Virtual Work Space for 3-Dimensional Modeling

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Abstract. To develop a human interface for three-dimensional modeling it is necessary to construct a virtual work space where we can manipulate object models directly, just as in real space. In this paper, we propose a new interface device SPIDAR (SPace Interface Device for Artificial Reality) for this virtual work space. SPIDAR can measure the position of a finger and give force feedback to a finger when it touches the virtual object. We construct a virtual work space using SPIDAR. We make experiments to show the effect of force feedback on the accuracy of work in the virtual work space.

1 Introduction

Many input devices for computers have been proposed. We usually use keyboards for symbolic information. Mice are used for two-dimensional information. Devices to handle shape of three-dimensional objects don't exist although they are necessary. In the case of input and modification of three-dimensional shapes, we presently usually handle the shape of the objects as sets of values of three-dimensional coordinates and then input these values from keyboards, or manipulate two-dimensional projection charts of three-dimensional objects by mouse. It is desirable to be able to manipulate three-dimensional object models as we handle real objects in real world.

Recently, some experiments with realizing a virtual space on a computer were begun[1]. In this virtual space, we can manipulate object models like real objects. We call this space 'virtual work space'. To realize a virtual work space, it is important to give visual, tactile and force sensation to an operator who manipulates objects in a virtual space[2].

In this paper, we propose a new interface device SPIDAR(SPace Interface Device for Artificial Reality) for the realization of this virtual work space [3]. Using SPIDAR, we can input finger position to a computer. We can manipulate virtual objects on a computer directly by fingers. Furthermore, we can receive force feedback when a finger comes into contact with a virtual object.

By combining SPIDAR with a display, we construct a virtual work space. We make experiments on the effect of the force feedback on the accuracy of work in the virtual work space.

2 Realizing a Virtual Work Space

2.1 Flows of Perceptual Information in Manipulation of objects

First, we analyze manipulation in making clay works as a concrete example, noticing the flow of information in manipulation.

There is a mass of clay on a work table. An operator is imagining a shape that he wants to make. Processes of the work are as follows.

STEP 1 : Compare the shape of the clay and the imagined shape.
Search for a part to be deformed and notice the part.

STEP 2 : Move a finger to the noticed part of the clay watching relative position of the finger to the position of the clay.

STEP 3 : Confirm completion of movement by contact of the finger with the clay.

STEP 4 : Deform the clay partially to be similar to the imagined shape watching the shape of the clay.

Repeat STEP 1–4 until the shape of the clay becomes similar to the imagined shape. Information used in STEP 1–4 are assorted into three kinds as follows.

(a) visual sensation

- Look at the shape of the clay. (1)
- Watch the relative position of the finger to the clay. (2)
- Observe the deformation of the clay. (4)

(b) tactile sensation

- Confirm contact of fingers with the clay. (3)
- Measure strength of force applied to clay. (4)

(c) control information given to finger

- Move the finger to desired position. (2)
- Stop movement of the finger. (3)
- Apply force to the clay. (4)

(a) and (b) are centripetal information to the brain. The next action is decided based on this information. On the other hand, (c) is centrifugal information from the brain. This is used as control information to perform the action decided.

This information of flow makes a cycle as illustrated in Fig.1. This cycle is called the 'perception cycle'. When we do various tasks we use this cycle unconsciously.

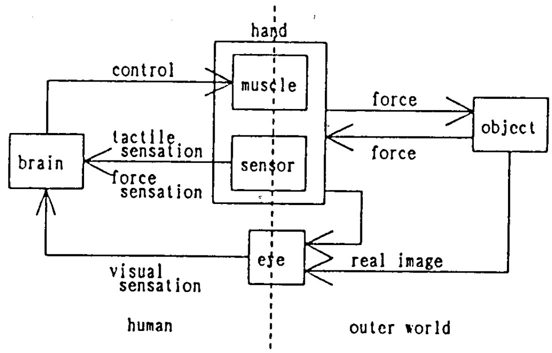


Figure 1: Perception cycle

2.2 Information of sensation in a virtual work space

To construct a virtual work space, it is necessary to generate information of visual, tactile and force sensation. In this subsection, we investigate ways to generate this information of sensation in a virtual space.

