Undulation detection of virtual shape by fingertip using force-feedback input device

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Abstract: To trace along the contours of virtual shapes, a force feedback input device was developed. Two kinds of experiment using the device were carried out. The visual and tactual sensitivities of undulation on a curved contour were obtained. The visual sensitivity was superior to the tactual one. However, tactual sensing by the force feedback mechanism in addition to the visual sensing brought about more reliable result.

1. Introduction

The input devices for shape input and manipulation used in the current CAD systems are keyboards, mouses and tablets. Operations using a mouse (or a tablet) are easier than a keyboard, because the operation using it is directly assigned to the movement of the cursor on the CRT display.

Although these movements are analogous, there is no feedback information from the cursor to the mouse, that is, the movement of the cursor cannot have influence on the movement of the mouse. This no-feedback characteristics of the mouse would become fatal defect when the contour of the shape is traced by the mouse. This contour tracing is usually executed in the real world when we build a desired shape with a clod of clay. If the contour tracing of shape in the computer is executed as in the real world, many shape designers would be willing to use the system.

Therefore, the development of such a system is necessary to make the conventional CAD system more friendly to the designers. The aim of this research is to develop a CAD system with which the operator directly deforms the shape with his or her fingers.

In such a system, force-feedback mechanism to the input device is the one of the most essential functions. However, it is rather difficult to realize real-time force-feedback mechanism, because it requires complicate mechanism and enormous computing power. The more precise and higher response the mechanism have, the more the initial and running cost for using it becomes.

On the other hand, the tactile sensory function of the human hand has its own characteristics[1]. Recently, it became possible to explore the characteristics of the mechanoreceptive afferent units innervating the glabrous skin of the human hand[2]. Therefore, the specification of the input device should rationally be designed to meet the characteristics of the human sensory system. The functions of glabrous skin receptors for object recognition are investigated when the skin directly touches a real object[3].

However, when the skin indirectly touch a real object, or touch a virtual object, the characteristics of the receptors would be somewhat different. For example, the tactile impressions of surface texture is stronger when an intermediate paper is inserted between the fingertip and the surface than without the paper [4][5]. To recognize the local shape features such as curvature deviation or undulation, craftsmen haptically explore the surface with his hands. This haptic exploratory procedures would also be effective on a virtual shape.

This paper reports the characteristics of virtual shape recognition by tracing contours with fingertip via a force feedback mechanism. Although the tracing of a virtual shape using this device does not bring about shearing friction, it would still be effective because of the similarity to the case of inserting an intermediate paper mentioned above[5]

2. Experiment

We had two kinds of experiments. Our purpose in the first experiment was to compare the sensitivity of the human visual and tactual perceptive functions in case that the target is a virtual object. In the second experiment, the task was to detect curvature deviation of a circle by tracing its contour with his/her eye or by his/her fingertip with a force feedback input device.

Method

Subjects: Four subjects of ages of teens, twenties, thirties and forties. All of them have normal visions (more than 1.0 visual power) and have no motor disturbances.

Apparatus: The virtual shape is defined in the graphic workstation(IRIS 4D, Silicon Graphics) and it is displayed on the CRT(19 inch, with resolution of 1280x1024 dots). The subject sits in front of the display, about 90cm apart from the display surface. The subject touch the input device with his/her fingertip. The input device, which is experimentally developed, is a 2-D locator with a 2-D force sensor on it. The 2-D locator is actually a XY-recorder(3078, Yokogawa), the analogous signal to which is obtained by converting digital signal from the workstation.The 2-D force-sensor, which is developed and has size of 3cm x 3cm x 1cm, is attached to the moving head of the XY-recorder. The analogous signal from the force sensor is converted to a digital one and is sent to the workstation. The data flow is as follows.

The subject puts his/her fingertip on the force sensor and wishes to move it toward a certain direction, then the force sensor outputs 2-D force vector data. The data is sent to the workstation via a microcomputer(PC9801, NEC) for A/D conversion. In the workstation, the data is regarded as the user's intentional displacement vector of the cursor. If this displacement is allowed (there is no object to be collide with), then cursor shifts toward that direction, and the amount of the displacement is proportional to the length of the force vector. Then workstation sends the new cursor position to the XY-recorder, following the displacement of the force sensor with the subject's fingertip on it. So, the force sensor moves toward the direction according to force direction indicated by the fingertip of the subject. This force sensor, however, does not follow the subject if it collides with a virtual object defined in the workstation, because the workstation always checks if the cursor collides with the virtual object. If the force sensor collides obliquely with an object, not equal to the normal to the object, the force sensor then moves along the contours of the virtual object. Observed from the subject's situation, the force sensor, with his fingertip, behaves just as if the sensor collides with a real object and it traces along the contours of the object. This input device is therefore a kind of a virtual world.

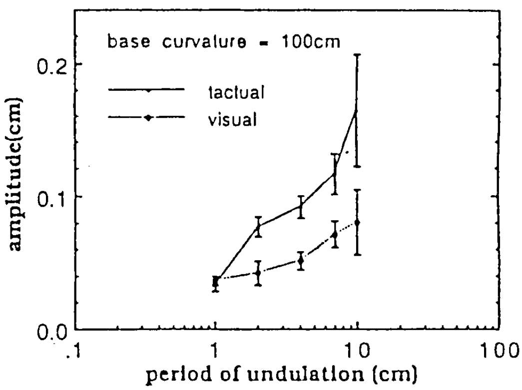
Following experiments are carried out with this input device.

