar except that all "twist" vectors are set to zero

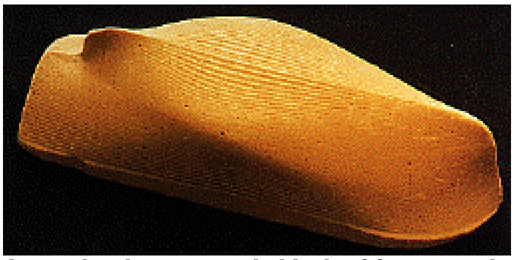

Figure 3: Ship Hull Example: 3D hard copy revealed lack of fairness at bow and stern when touched

These two examples illustrate a procedure common in everyday life: running one's hand over a surface such as car body or a yacht hull is a good test of the overall quality of the surface. Touch provides two distinct perceptions in this case: an indication of the roughness or texture of the surface, and an indication of the fairness or variation of surface curvature.

Our initial aim was to mimic this kind of tactile perception in an ergonomic manner, but we also felt that touch could be used to convey other forms of information not normally associated with touch. We felt that this could be achieved by combining touch transducers with a desktop mouse, thus bringing touch to the user of an average workstation without imposing the constraints on the user which are generally mandated by immersive virtual reality and force-feedback touch systems.

3 ASPECTS OF TOUCH

Touch is a complex sense [21], and includes the sensation of wetness, temperature, and the experience of pain. Loomis and Lederman [16] classify touch using the terms "tactile perception" (touch mediated solely by cutaneous stimulation), "kinesthetic perception" (mediated exclusively or nearly so by variations in kinesthetic stimulation, i.e. motion or muscular effort), and "haptic perception" (tactual perception combining cutaneous and kinesthetic sensation). Haptic perception is the most common form of tactual perception. Many processes are involved, see for example the literature on the psychophysics of touch [15, 16, 22]. The characteristics of the various tactual mechanisms indicate that some mechanisms are quite limited both spatially and temporally, but other mechanisms can be extremely precise. For example, if an area of skin is stimulated by an array of points, then the spatial resolving power of tactual perception is rather poor, but an engraver can control the position and depth of engraving to amazingly high precision.

We have deliberately confined our interest to touch mediated by vibrational or other stimulation or displacement of the skin. This enables us to use simple, inexpensive and unconstrained touch devices which can be combined ergonomically with conventional interaction devices such as the mouse. Kinesthetic and haptic devices, by contrast, operate in a limited volume, or require the user to wear special equipment or other wise constrain the user, and are generally expensive.

4 PREVIOUS WORK

Outside of the computing community, haptic displays and devices have been developed to act as artificial ears for the deaf [13, 14, 20] or artificial eyes for the blind [4, 7, 8]. These devices have had limited success due to the limited temporal response of the tactual perception mechanisms in the case of artificial ears and the limited spatial discrimination in the case of systems for the blind. Because our work is not concerned with prosthetic use of touch but with the additional perception afforded by touch in synergy with hearing and vision, these devices are of little relevance to our explorations.

In the computing community, touch has generally meant either the input of position by touching (touch sensitive screens, for example), or by pressing (pressure-sensitive tablets and drawing tools) [6], or the use of force feedback to give the illusion of contact or weight in manipulating virtual objects or real objects using remote manipulators [5, 19]. Force feedback generally requires the input device to be mechanically linked to some anchorage or attached to the user and consequently rather limits the space within which it can operate. Early examples are described by Batter and Brooks and by Geyer and Wilson [2, 10]. Geyer and Wilson discuss a proposed "Magic Glove" which not only inputs positional information to the computer but conveys a sense of touch by "numerous computer controlled small gas jets which push at different positions on the fingers and palm in response to calculations of their positions relative to the simulated external object world." We have not been able to determine whether this proposal was ever put into effect, and, if it was, whether it proved useful for visualisation.

Akamatsu and Sato [1] describe a mouse with tactile and force feedback, tactile sensation being provided by a small pin with approximately 1mm travel which is used as a binary touch indication, and force feedback being generated by adding resistance to mouse motion by means of an electromagnet. The forces generated are obviously restricted and given the propensity of mice to stick, may be annoying to the user rather than informative.