2.2.1 visual sensation

Information for visual sensation is generated by stimulus to a retina. So it is necessary to simulate the propagation of light rays. Holography is a means to generate a complete space image. However, it is very difficult to update the image for deformation of objects in real time. Another way is to use stereoscopy . For stereoscopy some basic methods have been proposed and have been put to practical use. As the image for stereoscopy can be generated by using computer graphics it is not difficult to update the image for deformation of objects in real time. One problem with stereoscopy is that the position of the space image differs form the true position when the view point moves. To avoid this problem, there are two solutions. One is to fix the view point. The other is to measure the position of the view point and then generate the image seen from that new view point.

2.2.2 tactile sensation

To generate tactile sensation, we must simulate the contact of a finger with an object in real space. For this purposé, we need to know the position of the finger.

In order to generate a tactile sensation, it is necessary to give physical stimulus to the finger. It may be possible to give electrical stimulus instead of physical stimulus. Also giving auditory stimulus can be used as a substitute for tactile sensation.

2.2.3 force sensation

A force sensation is useful when we try to move or to deform an object. The magnitude of the force is determined by the physical properties of the object, such as solidity, mobility, etc. To generate force sensation, we need the position and the direction of movement of the finger, and the physical properties of the objects.

To give the perception of force, we must simulate the real world physical forces in the virtual work space. When the finger isn't in contact with any object, we must be able to move a finger with no resistance. At such time, we have to apply as little force as possible.

We need to attach some apparatus to the finger in order to apply force directly to it. However, when performing tasks in a virtual space, it is desirable that the finger actually manipulating objects is visible. Therefore, it is undesirable for the finger to be hidden by putting a large apparatus on the finger.

For the realization of a virtual work space where we can manipulate objects naturally, apparatus to generate these sensation must be realized and integrated. As it is difficult to generate these sensation exactly, it is necessary to approximate these apparatus to each sensation in a balanced manner. The perception cycle after including these apparatus is illustrated in Fig.2.

3 Space interface device for virtual work space

In this section, we explain SPIDAR(SPace Interface Device for Artificial Reality) which realizes a force sensation for the virtual work space explained in Sec.2. SPIDAR gets positional information of a finger and gives the finger a force sensation when the finger is in contact with a virtual object . When the finger is not in contact with anything it can be moved with little resistance. As the device attached to the finger is small, the finger is well visible. The following is a description of the components of SPIDAR.

3.1 Position measuring apparatus

This apparatus is for measuring position of a finger. It consists of an instruction pointer and a position measuring section.

3.1.1 Instruction pointer

The instruction pointer is a cap which is held by four lines. From the cap, each line goes to a seperate fulcrum point. The lines are held taut by weights on the other side of a pulley(Fig.3). By attaching this pointer to a finger of the operator, an arbitrary point to be instructed can be directly indicated by the finger.

3.1.2 Position measuring section

Each line is wound around a pulley attached to a rotary encoder. When the instruction pointer moves, the pulley rotates and the length from the instruction pointer to the fulcrum changes. Pulses corresponding to the rotation of the pulley are generated from the rotary encoder. By counting the number of pulses, the degree of rotation of the pulley can be measured. The change in distance from the pointer to the fulcrum is calculated from the degree of rotation and the diameter of the pulley. The distance from the pointer to the fulcrum is given by an initial value and the integral of the change in distance.

