A 3D Interface Device for Pick-and-Place Task[1]

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Abstract

This paper describes a 3-D interface device for pick-and-place tasks in virtual environment. The pick-and-place task is one of the most basic assembly processes using a hand. In a virtual work space which is constructed using the 3D interface device, an operator uses his/her thumb and forefinger to manipulate a virtual object. The operator wears two caps on his/her thumb and forefinger, each of the caps is pulled by four strings which arranged at four corners of a cubed frame. The positions of the thumb and the forefinger are obtained by measurement of the lengthes of the strings. Tensile strength generated by electrical motors generate a resultant force which is provided as force sensations. Experiments on the pick-and-place tasks are performed. Effect of the difference in weight of the virtual objects is estimated.

Key Words:

- pick-and-place tasks
- virtual work space
- force sensation
- tensile strength

Categories:

- Virtual Reality
- Force Feedback

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1 Introduction

The handling of 3D objects in virtual environment requires an efficient input device to be able to handle virtual objects as humans do in real world.[1] The direct manipulation which use the hand motion is a natural form of control that can bring significant improvements in operation efficiency. We have proposed a 3D interface device named SPIDAR (SPace Interface Device for Artificial Reality). The device measures the position of an operator's finger tip in 3D space by a cap placed on the finger, attached to four strings from four corners of a cubed frame where each length of the strings is measured by a rotary encoder. The device, moreover, can provide a touch sensation by restricting the strings with brakes. A virtual work space of a potter's wheel is constructed with the device. In the virtual space, the operator deforms a virtual clay on the virtual potter's wheel by pushing with his/her forefinger. While the finger is in contact with the cray, a sensation of touch is fed back.[2]

It is interesting to work out a design for something in virtual environment. Putting some parts together is one of the most important works of design, and is called assembly-process. The assembly process consists of three motions;

1. gross motion
2. grasp
3. fine motion.

To perform the assembly process in virtual environment, the operator needs a 3D interface device which allows the above motions. In this paper, we deal with pick-and-place tasks which are the most basic assembly processes. Pick-and-place tasks consist of

1. moving the hand from its current position to a position on a desired object,
2. grasping the object by the hand,
3. moving the object to some specified position.[3]

When we construct a virtual work space for pick-and-place tasks using SPIDAR, we are confronted with two problems; the first is the way to grasp an object. The second is the way to generate force sensations not touch sensations. For solving the questions, we propose a new 3D interface device named SPIDAR II which is an improvement of the former one. The SPIDAR II is improved on the configuration as follows: 1) a thumb and a forefinger are available using two caps, 2) force sensations are generated by pulling the strings using electrical motors.

This paper mainly describes the configuration of SPIDAR II, and its implementation on pick-and-place tasks in a virtual work space. This paper is organized as follows: Section 2 describes the structure of SPIDAR II. A virtual work space for pick-and-place tasks with SPIDAR II is presented in Section 3. Experiments on pick-and-place tasks in the virtual space are presented in Section 4. Finally, concluding remarks are given in Section 5.

2 Structure of SPIDAR II

This section describes the structure of SPIDAR II. We begin with the description of the overview of SPIDAR II. Then, the way to generate forces by electrical motors is given. Finally, the measurement of the position of the finger is presented.

2.1 Overview of SPIDAR II

Figure 1 shows the overview of SPIDAR II. In this figure, the operator wears two caps on his/her thumb and forefinger. Each cap is held by four strings. Each string goes to a separate corner of the cubed frame. The string is wound around a pulley attached to an electrical motor placed at the corner, and is drawn by the motor for the purpose of giving proper tension all the time.(See Fig.2) The motion of the cap is detected by rotary encoders attached to the motors. The operator can move both the thumb and the forefinger as he/she pleases. What has to be noticed is an interference of the strings, that may particularly caused by an excessive adduction or abduction. However, this scarcely prevent the fingers moving naturally.

