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VIRTUAL FIGURE PRESENTATION USING PRESSURE-SLIPPAGE-GENERATION TACTILE MOUSE

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Abstract - Since our tactile mouse can generate not only distributed pressure but also slippage force, it is expected that it can enhance the reality degree of virtual reality generated by it compared to conventional tactile displays. In previous works, this tactile mouse was effective for edge tracing of virtual figures. However, advanced tests are required using psychophysical experiments to evaluate this tactile display. In this paper, four virtual relief-like figures, a triangle, square, pentagon and circle, are presented using the tactile mouse. These virtual figures have a constant height of around 1 mm against the background. To evaluate the effectiveness of combined presentation of pressure and slippage, not only pressure but also tangential force is generated on the tactile pad on which an operator puts his finger in combined presentation tests when the mouse cursor travels on the figure. In a series of experiments, five male subjects judge which figure is presented. It is found that the percentage of correct answers is increased in the combined presentation when the circle and pentagon are presented. Therefore, the combined presentation provides plain virtual sensation to allow the operator to more easily understand the sensation.

Index terms: Tactile Sensing, Virtual Reality, Figure Presentation, Pressure-slippage, Mouse.

I. INTRODUCTION

Several tactile displays have been developed to generate tactile sensation in virtual reality (VR). These tactile displays are divided into two types: fixed type and movable type. The fixed type display is equipped with a tactile-pad composed of many tactile points to generate texture that is palpated by the operator. In this tactile display, since the operators actively palpate the display pad, it must have a relatively wide area [1]-[3]. Although these displays accomplish natural tactile sensation because of active touch, they require a huge number of motors to produce precise texture. On the other hand, the movable type does not require many actuators because small finger-size tactile pads are sufficient. The operator does not move his finger on the tactile pad, and the tactile display moves together with the operator's hand. The position of the operator's hand is measured by an appropriate pointing device [4]-[6]. Although from the viewpoint of size the movable type is attractive because of few actuators, its palpation is unusual because of non-relative motion between fingertip and tactile pad.

To improve the movable-type tactile display, we added tangential stimulus generation for slippage sensation to the display to direct relative motion between finger and object. In previous works [7][8], we developed a new tactile display mounted on a mouse capable of presenting not only distributed pressure but also tangential force. The mouse is equipped with a bimorph-piezoelectric-actuator array and a two-dimensional electro-magnetic-linear motor to present pressure and slippage forces, respectively. To evaluate this tactile mouse, we performed edge tracing tests for virtual circles, triangles, and squares with four male subjects. The experimental results showed that presentation capability was enhanced with the combined stimulation because the edge tracing precision obtained using combined stimulation exceeded that using only pressure stimulation. Furthermore, we performed a series of psychophysical experiments using a real-edge presentation apparatus and a tactile mouse. Although the combined presentation of distributed pressure and vertical slippage force is rather worse than only distributed pressure presentation, the combined presentation of distributed pressure and parallel slippage force is effective for presenting the virtual edge. These experiments show that precision of edge tracing is enhanced by pressure-slippage presentation. However, from these experimental results, we cannot judge whether the pressure-slippage presentation enhances perception of figure shape.

In this paper, four virtual relief-like figures, a triangle, square, pentagon and circle, are presented using the tactile mouse. These virtual figures have a constant height of around 1 mm against the background. To evaluate the effectiveness of combined pressure-slippage presentation, not only pressure but also tangential force is generated on the tactile pad on which an operator puts his finger in combined presentation tests when the mouse cursor travels on the figure, while pressure only is generated in the pressure-only presentation test. In a series of experiments, five male subjects judge which figure is presented.

