

A multi-modal mouse with tactile and force feedback

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We have developed a mouse with tactile and force feedback. Tactile information is provided to the operator by a small pin which projects slightly through the mouse button when pulsed. Force information is provided by an electromagnet inside the mouse in conjunction with an iron mouse pad. Tactile and force feedback are controlled by software linked to the visual information of targets on the visual display. In an empirical evaluation using a target selection task, the addition of tactile and force feedback shortened the response time and widened the effective area of targets. Design issues for interactive systems are discussed.

1. Introduction

In human-computer interfaces, it is important to match interaction modalities with the motor-sensory functions of the human operator. The traditional VDT-plus-keyboard interface combines visual output with restricted finger input. However, when using a graphical user interface, we manipulate a mouse in a two-dimensional space, according to the position of the cursor on the screen. Thus, we obtain both a visual and kinesthetic sense about the movement and position of the device and cursor. Since a mouse interface provides more than one sensory modality, it is a more natural device than a keyboard. This is analogous to the interface between humans and the real world, where multi-modal interaction—visual, auditory, tactile and kinesthetic—is the norm. The rich assortment of sensory information presented to us affords natural interaction with the objects in our everyday world.

A typical task in human-computer interaction with a mouse is to move a cursor to a target and click on it. This is analogous to reaching and touching a target with our finger. However, touching an object gives rise to a tactile sensation in addition to a kinesthetic sensation. One purpose of tactile information is to inform us that the finger is on an object. Although visual information can perform this function (instead of tactile information), when tracing the shape of an object using the finger tip, the effect of tactile information added to visual information is to increase the velocity of finger movements and at the same time reduce the dependence on vision (Akamatsu, 1992). It is therefore expected that an interface device capable of presenting tactile information as well as visual information should improve the efficiency of operations and reduce the visual load in interactive systems. Thus, we have developed a human-computer interface device based on a mouse that is capable of presenting tactile and force information. In this paper, we will describe the design of the device and present results from preliminary experiments conducted to test the effectiveness of added tactile and force information.

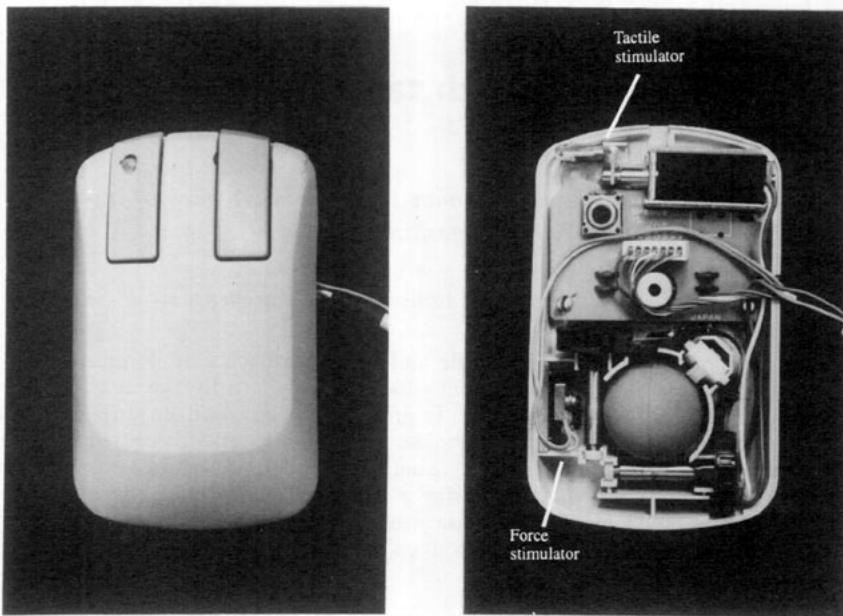


FIGURE 1. Outside and inside appearance of the multi-modal mouse.

