Surface Display: Concept and Implementation Approaches

Koichi Hirota
Department of Information and Computer Sciences, Toyohashi University of Technology
1-1 Tempaku-cho, Hibarigaoka, Toyohashi 441, Japan
hirota@axia.tutics.tut.ac.jp

and

Michitaka Hirose
Department of Mechano-Informatics, Faculty of Engineering, University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113, Japan
hirose@ihl.t.u-tokyo.ac.jp

ABSTRACT

In the real world, the sensation of force is mainly caused because our body makes contact with objects. If we can represent the surface of virtual objects, we can obtain the sensation of contact and force through the interaction with the surface. We call this idea in the implementation of force feedback the concept of surface display. In this paper, the implementation approaches of this concept are discussed. Three prototype devices of surface display are introducedand and experiments using them are stated.

1. Introduction

It is often pointed out that the sensation of touch and force is indispensable in dexterous manipulation of objects in the virtual environment. The implementation method of force feedback has been studied mainly in the fields of tele-robotics and tele-manipulations, and the results in these fields have been introduced also into the field of virtual reality [Shimoga, 1993].

The most typical method applied in these fields is to simulate the force affected to the user or operator. However, if we observe the mechanism that causes the sensation of force and contact, we find that the most of these sensations occurs from the interaction with objects. This fact leads us to another method for the implementation of force feedback, in which the existence of objects is simulated.

In the following sections, the idea of this method is made clear through the classification of the implementation methods of force feedback, and experimental implementing approaches based on this idea is introduced.

2. Concept of Surface Display

Force feedback is an interface between the virtual object and the user through the phenomenon of contact. In a virtual reality system, the virtual object is in the computer and the user is in the real world. Hence, there must be a boundary that separates the virtual world and the real word between the virtual object and the human user. And, the force feedback device is needed to interface these two worlds with each other. We call this boundary the cross-section of interface. We tried to classify the implementation methods of force feedback from the difference in the portion where the cross-section is assumed [Hirota et al, 1994].

In the real world, there are two types of interface with the object: indirect contact using tools, and direct contact using finger or other part of skin. In the former case, the user's finger or hand makes contact with the tool and the tool makes contact with the object. From this observation, we can define three typical cross sections in the interface of force feedback: surface of tool, surface of hand, and surface of an object. The difference in the cross-section causes the methodology and implementation of the force feedback system to be different.

If we take the cross-section on the surface of a tool, the existence of a tool must be presented to the user. Usually, it is realized by using a robot arm equipped with a grip. The usage of the master arm in the GROPE project [Brooks et al, 1990] may be categorized as the type of device that is implemented on this cross section.

If we assume the cross-section on the surface of human skin, or usually on human hand, we are remarking on the relationship between the displacement and force affected on the surface of the human. Sensation of force is detected as a pressure distribution on the surface of the user's skin. Therefore, by emulating the pressure distribution on this surface, the sensation of touch to any object is thought to be synthesized. Usually, the implementation of the device at this cross section is limited to hand or arm, because the most of manipulation tasks is performed by using this part of body. Many dexterous master arms developed for tele-robotics systems may be categorized into this type of implementation. In the field of virtual reality, the glove type force display system at Tsukuba University [Iwata, 1990] may be categorized into this type.

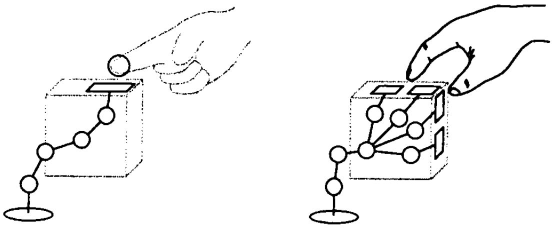
We can also find another method assuming the cross-section to be on the surface of object. At this cross-section, the existence of the surface of the object must be displayed by the interface device. In this method, the existence of objects is simulated, and the sensation of force or contact is obtained as a result of interaction with the simulated object by the user. As is mentioned in the introduction, we believe this method is a more natural way for the implementation of force feedback in virtual environment. We call a force feedback device based on this method 'Surface Display'. For the investigation of feasibility and technical problems of Surface Display, we have developed three experimental prototype devices as described below. In the first prototype, the most simplified mechanism for the presentation of constraint caused by the surface of an object was developped. In the second prototype, interaction with the virtual object using force was enabled. In the third prototype, we tried to present the arbitrary shapes to the user.