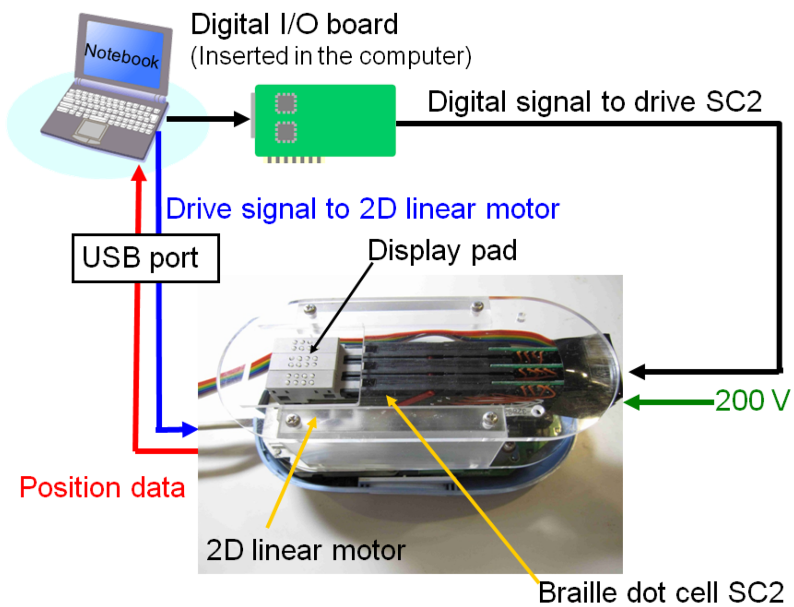


Figure 1. Schematic block diagram of tactile mouse

II. TACTILE DISPLAY

a. Tactile presentation system

In previous papers [7][8], we developed a tactile display capable of presenting distributed pressure and slippage. Since we adopt the display as a tactile presentation system, we introduce the tactile display first. A block diagram for controlling the tactile mouse is shown in Fig. 1. The x- and y-directional position data of the mouse cursor are sent to a computer through a USB interface to calculate the output stimuli of the distributed pressure and the tangential forces on the basis of the positioning relationship between the mouse cursor and the virtual object. The stimulus pins of the display pad are driven by the driver boards for the piezoelectric actuator installed on the Braille dot cell controlled by the digital input output (DIO) board to generate the specified pin-protrusion pattern. The signals for the tangential force are transmitted to a motor control board installed in the mouse through a USB interface to generate slippage force.

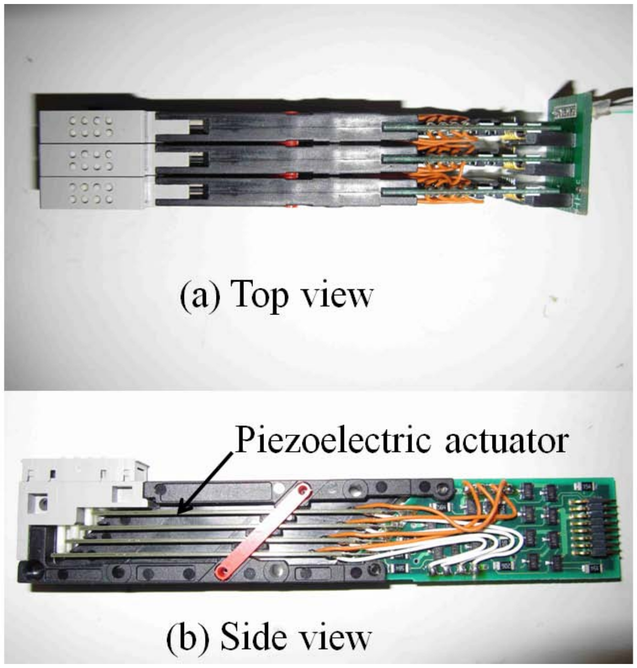


Figure 2. Braille dot cell SC2

b. Distributed Pressure Display

In this paper, we use the Braille dot cell (SC2, KGS, Co.) [9] (Fig. 2) as the distributed pressure display. The Braille dot cell generates a 2×4 dot pattern, and 2×3 and 2×1 dots are used for the Braille dot and cursor, respectively. Since each dot is driven by the piezoelectric ceramic actuator of a bimorph type, the actuator is controlled by the voltage applied to the core electrode. When source voltage of 200 V is applied between the upper and bottom electrodes, the end of the actuator bends downward if 200 V is applied to the core electrode. If 0 V is applied, the end of the actuator bends upward. The stroke of the upward and downward motion is about 1 mm. The strength of the generated force is around 0.1 N. Each dot is the top of a stimulus pin, which is moved up-and-down based on the upward and downward bending of the piezoelectric ceramic actuator. Since we used three Braille dot cells, a dot pattern of 6×4 is formed on the display pad. SC2 includes a shift register (BU4094BC, BU4094BCF, or HEF4094) consisting of an 8-bit register and an 8-bit latch to control the piezoelectric ceramic actuator array. As the data in the shift register can be latched by an asynchronous strobe input, it is possible to hold the output in data transfer mode. Since each line of the parallel 3-bit output is connected to a switch of the piezoelectric actuator, the shift register controls the 2×4 dot pattern of the cell. Since a serial output of SC2 is connected to a serial input of the next SC2, a 6×4 dot pattern formed by three cells is presented by at first sending a 24-digit binary signal and then sending strobe input.