2. Structure of the device

Tactile and force information are transferred from the device to the operator when the cursor on the visual display has reached the target. The information is controlled by means of an on-off signal that indicates contact or non-contact with a target. Because the operator obtains visual, tactile and force information with the interface device, it is defined as a *multi-modal integrative mouse* or a *sensory integration mouse*. To achieve this, additional components in the form of a tactile stimulator and a force stimulator are added to an otherwise ordinary mouse (Figure 1). Signals to drive these components are sent from an input/output port to each component in the mouse. The mechanism of these components is discussed below. Excluding the cables, the components increased the weight of the mouse from 103 g to 148 g.

In our test interface, the visual display screen shows windows, on which key-like shapes are displayed as targets (Figure 2). By means of shading, the targets appear in an artificial, raised perspective. If the mouse button is pressed while the cursor is over the target, the shade disappears, simulating the target being pressed down.

When using a mouse, the finger tip of the index finger rests on the left button. Tactile information is given by means of an aluminum pin (1 mm $\times$ 2 mm) projecting from a hole at the tip of the left button. When pulsed, this pin lightly presses the user's finger pad. By this tactile information the sensation of touching something with the finger tip is achieved.

The pin is driven by a pull-type solenoid (KGS Corp., 31 mm $\times$ 15 mm $\times$ 10 mm) via a lever mechanism [Figure 3(a)]. The pin is covered by a rubber film which is fixed to the underside of the button. The rubber film serves to return the pin to its resting position when the control signal for tactile information is turned off. The stroke of the tactile stimulus is 1 mm. When the solenoid is driven by a 12 V DC

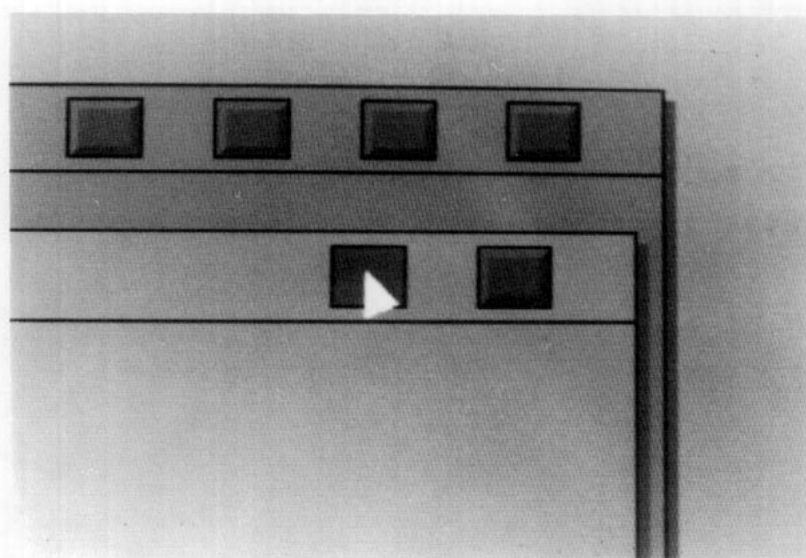


FIGURE 2. Design of visual information for tactile and force feedback.

signal, the pin takes 4 ms to rise and 8 ms to return to its resting level. Tactile information is present when the tip of the cursor is within the target area, and disappears when the cursor leaves the target area or when the target is selected.

A force sensation is produced by adding resistance during mouse movement. This is generated by a small electromagnet (KGS Corp., 14 mm × 13 mm × 7 mm) attached to the bottom of the mouse [Figure 3(b)]. When the mouse is operated on an iron surface, the resistance to movement is increased by applying current to the electromagnet. When in use, the mouse is usually held against the work table (mouse pad) with a force of 2–3 N. With our modified device and a vertical load of 3 N, a horizontal force of 0.8–0.9 N is required to move the mouse. A 10 VDC signal increases the moving friction by 0.1 N. Thus, the increase in the moving friction of the mouse was 12–13% due to the electromagnet. This is perceived as resistance (i.e. force information). Added force is given in addition to the tactile information when the cursor is within the target area. This is also generated for 3.3 ms when the cursor crosses the boundary of a window. A slight resistance is perceived when the cursor moves out of or enters a window.