Whilst most previous work on touch has been aimed at kinesthetic perception for virtual reality applications, our work has concentrated on tactile perception for perceptualisation of data.

5 TACTILE MICE

In order to pursue our research we have experimented with a number of different mice using different technologies to provide the sensation of touch. They are all based on modified Apple Macintosh mice and are activated by the sound channel of a Macintosh Quadra 950 using standard Macintosh sound functions. Our mouse designs were inspired by the roller mouse built by Apple and described by Venolia [23] which mounts two rollers, one on each side of the mouse button, and is thus controlled quite naturally by the first and third fingers. The advantage of concentrating on tactile perception using a mouse is that the user is virtually unrestricted in movement and the sensors are naturally to hand when needed whereas kinesthetic and haptic devices require either a fixed position for the device or for the device to be physically attached to the user. However, incorporating a tactile transducer on a mouse restricts the size and type of transducer that can be employed: for example, tactile arrays {4, 7] are, for our purposes and budget, impractical. Use of the sound channels to drive the tactile transducers leads to simplicity and reduced cost.

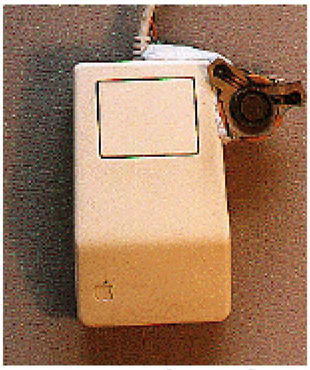

Figure 4: Mono Vibrotactile Mouse

Mono-Speaker Mouse

An audio speaker of the kind typically found incorporated in a personal computer can be used as a device to transmit vibrotactile information, however, such a speaker in its unaltered state is too big to attach to a mouse. A speaker was stripped down until all that remained was the coil and the magnet with its casing. This proved to be sufficiently small and light enough to be attached as a vibrotactile pad to the front right-hand side of an Apple single-button mouse so that the fourth finger of a right-handed user rests naturally on it, Figure 4. The pad is driven by a sound channel via a simple amplifier.

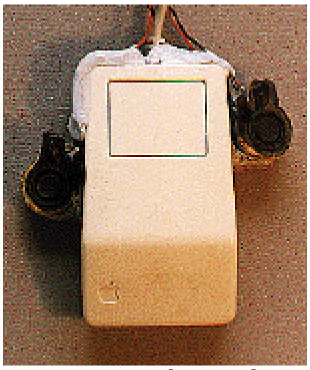

Figure 5: Stereo Vibrotactile Mouse

Stereo-Speaker Mouse

The stereo vibrotactile mouse which was built was designed for use by a right handed user with the vibrotactile pads positioned so that the thumb rests on the left pad whilst the fourth finger rests on the right pad, Figure 5. The vibrotactile pads were constructed in the same manner as for the mono-speaker mouse: each was positioned so that it just avoided contact with the surface over which the mouse was to be moved. This means that the thumb and fourth finger are still free to control the mouse whilst receiving tactile stimulation. The use of two vibrotactile pads increased the weight of the mouse considerably, although users soon became accustomed to this increase in weight.

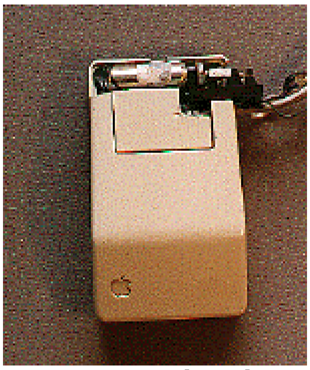

Figure 6: Mono Solenoid Mouse

The Solenoid Mouse

As an alternative to using a modified speaker as a vibrotactile pad, we experimented with a solenoid which was placed along the front edge of the mouse after some reshaping of the upper casing, Figure 6. The solenoid was driven once again by the sound output from the Macintosh.

The solenoid mouse has the advantage that its vibration is more comfortable for the user and its strength can be manually controlled by varying the power used to drive it. Users preferred the lower power settings which also reduced the noise generated by the solenoid. The main disadvantage over the other two mice is that, due to the nature of a solenoid, the amplitude of vibration is fixed.