3. Prototype 1: Presentation of Constraint Surface

In a typical virtual environment, objects of various shapes at various positions must be displayed. However, it is difficult to prepare real objects of so many different shapes. In the first prototype we assumed that only a small part of the user's body makes contact with the virtual object, then only the neighborhood of the contact point must be simulated [Hirose et al, 1992]. We also assumed that the contact area is very small, therefore, it is possible to approximate the area as a plane or some other similar surface. It is also difficult but indispensable to know the point on the surface of the user's body where a virtual object is making contact, because the position and orientation of the tactually displayed surface should change according to the motion of the user. In the development of this prototype, the area of feedback for tactile or force sensation was limited to a finger tip, and the shape of the finger tip was assumed to be spherical (Figure 1(a)). This assumption makes the tracking of user motion and calculation of the contact point significantly easier.

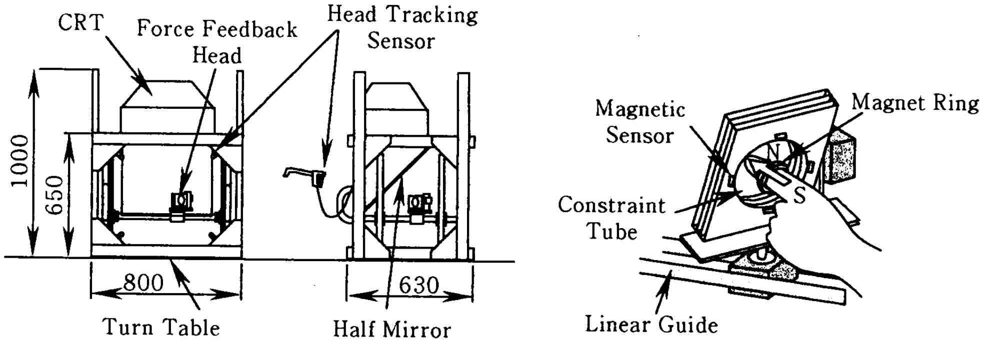
Measurement of the absolute position and directional orientation of a finger in a wide work space is not easy. Further more, from the view point of simulating reality, contactless measurement is desired. Our solution was to make use of a tracking mechanism incorporating a sensor which detects position and directional orientation in a small range by magnetic field. Namely, the user wares a magnet ring, and magnetic sensors attached to the force feedback head detects the motion of the user's finger by measuring the intensity of magnetic field (Figure 2(b)). According to this information, the mechanism moves the head to track the user's finger.

The mechanism of this prototype has three degrees of freedom, which are used for both tracking the user's finger in 3D space and displaying the surface for tactile sensation (Figure 2(a)). The control



(a) Approximation by plane (b) Presentation of shape

Figure 1: Implementation Approaches of Surface Display



(a) Tracking Mechanism (b) Details of Head

Figure 2: Mechanism of Prototype 1

of the mechanism has two modes: tracking mode and display mode. The tracking mode is applied when the finger is not touching any virtual object. In this mode the finger is kept at the center of the contact tube on the force feedback head. When the finger is about to touch a virtual object, the display mode is selected in which the head stops moving towards that virtual object, and the finger moves off the center of the tube making contact with inner surface of the tube.

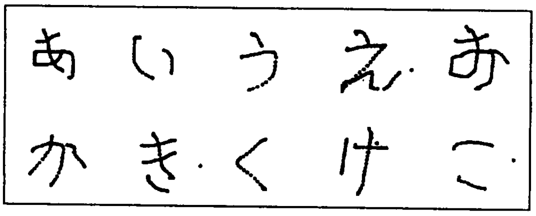
4. Writing in a Virtual Environment

The sensation of contact and constraint in motion is essential in writing tasks. A virtual blackboard was created using the prototype 1, and observations concerning the effect of virtual surface were conducted. Subjects were asked to write Japanese characters under several visual and force related conditions (Figure 3). The clarity of written characters was estimated subjectively by a third person. According to the average scores of clarity under each condition, it was shown that the sensation of force was very important for the writing tasks (Figure 4). It is also interesting that the result of clarity 'with vision, without constraint' is almost the same with the result 'without vision, with constraint'. From these results, we can say that the sensation of constraint is as required as vision in this task.