c. Slippage Force Display and Combined Stimulation Type of Tactile Mouse

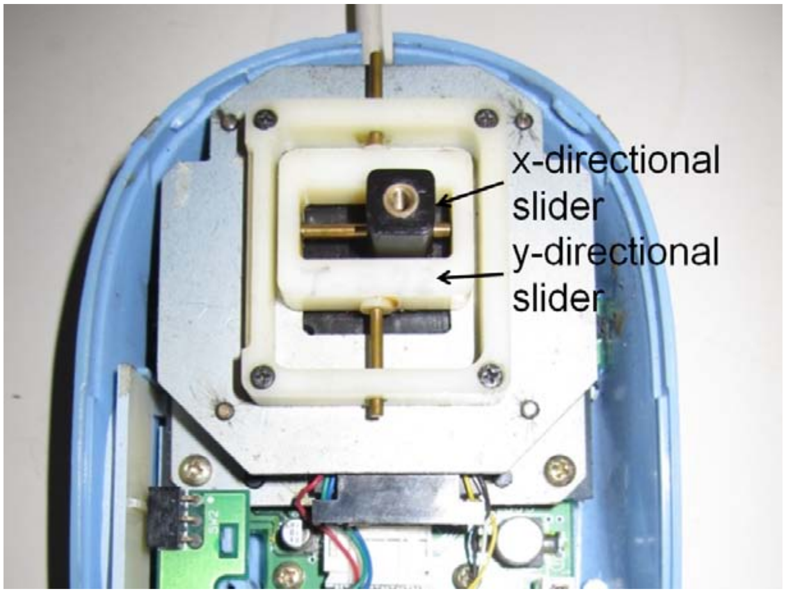


Figure 3. Linear motor of Fuji Xerox tactile mouse

We used Fuji Xerox’s tactile mouse [10] as a slippage force display and a mouse to transmit the tangential force on the fingertip. The mouse is equipped with an x-y linear motor on an optical mouse to generate static shearing force and its vibration.

The linear motor is equipped with x- and y-directional sliders as shown in Fig. 3. The y-directional slider resembles a square frame, and the x-directional slider is a square shaft that moves linearly within the square frame. Each slider has an 8-shaped coil, and a permanent magnet plate is installed under these sliders. The vertical squared shaft is moved on the x-y plane by controlling magnitude and direction of electric current applied to these coils. Two-dimensional force signals are transmitted to a motor control board installed in the mouse through the USB interface. The linear motor is controlled through the following API functions.

FMouseOpenDevice: open the device.

FMouseCloseDevice: close the device.

FMouseSetForce: generate a specific constant force.

FMouseSetPidParam: set parameters of PID control.

When we examine the linear motor's capability to generate force using FMouseSetForce, we found that the x-y linear motor generates x-y directional forces within about 0.7 N.

We developed a combined stimulation-type tactile mouse by combining the distributed pressure display and Fuji Xerox's tactile mouse, as shown in Fig. 4. In this mouse, the distributed pressure display is mounted on the x-y linear motor. If user fingers are placed on the tactile mouse's display pad and move the mouse on the virtual texture, operators can feel a convex or concave surface based on the virtual texture.