3. Method

3.1. SUBJECTS

Five subjects participated in the experiments. All were regular users of mice. Before the experiment started, subjects were instructed that the mouse provides tactile and force feedback which could be used as additional sensory information for positioning of the cursor.

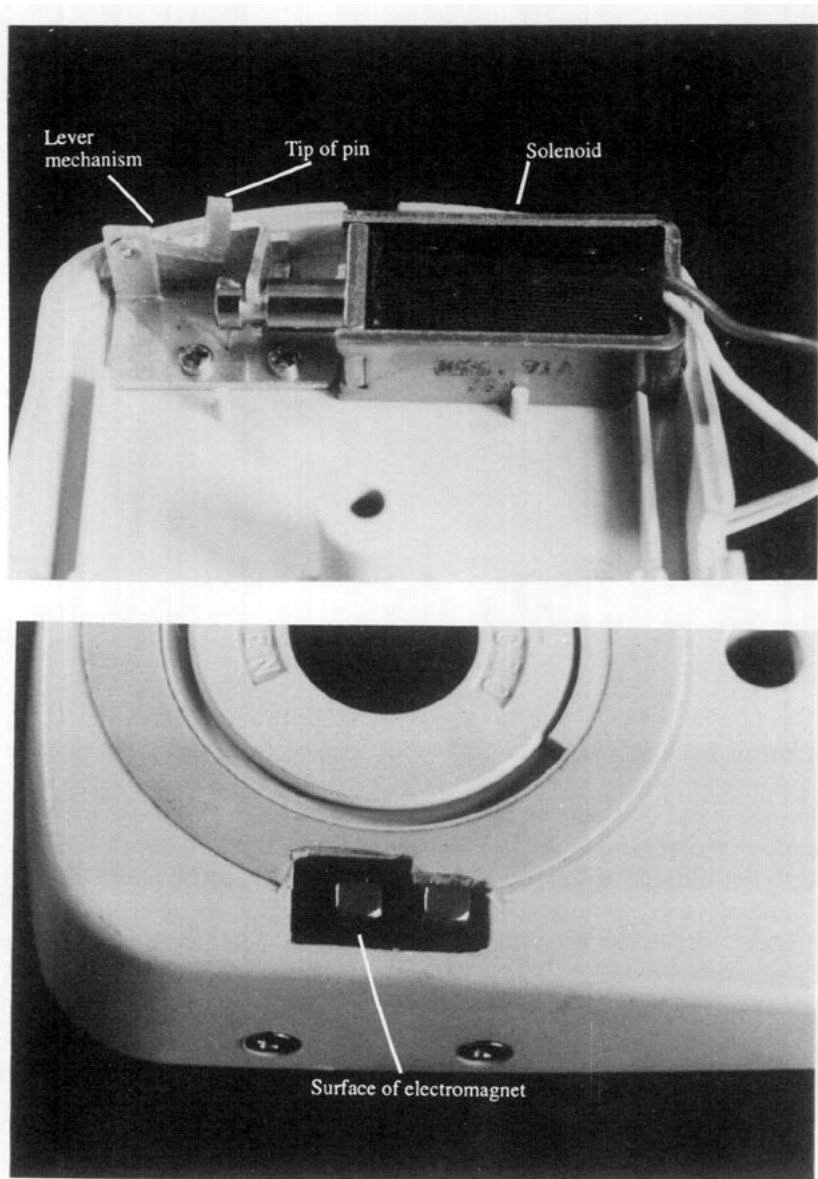


FIGURE 3. (a) The pin and the lever mechanism, and (b) the electromagnet at the bottom of the mouse.