Other Tactile Transducers

We are continuing to experiment with other transducers. A dot-matrix printhead, for example, provides the opportunity to experiment with variations in vibration impossible with a solenoid, relying on the low spatial resolution of the finger so that multiple pin activation can be sensed as intensity rather than being spatially discriminated. Alternatively, sequential activation of a sequence of pins can be used to indicate the sense of `up' or `down'. We have had some success with a transducer based on transcutaneous electrical nerve stimulation (administered as a mild electric shock). This, whilst not always popular with users, has some potential and in particular does not generate sound which can be intrusive with the speaker-based transducers. Both Bliss et al. [4] and Cholewiak et al. [7] describe matrix devices using piezoelectric transducer arrays which would be difficult to build in to a mouse. Our limited experience of piezoelectric devices used singly was unsatisfactory, but these devices might still prove to be suitable given good engineering resources. Users generally preferred the solenoid mouse due to its low noise and comfort of use although the electric shock mouse had one devotee.

6 EXPERIMENTS IN PERCEPTUALISATION

We describe here two from a range of experiments which we have conducted. One uses touch as a binary output from the computer and the other maps data to a range of vibrational frequencies. Our intention in discussing these experiments here is to demonstrate that touch can be used to perceive information rather than to demonstrate that touch is better than other senses for certain tasks. Full details of the experiments are given in [11].

Needle in the Haystack Experiment

Simple preliminary experiments had shown that the tactile mouse could aid the user in moving to a specified area of the screen even when both the target area and the mouse pointer could not be seen. The aim of the needle in the haystack experiment was to determine whether tactile perception could speed up the location of a single element in a complex display. The scene resembled a random scattering of straws, all of the same length except one which was smaller. Visually, the smaller straw was difficult to detect in the screen clutter.

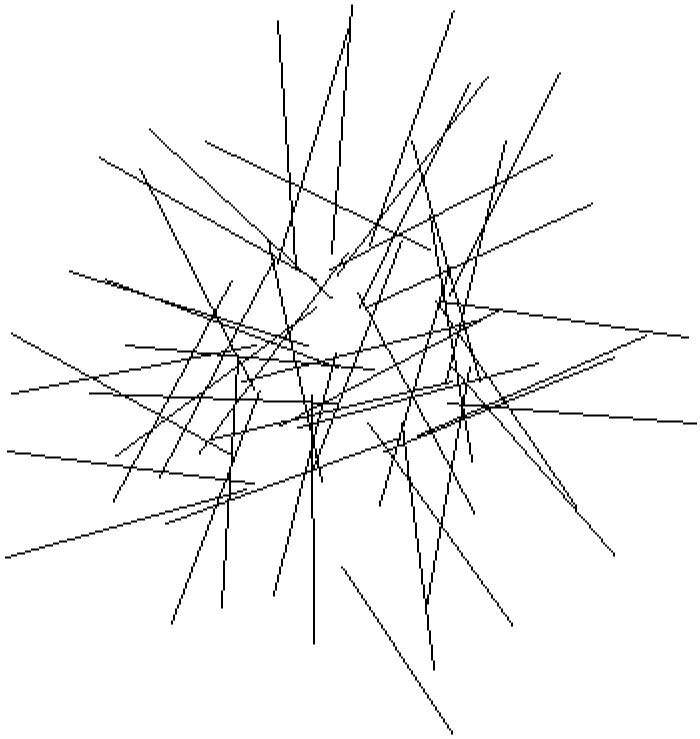

Figure 7: Typical Haystack Image

Each subject was initially placed in front of a monitor with a blank window at its centre. Once the mouse button was clicked a timer was started and 50 lines 125 pixels long and one 100 pixels long were placed at random positions and angles within the window as in Figure 7. The subjects were then required to find the shorter line by eyesight alone, and to identify it by moving the mouse pointer over it and depressing the mouse button. If the correct line was chosen, the timer would be stopped and the window cleared, otherwise searching would continue until the correct line was found. The searching process was then repeated a second time except that on this occasion the subject was assisted by use of a vibrotactile mouse: when the mouse pointer moved across the shorter line the mono-vibrotactile pad was vibrated at a pre-set frequency.