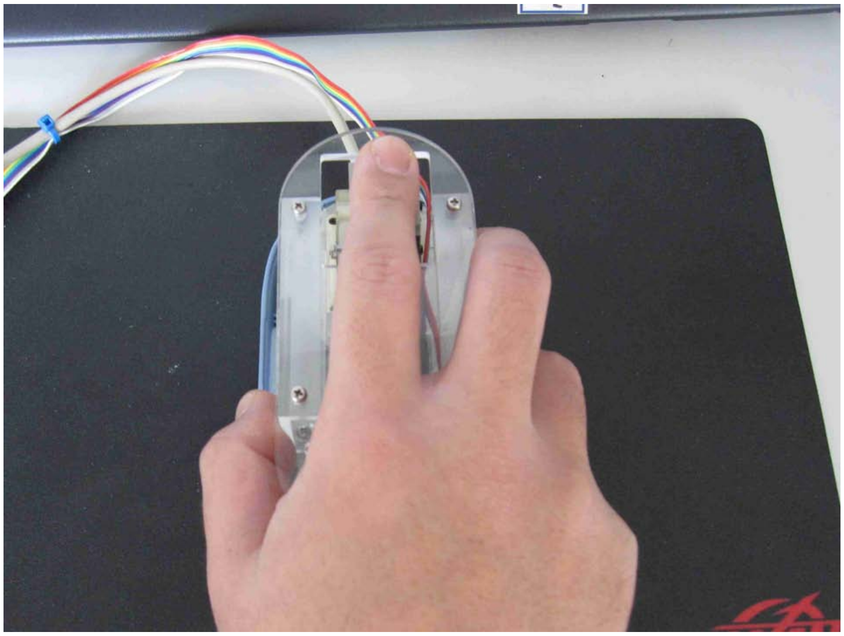
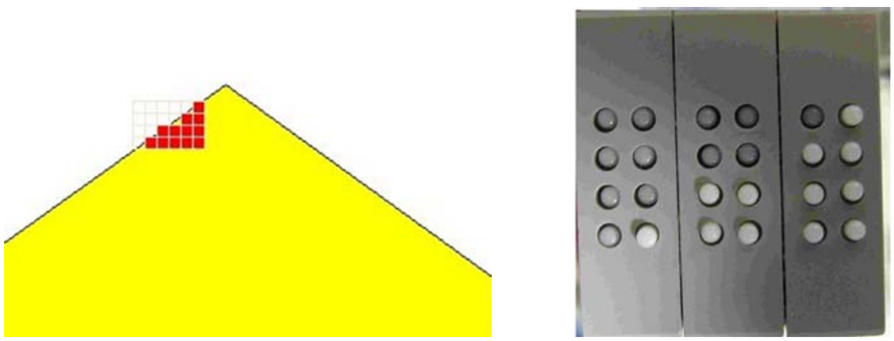


Figure 4. Handling of tactile mouse

III. VIRTUAL FIGURE PRESENTATION

a. Presentation software

To evaluate our tactile mouse for relief-like figure presentation, we developed presentation software. As shown in Fig. 5(a), if the grid cursor travels on the virtual figure generated on the screen, the dot corresponding to the element of mesh is protruded as shown in Fig. 5(b). Since an operator feels a virtual object as a plate of around 1 mm in height (stroke of the piezoelectric actuator), the operator can judge the object shape. Although this dot pattern display seems to be enough to represent the virtual figure, it is found that additional tangential stimulus is required. In previous studies [7][8], we found that operators did not judge whether their fingers were on the virtual figure. If the positions of all the stimulus pins are on a virtual figure and their fingers remain on it, all stimulus pins keep protruding and operators cannot judge whether the mouse cursor is on it or not because their sense of feeling is adapted for the continuing protrusion of the pins. To prevent this problem, the negative shearing force was generated in proportion to the cursor's speed when the cursor was on a virtual figure as shown in Fig. 6.