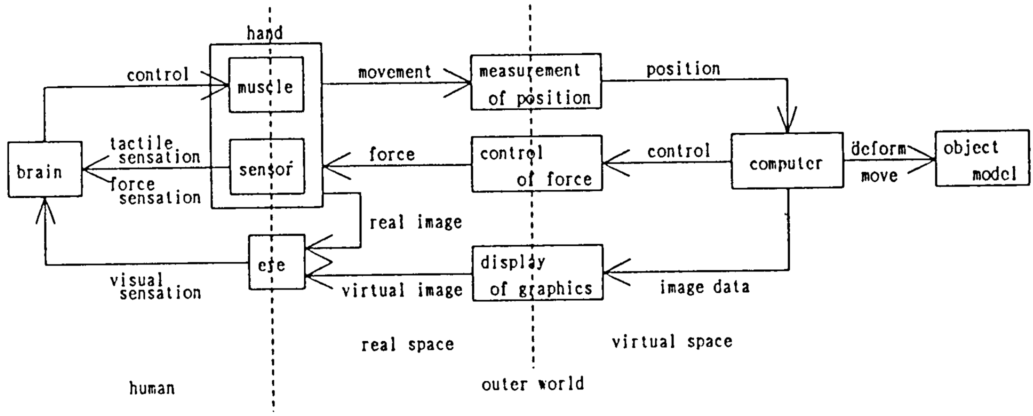


Figure 2: Virtual perception cycle

Let the coordinate of the pointer position be $P(x, y, z)$ and the length of *i-th* line be $l_i (i = 0 \cdots 3)$. To simplify the problem, let the four fulcrums A_i be on vertexes of a cube which are not adjacent to each other (Fig.4). Then the following Eqs.(1)-(4) hold.

$$(x + a)^2 + (y + a)^2 + (z + a)^2 = l_0{}^2 \quad (1)$$

$$(x - a)^2 + (y - a)^2 + (z + a)^2 = l_1{}^2 \quad (2)$$

$$(x + a)^2 + (y - a)^2 + (z - a)^2 = l_2{}^2 \quad (3)$$

$$(x - a)^2 + (y + a)^2 + (z - a)^2 = l_3{}^2 \quad (4)$$

Differences between Eq.(1) and Eqs.(2)-(4) make Eqs.(5).

$$\begin{cases} 4a(x + y) = l_0{}^2 - l_1{}^2 \\ 4a(y + z) = l_0{}^2 - l_2{}^2 \\ 4a(z + x) = l_0{}^2 - l_3{}^2 \end{cases} \quad (5)$$

We can obtain the position of the pointer as Eq.(6) by solving the simultaneous equations Eq.(5).

$$\begin{cases} x = \frac{l_0{}^2 - l_1{}^2 + l_2{}^2 - l_3{}^2}{8a} \\ y = \frac{l_0{}^2 - l_1{}^2 - l_2{}^2 + l_3{}^2}{8a} \\ z = \frac{l_0{}^2 + l_1{}^2 - l_2{}^2 - l_3{}^2}{8a} \end{cases} \quad (6)$$

3.2 Force generating apparatus

To simulate the force sensation that a finger would receive from an object, the apparatus restricts the movement of the finger. Movement of each of the four lines attached to the cap on the finger may be restricted by being sandwiched between a coil and a movable iron member of an electrically actived relay (Fig.3). By pulsing the relay a range of restricting forces may be simulated. When the finger is in contact with the virtual object, the movement of the finger is restricted by restricting all or some of the four lines.

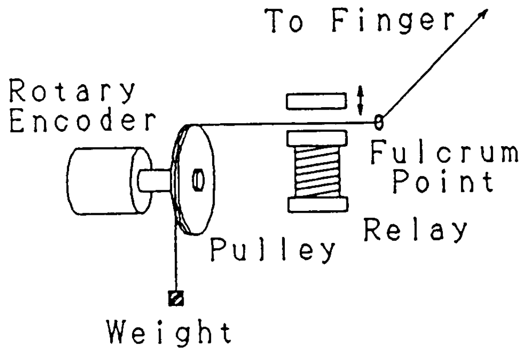


Figure 3: Pulley and relay

3.3 Construction of virtual work space with SPIDAR

The virtual work space is constructed by combining SPIDAR and a stereo display (Fig.5). The display is a CRT monitor which is set in front of the operator(it is not head mounted). The operator is