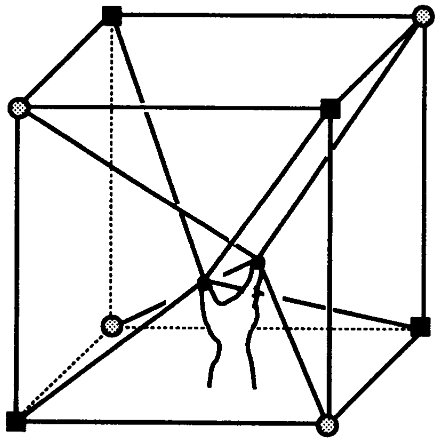

Fig.1 Overview of SPIDAR II

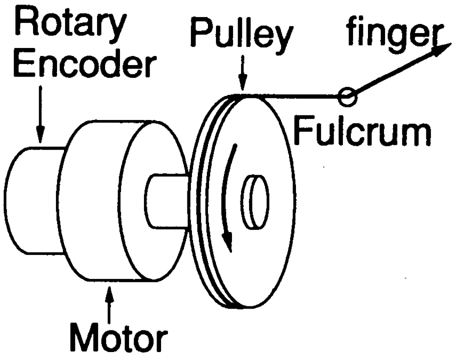

Fig.2 Motor and Rotary Encoder at Corner of Cubed Frame

2.2 Force Generation

SPIDAR II uses a resultant force of tension from strings to provide force sensations. As mentioned above, the cap is held by four strings; furthermore, each string wound around the pulley is pulled by an electrical motor, thus the tension is controlled by the electric current entering the motor.

When we give tension to the four strings by the motors, the resultant force occurs at the position of the cap. The following is similarly described about both the thumb and the forefinger. Let the resultant force vector be $\vec{f}$ and unit vectors of the tension be $\vec{u_i}(i = 0, 1, 2, 3)$, then resultant force is expressed as

$$\vec{f} = \sum_{i=0}^{3} a_i \vec{u_i} \qquad (a_i \geq 0).$$

where a_i is a value of the tension of each string, so it is required to non-negative value. By controlling all of the a_i, we can compose the resultant force of any magnitude in any direction.

We can use at most only three of four strings to compose the desired force. The way to select them is described as follows: the space around the cap can be partitioned into four triangular pyramid spaces, in which each space is shaped from three of four strings and has a common apex at the cap. The required force vector $\vec{f}$ appears in one of the four pyramids, thus $\vec{f}$ is expressed by positive cone of three $\vec{u_i}$ forming the pyramid.(See Fig.3)

We use a D/A convertor(8bit) to control the current entering the motors which had 256 torque varieties. Every motor can generate the tension range from 0N to 4N with a step of 0.016N.

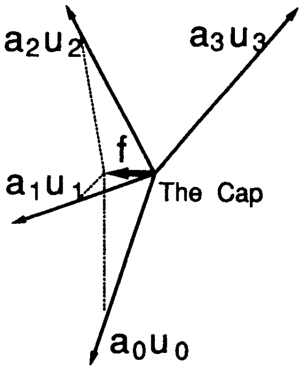

Fig.3 A Triangular Pyramid containing $\vec{f}$

2.3 Measurement of Finger Position

Each string is wound around a pulley attached to a rotary encoder, as described before. When the cap moves, the pulley rotates, and the length from the cap to the corner changes. Pulses corresponding to the rotation of the pulley are generated from the encoder. By counting the number of the pulses, the degree of rotation of the pulley is measured. The change in the length is calculated from the degree of rotation and the diameter of the pulley. The length is obtained from an initial value and the integral of the change in distance. Let the coordinates 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. Then the following Eqs.(1)-(4) hold.

$$(x+a)^2 + (y+a)^2 + (z+a)^2 = {l_0}^2 \qquad (1)$$
$$(x+a)^2 + (y-a)^2 + (z-a)^2 = {l_1}^2 \qquad (2)$$
$$(x-a)^2 + (y+a)^2 + (z-a)^2 = {l_2}^2 \qquad (3)$$
$$(x-a)^2 + (y-a)^2 + (z+a)^2 = {l_3}^2 \qquad (4)$$

Differences between Eq.(1) and Eqs.(2)-(4) make Eqs.(5)-(7).

$$4a(y+z) = {l_0}^2 - {l_1}^2 \qquad (5)$$
$$4a(z+x) = {l_0}^2 - {l_2}^2 \qquad (6)$$
$$4a(x+y) = {l_0}^2 - {l_3}^2 \qquad (7)$$

We can obtain the position of the pointer as Eqs.(8)-(10) by solving the simultaneous equations Eqs.(5)-(7).

$$x = \frac{{l_0}^2 + {l_1}^2 - {l_2}^2 - {l_3}^2}{8a} \qquad (8)$$
$$y = \frac{{l_0}^2 - {l_1}^2 + {l_2}^2 - {l_3}^2}{8a} \qquad (9)$$
$$z = \frac{{l_0}^2 - {l_1}^2 - {l_2}^2 + {l_3}^2}{8a} \qquad (10)$$

A rotary encoder whose resolution is 100 pulse/round, is used for measuring the position of the fingers. The diameter of the pulley is 16mm, so that the distance is measured in the precision of 0.503mm.