(a) Mouse cursor in virtual figure (b) Dot pattern on display pad

Figure 5. Example of figure presentation

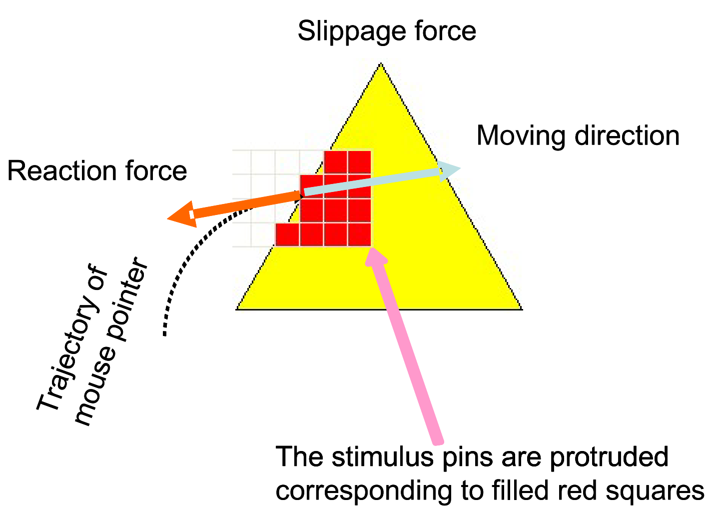
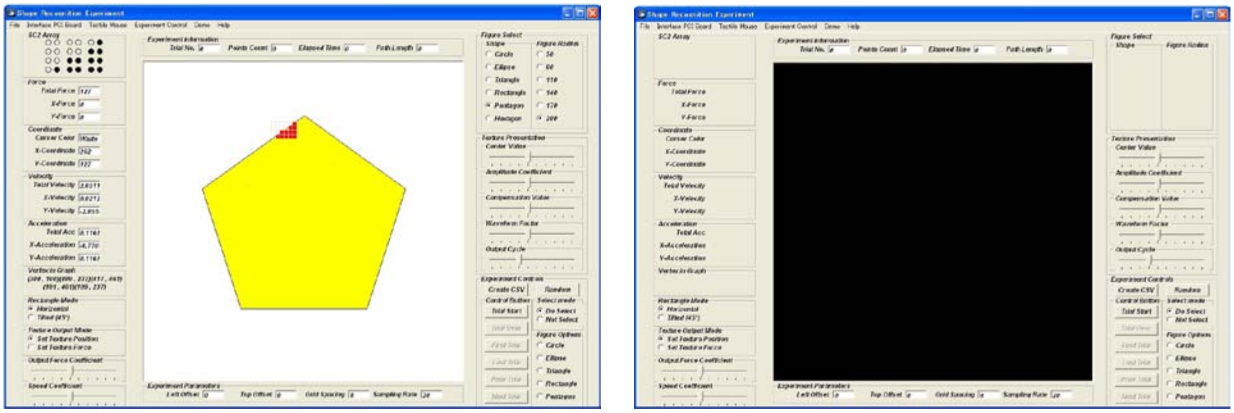


Figure 6. Slippage force generation



(a) before start of experiment (b) in experiment

Figure 7. Main panel of virtual figure presentation software

b. Experimental procedure

We adopted four figures, a circle, triangle, square and pentagon, as virtual figures. Since these figures are randomly presented 10 times for each human subject per figure, 40 trials are performed for each test. The human subject answered as to which figure was presented within 1 minute. To prevent from providing any visual information related to the presented figure, the presentation screen is changed to black as shown in Fig. 7. After 30 minutes, a short break is provided because over 30 minutes of work causes deterioration of tactile feeling. Room temperature is kept at 24 °C.

To examine the effect of tangential stimulation on figure presentation, we performed two series of experiments: one is only distributed pressure presentation (single presentation); the other is combined presentation of pressure distribution and tangential stimulation (combined presentation).

IV. EXPERIMENTAL RESULTS AND DISCUSSION

a. Percentage of correct answers

To examine presentation capability of this tactile mouse, the percentage of correct answers is shown in Fig. 8. In the case of single presentation, the percentage of correct answers is around 80% for the triangle and square, while it becomes low for the circle and pentagon. In particular, the percentage of correct answers for the pentagon is 54%. On the other hand, in the case of combined presentation, the percentage of correct answers is around 80% except for the pentagon, which is 60%.