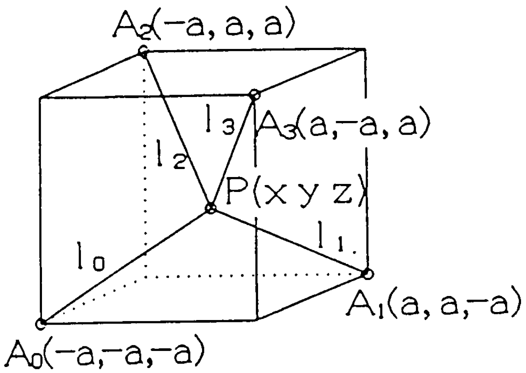


Figure 4: Measurement of finger position

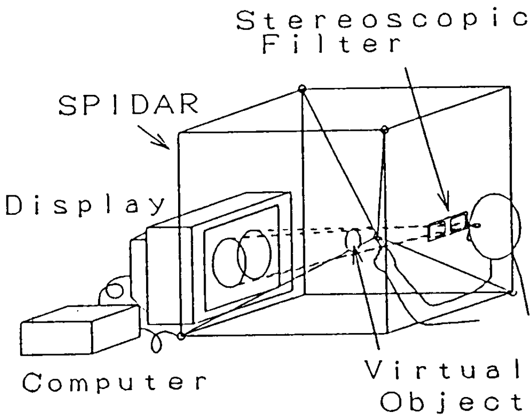


Figure 5: Virtual work space using SPIDAR

able to watch the virtual space fused with the real space through a stereoscopy filter. The position of a instruction pointer attached to a finger is measured, and if contact of a finger with a virtual object is detected. The operator will receive force sensation on the finger.

4 Experiments

In this section, we explain the results of evaluation experiments on ease of tasks in the virtual work space using SPIDAR. We made two experiments on the effect of force sensation on accuracy of tasks.

4.1 Pointing of 3-dimensional position

The task of this experiment was to point to the surface of a sphere with a finger. The radius of the sphere was changed each time. We made three subjects execute the task under two conditions– without force sensation and with force sensation. We recorded the locus of the finger.

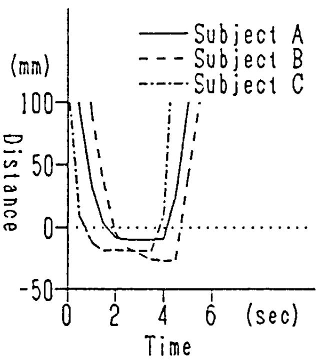
Fig.6 shows the movement of fingers of three subjects. (a),(b),(c) is the case without force, the case with force, and the case with sound instead of force respectively. The horizontal axis shows time, and the vertical axis shows distance between a finger and a surface of a sphere. The horizontal dashed-dotted line indicates the surface of the sphere. In case without force (a), the finger goes inside the sphere, or does not rest stably at the surface of the sphere. On the other hand, in the case with force (b), the finger rests stably at the surface of the sphere. In case with sound (c), the finger rests stably, but goes inside the sphere. In (b) the finger is stopped by the force on the surface of the sphere, while in (c) there is delay because the operator stops the finger after hearing the sound. Therefore, it is difficult to point accurately given only sound instead of force.

For the realization of the virtual work space where we can do accurate work, it is important to be able to point the position precisely. So, it is necessary to give a force sensation to the finger by restricting the finger.

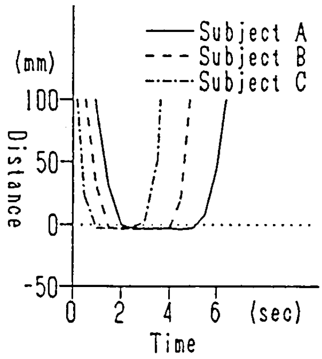
4.2 Deformation of 3-dimensional object

The task on this experiment is to deform a cup shaped object shown in Fig.7(a) into the shape of a rugby ball shown in Fig.7(b). We made three subject execute this task 4 times respectively under two conditions– without force sensation and with force sensation. We recorded the locus of the finger and process of deformation. The initial object is a shape having surfaces of revolution constructed from 21 control points. It is deformed by moving these control points.