3.2. APPARATUS

Experiments were conducted using a multi-modal mouse with tactile and force information and an ordinary mouse without added feedback. When the multi-modal mouse was used, an iron mouse pad was substituted for the conventional felt-surfaced mouse pad.

The host system was a NEC PC98. A second PC98 served as a dedicated data

collection system to sample mouse coordinates (1000 times per second) and button presses, with data saved in output files for subsequent analysis.

The experiment was conducted with subjects sitting in an isolated room free of distractions and with the experimenter in an adjoining room.

3.3. DESIGN

There were two targets displayed in a window on the CRT display. Target 1 was in the upper-left direction which was 14.6 degrees counterclockwise from the upward direction. The distance from the starting point to the center of Target 1 was 37.5 mm on the mouse pad, which corresponded to 60 mm on the display. Target 2 was in the upper-right direction, 41 degrees clockwise from the upward direction. The distance was 44 mm on the mouse pad or 70 mm on the display. The two targets were the same in size and colour; the size was 4.7 mm by 5.6 mm on the mouse pad or 7.5 mm (25 pixels) high by 9 mm (30 pixels) wide on the display.

3.4. PROCEDURE

The experimental procedure was as follows. After placing the cursor at the start position, an auditory signal was given to prepare the subject. When the preparatory signal was given, the target to be reached was indicated by an arrow on the screen. Then, a “go” signal was given after a random interval of from 0.5–1.5 s. The “go” signal was presented by deleting the circle of the start position. The subject moved the cursor to the target area as quickly as possible and pressed the left button of the mouse. In the experiment, there were 25 trials for each target.

Each subject participating in the experiment used the multi-modal mouse and an ordinary mouse. The order of the two experiments was randomized to cancel learning effects.

The measurements gathered were the response time from the “go” signal to pressing the mouse button, and the position of the cursor when the button was presented.

4. Results

Trials in excess of 2 s were considered outliers and were excluded from the data analysis. There were no errors (0%) for Target 1 with tactile and force information, and 0.8% errors without such information. There were 2.4% errors for Target 2 with tactile and force information and 1.6% without such information. They were not systematically related to the condition with and without tactile and force information.

For Target 1, the average response time was 988 ms with tactile and force information, and 1066 ms without such information. This represents an increase of 7.9%. For Target 2, the average response time was 1038 ms with tactile and force information, and 1147 ms without it, representing an increase of 10.5%. The

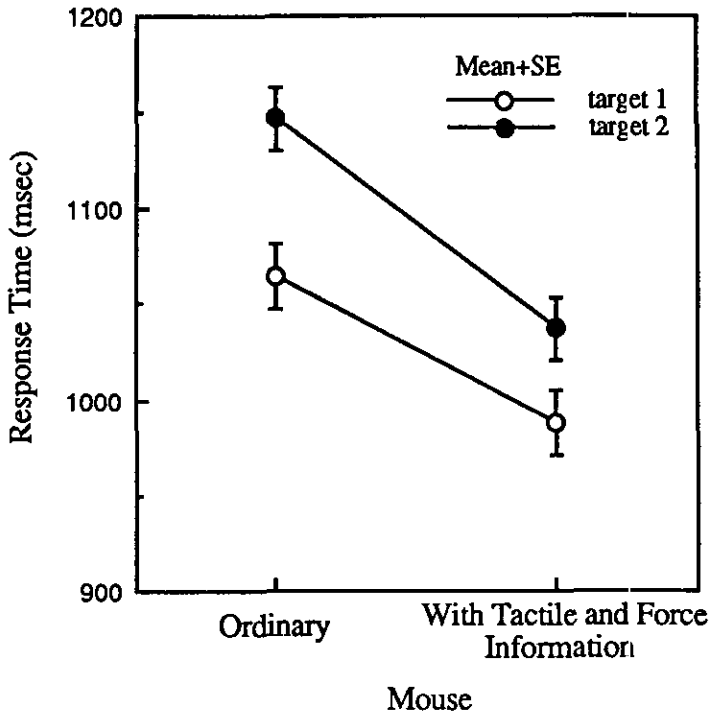


FIGURE 4. Comparisons of response times with the multi-modal mouse and the ordinary mouse.