Subjects who took part in the experiment were required to participate in an untimed practice at finding the line both aided by and unaided by the vibrotactile mouse so that they could become accustomed to the task they were required to perform. Each subject was then asked to complete the experiment with and without the vibrotactile mouse three times and the time taken was recorded for each attempt. In total 22 subjects took part in the experiment of whom 9 were regular users of mice and 13 were not. The average results for each subject are shown in Figure 8.

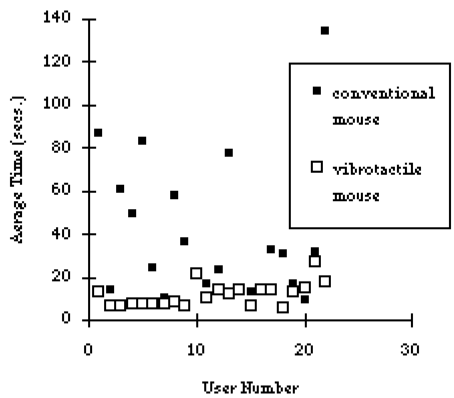

Figure 8: Haystack results.

The average time taken to find the shorter line using the vibrotactile mouse was 30% of the average time taken when using the conventional mouse. However, the figure for those familiar with a mouse was 17% compared with 42% for users who were unfamiliar with the use of a mouse: users not familiar with using a mouse had more difficulty in controlling the vibrotactile device. Curiously, our experienced mouse users were generally poorer at visual recognition of the shorter line. There was much less variation in the timings using the tactile mouse. This is probably

due to the users adopting a systematic sweeping search of the image when searching by touch whilst using a random technique using vision alone, hoping in this case for instantaneous recognition.
Of course, we could have distinguished the shorter line by visual means such as blinking, colour, intensity, line thickness or other visual attributes, in which case identification would have been instantaneous or nearly so. Identification by sound rather than touch might well be quicker or simpler. Our aim here was simply to demonstrate that visual clutter could be overcome by tactile means and hence could be used to extend the number of attributes that could be used to identify multidimensional data.

A Visual/Tactile Display for Multi-Dimensional Map Data

As Geographical Information Systems (GIS) become more popular, the range and volume of data available increases. In cartography colour, line styles, and glyphs are used conventionally to identify different aspects of data. Nowadays, users commonly wish to overlay two or more sets of map data at the same time. For example, one may wish to know simultaneously how many people live in an area and the radiation levels due to a power station near by. Various conventional methods exist to display overlapping data, but none really allow an exact overlay whilst avoiding visual clutter. Side-by-side display is of course an option but has a serious disadvantage for GIS where small screen size is already a problem.

The Vibro Map Software

A possible solution to this problem is to view one of the maps on the screen as it would normally be displayed and overlay on it an invisible tactile map. This map could be felt using a vibrotactile mouse. One possible mapping of the overlay map data into tactile stimuli values would be to translate the colour scale in the map so that blue areas induce no vibration and red areas induce high vibration, Figures 9 and 10.
Software was developed on the Macintosh to perform this task. Simple square sound waves were created using a sample editor package This sample was then used as a resource within the program. (Samples were used to prepare for future versions of the program which will use the stereo vibrotactile mouse for location on one tactile channel and value on the other.)
The program has just three main options. The first loads the image which is to be displayed on the screen, for example Figure 9. The second option loads an image and stores it in an off screen bit map, (Figure 10 shows a typical example in visual form). The final option enables the user to explore the off screen bit map in tactile mode. Once this option has been selected the mouse becomes `live'. As the mouse is moved over the on-screen bit map the corresponding colour value in the off screen bit map is converted into a number which is interpreted by the system as a frequency of vibration of the tactile transducer on the mouse. Colours are mapped in spectral order.
The initial system appeared to work quite well, but it suffered from the problem that because data values could alter considerably from pixel to pixel, it was quite difficult to appreciate what information the mouse was transmitting except when the mouse was still. This problem was alleviated by adding a smoothing function: 10 frequency values are sampled during a set time period and averaged to produce the actual vibration felt. This means that as the user moves over a mainly red region and then briefly touches a green pixel, this will hardly be felt. However if the user moves over the area slowly, then the change will be felt. When the smoothing system is used it is much easier to understand the data For example, it proves to be quite easy to find an area in which there may be, say, both high population and high radiation.