5. Prototype 2: Interaction using Force

In the second prototype, the measurement of force affected on the presented surface was enabled [Hirota et al, 1993]. This input of force is essential in such tasks as the manipulation of objects and recognition of elasticity of objects, because, in these tasks, the force affected on the surface of the object must be reflected on the motion of the object.

(a) with Constraint



(b) without Constraint

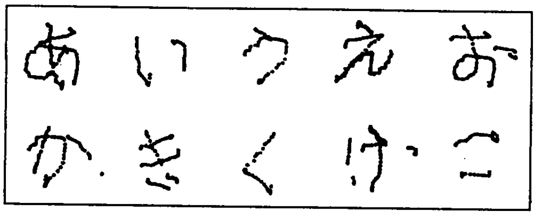


Figure 3: Example of Written Characters

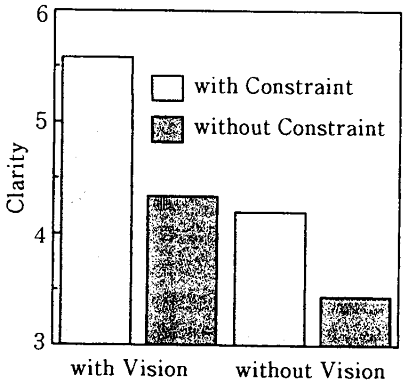
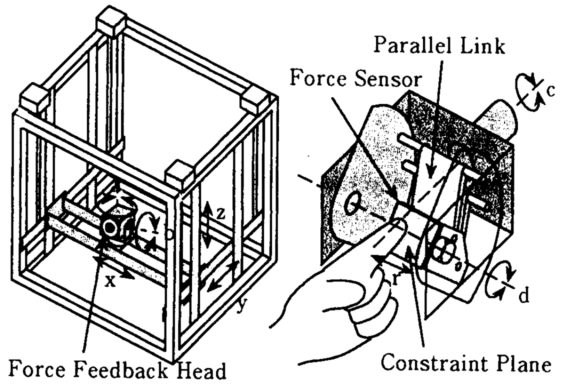


Figure 4: Estimation of Clarity



(a) Tracking Mechanism (b) Force Feedback Head

Figure 5: Mechanism of Prototype 2

The mechanism was divided into two parts: a tracking mechanism and a display mechanism (Figure 5,6). The tracking mechanism contained five degrees of freedom for translational and rotational motion. Similar sensors as the type used in prototype 1 were used for tracking the movement of the user's finger. The display mechanism had three degrees of freedom to present the simulating plane, each of them changes azimuth, elevation, and distance of the plane relative to the user's finger. Also, This prototype contained a force sensor that measured the force applied by the user's finger. It detects the intensity of force perpendicular to the simulated surface.

6. Compression of One Dimensional Spring

One of the most simple examples of interaction using force is the compression of an elastic object such as a spring. A one dimensional spring with a mass and damper was built, and its behavior was observed.

Generally speaking, motion or transformation of a virtual object is realized by updating the model of the object. The relation between force and displacement is usually defined by a differential equation, and in the application of surface display, such an equation must be solved as a problem of