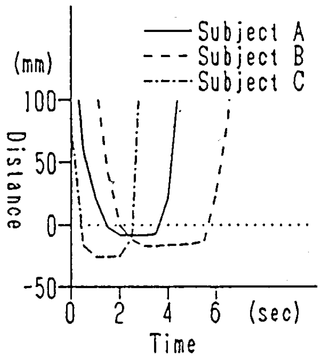
We define rate of attainment R_a and rate of error R_e as Eqs.(7), (8). Fig.8 shows a vertical section



(a) Without force

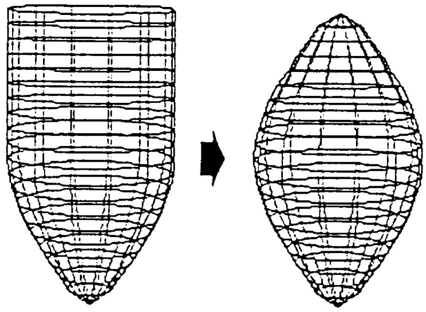


(b) With force



(c) With sound

Figure 6: Movement of a finger in pointing of position



(a) Initial shape (b) Target shape

Figure 7: Task of deformation

including the axis of the object. S_1 is the area of the target shape, and S_2 is the area of the part to be processed. S_a is the area of the part which is not sufficiently processed, and S_e is the area of the part which is excessively processed. At the beginning of the task, R_a and R_e are 0. At the ideal deformation, R_a is 1 as R_e is 0.

$$R_a = 1 - \frac{S_a}{S_2} \tag{7}$$

$$R_e = \frac{S_e}{S_1} \tag{8}$$

Fig.9 shows R_a and R_e of three subjects at the time when the shape seemed to draw nearest to the

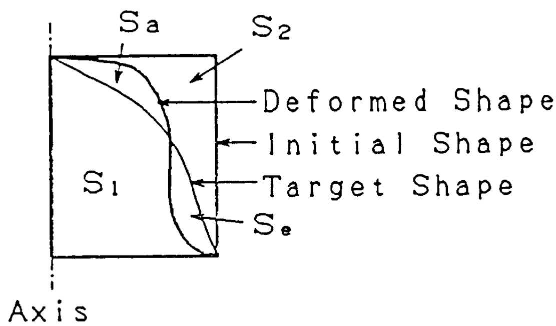


Figure 8: Definition of rate of attainment and error

target shape. The vertical axis shows R_a, and horizontal axis shows R_e. o indicates the case with force sensation , and × indicates the case without force sensation. In Fig.9(a) when force was given, the subjects performance improved in various way.

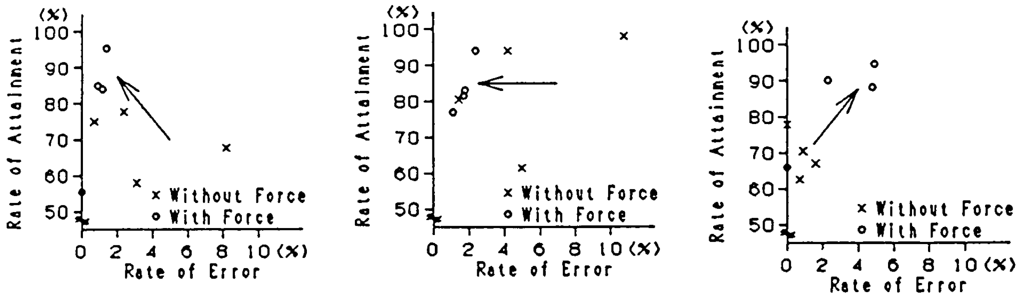
with subject A, R_a became higher and R_l became lower, an improvement in both.