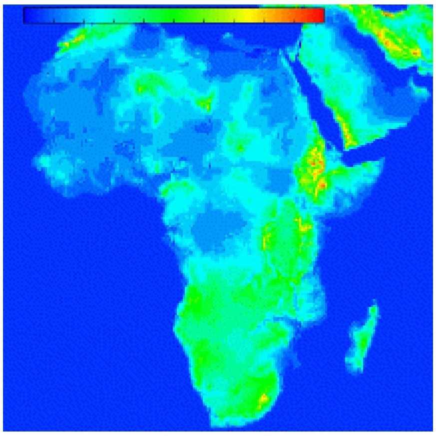

Figure 9: Displayed Map (depicting elevation)

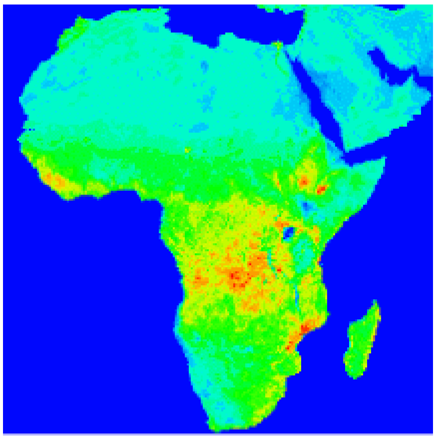

Figure 10: Hidden Map, Sensed by Touch (depicting vegetation)

The main problem with the current system is that although the user can identify qualitative changes in the data, it is difficult to determine the actual values. A tactile scale on the screen, similar in form to the colour coded scale in Figure 9, has been implemented and can be used to aid comprehension. Training in the use of the system increases user awareness of changes in levels and frequencies of vibration. An alternative option would be to encode digits as vibrations: the mouse could then be sent a stream of digits to denote an exact value.

It has been found that a user can distinguish the values on the overlaid map with the assistance of the scale to quite a high degree of accuracy. Even on their first attempt some users correctly chose the right value on the overlaid map (values ranged between 0 and 100) and most users can perceive the value to within 5% on a regular basis.

8 CONCLUSIONS

It has proved difficult to find touch generating devices which are entirely satisfactory and this has inhibited integration of a touch module as part of a visualisation system along the lines of our previous incorporation of a sound module in NCSA Image [18]. It has also made it difficult to explore the somewhat limited range of tactile values which can be distinguished by mapping data values onto parameters such as frequency and amplitude of vibration. We have not yet attempted to simulate roughness and curvature to emulate the tactile perception afforded by the solid models mentioned in Section 2. Fairness or curvature sensation perhaps requires haptics, but roughness could be simulated by vibration. Nevertheless, we claim useful improvements to perceptualisation can be achieved by tactile means and improved transducers will simply serve to expand the useful range of tactile effects which can be exploited.

Users can perceptualise the two tactile dimensions of the stereo mouse; it is not clear whether overload would occur if all fingers were independently stimulated by tactile pads. Our experiments suggest that touch can potentially increase the dimensionality of data that can be perceived by two dimensions. Our experiments also indicate that touch is a good agent for reinforcing other sensations. Earlier experiments with sound [17, 18] showed that four channels of sound could be tracked simultaneously. Whether sight, sound and touch can usefully be employed simultaneously for high-dimensional perceptualisation is still an open question.

Concentrating on one simple aspect of touch, tactile perception, leads to a relatively simple and ergonomic device. Since touch, unlike vision, is essentially a localised and serial sense, the combination of tactile output with a pointing device such as a mouse is quite natural, thus enabling tactile exploration on a location by location basis in conjunction with the overall perception of displayed data afforded by sight. Our initial results are encouraging and we believe touch has a place in the visualisation of complex data where visual complexity or limited display area is a hindrance to visualisation. Touch may also find an application where menus or control buttons may need to be hidden in order not to impair visualisation of an image.

9 ACKNOWLEDGEMENTS

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Virtual "squishiness" event cues, Avatars with unique "feel" properties, User-definable tactile response signatures, Libraries of addressable "feel event" tactile texture models, Universal force reflecting interface devices, Objects that become "hard" or "soft," or "resist" when touched in cyberspace...