Experiment 1

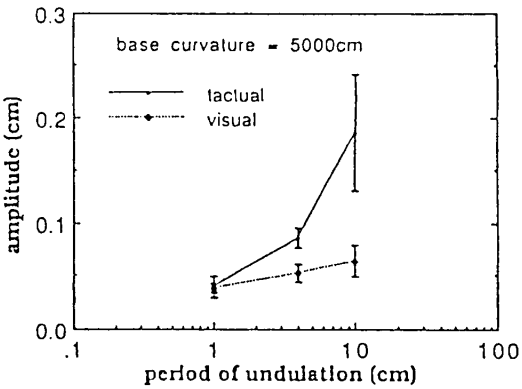
Stimuli and procedure: The virtual object to be traced along its contour is defined in the workstation. The contour is curved line (base curve) with small curve superimposed on it (undulation). When the amplitude of undulation is changed stepwise from zero to 0.5mm, the subject checks which amplitude is the limit of sensation by his/her visual organ or by his/her fingertip with the above device. This procedure is repeated several times, then the curvature of the base curve and/or the spatial frequency of undulation is changed, then the procedure is repeated again. Through this process, we find the human discrimination performance of undulation of a virtual object by the visual organ or by tracing the contour with the finger.

Result: Figure 1 shows the result of the experiment 1. The abscissas of both Fig.1(a) and Fig.1(b) represent period of undulation superimposed on the base curve of the virtual object. The ordinates of both figures represent the amplitude of undulation the subject could hardly detect. The solid line graphs of both figures represent the limit amplitude of undulation detected by tracing the contours with his/her fingertip on the force sensor. The dotted ones of both figures represent the limit amplitude of undulation detected by looking at the object displayed on the CRT from a distance of 90cm. Figure 1(a) shows the case that the curvature radius of the base curve is 100cm, while that of Fig.1(b) is 5000cm, almost a strait line.

Discussion: The figure 1 shows that the sensitivity of undulation by the eyes (visual) is superior to that by tracing the contour with the fingertip (tactual), so long as the spatial frequency of undulation is longer than 1 cm/cycle. The case that the undulation frequency is shorter than



(a)



(b)

Fig.1 Human discrimination performance in undulation detection using the force feedback input device

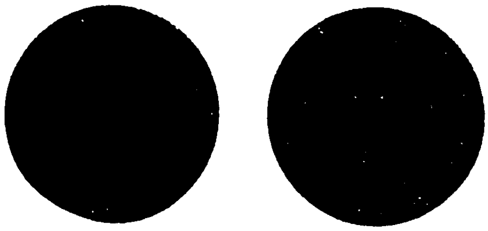
1 cm/cycle could not be carried out because of the limit of hardware responsibility.

At the first glance of the both graphs, the fact that the visual sensitivity is superior to the tactual one implies that the tactual media is not necessary to the interface. However, from the experience of using the force-feedback interface, we recommend strongly any kind of such interfaces should be available because it is very comfortable to use the force-feedback input device. We planed experiment 2 to confirm this feeling.

Experiment 2

Stimuli and procedure: The tasks are to trace the contour of some figures(approximate circles of about 10cm in diameter)and to report if there are any change in the curvature of the contour of those figures. Eleven figures, of which the amount of changes of curvature are all different to one another, are presented with arbitrary order. The subject reports which part of the figure is deviated toward outside or inside to an exact circle. The tracing is executed first by the eyes only. After finishing all the figures, then tracing is done both by eyes and fingertip on the force-feedback system.

Result: In case that deviations from an exact circle is apparent, the report of the subject is reliable, while when the deviation is small, the subject hardly tell the part by looking at it. However in such a case, if the force-feedback system is allowed to use, the report shifts to more reliable one. Examples of such figures are shown in Fig.2(a), (b).



(a) (b)

Fig.2 Approximate circles with small deviations toward inside or outside, which deviations is confirmed by tracing with fingertip on the force feed-back device

Discussion: We found through these experiments that it is fairly difficult to explain from the data that the tactual (force-feedback) system is necessary in addition to the visual display. However the use of force-feedback system as an input device is very natural in operation and more accurate especially when the amount to be detected is too small.

One reason of easiness of detection of curvature deviation in Fig.2 by introducing the force-feedback system is the feedback force vector. The feedback force is received through the force sensor by the fingertip when the fingertip manipulates the force sensor. The direction of the force vector felt by the fingertip changes uniformly when the curvature of the contour changes uniformly as the finger moves along the contour. However if there is any deviation of curvature during the trace, the force vector also changes unexpectedly. This unexpected change of direction is detected by the fingertip, and hardly by the eyes.

3. Conclusion

We developed a force feedback input device as the first step of developing a direct-operation CAD system. Using the device, we found both the visual and the tactual sensitivities on undulation in the virtual contour of an object. The sensitivities depends on the spatial frequencies of the undulation and the visual sensitivity is superior to the tactual one in the range that the period of undulation is above 1 cm. The merit of using both visual and tactual feedback system is shown in such a task as tracing and searching a curvature deviation, because the direction of the feedback force changes unexpectedly at the position of curvature deviation.

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