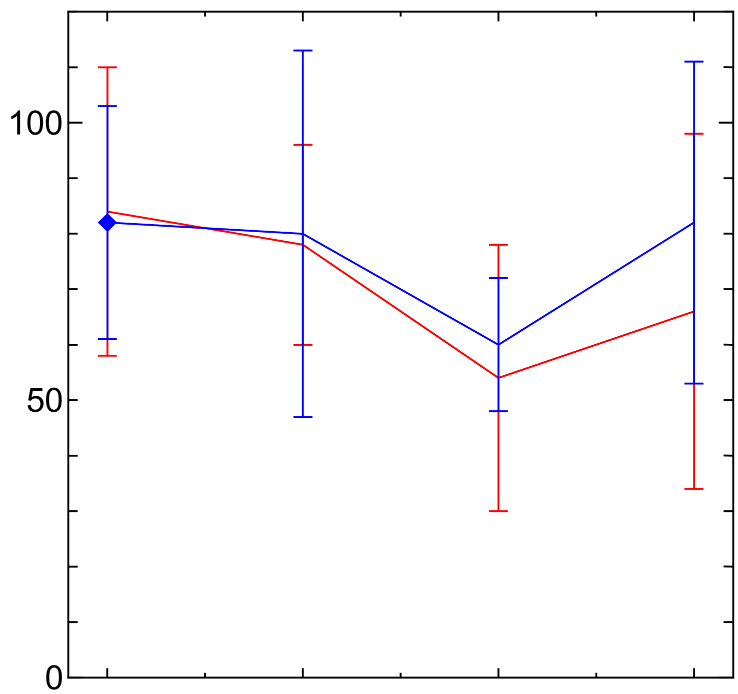


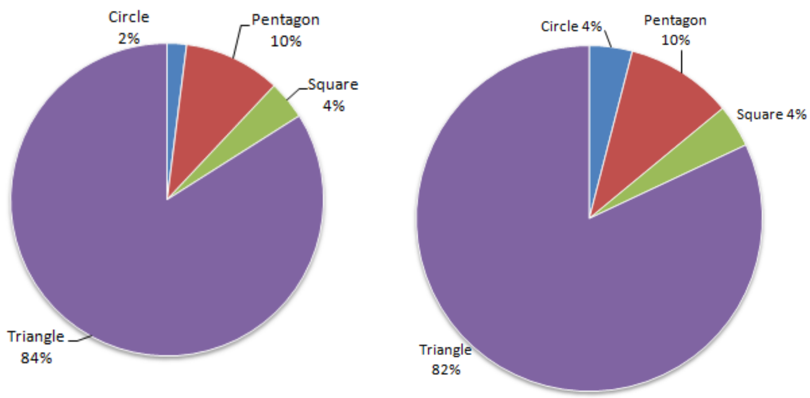
Figure 7. Percentage of correct answers for each figure

b. Figure selected by mistake

To examine mistakes in judgment, pie charts of answers are shown in Figs. 8-11 for each virtual figure. The ratio of components of the chart is close to same value between two presentation modes in the case of a triangle as shown in Fig. 8. Although the ratio is slightly changed for two presentation modes in the cases of the square and pentagon in Figs. 9 and 10, two presentation modes of square and pentagon have roughly similar rations compared to the circle.

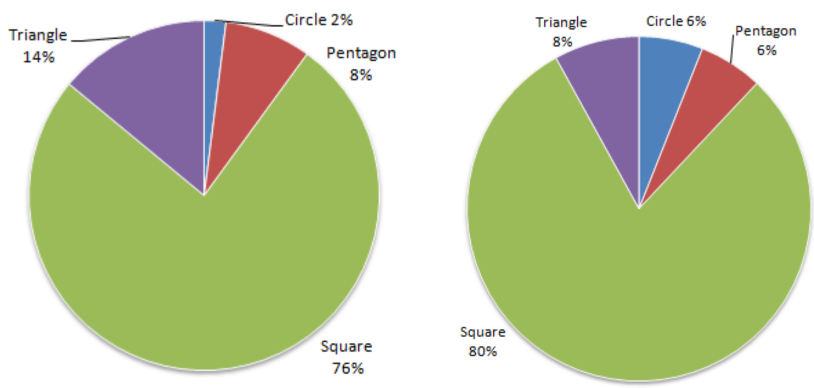
On the other hand, in the case of the circle, the result of combined presentation is completely different from single presentation. In particular, there is no triangle selection in the case of combined presentation, while 10% of answers were for triangle in the case of single presentation.