Most people tend to think of current day virtual reality computer systems as having some sort of 3D display device that is worn or can be peered into, and a motion tracking device/manipulator to interact with the objects in the displayed 3D "world." But what if you could "feel" the contents of that world you are interacting with, and perhaps more interestingly, what if multiple participants in the same virtual world experience could "feel" each other?

This is one of those curious moments in time where a seemingly unrelated combination of different technologies come together to provide yet another "rung" on the ladder of VR development. Having personally worked with so-called "engineered materials" development many years ago, and in particular, investigation into shape changing alloys and their applications, it is worthy to note how the long and winding road of "techno-symbiosis" can lead to new, and unexpected places.

Out from an obscure realm of solid state physics often referred to as "dual shape memory effect," or DSME, particularly as it applies to collection of homogenous metallic alloys, most notably a nickel-titanium alloy often referred to as NiTiNOL (Nickel Titanium Naval Ordnance Laboratory, where it was first discovered), comes what may become the next step in bi-directional tactile response virtual reality interface devices.

One of the early pioneers in exploring the potential of DSME alloys, and specifically NiTiNOL, is Dr. David Johnson. He now has his own company (TiNi Alloy, San Leandro CA), and can most often be found in his laboratory along with a small but dedicated cadre of technical support staff. I personally had the good fortune of working with him as a research technician in the early 1970s at Lawrence Berkeley Lab. Back in those days, DOE (Department of Energy) funded a myriad of alternative energy related projects, including investigation into the thermo- and electro-kinetic properties of DSME alloys.

Consider for a moment a homogenous metallic alloy, with extraordinary tensile strength and durability characteristics, that can be "trained" to rapidly conform to a predetermined shape or volume as a function of an electrical, or thermal gradient control stimulus. Translated into viable commercial applications, the possibilities include such diverse products as artificial muscle fibers (with considerably higher load bearing capabilities than most organic fibers), ultra miniaturized valve and actuator components, tactile response feedback devices, thermally or electrically induced "shape morphable" devices, and so on.

Dr. Johnson has become an internationally recognized authority on the physics of DSME alloys, and has applied much of his research to two specific areas of interest, tactile response I/O devices, and ultra thin morphable film applications.

One of his current product "prototypes" is a NiTiNOL "mouse" . What looks like a typical computer mouse actually has an array of NiTiNOL pins which protrude from a series of small holes at the upper right comer of the mouse body. The idea here is that the pins can be "instructed" to vibrate, or elongate through the holes, when a specific event has occurred. I personally worked on an adaptation of this technology which was designed as a Braille translation device for sight-impaired PC computer users.

In an interactive VR world environment, an important feature is the linkage of perceived "event cue" boundaries within a spatial co-ordinate set of parameters. In other words, when a predetermined region or "edge" of a region of a virtual object in a 3D realm is approached, or actually "touched", a logical value representing that event can then be recognized as a cue to stimulate some sort of response in the virtual environment.

In most VR systems, this is a visual and/or audio event or event sequence. But why not "feel" the event as well? This type of tactile response device actually has many potential applications. For instance, a CAD application could be configured so that when the user contacts a desired point or line in a complex 3D drawing on the computer screen, a brief tactile signal is sent to the user. This is particularly useful for multi-layered 3D drawings, in which the determination of "where" in 3D space is often cryptic at best. For example, at the University of North Carolina, research chemists are now using an adaptation of this device with a molecular modeling work station system.

As a bi-directional tactile response interface device, however, the VR applications possibilities are most interesting. Imagine, for instance, a very large "pin grid array," somewhat like topographical feature "pixels" on a tactile display device. Not only could "tactile cue events" directly influence the dynamic interactivity of a VR world, but more interestingly, a tactile response could then be sent back from the virtual environment to the user via the same tactile "display" device. Moreover, any number of individuals, located anywhere in a telepresense connectivity grid, could experience each other's tactile "events."