3 Virtual Work Space for Pick-and-Place Tasks

This section describes the configuration of a virtual work space for pick-and-place tasks using SPIDAR II. In the first place, the configuration of the virtual work space is given. Then, the kinds of forces required from pick-and-place tasks are presented.

3.1 Virtual Work Space

The configuration of the virtual work space consists of two systems, a real-time computer graphics system and SPIDAR II, as shown in Figure 4. A screen which displays the real-time image of the virtual work space is set in front of SPIDAR II. A graphics workstation provides the real-time image. SPIDAR II which is set in front of the operator measures the caps' positions, and provides force sensations. A personal computer provides I/O control of the A/D and the D/A convertors for SPIDAR II. 3D graphics and I/O processors are connected by a serial(RS-232C) communication line. The cycle of the overall processes (position measurement-force feedback-screen update) is 20 Hz.

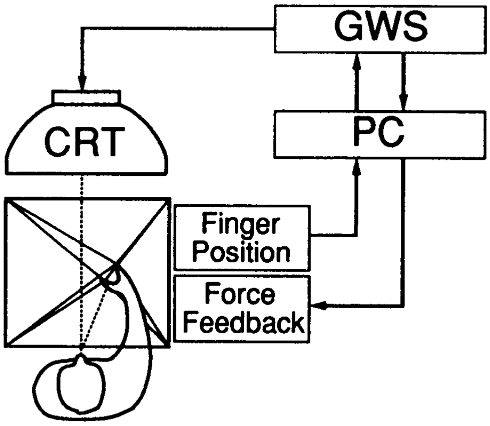

Fig.4 Configuration of Virtual Work Space

3.2 Forces during the Task

During the pick-and-place task, three types of forces occur as shown in Figure 5. The forces are:

N reaction from the holded object to the thumb and forefinger

R reaction from another object or the platform which collides with the holded object

W mass of the holded object.

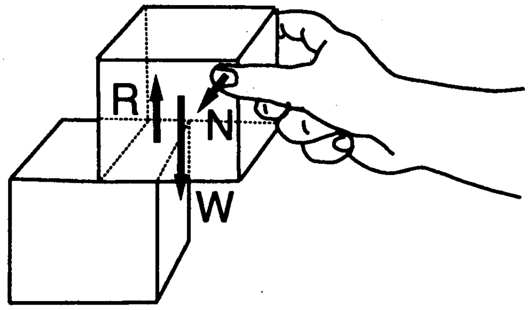

Fig.5 Forces under Pick-and-Place Task

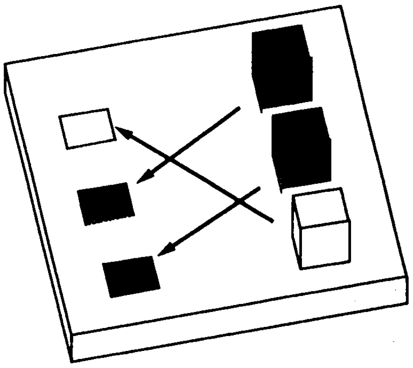

Fig.6 Pick-and-Place Task

The virtual work space provides the above forces to the operator. The caps, the building blocks, and the platform are given as the rigid bodies to the operator as like real world. When two rigid bodies collide in real world, they don't interpenetrate definitely. However, in the virtual work space, they, in spite of the rigid bodies, may interpenetrate in small degree because of the limit of cycle time of the system. Therefore, in our virtual space, even the rigid body is treated as an elastic body whose stiffness K is sufficiently large. The forces generated from the reaction are simulated based on Hooke's law. In other words, the forces are calculated as proportional to the depth of penetration in the virtual space.