differences in the response times were statistically significant ($F(1, 243) = 10.3$, $p < 0.001$ for Target 1, and $F(1, 239) = 21.4$, $p < 0.0001$ for Target 2). This indicates that the presentation of tactile and force information reduced the response time of the positioning task with a mouse (Figure 4).

Figure 5 gives sample trajectories with and without tactile and force information. The dotted lines show the trajectory of the cursor from the start point to the position where the subject clicked the target. There was no clear difference in the trajectory patterns. Circles in the figure indicate the position of the cursor at the time when the mouse button was pressed.

Examples showed that the position had a wider scattering when subjects used tactile and force information. The mean distance from the center of the target was greater with tactile and force information than without it (Figure 6). In order to test the difference in scattering, the variances of the spatial distributions were compared. As it was a two-dimensional task, the marginal distributions in the horizontal and vertical axis were used for the F -test for the variance ratio.

In both the horizontal and vertical directions, the marginal distributions of the position were wider with tactile and force information than without it. The variance ratios for Target 1 in both directions were statistically significant ($F(124, 125) = 2.085$, $p < 0.005$ for the horizontal direction, $F(124, 125) = 2.185$, $p < 0.005$ for the vertical direction). They were the same for Target 2 ($F(122, 123) = 2.186$, $p < 0.005$ for the horizontal direction, $F(122, 123) = 1.753$, $p < 0.005$ for the vertical direction). We interpret this as follows: if one operates the mouse using visual feedback only, the tendency is to press the button when the cursor is close to the center of the

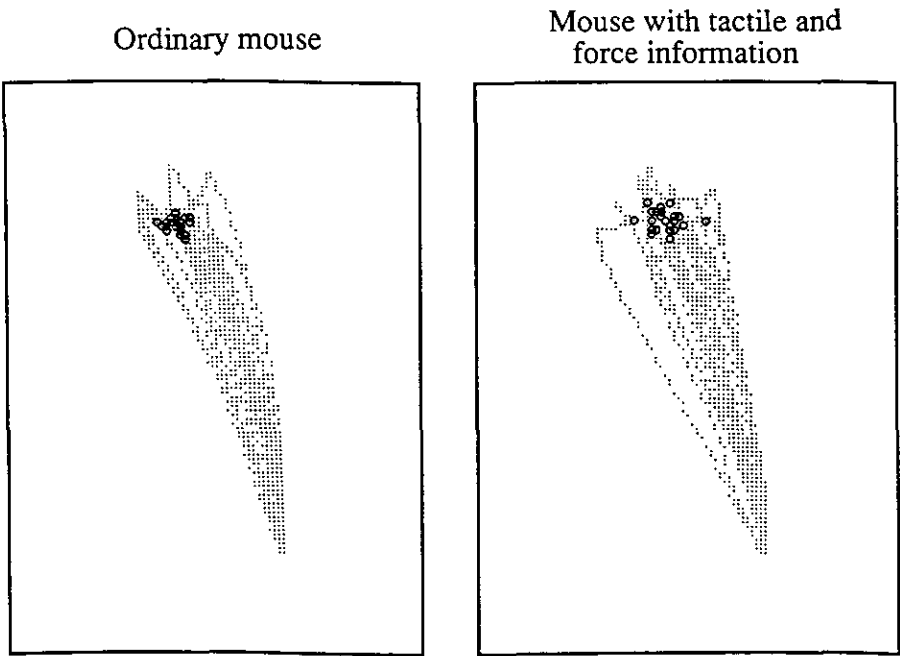


FIGURE 5. Samples of trajectories of the mouse movement.