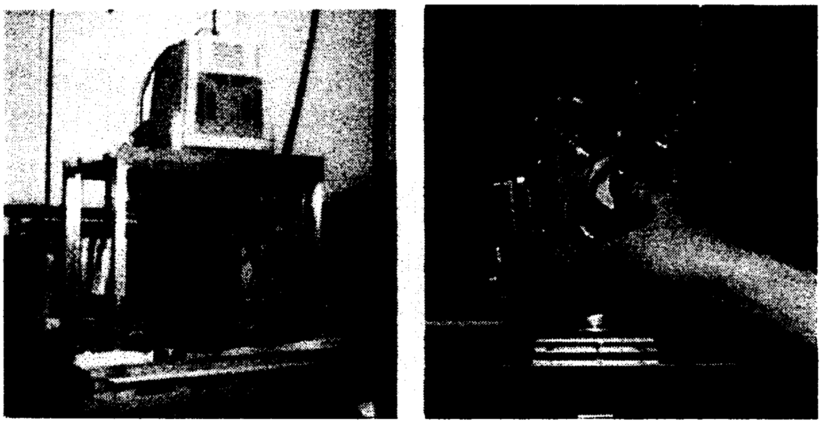


Figure 6: Photograph of Prototype 2

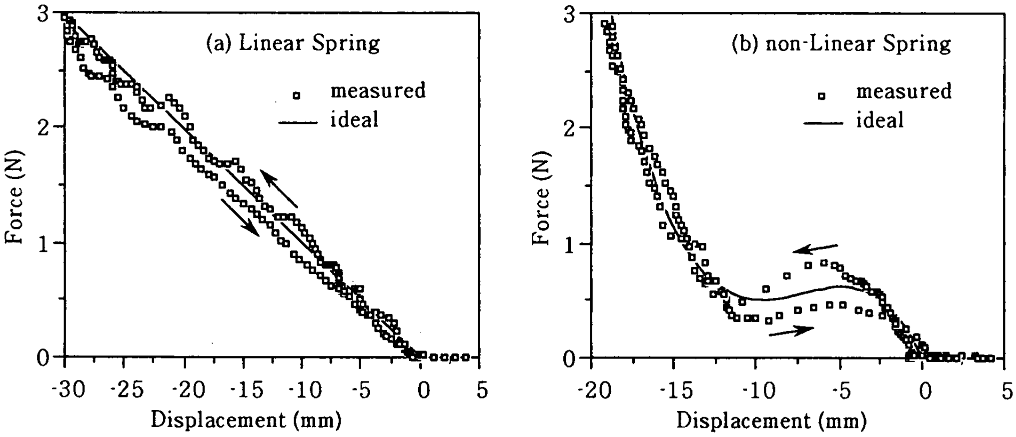


Figure 7: Compression of Spring

direct dynamics, namely displacement must be calculated when the force is given.

Two types of spring was simulated: linear type and non-linear type. In the linear type, the constants and the relation between the displacement and force was defined as follows (Figure 7(a)).

$$\text{mass: } 10(\text{g})$$
$$\text{force from spring: } F_x(x) = -k_x x$$
$$\text{force from damper: } F_v(\dot{x}) = -k_v \dot{x}$$

where,

$$k_x = 9.8 \times 10^4 (g/sec^2) \approx 0.1(N/mm)$$
$$k_v = 2.0 \times 10^3 (g/sec) = 0.002(N/(mm/sec))$$

In the non-linear case, the relation between the displacement and force was changed as follows. This function was intended to realize a slight 'click' sensation that is felt in such cases as pressing button switches (Figure 7(b)).

$$F_x(x) = a_3 x^3 + a_2 x^2 + a_1 x$$

where,

$$a_3 = -1.98 \times 10^3 (g.mm/sec^2/mm^3)$$
$$a_2 = -4.41 \times 10^4 (g.mm/sec^2/mm^2)$$
$$a_1 = -2.94 \times 10^5 (g.mm/sec^2/mm^1)$$

Through this experiment, we could make clear that the sensation of elasticity and motion is obtained using surface display, if we implement physical model of the virtual object.

7.Prototype 3: Presentation of Curved Surface

In this prototype, we tried to widen the area of contact on the surface of user [Hirota et al, 1995]. By widen the area of contact, it becomes passible to manipulate objects using more than one fnger, and even the other part of the hand. To realize this requirement, a mechanism to present arbitral shapes in real-time had to be designed (Figure 1(b)).

This prototype device is divided in two parts: a Tracking Part and a Display Part. The Tracking Part consists of two degrees of freedom to passively change the position of the Display Part (Figure 8). This mechanism offers the user the ability to select the operation area on the surface of the object. In future prototypes, active tracking with more than six degrees of freedom is being considered.

The Display Part has sixteen parallel rods, whose projecting length is controlled by servo motors attached to each of the rods. The rods are arraigned on the grid points of a 4 × 4 square lattice, and the intervals of the gird points are 20 × 20[*mm*]. Each of the rods has a stroke of 50[*mm*]. The Display Part presents the given physical shape of the object by changing the projecting length of the rods. Measurement of the force exerted on to the surface of the object by the user was also an essential in the implementation of surface display as is stated in the development of prototype 2. In prototype 3, the axial force exerted on each rod was measured from the voltage charged on each motor. Torque offered to the motor cause error in the servo control, and the error reflected on the voltage.