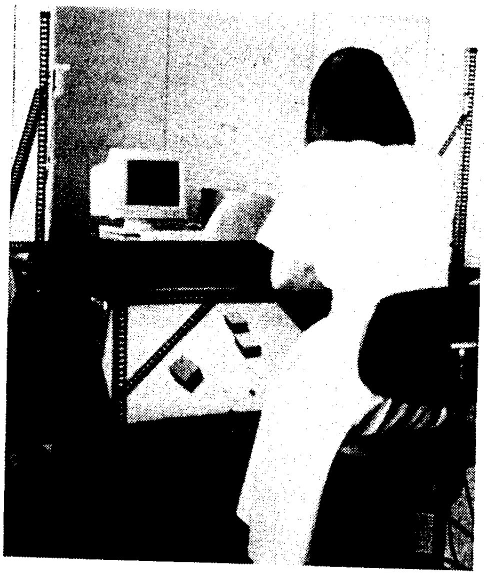

Fig.7 A Scene of Examination

4 Experimental Results

Experiments on the pick-and-place task as shown Figure 6 were performed. The task of the experiment was to rearrange three building blocks from initial places to specified places. The building blocks were provided as five centimeters cubes. Each of the three blocks and marks of target was colored randomly to red, green, or blue, and was arranged on initial places. Subjects who were three young adult male were asked to perform pick-and-place task. Ten pick-and-place tasks were performed for each subject. Effects on difference in weight were eatimated by changing the mass of block to 20, 35, 50, 70, 100, and 150 grams.

Figure 8 shows the effects of weight on the mean completion time and the accuracy of arrangement. The average of three subjects on the time and the accuracy are plotted by dots and squares. The results of mean completion time indicate that when the weight became heavier than 50 grams, the time was increased steeply. The results of accuracy indicate that when the block is weighed from 35 to 50 grams, the operators performed pick-and-place task accurately. It follows from what has been said that the block which is weighed about 50 grams has an effect on our pick-place-task.

Because the blocks were provided as five centimeters cubes, as described before, the virtual block which was weighed 50 grams was equivalent to a block made of wood of real world. This agrees with the results of a pick-and-place task in real world.

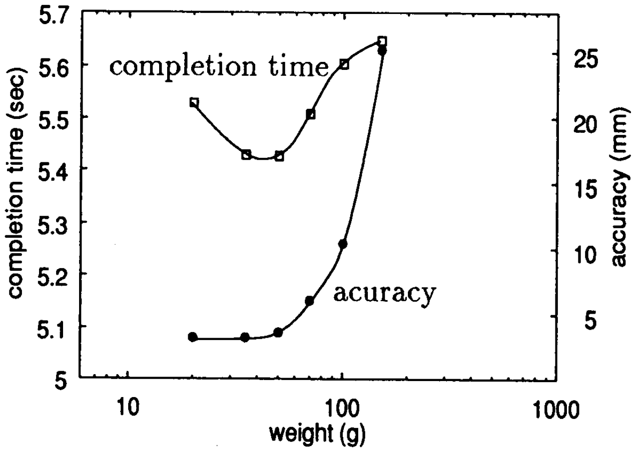

Fig.8 Effects of Weight
on Completion Time and Accuracy

5 Conclusion

This paper presented the construction of the virtual work space for pick-and-place tasks with a new 3D interface device named SPIDAR II. The device can measure the motions of the thumb and the forefinger, and can provide the force sensations to the thumb and the forefinger. The operator can manipulate the virtual objects directly in the virtual work space using the device. The pick-and-place tasks were performed in the virtual space. Effects of the force sensations which were provided by the device were estimated. The results indicated that the appropriate forces were important for the pick-and-palce task. The virtual block which was weighed as like as a wooden block of real world, was the best on performance of pick-and-place tasks in virtual work space.

References

[1] S.S. Fisher, M. McGreevy, J. Humphries and W. Robinett, "Virtual Environment Display System", *Proc. of 1986 ACM workshop on Interactive Graphics*, pp.77-87,1986

[2] Y. Hirata, M. Sato, "3-Dimensional Interface Device for Virtual Work Space", *Proc. of the 1992 IEEE/RSJ Int. Conf. on IROS*, Vol.2,pp.889-896,1992

[3] T.Lozano-Perez, "Automatic Planning of Manipulator Transfer Movements", *IEEE Trans. Systems, Man, Cybernetics*, SMC-11, 10, pp.77-87,1981