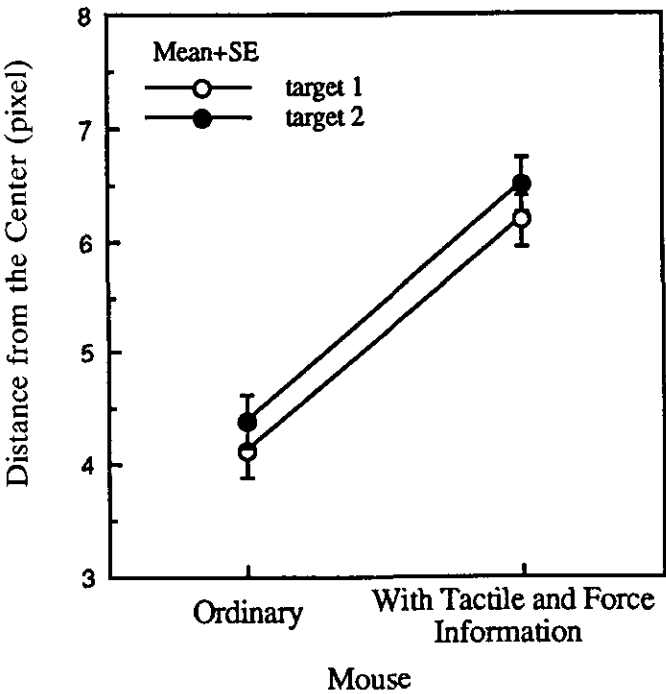


FIGURE 6. Comparisons of the distance between the position of cursor when the target was clicked and the center of the target.

target area. In contrast, when tactile and force information are present, the button presses occur over the full area of the target, sometimes near the target's edge. This means that the presentation of such information increases the effective target area.

5. Discussion

In order to introduce tactile information to the human-computer interface, a new interface device has to be developed. Interface devices for telepresence and virtual reality have been studied to give force or tactile information (Zimmerman, Lanier, Blanchard, Bryson & Harvill, 1987; Hanger & Webster, 1988; Ouh-young, Pique, Hughes, Srinivasan & Brooks, 1988; Iwata, 1990; Driels, 1991; Fukui, 1992; Hirose, Hirota & Kijima, 1992). Since telepresence and virtual reality are three-dimensional, the interface devices are complicated and bulky. In the case of a mouse, however, because of having only two degrees of freedom, it is possible to implement tactile and force information within the body of the mouse.

There are several ways of presenting tactile information through the mouse. One simple method is to provide vibration to the operator's finger. For vibration, electromagnetic or piezoceramic devices can be used (Zimmerman, Lanier, Blanchard, Bryson & Harvill, 1987). However, in a window type visual interface, vibration will not correspond to tactile information because, in many cases, there is no vibratory component of the visual information. A common visual display technique used in graphical user interfaces is to present images of objects such as key buttons in relief (e.g. *Windows & NextStep*). Tactile information associated with seeing the object will help convey the impression of the physical properties of the object. Also, the tactile stimulation to the finger pad can give the impression to the operator of actually touching the object with the finger tip.

It is known that an operator can perform pointing tasks more quickly with a mouse than with joysticks or other devices (Card, English & Burr, 1978). The study in which touchscreens were compared with a mouse for the selection of targets showed lower error rates and shorter selection times with the mouse if targets were small (Sear & Shneiderman, 1991). Our experimental results suggest that the addition of tactile and force information can further reduce response times and allow the operator to select the target over a wider area. This means that multi-modal information facilitates cursor positioning over an interface only with visual information. According to Fitts' law (Fitts, 1954; MacKenzie & Buxton, 1992), increasing the size of the target results in reducing the time required for operation. Therefore, it is reasonable that response times were shortened and the effective target size was increased by the addition of tactile and force information. From the results of response times in our study, the index of performance of the pointing task with an ordinary mouse was estimated at 2.96 bits/s, and with the multi-modal mouse, 3.23 bits/s. Thus, tactile and force information increased performance by 0.27 bits/s. The reduction in response time by tactile and force information corresponded to a 24% increase in W of the target compared to the same task with an ordinary mouse. On the other hand, the average increase in the standard deviations of marginal distributions of the clicking point was 45%. This difference suggests that prediction by Fitts' law for the multi-modal mouse is not perfect. Fitts' law was established for visual pointing tasks; modification of Fitts' law for