A variety of touch-sensitive input devices, particularly in the realm of pressure sensing arrays, currently exist. These can range from extremely sensitive pneumatic bladder systems currently used on the fingertips of "intelligent" robotic hands and grippers, to deformable electrically conductive "pad arrays", and even deformable fiber optic grid arrays. But most interesting of all, perhaps, is that NiTiNol itself also outputs both thermal and electrical signals when deformed, as well as changing shape when triggered by an input electrical or thermal stimulus.

An example of an interactive tactile response VR "glove," being developed by Ron Renzi and his research team at Sandia National Laboratory, Livermore CA. Tactile "texture events" can be rendered to the user as a data stream, via an electromagnetic driven set of rods, or pin grid array, which provides a topographical feature set representing the textural "content" of a virtual object

TiNi Alloy has indeed produced some prototypical tactile response interface "gloves" for the Air Force as part of an aircraft cockpit control interface system, although some details of this development are still classified. However, the potential for creating the "civilian" version of a tactile response interface pin grid array, or a "morphable foil" device, which could be placed anywhere on the human body that might be "interesting," is certainly within the range of feasibility.

What's available today?

Although the realm of shape changing alloys is an entirely unique technology, there are other tactile response interface devices that do indeed provide a very robust "feel" effect, and more importantly, libraries of "touch cue" events can be associated with specific objects, with varying degrees of resistance, hardness and softness, even a "virtual squishiness" attribute.

In order to provide such an analog variable tactile response envelope, there needs to be a relative position feedback loop, as well as a definable resistance feature set that can be applied when a spatial boundary is crossed. One particularly interesting version of this process is currently offered via a tactile response interface device is the PHANToM system, offered by SensAble Devices, Inc. Originally developed for virtual telepresense applications requiring an extremely high degree of spatial and tactile accuracy, such as virtual surgery and telerobotic medical procedures, a version of this technology is now available to the general public.

Indeed, the Dept. of the Army has been actively involved in just such applications, specifically so that wounded soldiers in the battlefield could be operated on via telerobotic interface via satellite link from a remote location almost anywhere in the world. The example provided by SensAble was perhaps even more compelling. There, a tactile "response signature" of a needle probe, as it was pressed through the skull and into the brain to a precise location within the cerebral tissue for a tumor biopsy, was demonstrated as a method for training neurosurgeons who wanted to "experience" the feel of puncturing a human skull with a probe and subsequently targeting a region of neural tissue on a sensory model, before performing such an operation on a real human.

Incidentally, the creation and retrieval of such "feel events," as an addressable library of tactile event signatures, is exactly the paradigm that would be used in eventually establishing a tactile event stream protocol that could be linked into a VRML 3D "page" or world that could be transmitted through the internet.

The PHANToM is a finger insertion device, somewhat like a thimble. It is described by its developer as a "universal force reflection interface." The system actually contains three DC motors which directly control the forces exerted upon the X, Y, or Z axis. Position of the thimble, which is attached to a manipulator arm, is determined by optical encoders, which in turn provide feedback information to the system. Depending upon the particular details of the virtual "feel" properties of the item being "handled," the motors will exert force, and transmit torque against the manipulator arm, and the person's finger inserted into the attached thimble.

An entire glove constructed in a similar fashion is already in development. At Sandia National Laboratory, Albuquerque, NM, there has been considerable effort spent in investigating the potential applications of force and feel-dependent interface applications, including virtual surgery events. However, Sandia Lab has

also been investigating other devices for interactive "feel event" simulations as well.
Ron Renzi, who heads a group there specifically devoted to this realm of development, has also been experimenting with a magneto-resistive glove device. In this particular implementation, "traditional" positional tracking VR gloves were retrofitted with electromagnetic rod structures which could be stimulated via an electrical signal to move out of a sleeve, and then retract back in again. By creating a vibration pattern against the users finger tips, an entire variety of various tactile surface emulations could be generated, ranging from a "bumpiness" factor, to a "rolling" sensation, or the effect of an "edge object" with varying sharpness attributes.
In fact, the combination of various addressable vibrational frequency patterns have yielded a very wide array of potential "feel event objects" with user definable properties. Already the research team at Sandia is looking into entire wearable "feel suits" that would stimulate the entire human body via an interactive tactile experience protocol, with libraries of addressable tactile texture models available as part of a virtual pre-sense domain.
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