c. Effectiveness of combined presentation



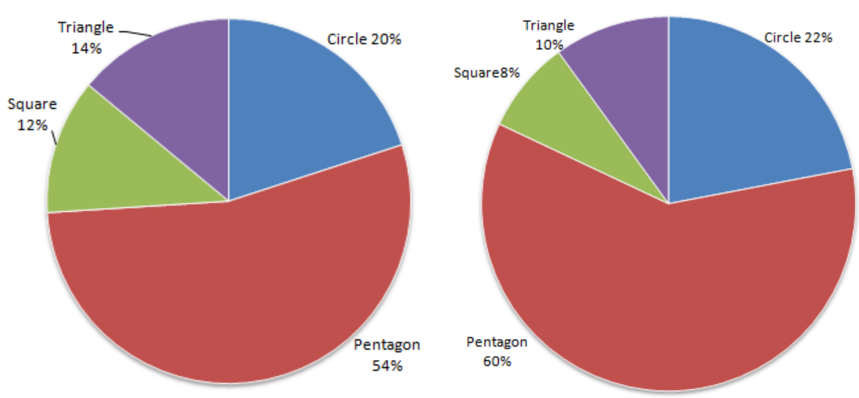
(a) Single presentation (b) Combined presentation

Figure 8. Ratio of answers for triangle presentation



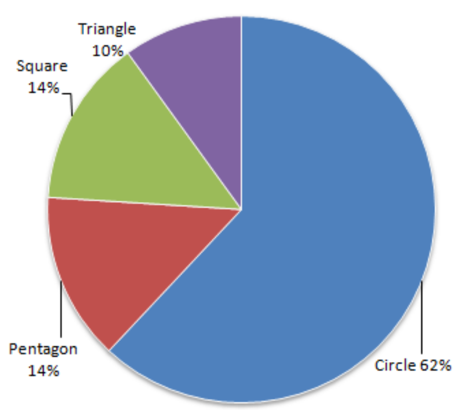
(a) Single presentation (b) Combined presentation

Figure 9. Ratio of answers for square presentation

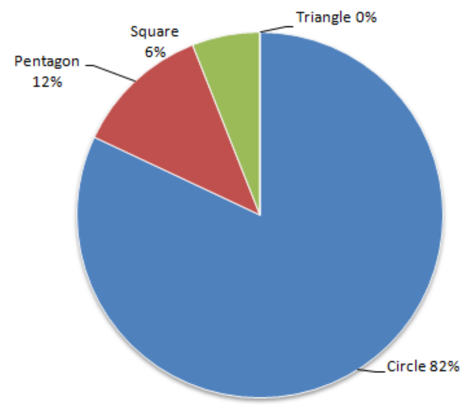


(a) Single presentation (b) Combined presentation

Figure 10. Ratio of answers for pentagon presentation



(a) Single presentation



(b) Combined presentation

Figure 11. Ratio of answers for circle presentation

As previously described, the triangle, square, pentagon and circle have similar size because these figures have the same circumscribed circle. In the single presentation, if the positions of all the stimulus pins are on a virtual figure and the operators' fingers remain on it, all stimulus pins keep protruding and operators cannot judge whether the mouse cursor is on it or not because of adaptation. At that time, since the operators have to judge the presented figure based only on the contour of the virtual edge, they sometimes mistake the triangle for the circle if they miss the vertex of the triangle.

On the other hand, in the case of combined-mode presentation, since tangential stimulus distribution is added on the contour of the figure, ease of recognition from tactile information is enhanced. This mechanism is similar to the following characteristic of vision: a filled-in figure is easier to recognize than a line drawing. Furthermore, we sometimes perceive with tactile sensation the shape of a sticky area such as that left by peeled tape. Therefore, the operators did not mistake the circle for the triangle in the case of combined presentation as shown in Fig. 11 (b). Consequently, we can obtain a relatively high percentage of correct answers in the combined presentation.

V. CONCLUSION

Since our tactile mouse can generate not only distributed pressure but also slippage force, it is expected that it can enhance the reality degree of virtual reality generated by it compared to conventional tactile displays.

In this paper, four virtual relief-like figures, a triangle, square, pentagon and circle, were presented using the tactile mouse. To evaluate the effectiveness of the combined presentation of pressure and slippage, not only pressure but also tangential force was generated on the tactile pad on which an operator put his finger in combined presentation tests when the mouse cursor traveled on the figure.

In a series of experiments, five male subjects judged which figure was presented. It was found that the percentage of correct answers increased in the combined presentation when the circle and pentagon were presented. Therefore, the combined presentation provides plain virtual sensation to allow the operator to more easily understand the sensation.

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