visual-tactile (i.e. multi-modal) pointing tasks should be considered after further detailed analysis.

Another explanation for the reduction of response time is the effect of sensory modality in sensory-motor linking. The subject can respond quicker to a somesthetic stimulus than to a visual stimulus with motor responses (Nelson, McCandlish & Douglas, 1990). There may also be an effect of S-R compatibility on reaction time (Hasbroucq & Guiard, 1992). With the multi-modal mouse, tactile information is given to the finger that presses the button of the mouse.

This is an S-R compatible reaction time task. Although there have been studies on the compatibility between modalities of input and output in human-machine interfaces, the focus was mainly on auditory and visual information. Wickens, Sandry and Vidulich (1983) have examined visual and verbal displays with manual and speech responses in spatial and verbal tasks, and found an effect of the compatibility between display, response and task. In the case of target pointing tasks, a pointing task for a mouse is analogous to a reaching task with a finger. As tactile and force information arise when we touch the objects with a finger, display of the somesthetic sensation is a compatible response. In human-computer interfaces, as it is easy to give auditory information, Monk (1986) introduced sound information to avoid mode errors. Auditory information is particularly useful when one cannot be sure that the operator is concentrating on the visual display. Tactile and force information is also useful from this point of view. In order to assess the effectiveness of tactile and force information on the pointing task, precise comparisons between different sensory modalities will be needed.

Using an ordinary mouse requires visually concentrating on the cursor position on the screen. In the case of the multi-modal mouse, tactile and force information also have a role in detecting the target area. With added somesthetic information, one need not depend solely on visual information. Therefore, although it was not examined here, inferring from the results of psychophysical studies on sensory integration (Akamatsu, 1992), one can also expect that the use of the multi-modal mouse would reduce the load of the visual function in computer work.

As the multi-modal mouse can give height information of the object through tactile information, the human-computer interface achieves three-dimensional characteristics. In this sense, the interface acquires properties akin to virtual reality. The tactile and force information given by the mouse was limited to that controlled by on-off signals, informing us that the cursor is in contact with the target. With on-off signals, the tactile and/or force information can also inform users when the cursor crosses the edge of windows. This signals that the cursor has moved from one window to the other. This kind of somesthetic edge information may help reduce window selection errors. However, one must bear in mind that the response time may be affected by tactile and force information if there are many targets and edges along the trajectory to the destination target. By controlling the driving signal (duration and pitch), other tactile surface information can also be projected through the mouse. When the duration of the signal is changed in the range of 0-5 ms, we can feel, at least, 3 or 4 different heights of the pin. This can be used for generating virtual texture (Minsky, Ouh-young, Steele, Brooks & Behensky, 1990) by the multi-modal mouse.

Although the multi-modal mouse was developed to give additional tactile and

force information for computer operation with a mouse, the device can be applied to a human-computer interface for blind people as well. Many of the Braille displays for blind people have limited dimensions. To overcome this problem, the concept of a Braille mouse, a kind of movable Braille display, has been proposed by several people (Anbary & Mardiks, 1982; Weber, 1993). However, as most software for sighted persons employs a window-type graphic display with a mouse, operation by blind persons is excluded. Following up on the ideas presented herein, an interface device which can present not only characters but also the cursor position by tactile stimulus could be developed.

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