With subject B, R_a stayed the same but R_l became lower.

With subject C, R_l became higher(i.e. worse), but the improvement in R_a more than conpensated for this.

Subject C was timid with regard to touching the object when there was no force feedback.

Fig.10 shows the rate of attainment and error of subject A over time with the final result shown in Fig.9(a). (a) and (b) shows the transition of R_a and



(a) Subject A (b) Subject B (c) Subject C

Figure 9: Rate of attainment and error in deformation of object

R_e respectively. The solid line indicates the case with force sensation, and the dashed line indicates the case without force sensation. In the case without force, R_e showed an initial rapid increase after which the subject stopped deformation(Fig.10(b)). On the other hand, in the case with force, the shape drew near to the target shape without sudden error(Fig.10(a)). Fig.11 is part of the locus of the finger. The horizontal axis indicates distance from the object axis and the vertical axis indicates height. In the case with force, the finger moves more regularly and less wastefully than in the case without force. These results show the importance of force sensation in assisting with the task of deformation of an object in the virtual work space.

5 Conclusion

We have investigated a virtual space where we can manipulate object models on a computer by finger. We have shown the importance of realization of the perception cycle in the virtual work space.

On the basis of the investigation, we proposed SPIDAR. We can input three-dimensional position of a finger using SPIDAR, while SPIDAR can give a force sensation to the finger.

We constructed a virtual work space using SPIDAR. We made experiments on the effect of the force on the accuracy of task in the virtual work space. We found that the task is done more accurately when force feedback is given. But when sound feedback is given instead of force feedback, position accuracy deteriorates. For the realization of the virtual work space where we can do accurate work, it is important to be able to point precisely. Therefore it is necessary and effective to give a force sensation to the finger.

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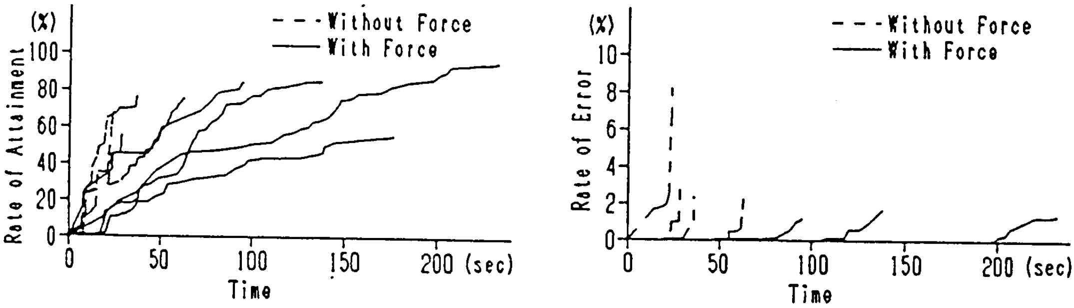
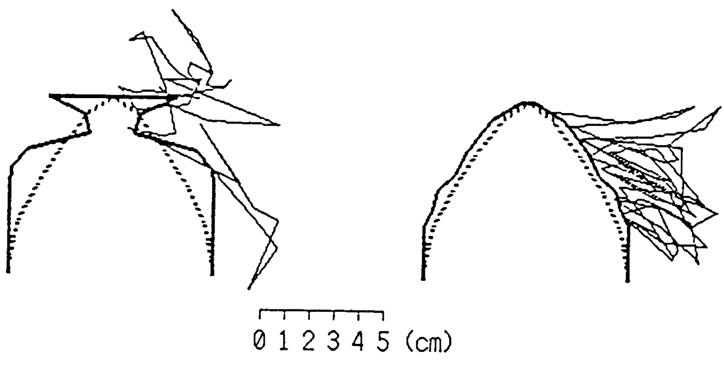


(a) Rate of attainment (b) Rate of error

Figure 10: Transition of rate of attainment and error of subject A



(a) Without force (b) With force

Figure 11: Locus of a finger in deformation of object