Figure 9 shows the synthetic image of an application of this device into the presentation of a cubic object. The display part of the device is oriented to the corner of the cubic object where the user is going to touch. The shape of the corner is created by the device and the user makes contact with the

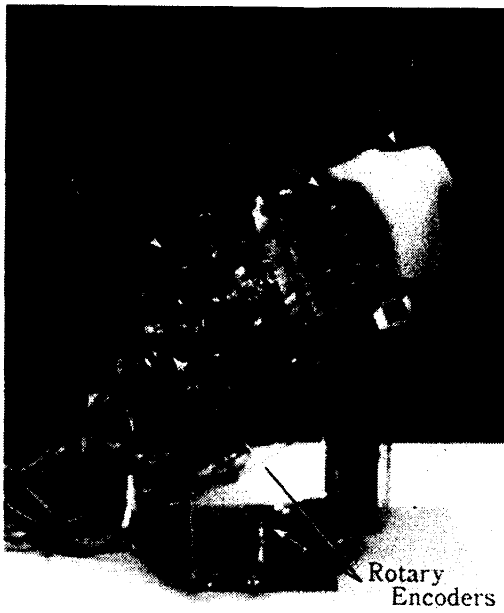


Figure 8: Mechanism of Prototype 3

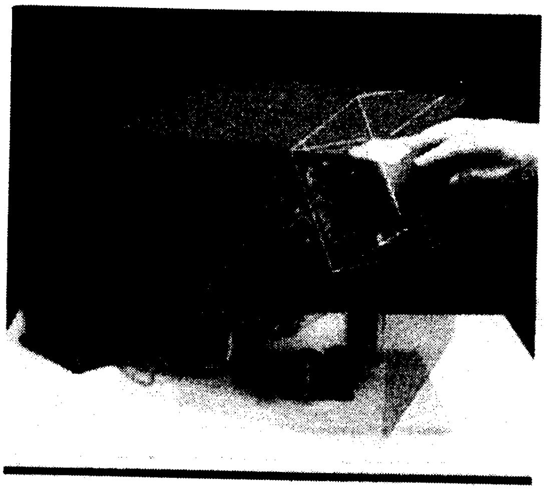


Figure 9: Presentation of Cubic Object (Composite Image)

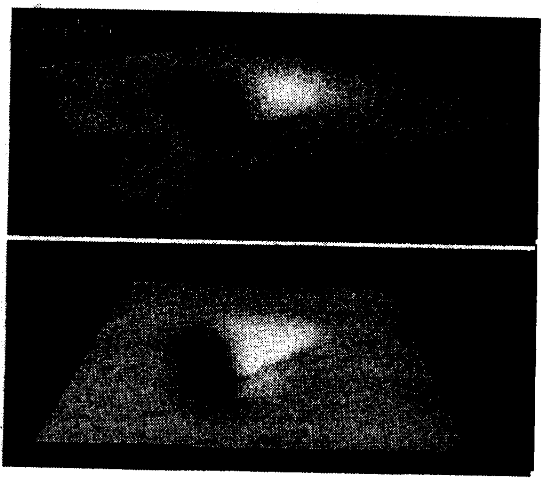


Figure 10: Transcription of Real Shapes onto Virtual Object

presented shape. In this way, the user can get the sensation of touch on the object.

8.Transcription of Shape

As an example of the simulation of an object reacting to the force, we tried to make a virtual sheet whose shape transforms according to the force affected onto the sheet. The virtual sheet was defined as a mesh. Height was defined on each of $38 \times 38[grids]$, whose size of lattice is $4 \times 4[mm]$. Displacement of the surface was calculated according to the following expression:

$$dz(d,F) = \frac{F}{F_0}\{\exp(-\frac{d^2}{k}) - \exp(-\frac{d_0^2}{k})\}$$

Where $d[mm]$ is the plane distance from the rods, and $F[N]$ is the intensity of force affected on the rod. Constants appearing in the expression are defined as follows: The maximum distance influenced by the force $d_0 = 44[mm]$, constant determining the acuteness of transformation $k = 200[mm^2]$, and the constant to determine the sensitivity against force $F_0 = 3.0[N/mm]$. The transformation is calculated as a sum total of the displacement for all the rods in every calculation cycle. The presented surface should be handled in just the same way as the surface of a real object placed in the same place. Interaction with the object is not always made by hand but also made by other objects. We tried to transcribe the shape of a sphere and a convex corner of a cube onto the virtual sheet (Figure 10).

9.Conclusion

The concept of surface display is a relatively new idea for the implementation of force feedback in virtual environment. Hence, the implementation approach of this idea is still not established. In this paper, through the development of three prototype devices and experiments using them, we could make clear the feasibility and technical problems of this idea.

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